AN INVESTIGATION OF THE HYDROLOGICAL RESPONSE TO THIRD WORLD SETTLEMENTS IN PERIURBAN AREAS OF NATAL/KWAZULU

VOLUME I
OBSERVATIONAL ANALYSIS

by

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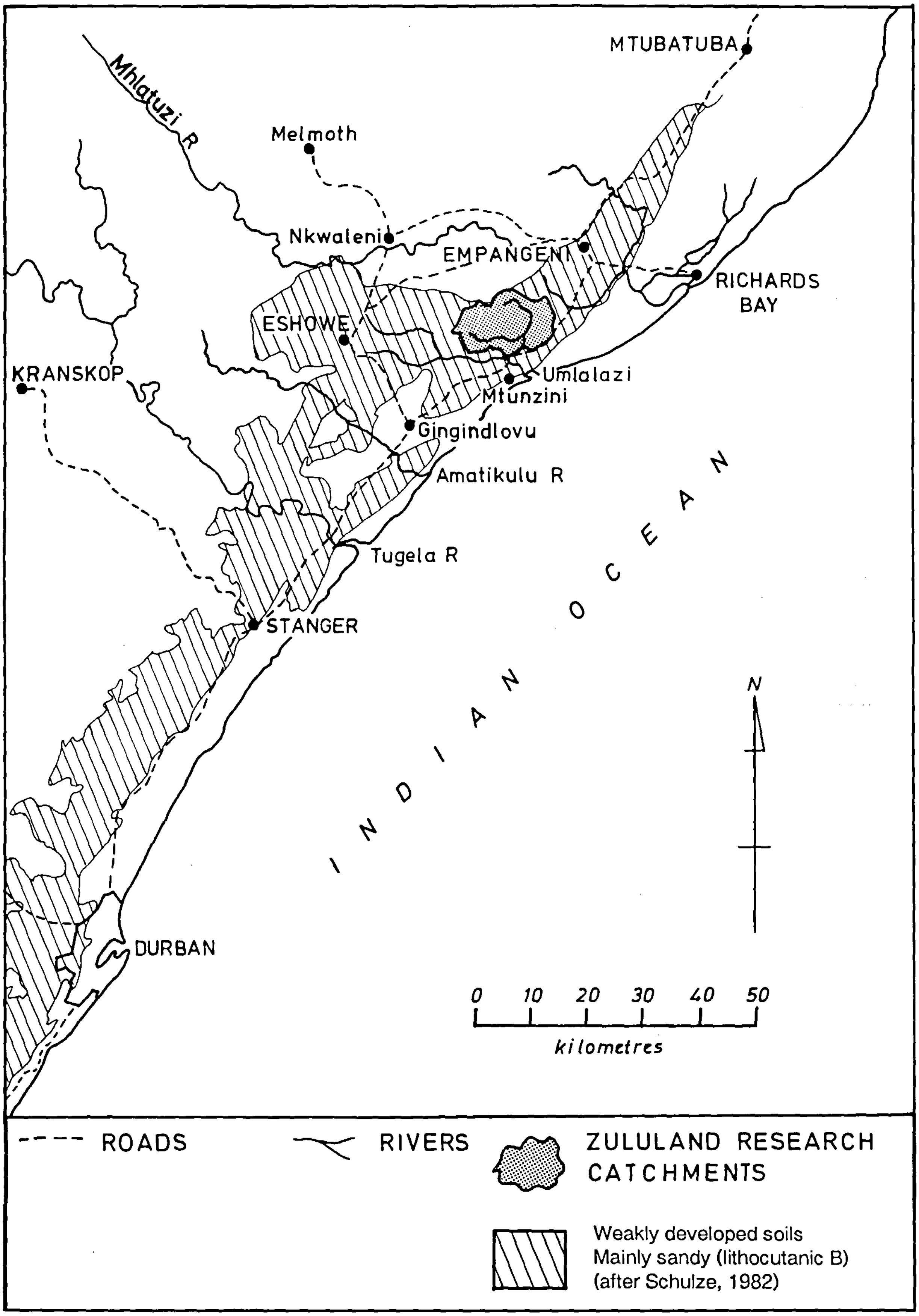


Figure 1.1 The Zululand research catchments relative to the main coastal metropolitan centres of Natal. The hatched area (from Schulze, 1982) represents similar physiographic areas comprised of weakly developed soils.

The study is being conducted in the small research catchments of the Ntuze river, near the University of Zululand (Figure 1,2). These research catchments, in the hilly Ntuze river basin, support both high density third world settlements and a protected natural ecosystem. The existence of the protected nature reserve in the research catchments provided the opportunity to compare two similar catchments with different land uses. The Ngoye Nature Reserve, controlled by the Department of Nature Conservation of KwaZulu, is a small forest reserve that was scheduled for re-fencing and stocking with indigenous fauna during 1988. This has not been achieved and the area is still used for controlled grazing by the local inhabitants surrounding the reserve. The grazing by a limited number of cattle is unlikely to exceed the utilization of fodder by indigenous fauna in a natural ecosystem except in the immediate vicinity of access gates where excessive degradation is likely to occur.

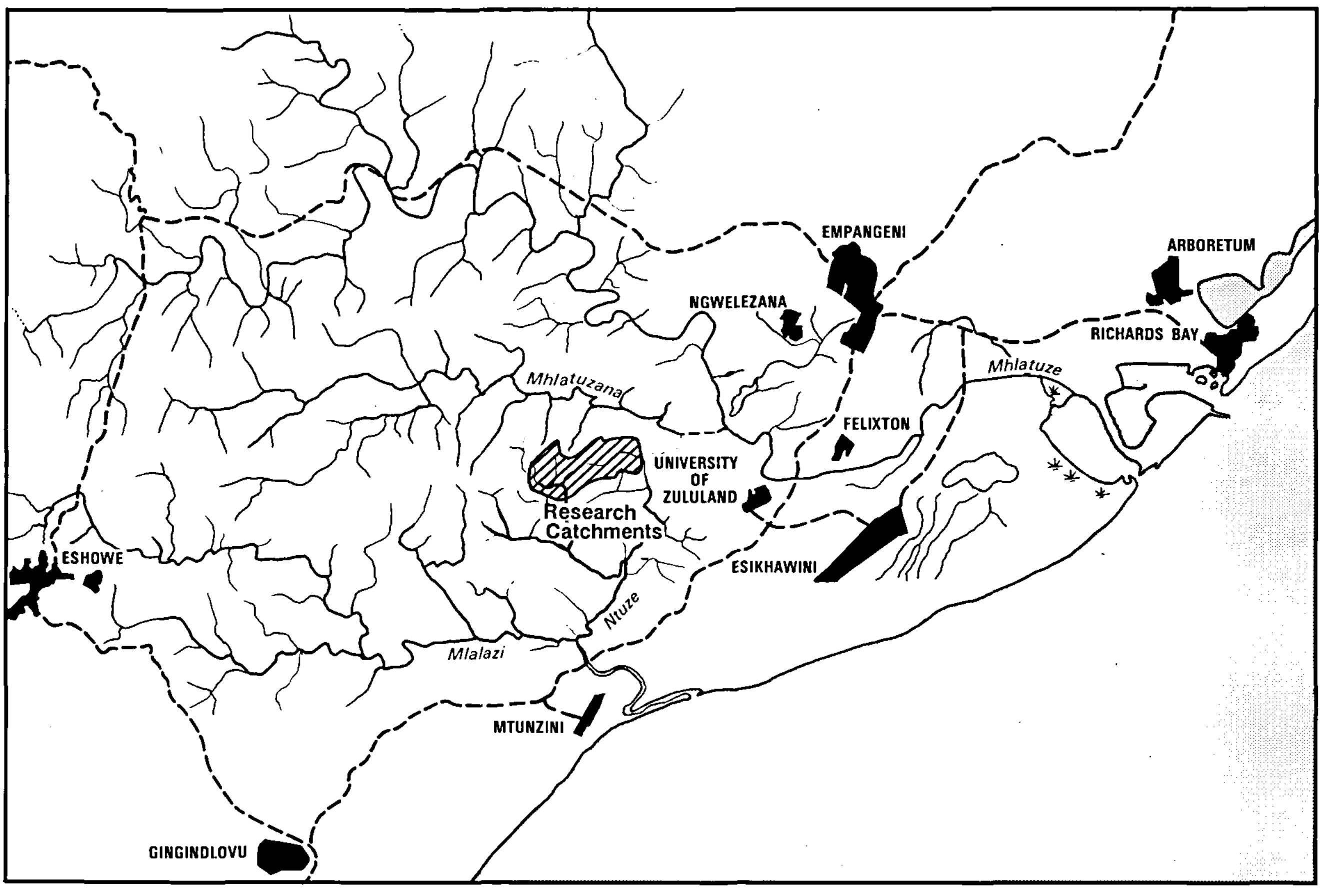


Figure 1.2 The Ntuze research catchments in relation to urban development.

3 RESEARCH CATCHMENTS, INSTRUMENTATION AND DATA COLLECTION

The Ntuze catchment is situated in the physiographic region referred to as the Natal Coastal Belt (Schulze, 1982). This region stretches along the entire coastal strip from the Transkei north to Zululand (Figure 1,1) and generally comprises weakly developed soils (mainly sands). The catchment, therefore, is fairly representative of large sections of the Natal coast including the areas surrounding the large metropolitan centres shown in Figure 1,1.

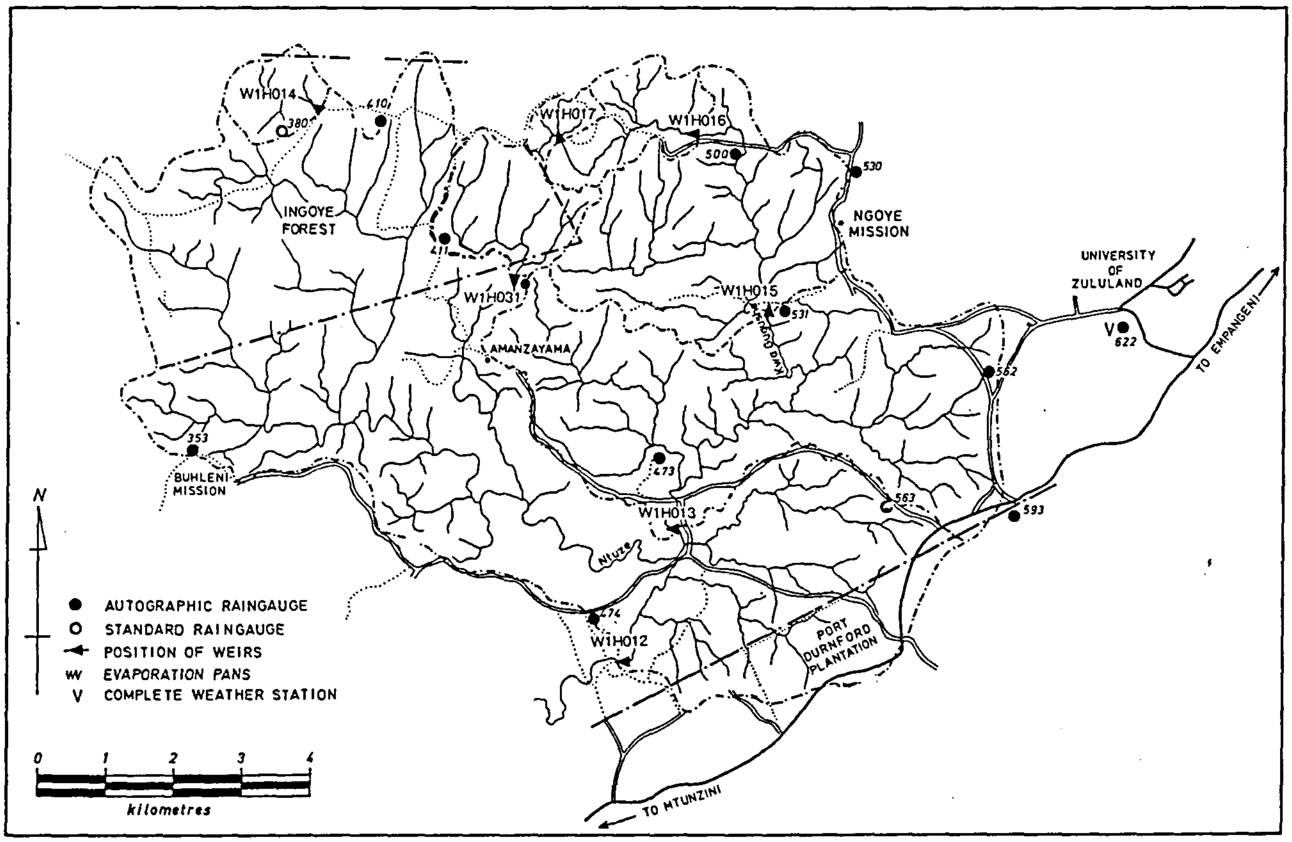
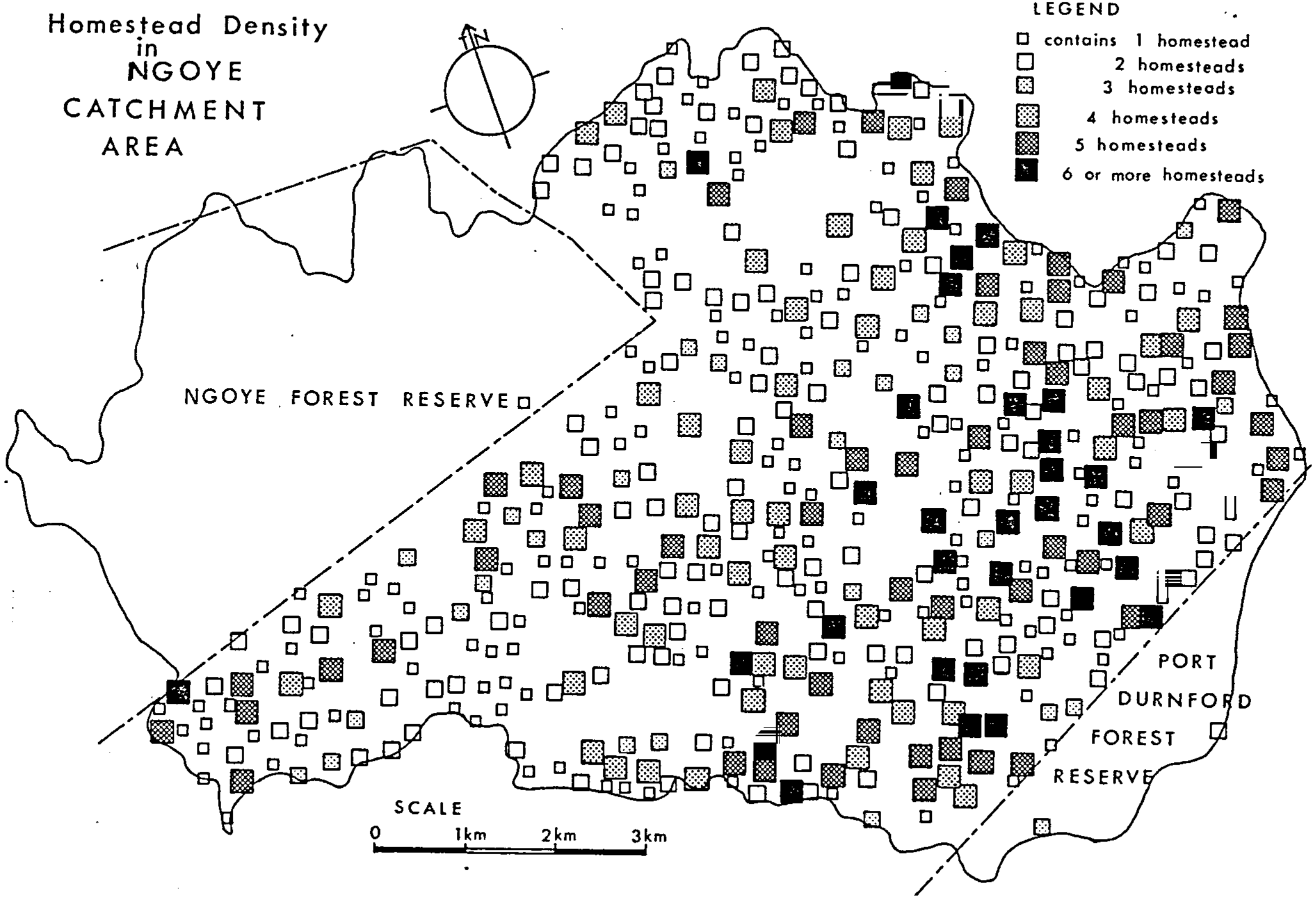


Figure 3,1 Location of instrumentation and selected topographical features of the Ntuze Research Catchments.

The Ntuze research area (Figure 3,1) comprised six nested catchments ranging in size from 0,7 to 82 km^2 that had been monitored for rainfall and runoff since 1974. Detailed climatological and geological surveys of the research catchments have been conducted and hydrological response units identified


Homestead Density in NGOYE CATCHMENT AREA
N
LEGEND
contains 1 homestead
2 homesteads
3 homesteads
4 homesteads
5 homesteads
6 or more homesteads
NGOYE FOREST RESERVE
PORT DURNFORD FOREST RESERVE
SCALE
0
1km
2km
3km

(Hope and Mulder, 1979; Mulder, 1984).

The settlements in the Ntuze catchment are concentrated along the access roads and have their greatest density in the south-eastern areas (Figure 3,2) which are closest to KwaDlangezwa (University of Zululand) and the main arterial roads leading to the industrial centres at Empangeni and Richards Bay. The more developed south-eastern area comprises small fields of sugar cane and cash crops. However, sugar cane has now been established in the northern areas (W1H016) and is expected to increase markedly with the allocation of quotas to Homeland areas and the shortage of cane at the new Felixton mill. This development is leading to improved roads and other communication facilities which will promote further settlements in the area.

In 1977, five weirs were designed and built by the Department of Water Affairs along the Ntuze river (Figure 3,1), a tributary of the Umlalazi river. These structures were designed to record

Figure 3,2 **Spatial density of dwellings in the Ntuze catchment (after Townsend, 1988).**

meters outside the south-eastern boundary of the reserve, an abandoned dam formed the outlet to a catchment situated almost entirely within the Ngoye Nature Reserve (Figure 3,3). This catchment shares a common divide with W1H016 and is situated in the same geological structure (Hope and Mulder, 1979). Situated at the same altitude and in such close proximity, these two catchments (W1H016 & W1H031) must also share a similar climate. Consequently, this control structure was adapted (Appendix III) to monitor discharge from the predominantly natural grassland system for direct comparison with the disturbed catchment W1H016.

The weir structure, rating table and other relevant information is given in appendix III. Hourly and daily discharge, rainfall and stilling well temperature have been obtained and published under separate cover (Kelbe, 1990).

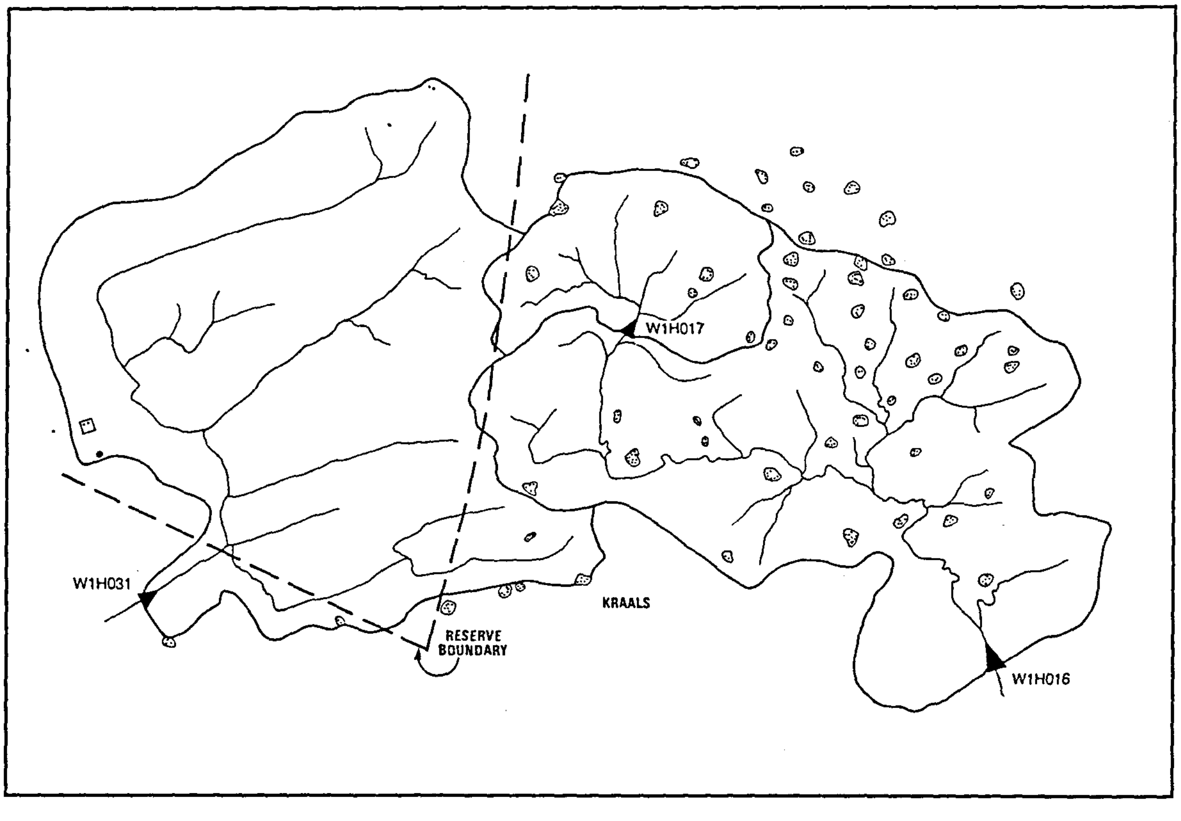


Figure 3.3. Stream network and location of dwellings in W1H016 & W1H031. Data from aerial photographs in 1976.

approximately one third of the peak summer amounts.

The annual total rainfall series for station 622 since 1938 and the coefficients of variation (CV) are shown in Figure 4,2. Spectral analyses of this annual and corresponding monthly rainfall series confirms the cyclical nature of the rainfall along the east coast found in other South African series by Tyson (1986) and Kelbe et al (1982). The annual cycle dominates but there is a strong indication that the 18 year cycle is also significant.

4.1.2 HOURLY RAINFALL

The total rainfall for each **hour** of the day, accumulated over each calendar month, have been plotted for each month since September 1989 when the tipping bucket raingauges were installed at weirs

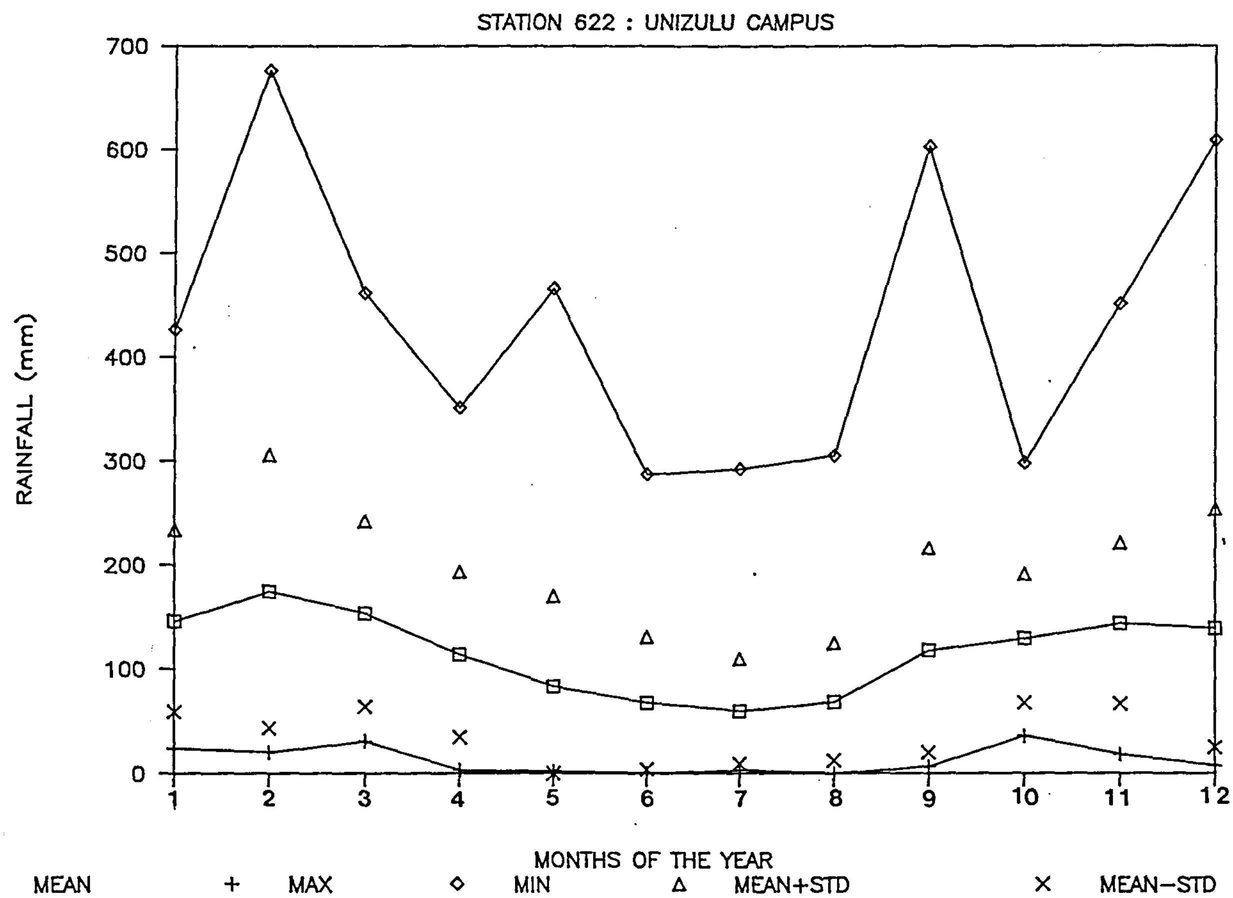


Figure 4,1 **Seasonal variation in monthly rainfall at station 622, University of Zululand campus.**

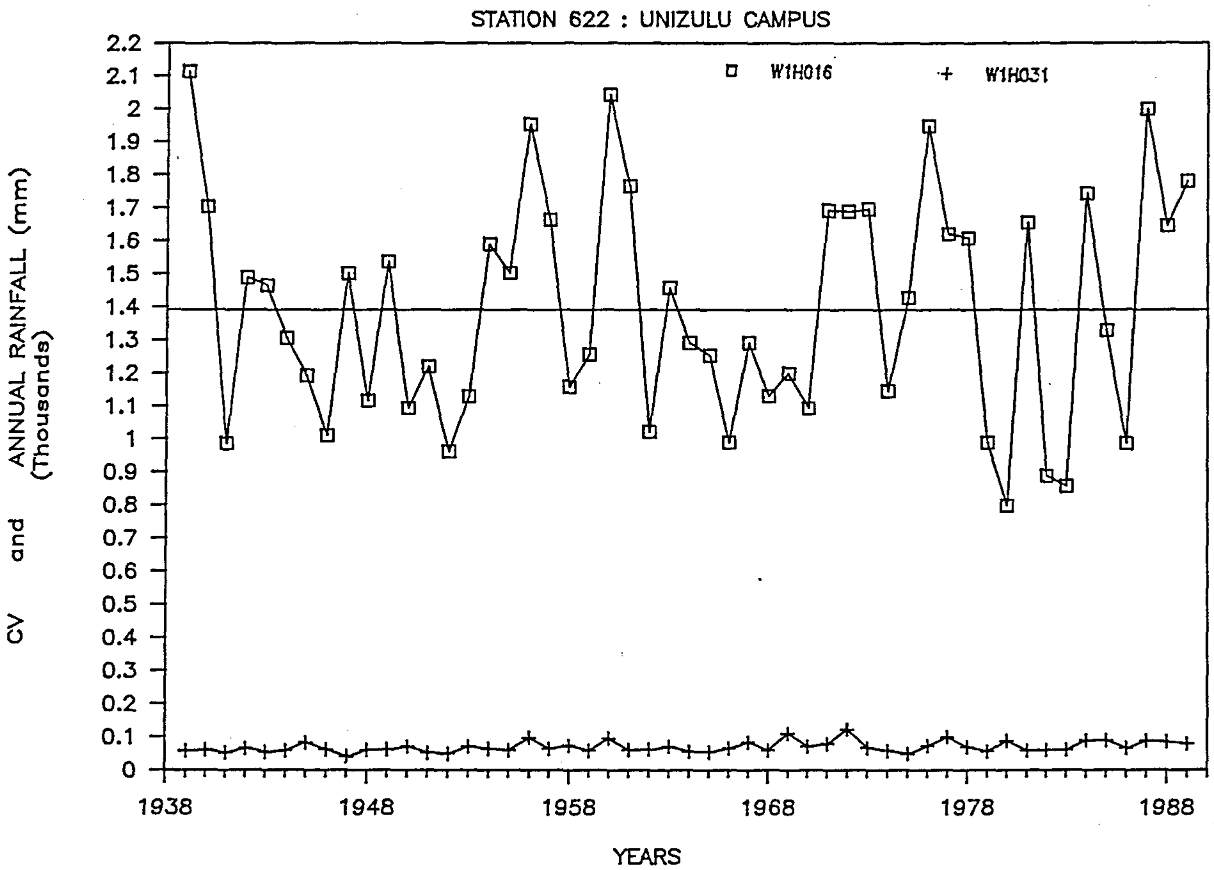


Figure 4,2 **Annual total rainfall and coefficients of variation series since 1938.**

W1H016 and W1H031 untill the end of 1989 (Figure 4,3 to Figure 4,6). A comparison of the hourly rainfall for the two stations show several large differences between the rainfall at the outlets to the two catchments, particularly during October and December. Despite the large differences between the two stations, the diurnal nature of the rainfall is evident in several months, particularly the late summer months (January to April) when the tropical influence is dominant in this region. In winter the low rainfall is evenly distributed throughout the day reflecting widespread frontal activity.

In the early summer months (October to December) the weather is influenced by the middle latitude frontal systems which often are preceded by intense cumulonimbus activity. However, Kelbe (1982) and Garstang et al (1986) have shown that the intensity of

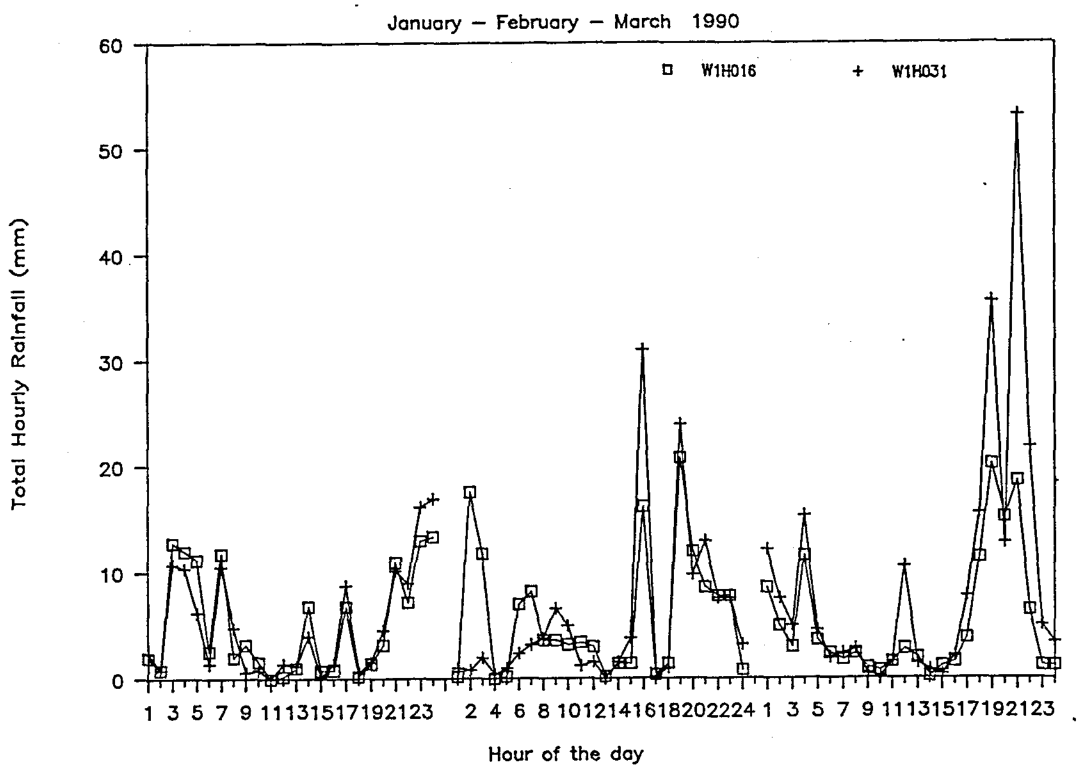


Figure 4,3 **Diurnal variation in total hourly rainfall at W1H016 and W1H031 for January, February and March.**

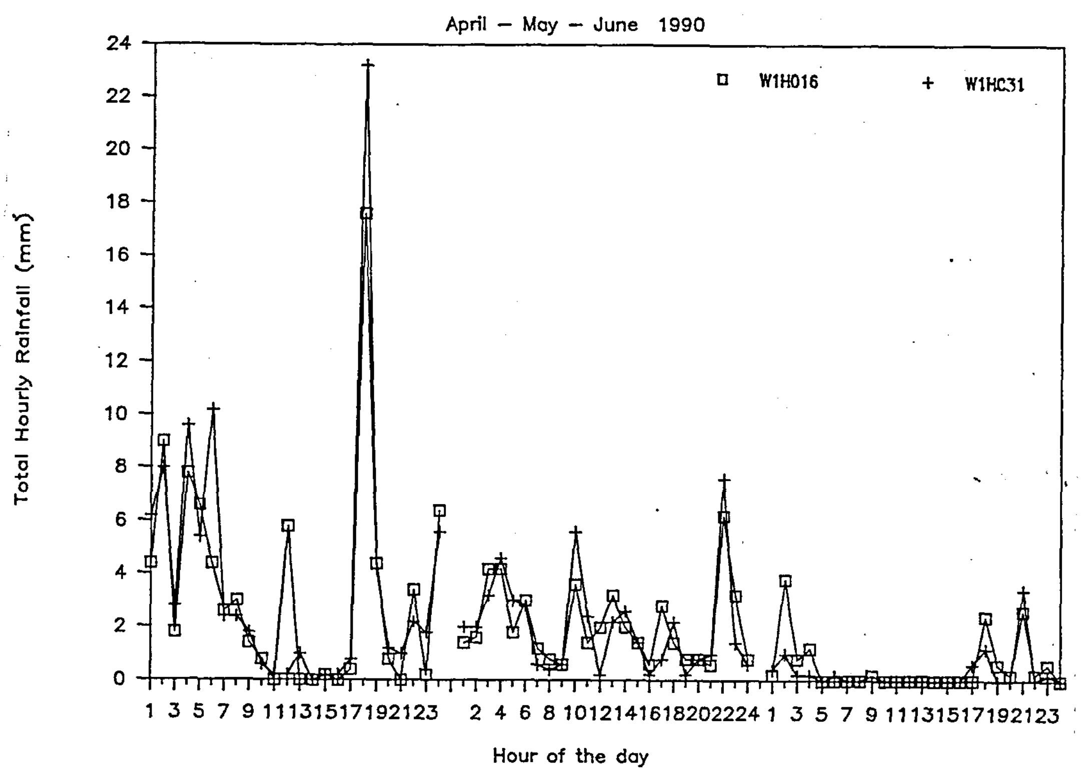


Figure 4,4 **Diurnal variation in total hourly rainfall at W1H016 and W1H031 for April, May and June.**

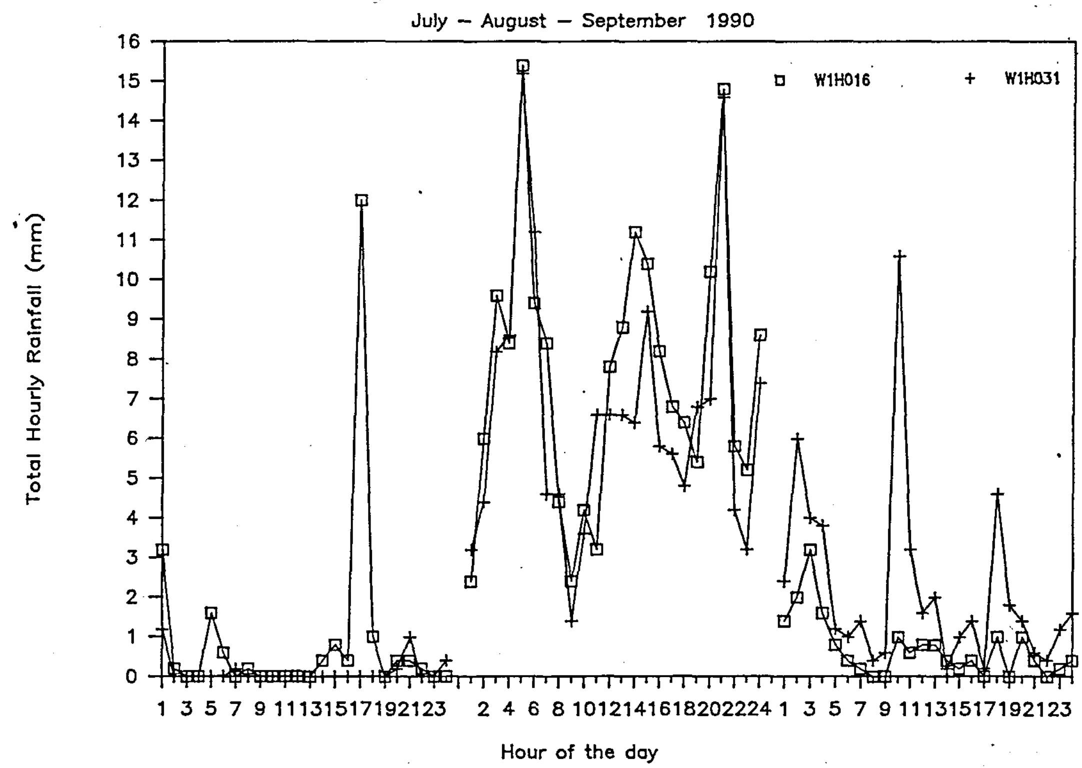


Figure 4,5 **Diurnal variation in total hourly rainfall at W1H016 and W1H031 for July, August and September.**

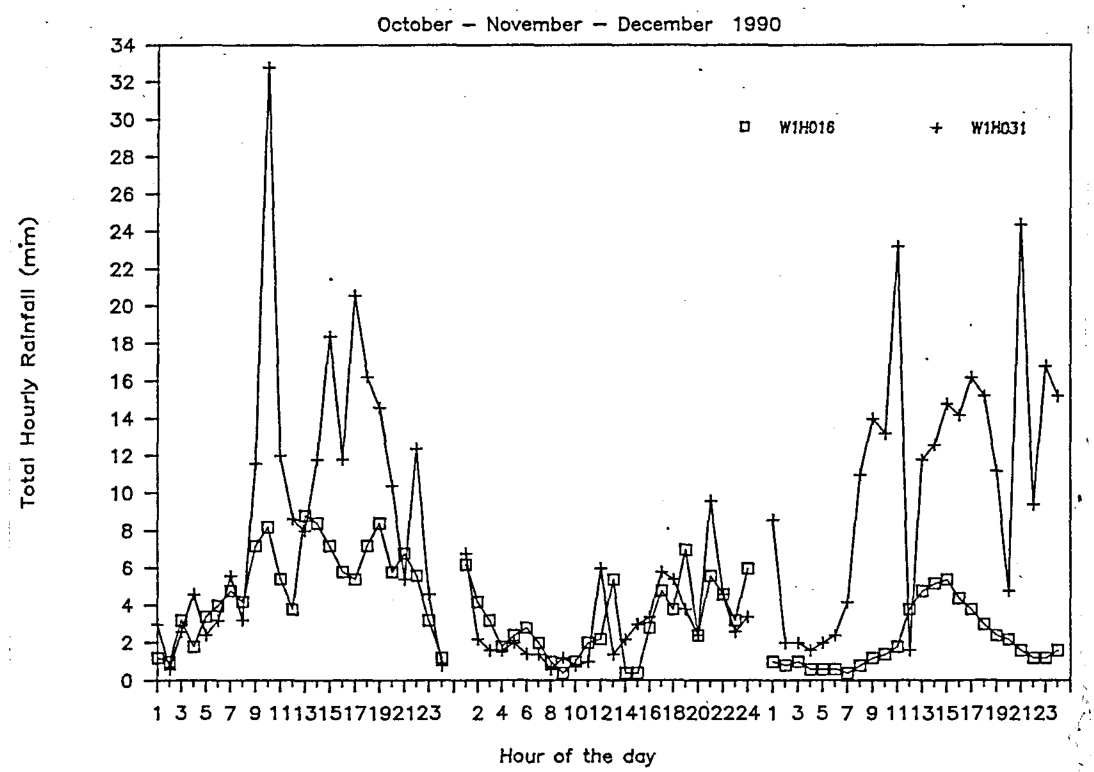


Figure 4,6 **Diurnal variation in total hourly rainfall at W1H016 and W1H031 for October, November and December.**

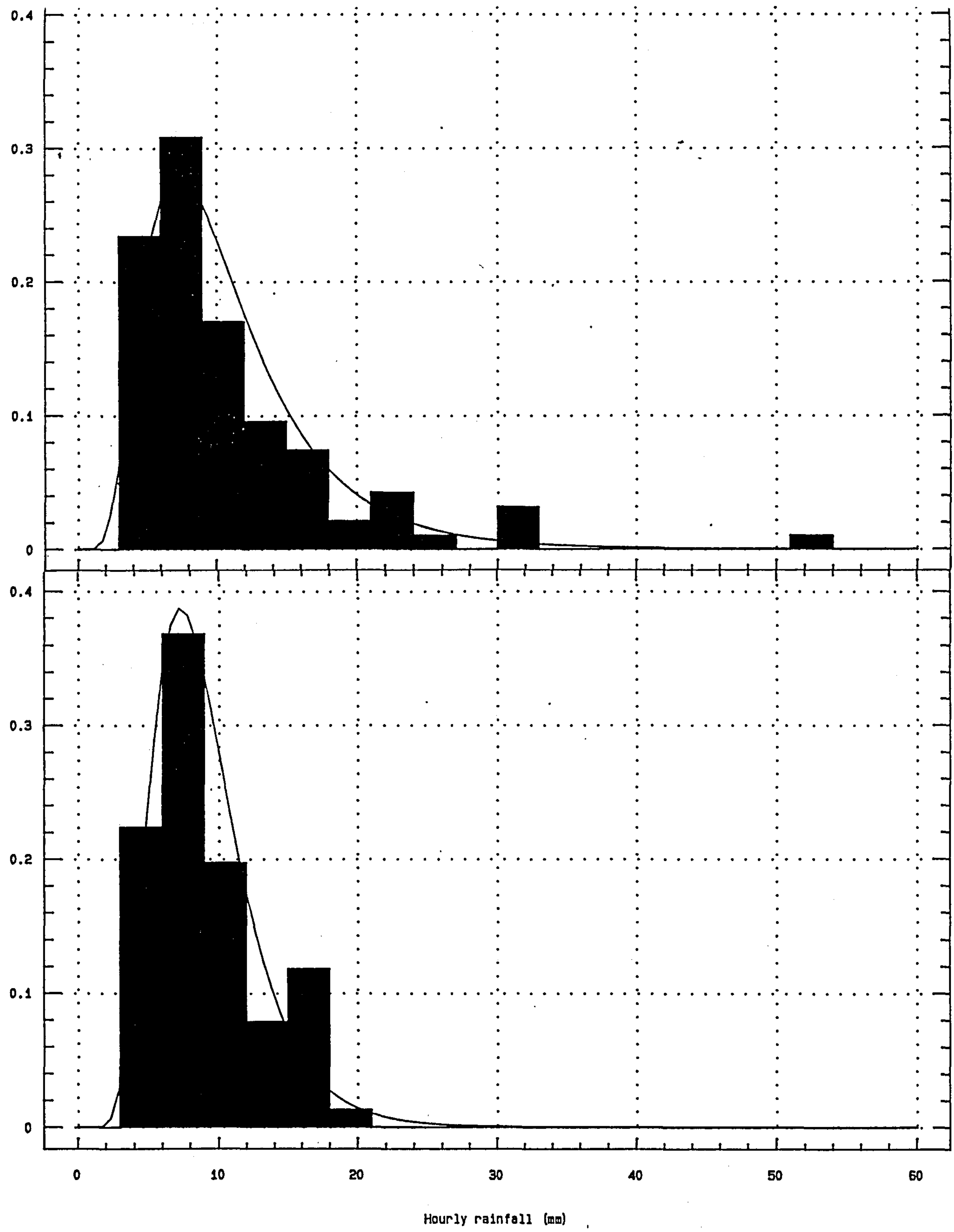


Figure 4,7 Frequency analysis of hourly rainfall rates exceeding 5mm/hr for W1H016 and W1H031.

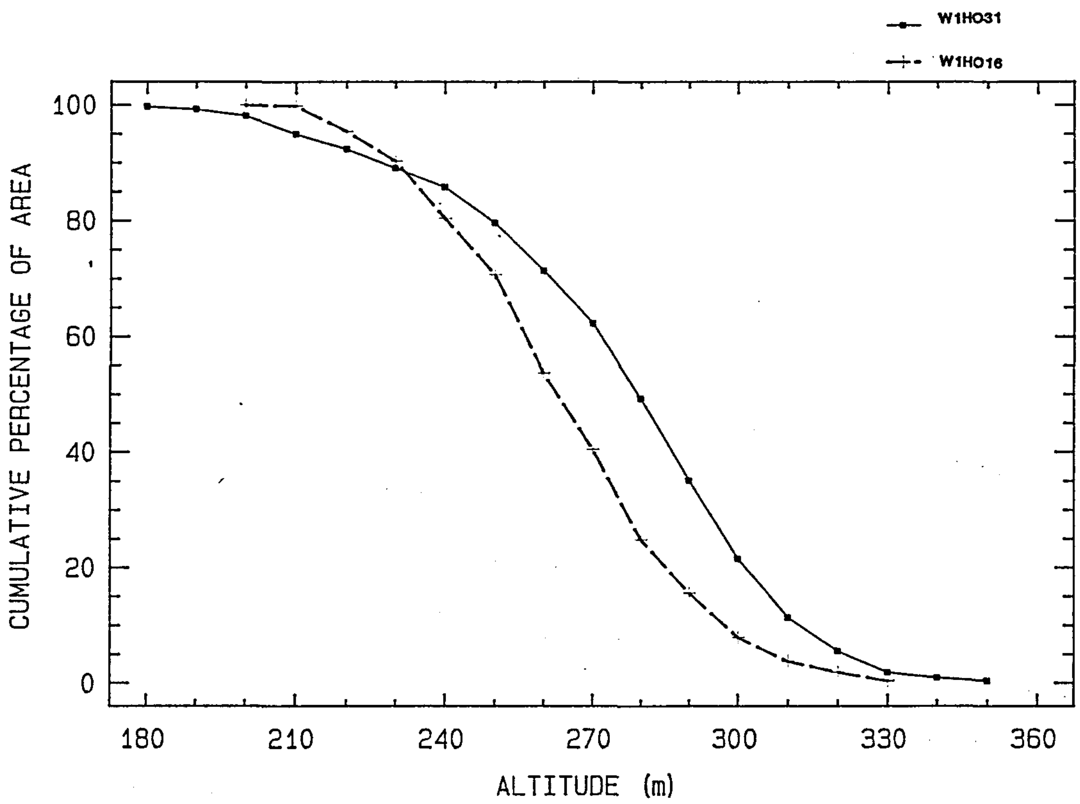


Figure 4,8 **The relative area of contour heights for catchments W1H031 (solid line) and W1H016 (dashed line).**

the bisector. The slope lengths were estimated along the slope lines and the average value determined. An estimate of the area representing each slope profile was then derived for specified classes of slope along the stream course (Figure 4,9). The relative area of each class of slope for both the catchments shows almost identical distribution (Figure 4,10). The disturbed catchment, W1H016, has approximately 10% more area with slopes of between 10° and 20° with a correspondingly lower frequency of slopes of below 10°. However, the relative areas of slopes steeper than 15° are almost identical for both catchments.

4.3 SOILS

Soils also have a significant role in the hydrological response of a catchment. Deep sandy soils with a high infiltration rate will tend to induce greater attenuation

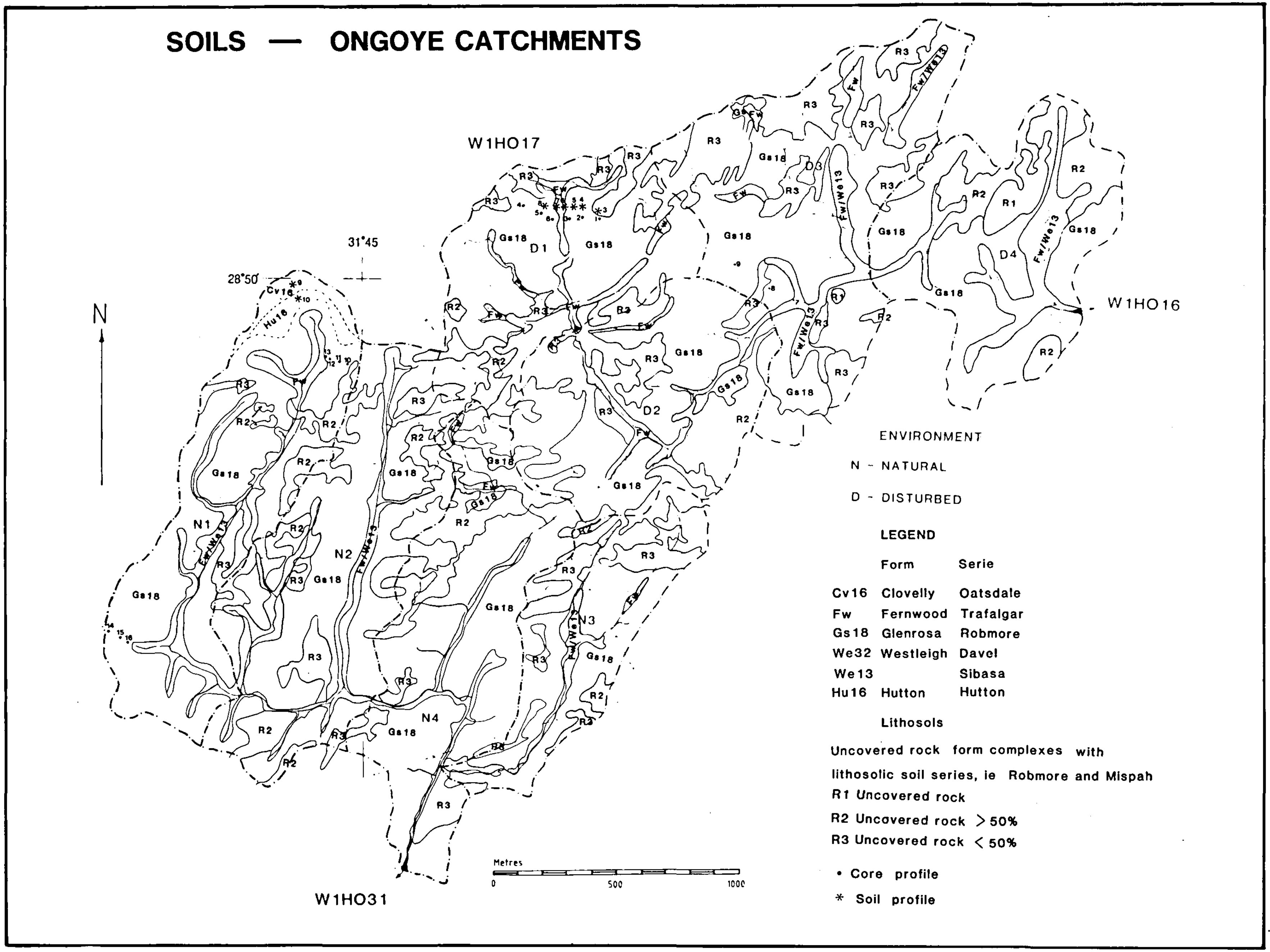


Figure 4,11 The distribution of soil series and lithosolic complexes in catchments W1H016 and W1H031 where N(w) is the number of streams of order w, L(w) is the mean length of order w, and A(w) is the mean area of the basin order w. R_B, R_L, and R_A represent the bifurcation ratio, the length ratio, and the area ratio.

Rodriquez-Iturbe and Valdes (1979) derive a dimensionless product $g = 0.58(R_B/R_A)^{0.55} * R_L^{0.05} = Q_p \cdot t_p$ which can describe the GIUH in terms of Q_p (the peak discharge) and t_p (the time to peak). They claim that g is a dimensionless ratio which is independent of the storm characteristics and which is intimately linked to the geomorphology of the watershed and to its hydrologic response structure. Consequently, the geomorphologic and physiographic parameters were derived for both catchments to enable a direct comparison in order to identify any hydrological response which could be attributed to factors other than land use.

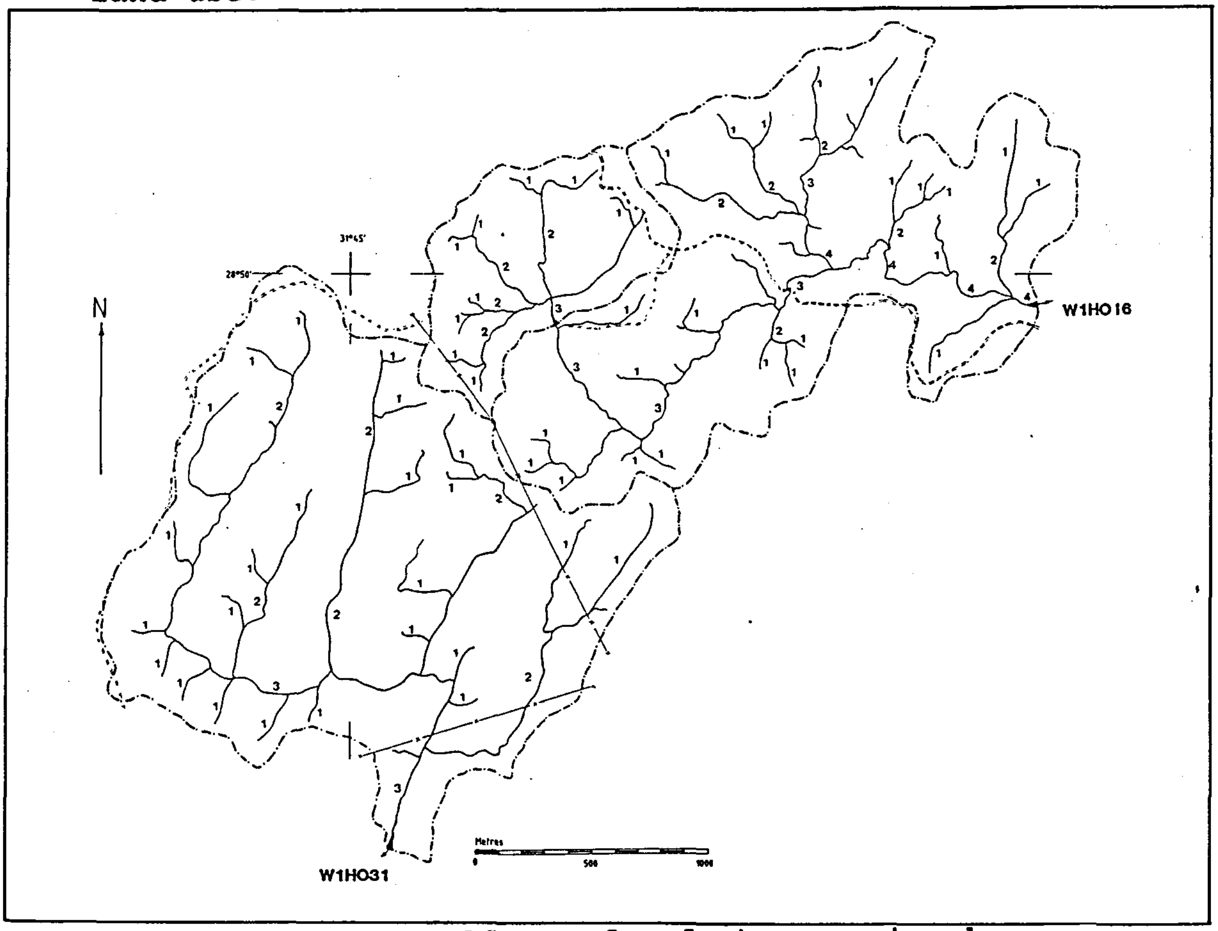


Figure 4,13 Strahler ordered stream network

Table 4,3 HORTONIAN NUMBERS FOR BOTH CATCHMENTS

	W1H016				W1H031		
ORDER	1	2	3	4	1	2	3
N(w)	22	6	2	1	19	4	1
L(w)	8.10	11.38	14.23	15.55	7.37	12.88	13.91
A(w)	2.06	2.90	3.03	3.23	1.78	2.80	3.19

(natural catchment) but three distinct peaks for W1H016 (disturbed catchment). This morphological difference is shown, in section 8, to produce clear differences between catchments in their peak discharges for certain rainfall events.

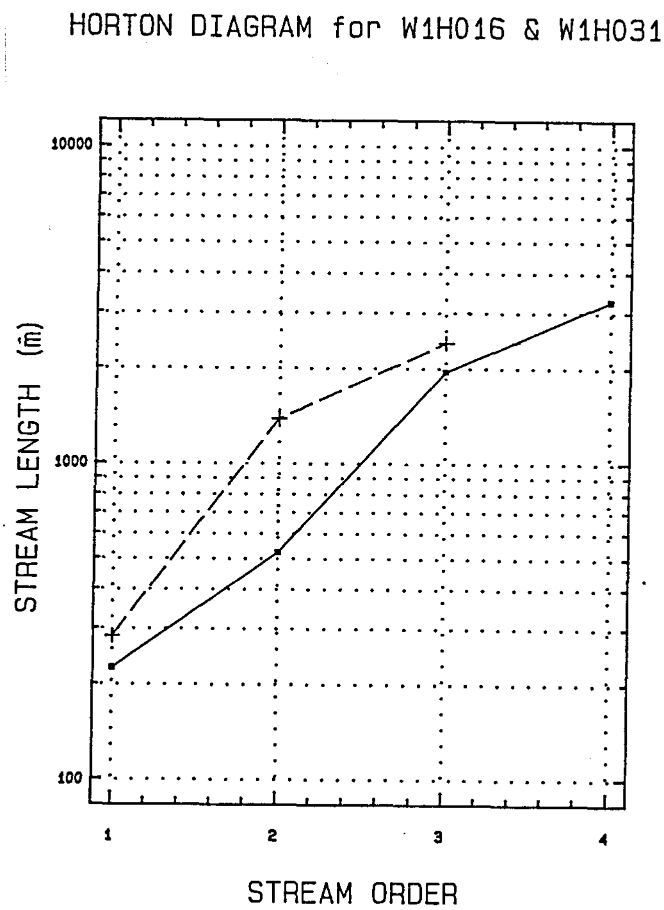


Figure 4,14 Stream length Horton diagram for catchments W1H016 and W1H031

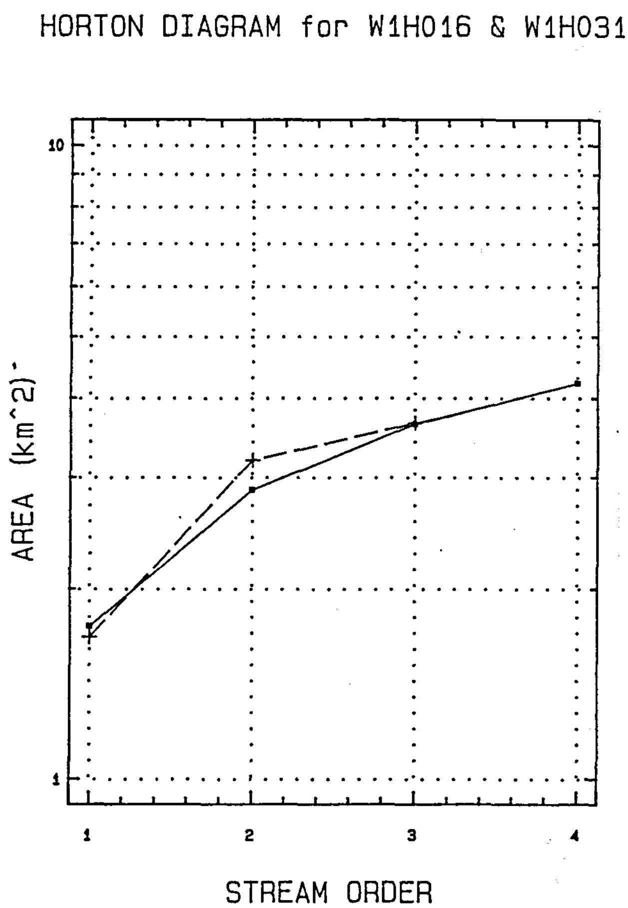


Figure 4,15 Stream area Horton diagram for catchments W1H016 and W1H031

Table 4,4 PROPERTIES OF THE CATCHMENT GEOMETRY

	CATCHMENT	W1H016	W1H031
A	Area of catchment (km^2)	3.23	3.19
L_b	Length main tributary (km)	4.25	4.00
P	Perimeter (km)	9.55	8.57

HORTON DIAGRAM for W1H016 & W1H031

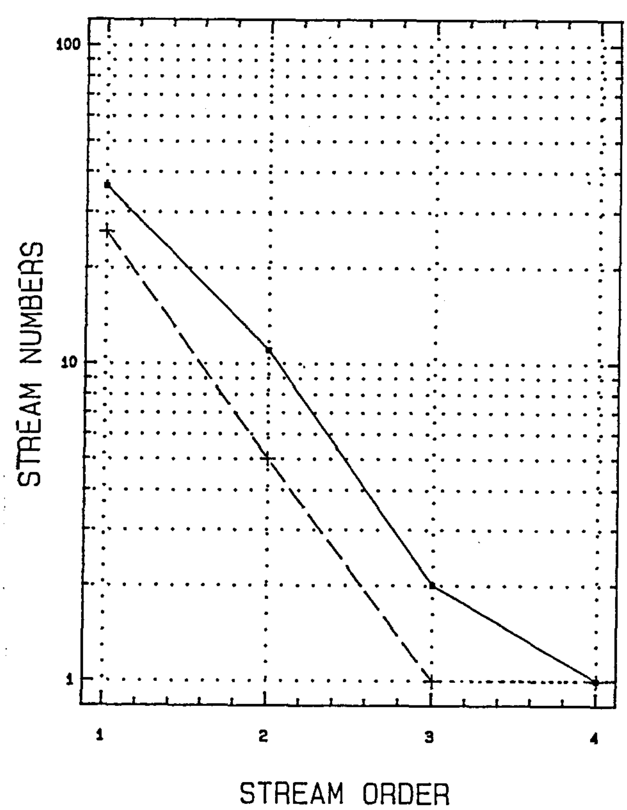


Figure 4,16 Stream numbers Horton diagram for catchments W1H016 and W1H031

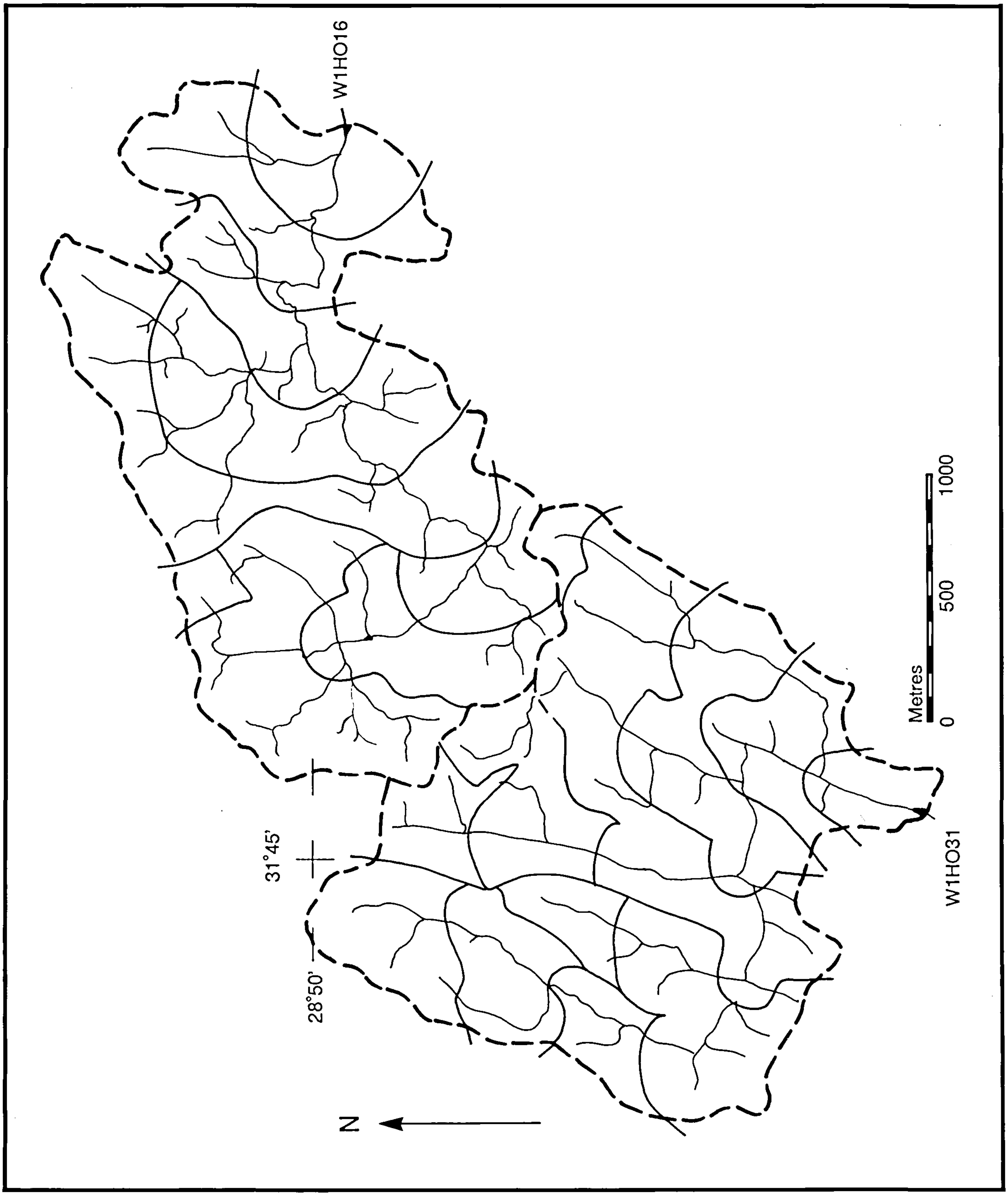


Figure 4,17 Areal map showing streams and isochrones.

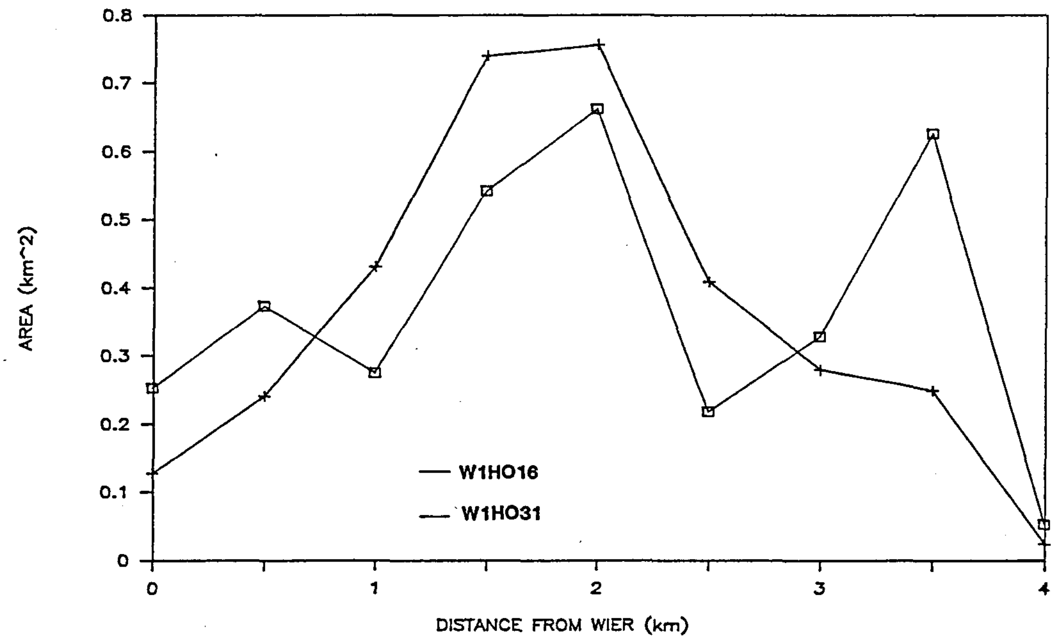


Figure 4,18 **Area contained within selected isochrones.**

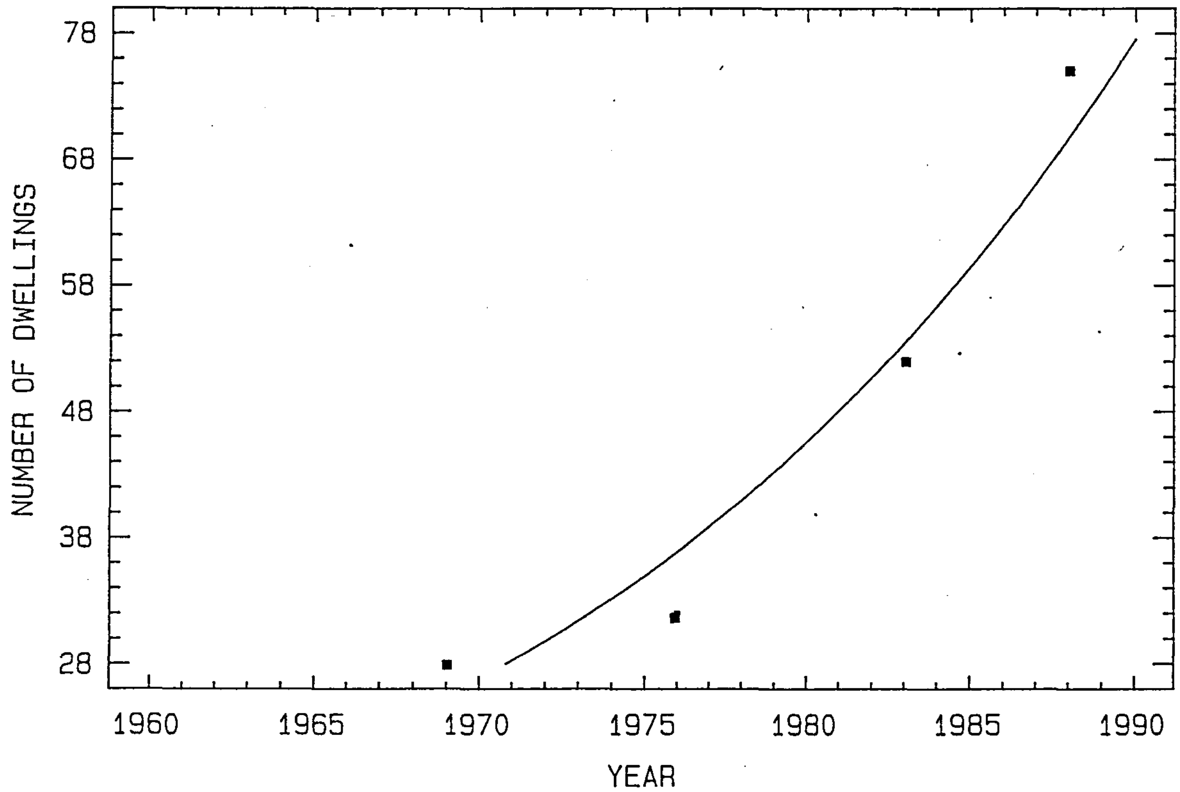


Figure 5,1 Temporal changes in the number of dwellings in W1H016.

The huts are generally located (Table 5,4) on the slopes (85%) although several (15%) were located on the crests of the hills. None of the respondents resided in the valley bottoms.

Table 5,4 Kraal locations

Kraal location	Freq %
Crest	15
Upper slope	50
Lower slope	35
Foot slope	0
Bottom lands	0

With an average of three people per hut this indicates that there are estimated to be approximately 3*300 people (300 people/km^2) in this catchment (W1H016). If the hut count continues to treble every 15 to 20 years, then the population in this catchment at the turn of the century is expected to be approximately 3*900 people (900 people/km^2). This increase is considered to be due to the natural birth rate of the present inhabitants. With the expected influx of people to the urban fringe areas around the metropolitan areas in this region, this catchment is expected to witness

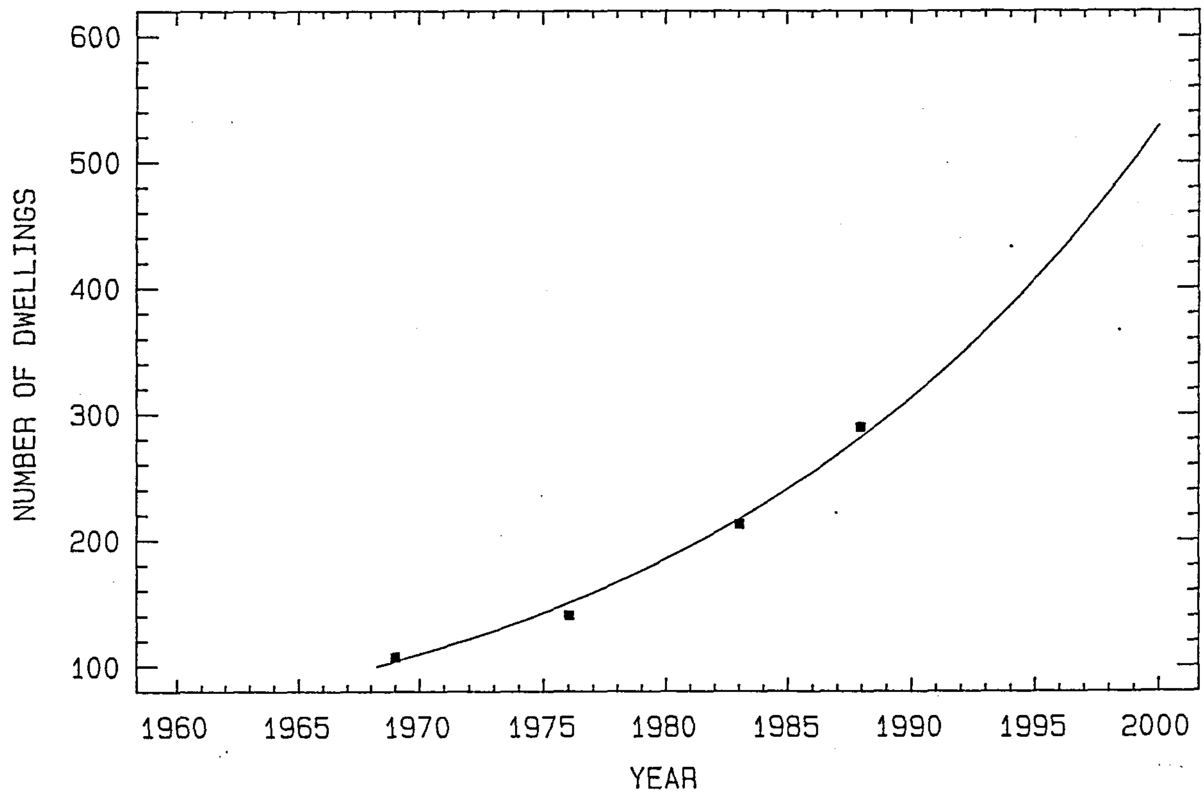


Figure 5,2 **Temporal changes in the number of dwellings in W1H017.**

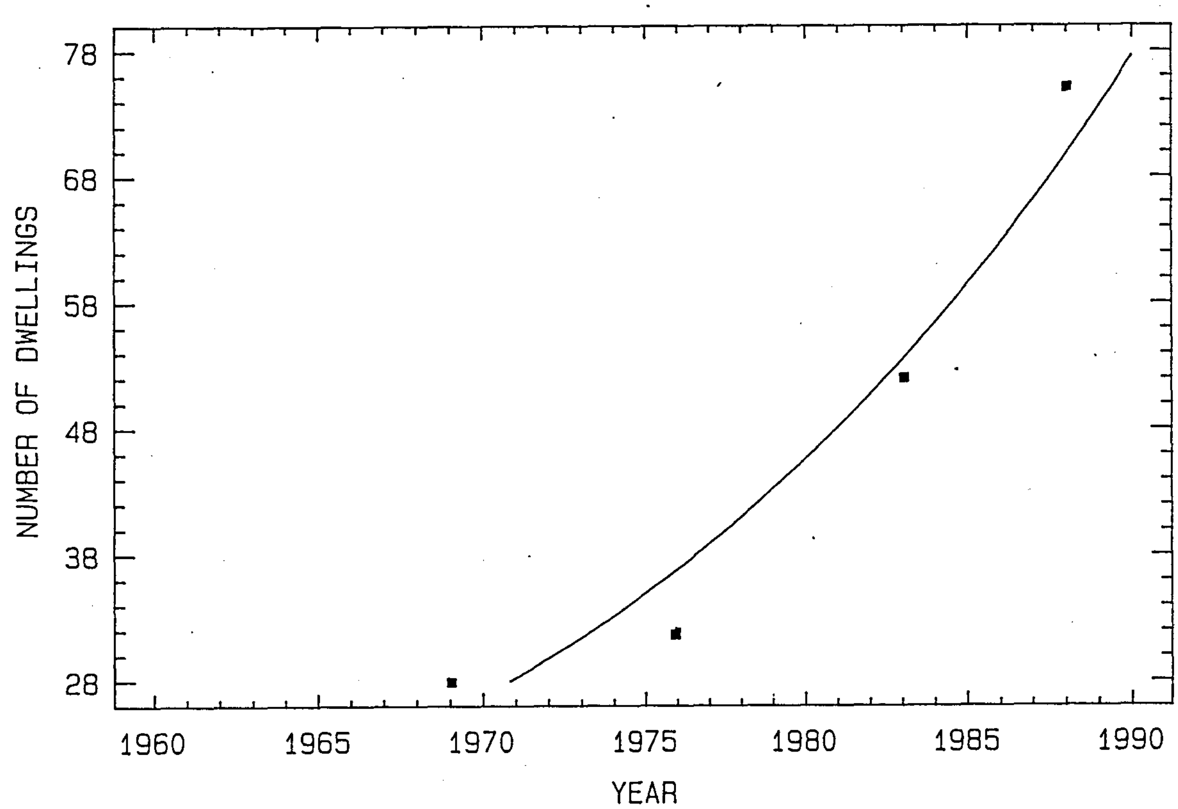


Figure 5,3 **Temporal changes in the number of dwellings in W1H031.**

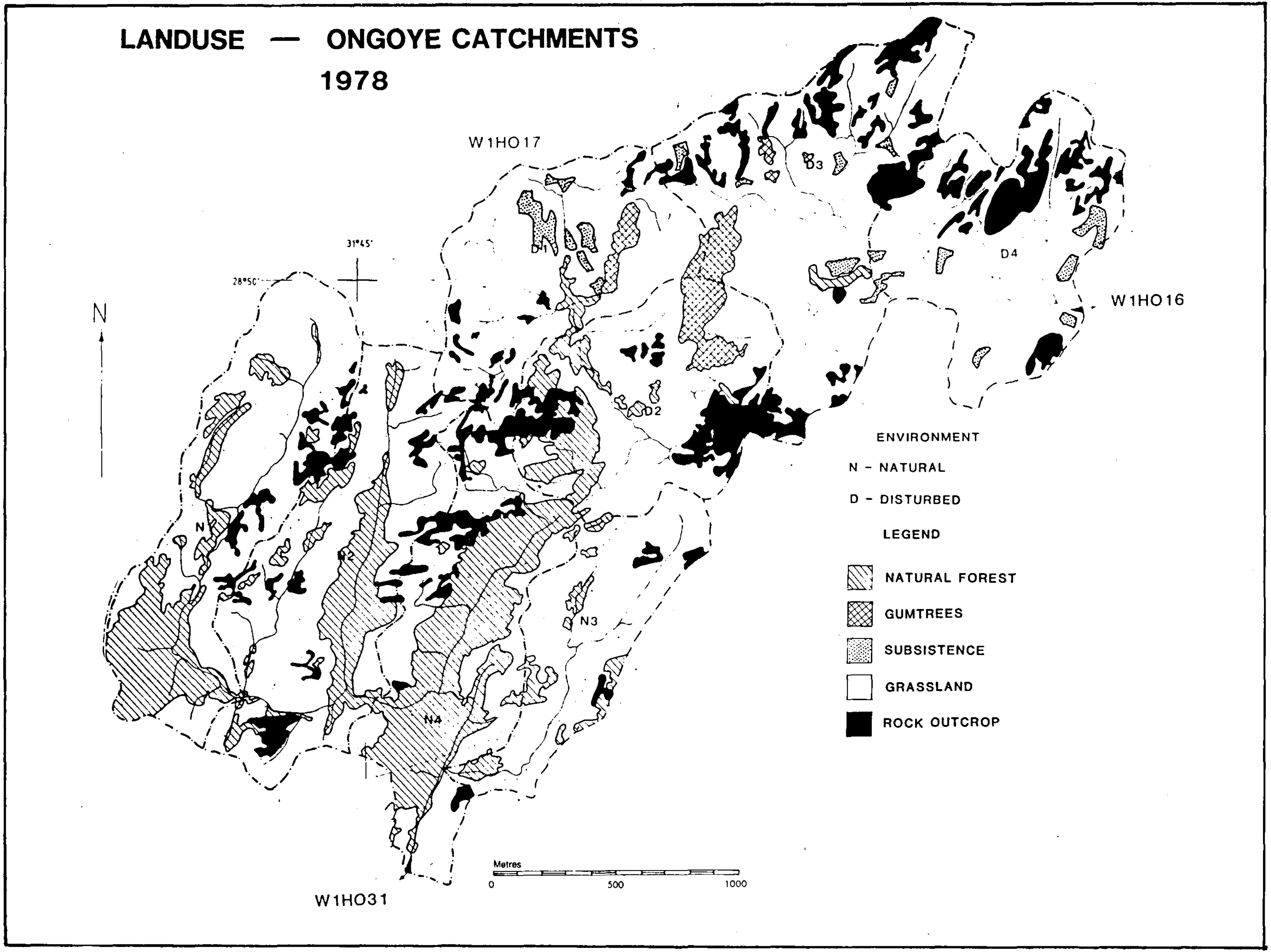


Figure 5,4 The landuse distribution in catchments W1H016 and W1H031 in 1978

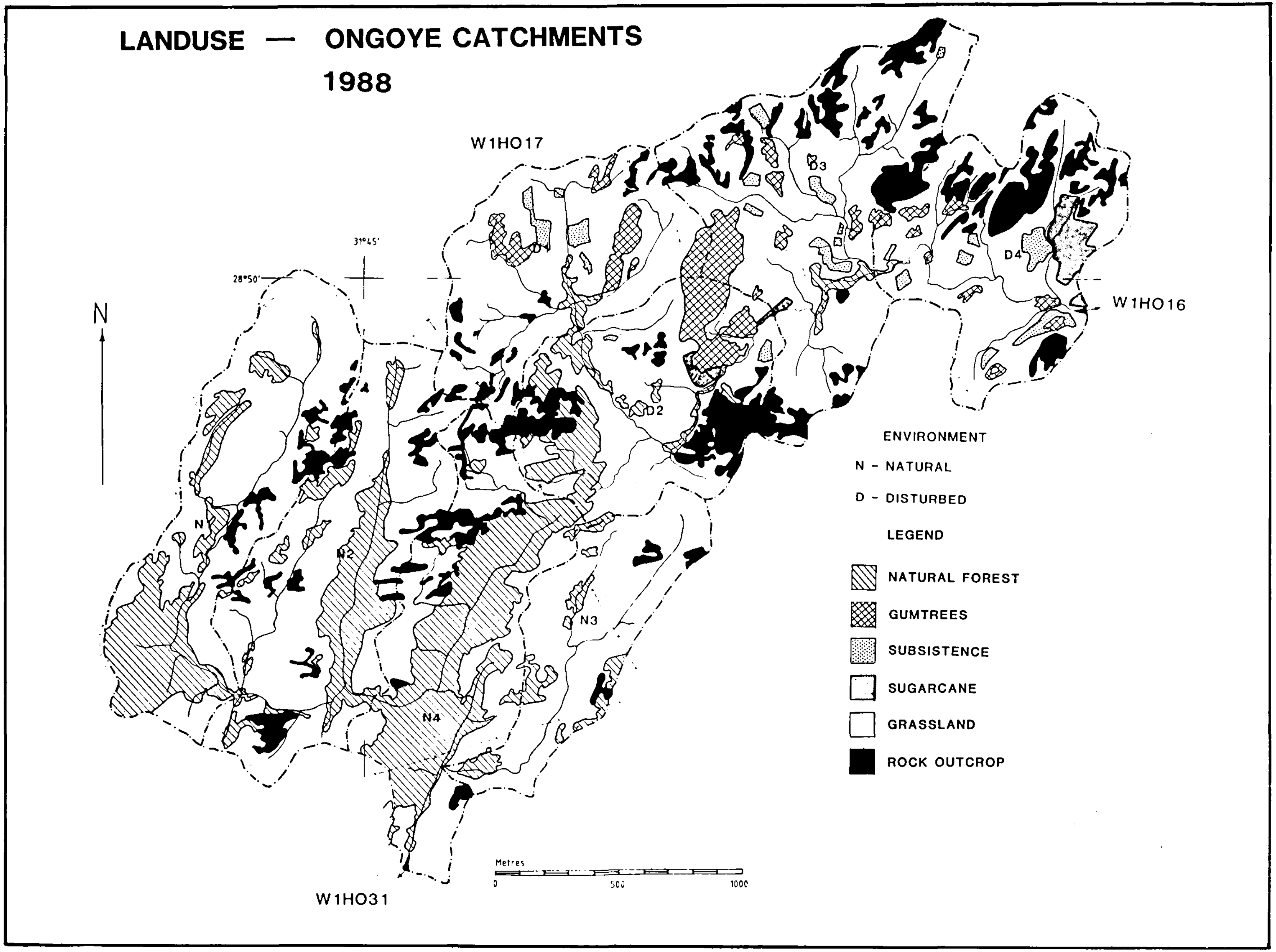


Figure 5,5 The landuse distribution in catchments W1H 016 and W1h031 in 1988

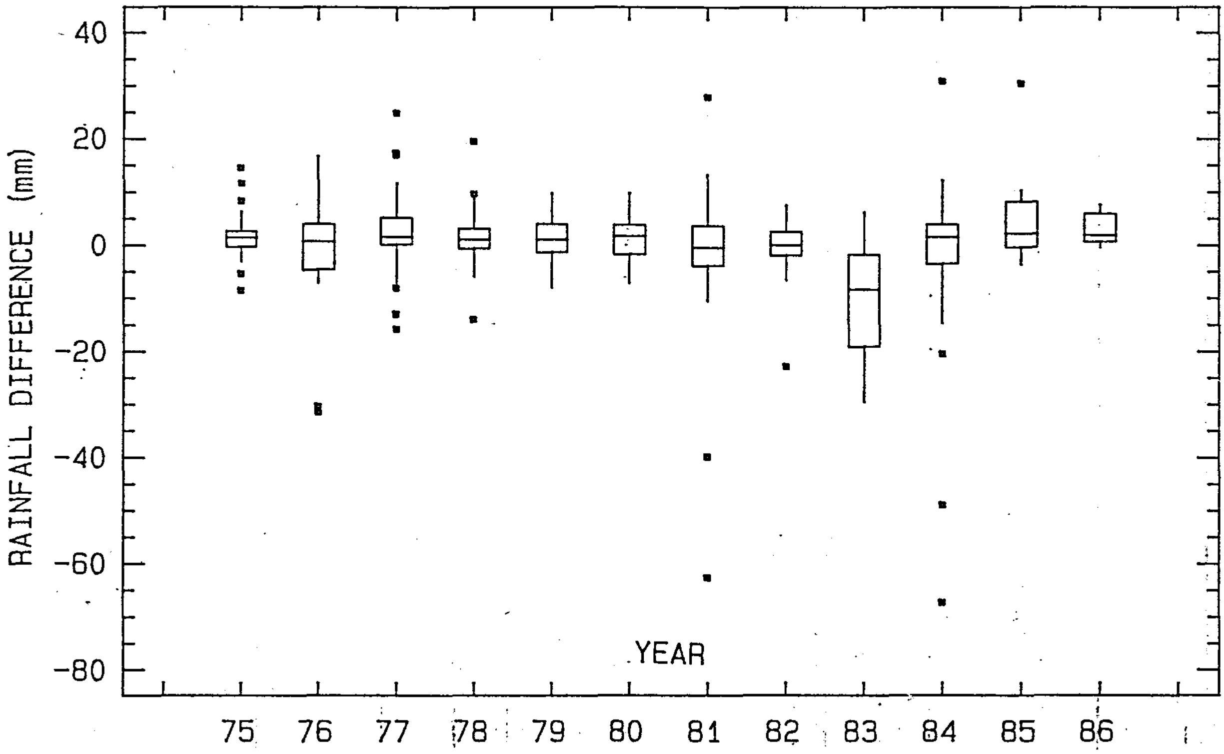


Figure 6,1 **Box and whisker plot of the difference between total rainfall accumulated per storm event at raingauges 470 and 501.**

exception of 1983, these two stations show similar depth of rainfall (per storm) over the period of measurement. The mean difference is close to zero with the upper and lower quartiles generally within 5mm. From this comparison it appears that station 470 has more rainfall per events than 501 since the mean difference is nearly always positive.

The difference in the storm duration (Figure 6,2) shows considerable variability over the years particularly after 1982. However, the mean difference is close to zero except in 1982 and 1983.

The variability in T_5, the chronological order of rainfall accumulation of 5 mm, is shown in Figure 6,3. The data after 1983 shows considerably more variability than the data prior to 1983. The mean differences in accumulation time in 1983, 1985, 1986 and 1988 appear to be approximately 60 minutes as opposed to a mean of less than 30 minutes in all other years. Consequently, temporal analyses utilising the time of a specific event is questionable. [NB any similarity in duration and depth

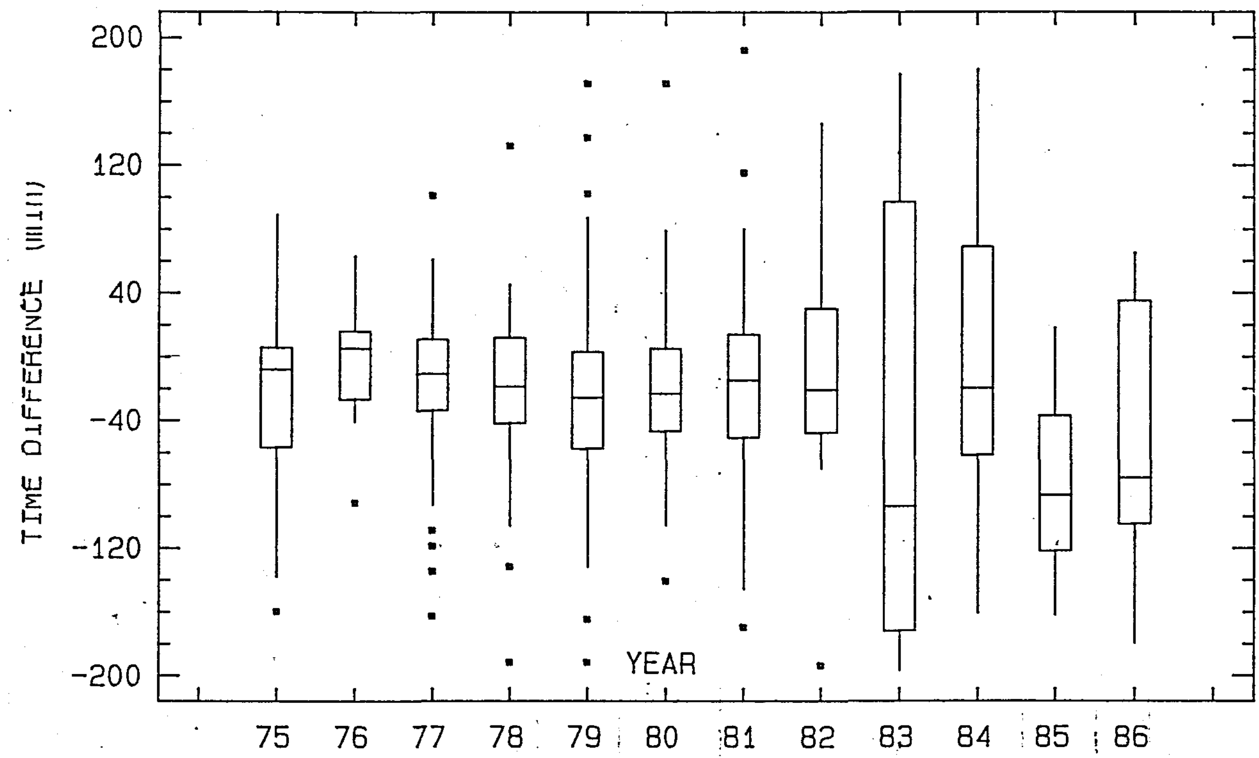


Figure 6,2 **Box and whisker plot of the annual variability in the difference between duration of each storm at raingauges 470 and 501.**

reflects accuracy in clock settings. Poor accuracy in accumulation time reflects difference in the time of clocks (synchronization)] Since there is such a poor correlation in the time factors of this data, it is considered inappropriate to examine, in detail, procedures that rely on the synchronization of the autographic instruments.

6.2 DOUBLE MASS PLOTS

Double mass plots have frequently been used to test rainfall and runoff records for nonhomogenuity (Schulz, 1976). They have also been used to identify the effects of land use (Braune and Wessels, 1980). This method plots the cumulative record of one station against the cumulative record of one (or more) other station(s). The record being tested should , if possible, be compared to at least 4-5 base station records of either rainfall or runoff. Because of the very limited length of record in this study and problems associated with missing data, it was decided to consider runoff from W1H014, an indigenous forest catchment in close proximity to W1H016 (Figure 1,2) as the base station. Only runoff was considered and not rainfall because of the problem associated with missing data and other recognized inherent errors in point source measurement of spatially variable fields. For the case of missing discharge data, the entire daily flow for both stations could be discarded from BOTH records under comparison. This assumes that the response of the two catchments are the same and are less than 24 hours. This is clearly the case for the small catchments under investigation in this project.

Cumulative DAILY total runoff and the cumulative DAILY quickflow component, as generated by the program RUNOFF (Schulze and Arnold, 1980), were used for catchments W1H016 and W1H014. The accumulated daily runoff and the accumulated daily quickflow series from W1H014 was plotted against the corresponding accumulations series from W1H016 for two separate periods (Figures 6.4 & 6.5). Since W1H014

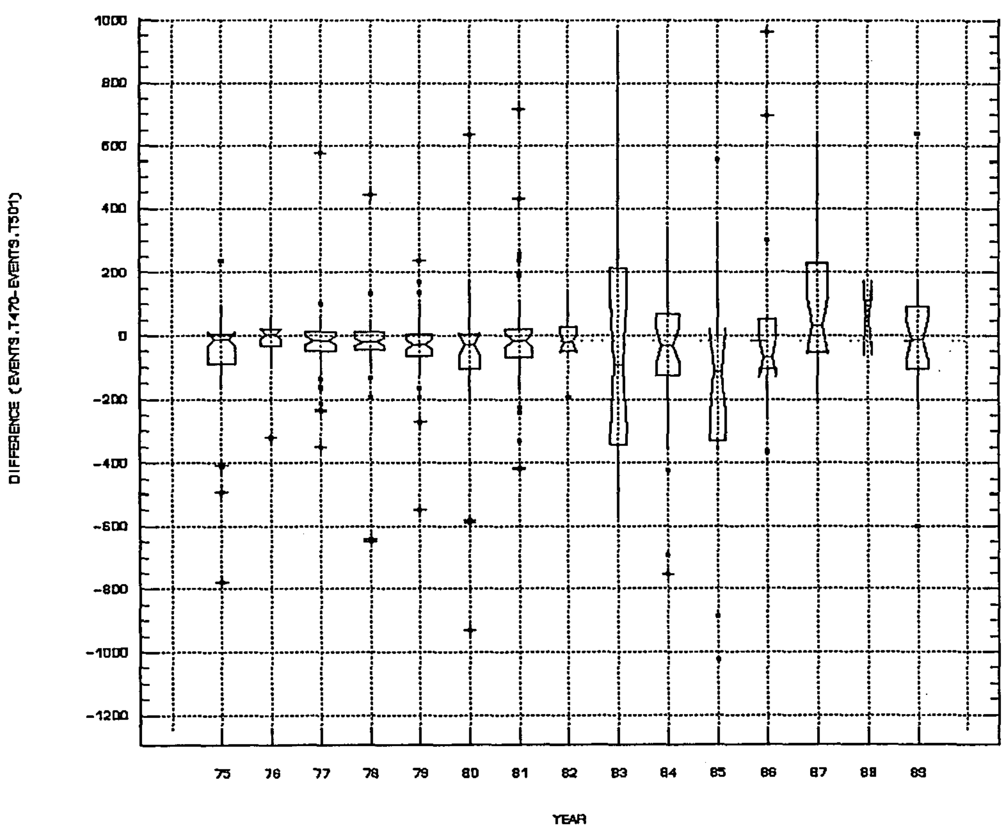


Figure 6,3 **Box and whisker plot of the annual variability in the difference between the time when 5 mm of rainfall had accumulated at raingauges 470 and 501 (stations 470 & 411 after 1987).**

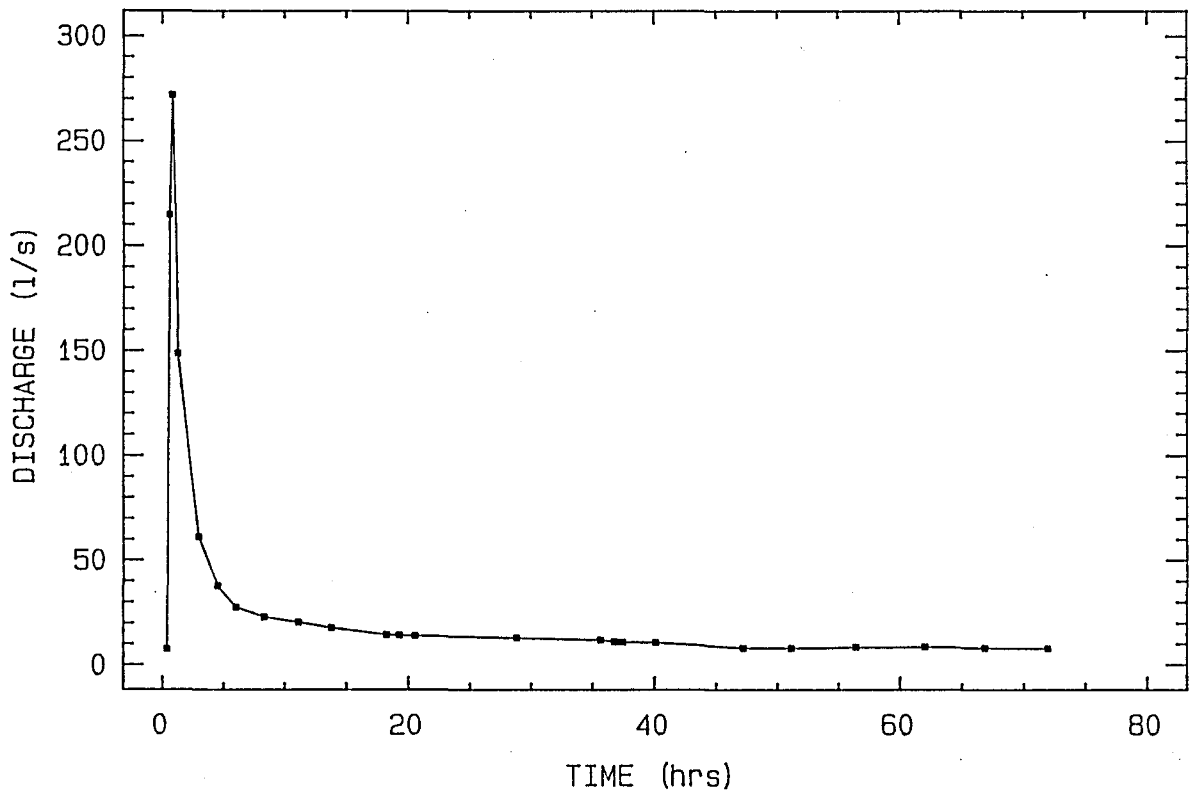
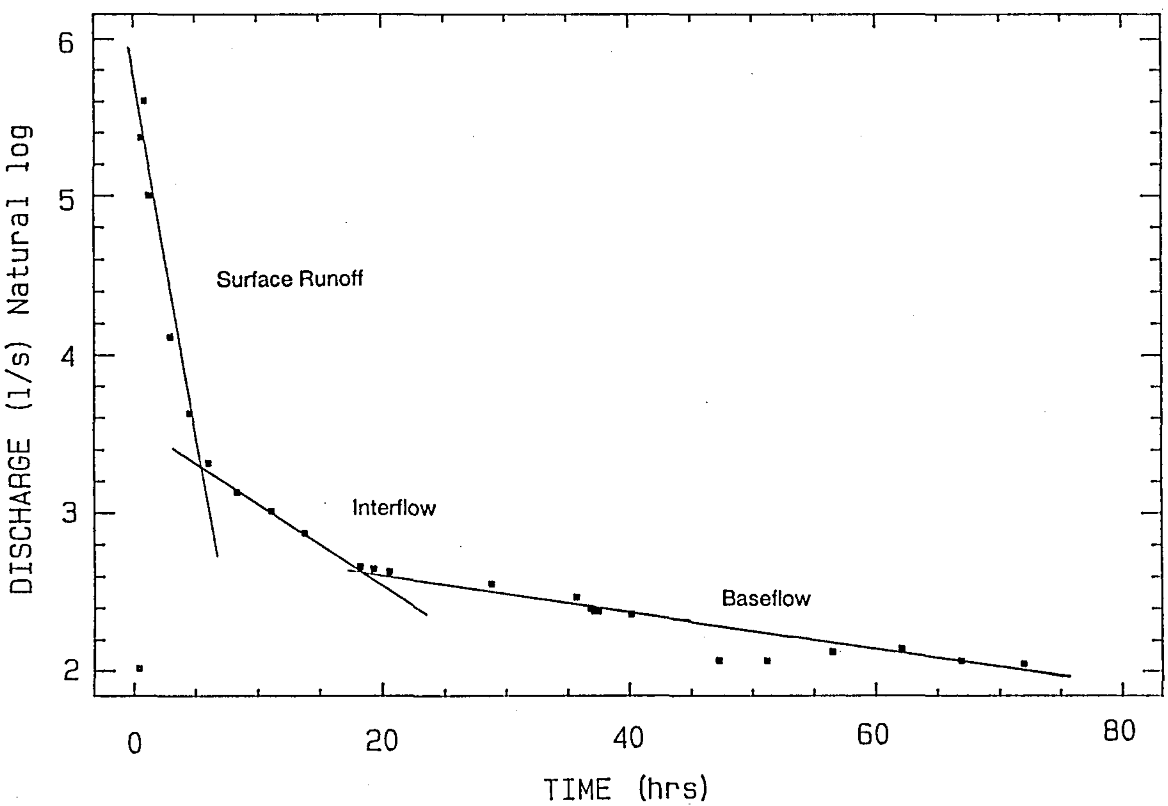


Figure 6.6 **An example of the logarithmic separation of the three components of a hydrograph.**



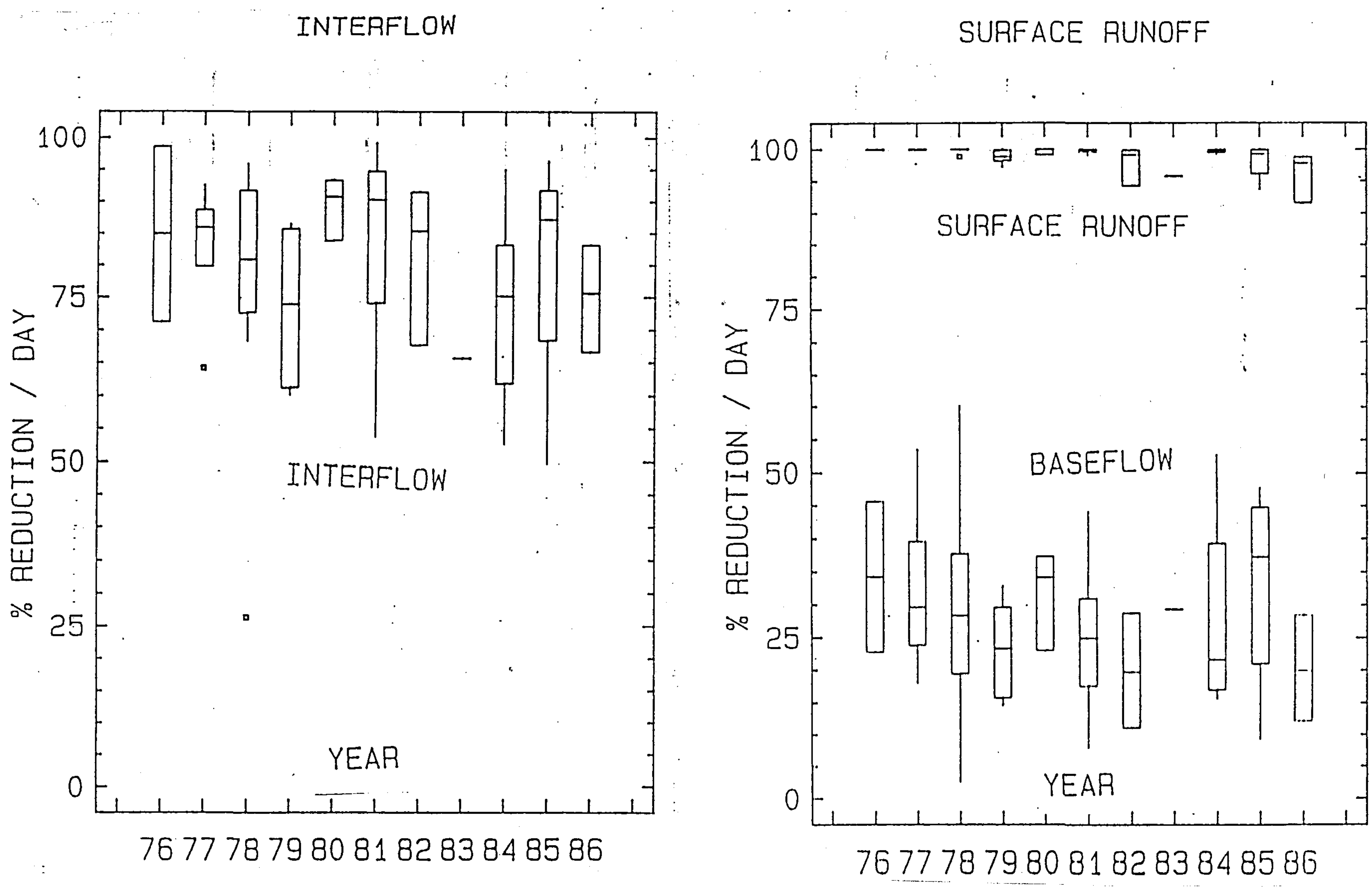


Figure 6.7 Annual variation in the recession coefficients.

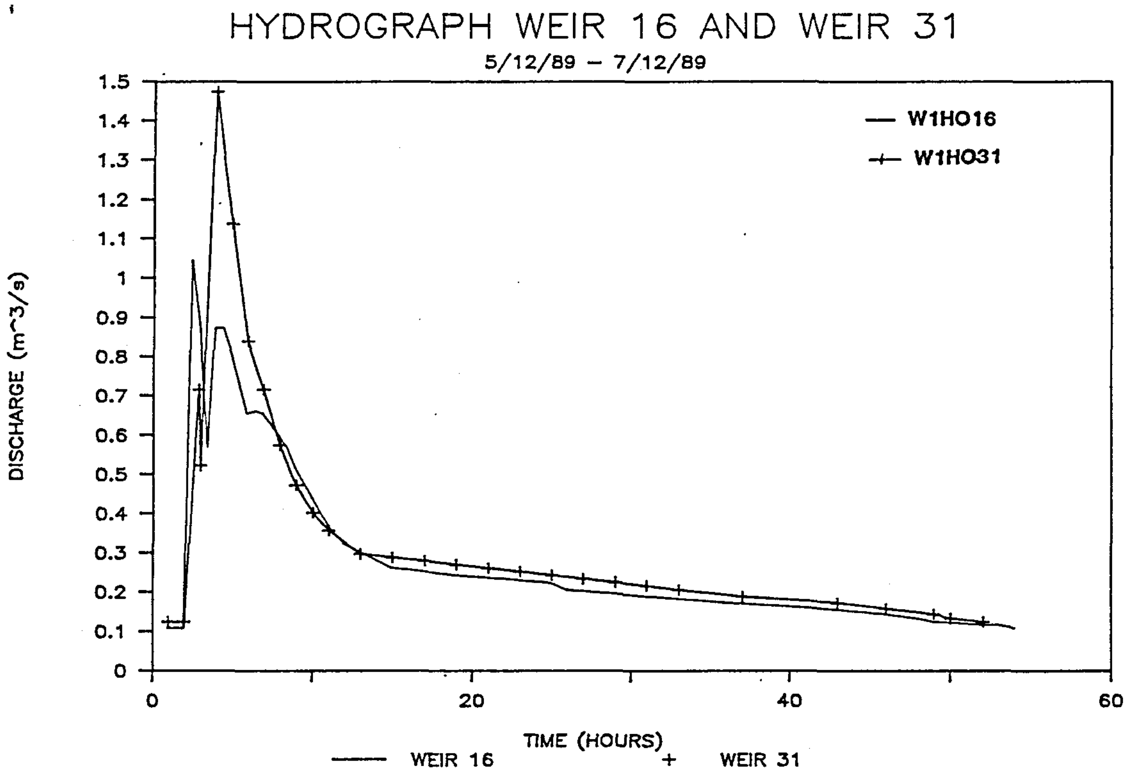


Figure 7.1 **An example of the discharge from W1H016 and W1H031 for very similar rainfall events at both weirs.**

certain comparisons. Consequently these events were included in the overall analysis because some comparisons would not be affected by the missing data. For example, missing data during the recession stage would not influence the peak discharge or time to peak estimates. However, these events have been identified where they influence the comparisons.

The total storm flow, the peak discharge rate and components of the quickflow were estimated for all storms that had similar rainfall. These estimates were then compared for W1H016 and W1H031. The **total stormflow** for both catchments (Figure 7.2) shows a good 1:1 relationship with the exception of three points. Two of these points have subsequently been found to include missing data during

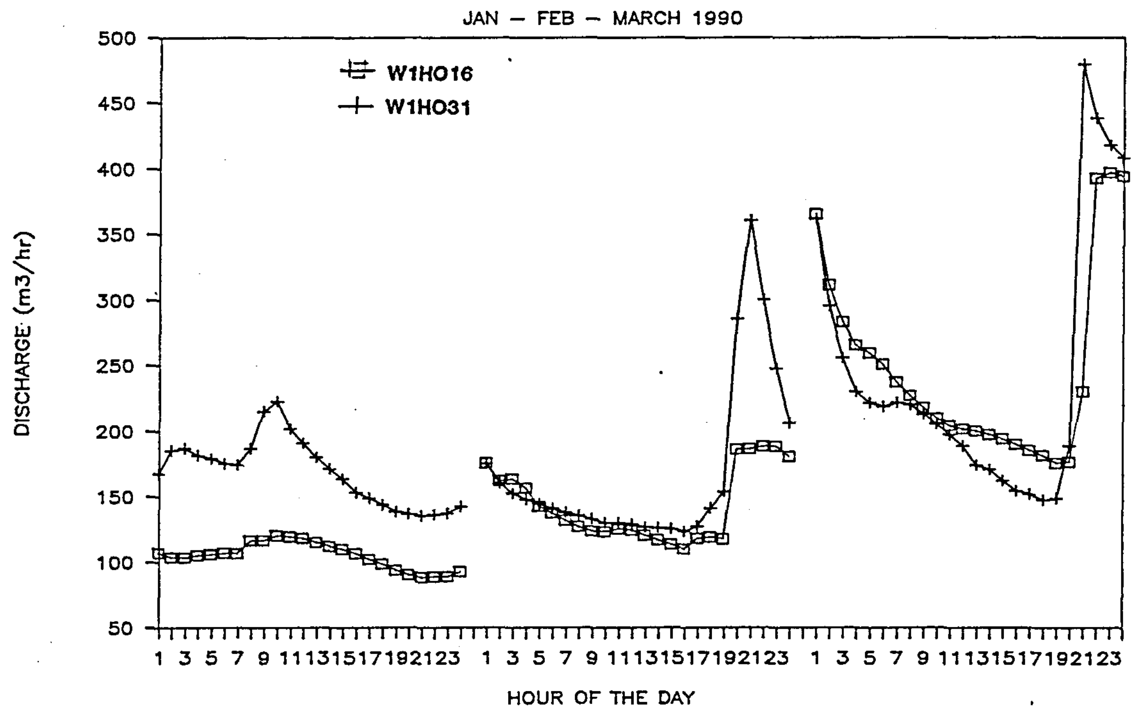


Figure 7.10 **Mean hourly values of discharge from W1H016 and W1H031 from January to March, 1990.**

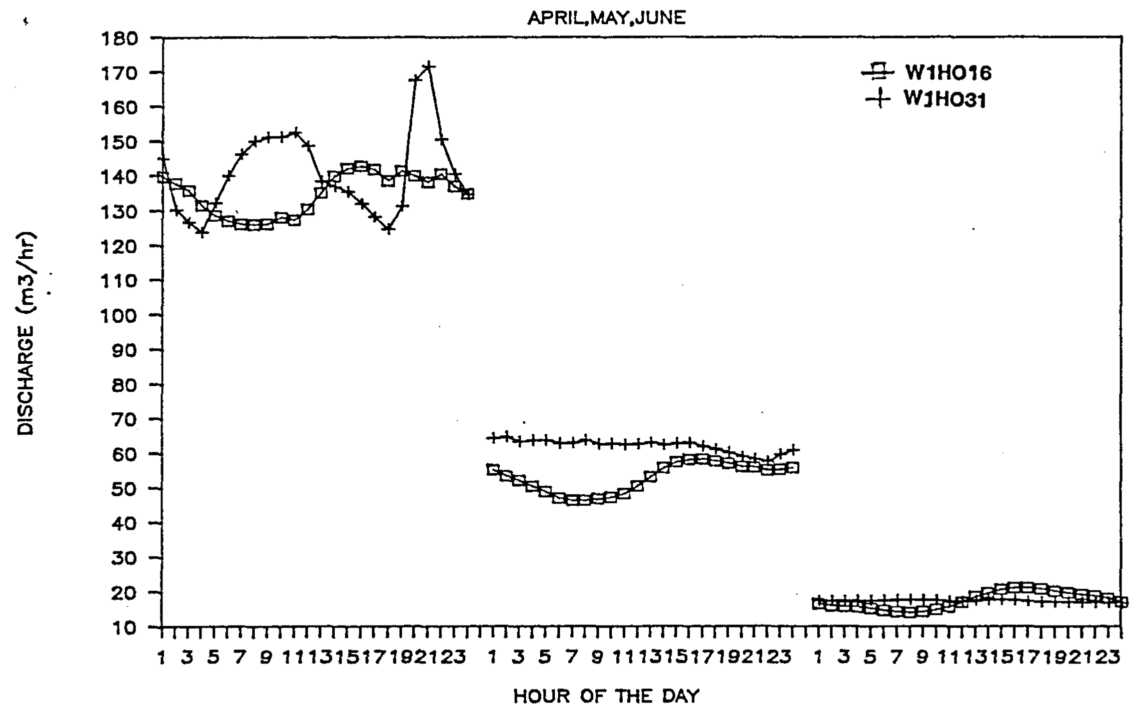


Figure 7.11 **Mean hourly values of discharge from W1H016 and W1H031 from April to June, 1990.**

seperation were identified and the points of inflection were digitised. These are summarised in Figure 7,12 & Table 7,1. In all cases these hydrographs were derived from short duration, high intensity storms. The three peaks in the hydrograph appear to correspond to the three peaks in the catchment areas contributing to the travel times derived from the isochromes (Figure 5.6).

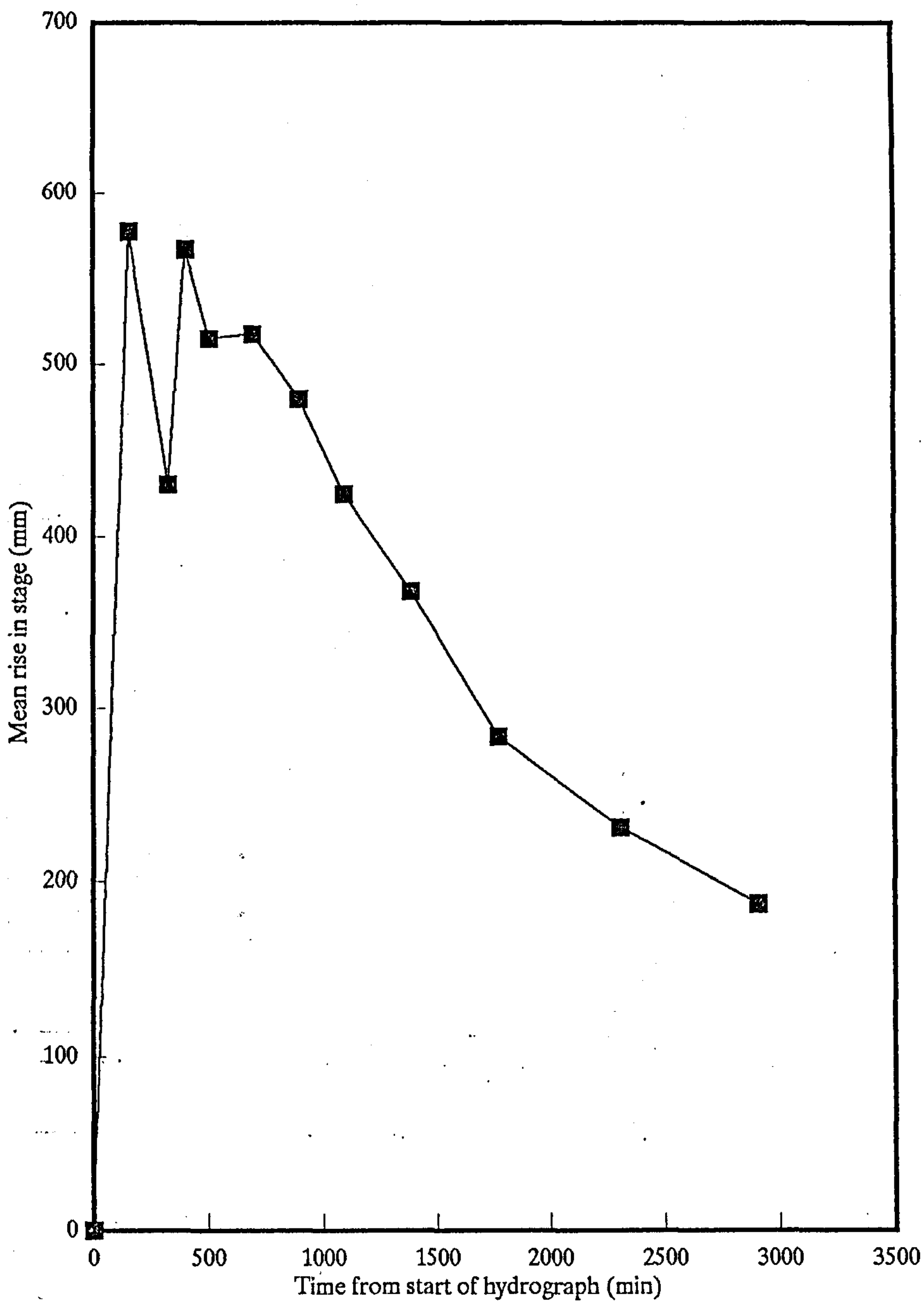


Figure 7.12 **Plot of the time of the points of infection at the three peaks in the stage of selected storms for W1H016.**

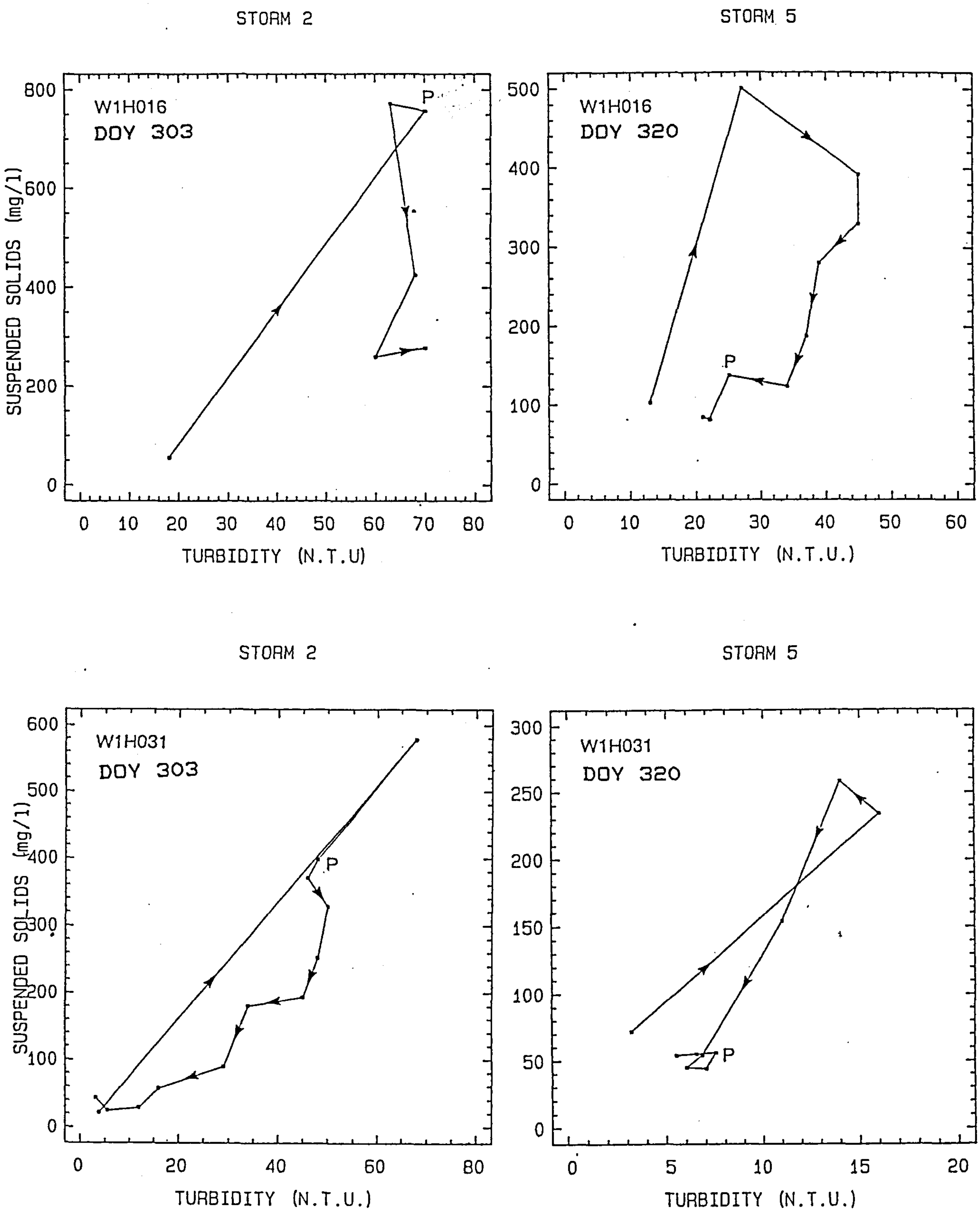


FIGURE 8.1 **Sequential plot of Suspended Solids Concentration (mg/l) against Turbidity (NTU) for selected storm events.**

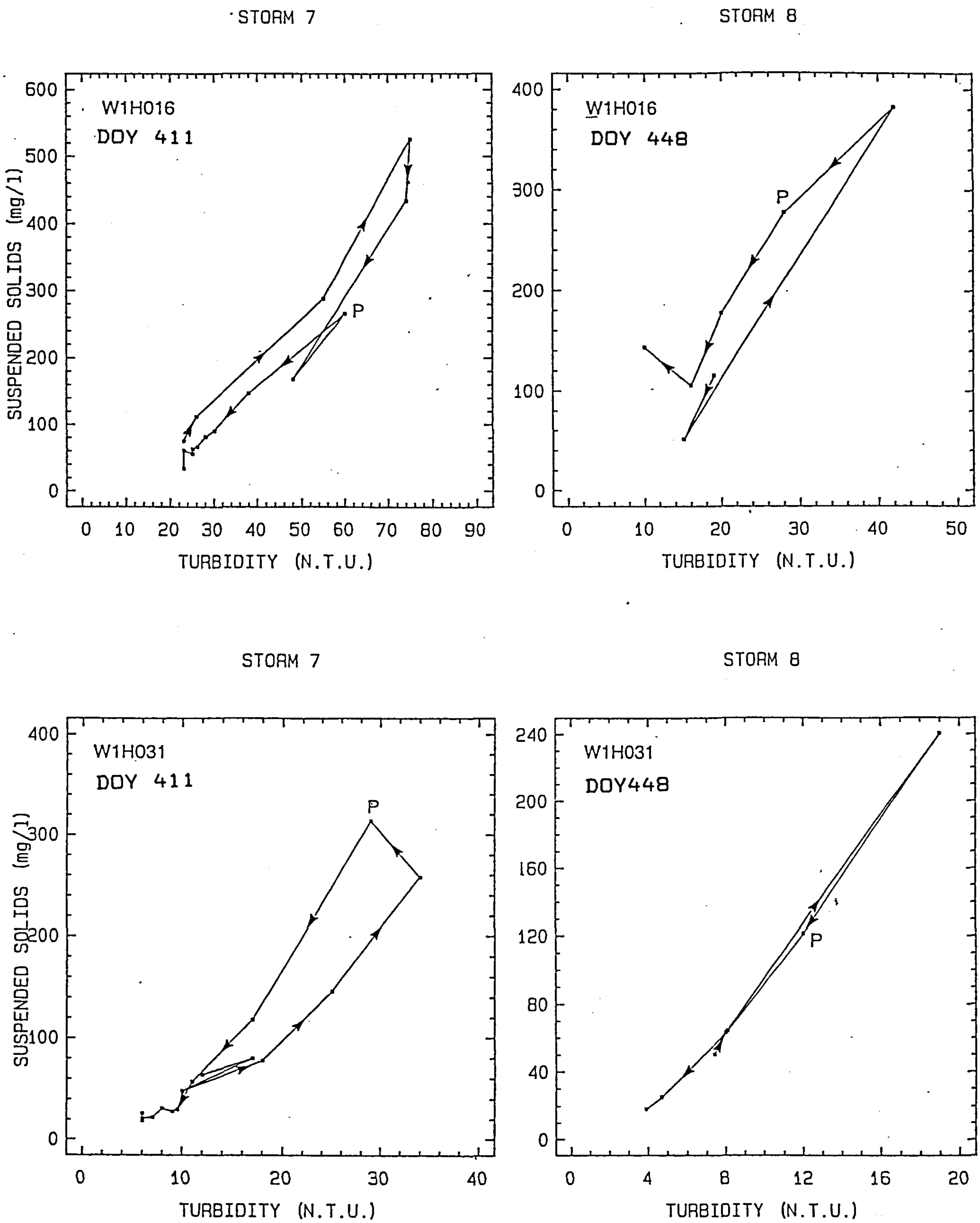


FIGURE 8.1 Continued.

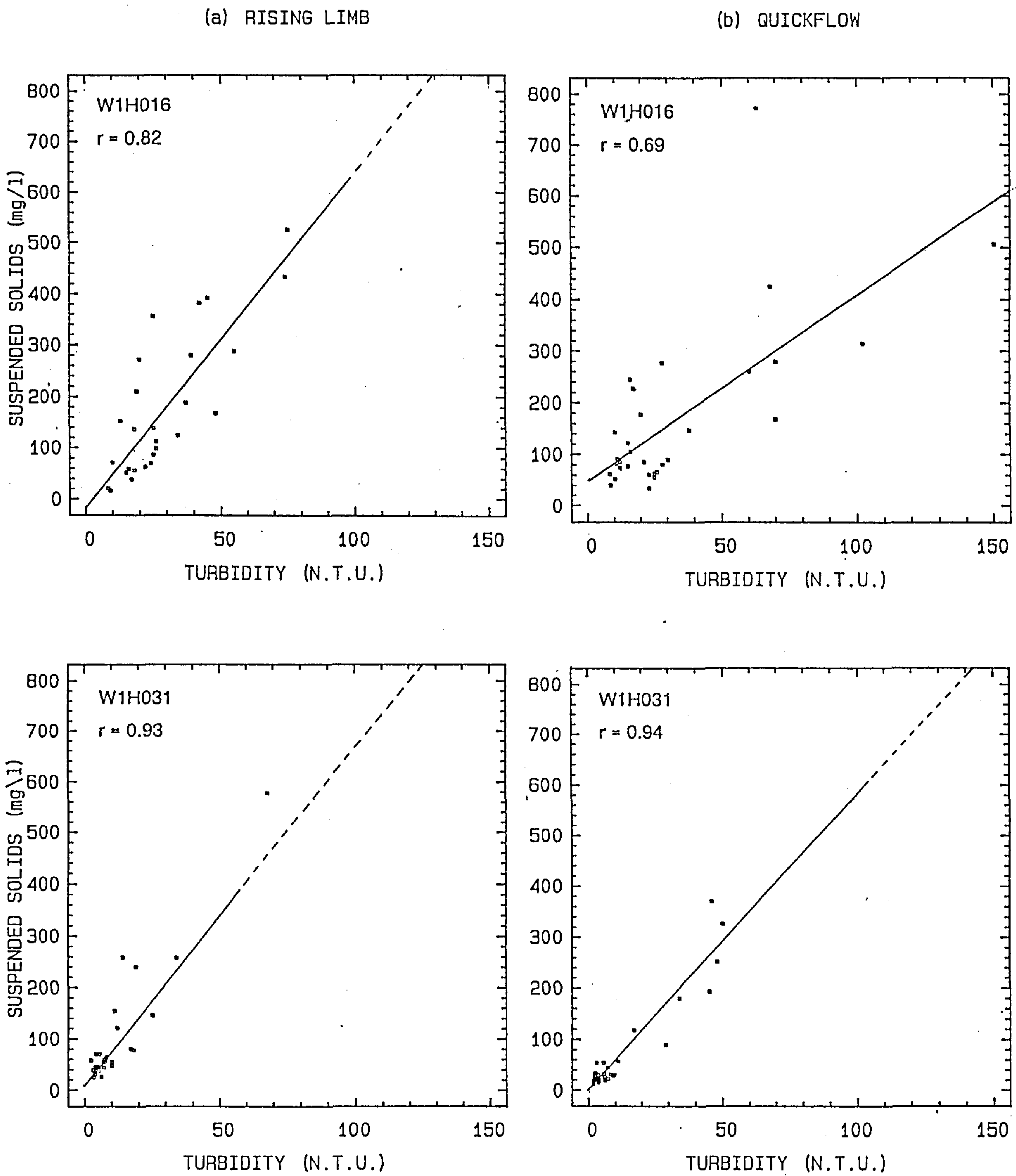


Figure 8.2 **Scatterplot of the suspended solids (mg/l) against Turbidity (NTU) for different stages of the storm hydrograph.**

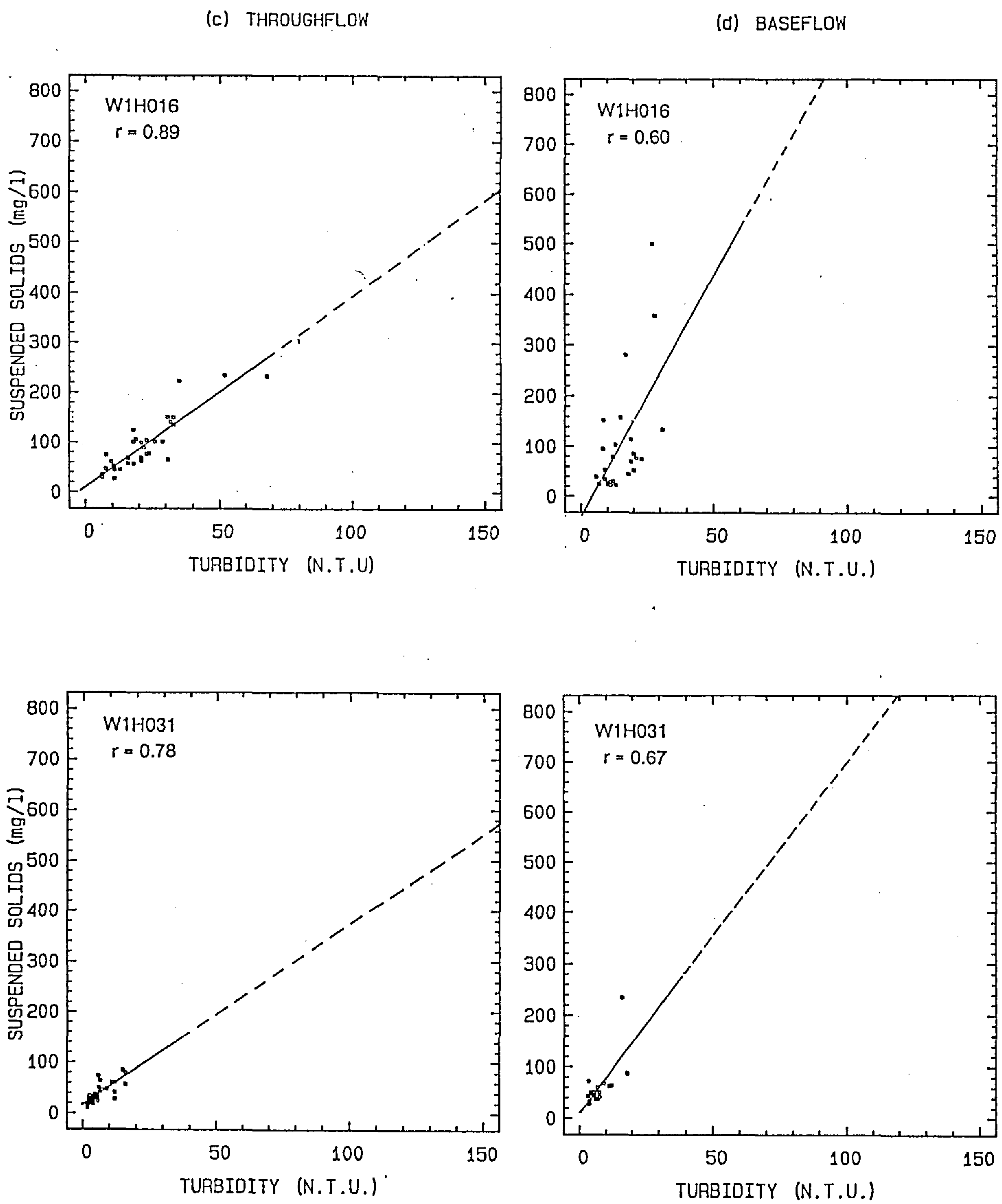


Figure 8.2 Continued.

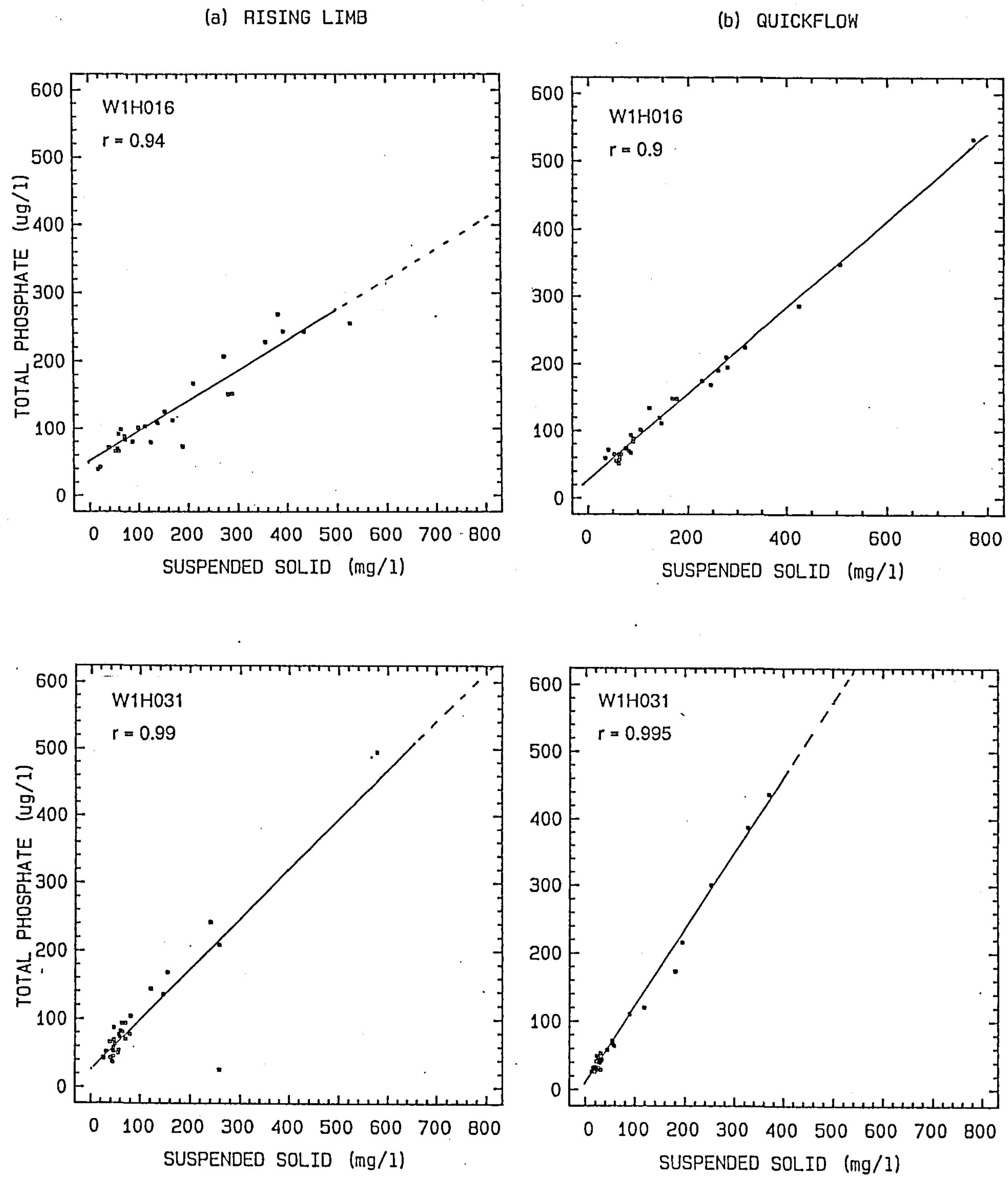


Figure 8.4 **Scatterplot of Total Phosphate concentration(ug/1) against Suspended solids (mg/1) for different stages of the storm hydrograph.**

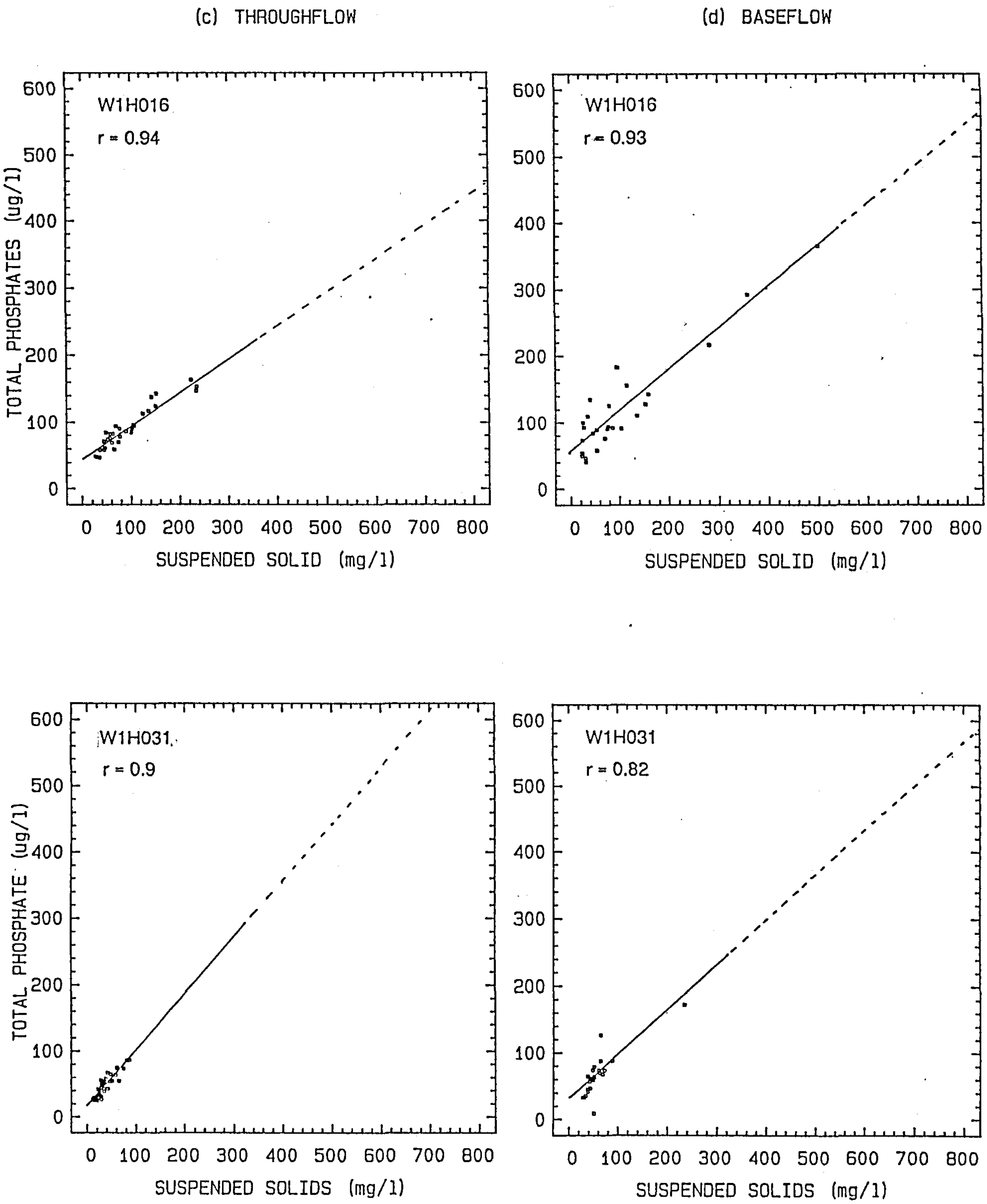


Figure 8.4 Continued.

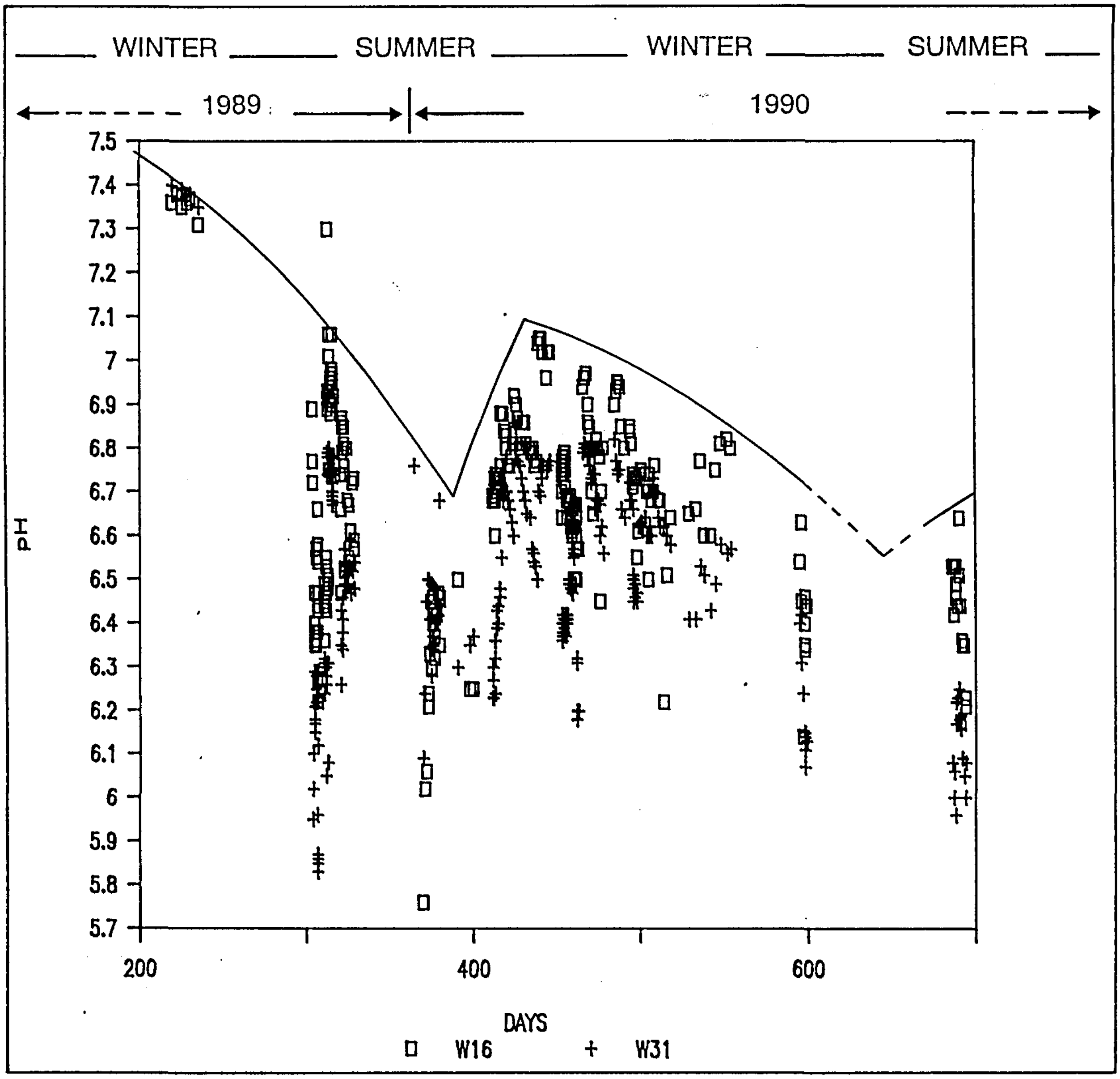


Figure 8.5 Plots of pH for the whole season.

available, this is speculative. However, there does appear to be a seasonal trend with a minimum value of conductivity during March when discharge volume was the highest.

There is little difference between the mean conductivities of the two catchments for the **rising limb**, **recession limb** and **baseflow** conditions (Table 8,5). There is, however, a small difference (3.0 mS/m) between the conductivities of the two

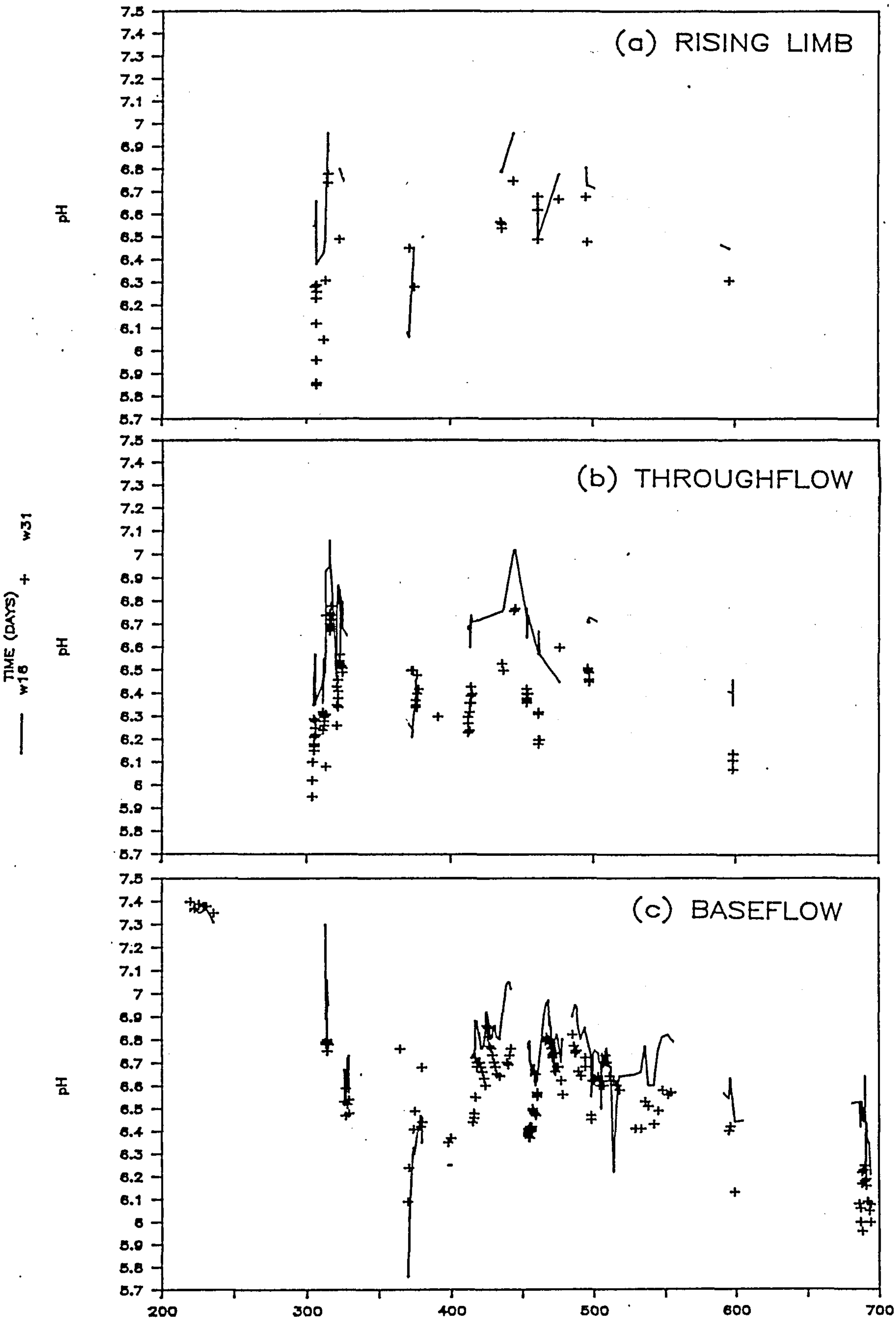


Figure 8.6 Seasonal variation in pH from both catchments for different stages of the hydrograph.

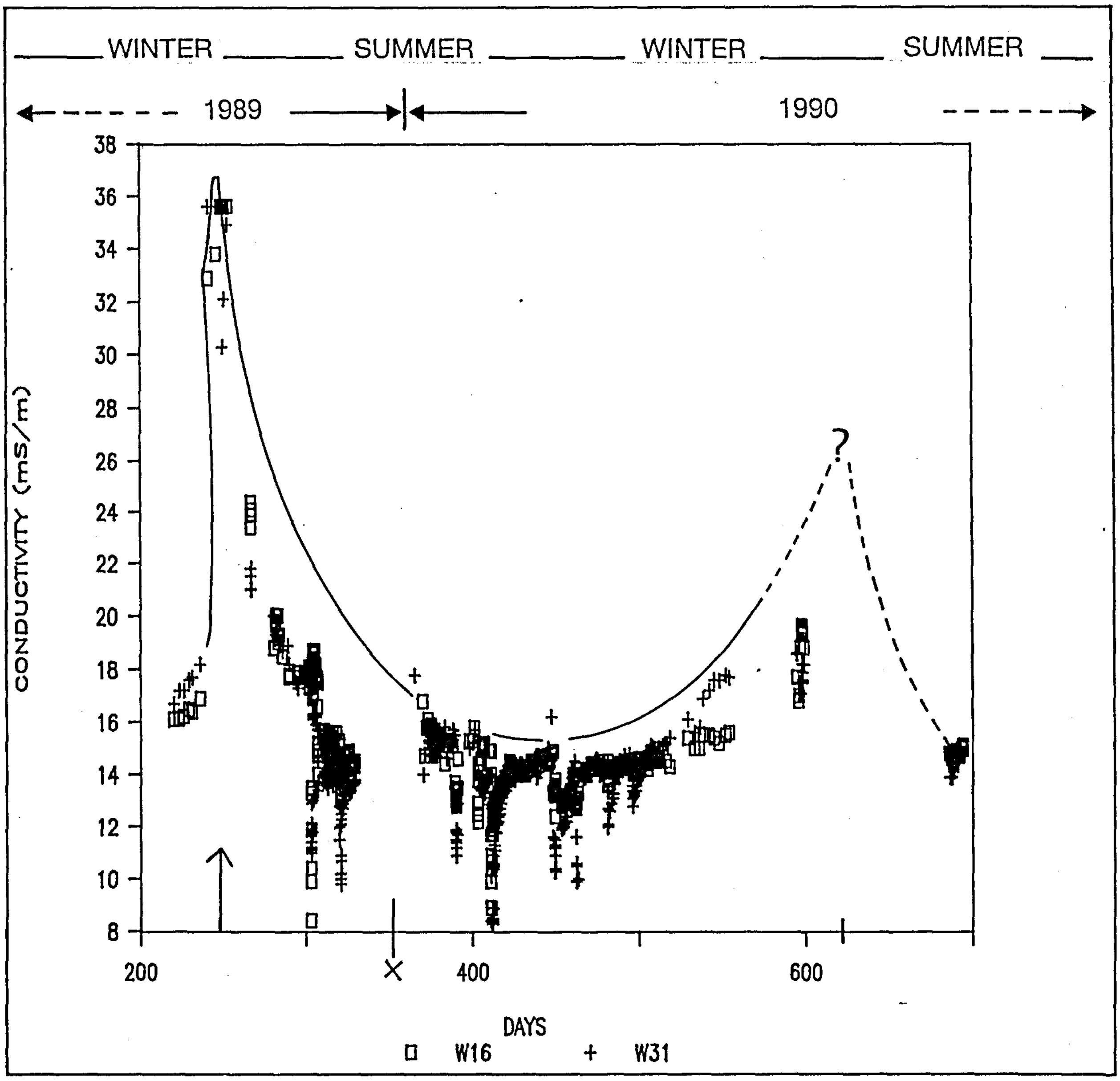


Figure 8.7 **Seasonal variation in Conductivity values**

catchments during the **peak** discharge stages of the storm hydrograph.

The samples for the separate components of the storm hydrograph are shown in Figure 8.8. For the **rising limb** there is little difference between the catchments although W1H031 generally has a lower conductivity value than W1H016. The **quickflow** conductivity plot shown in Figure 8.8b indicates that in most cases the sample values are generally lower for W1H031 compared

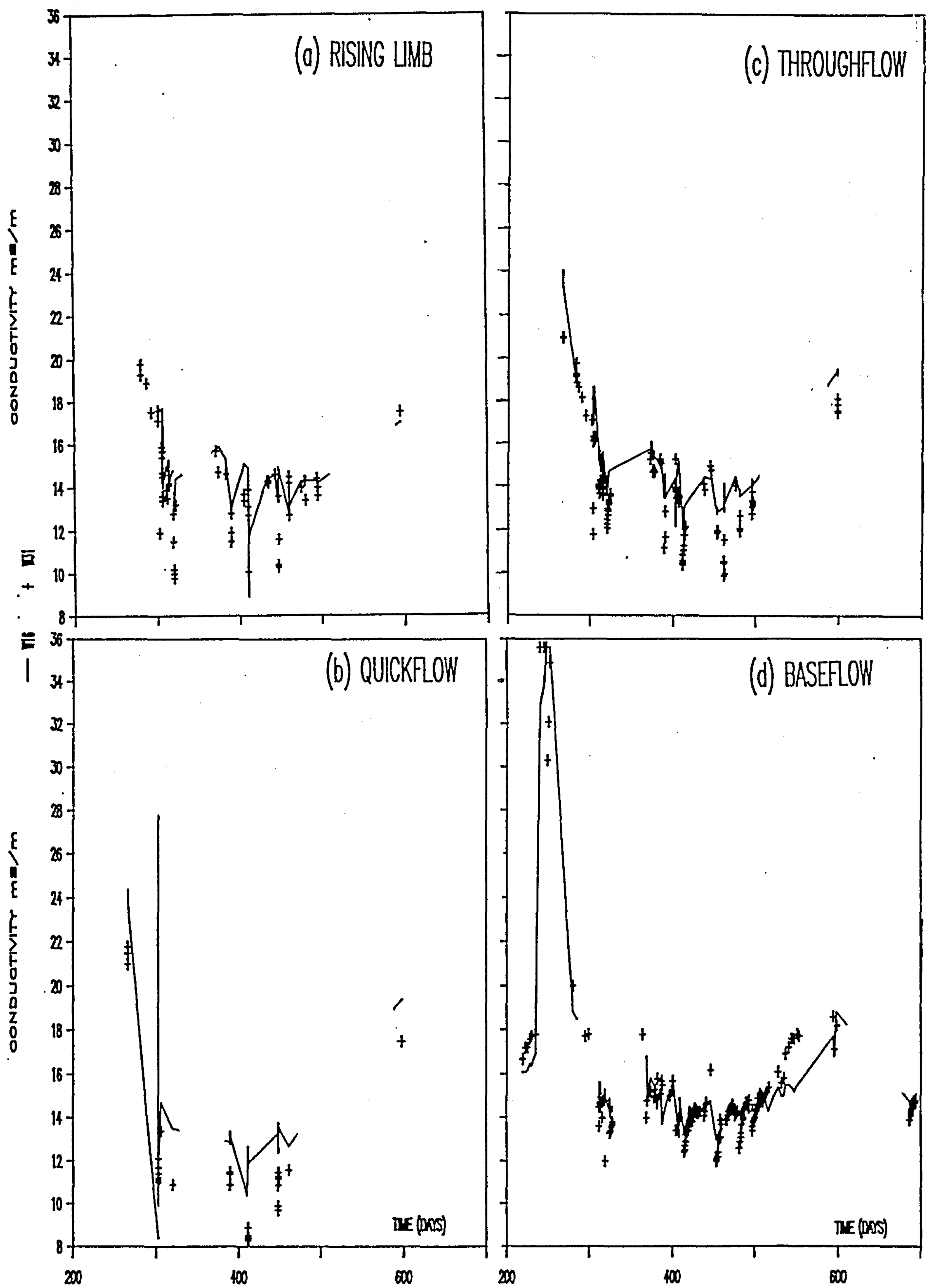


Figure 8.8 Seasonal variation in Conductivity values for the different stages of the storm hydrograph.

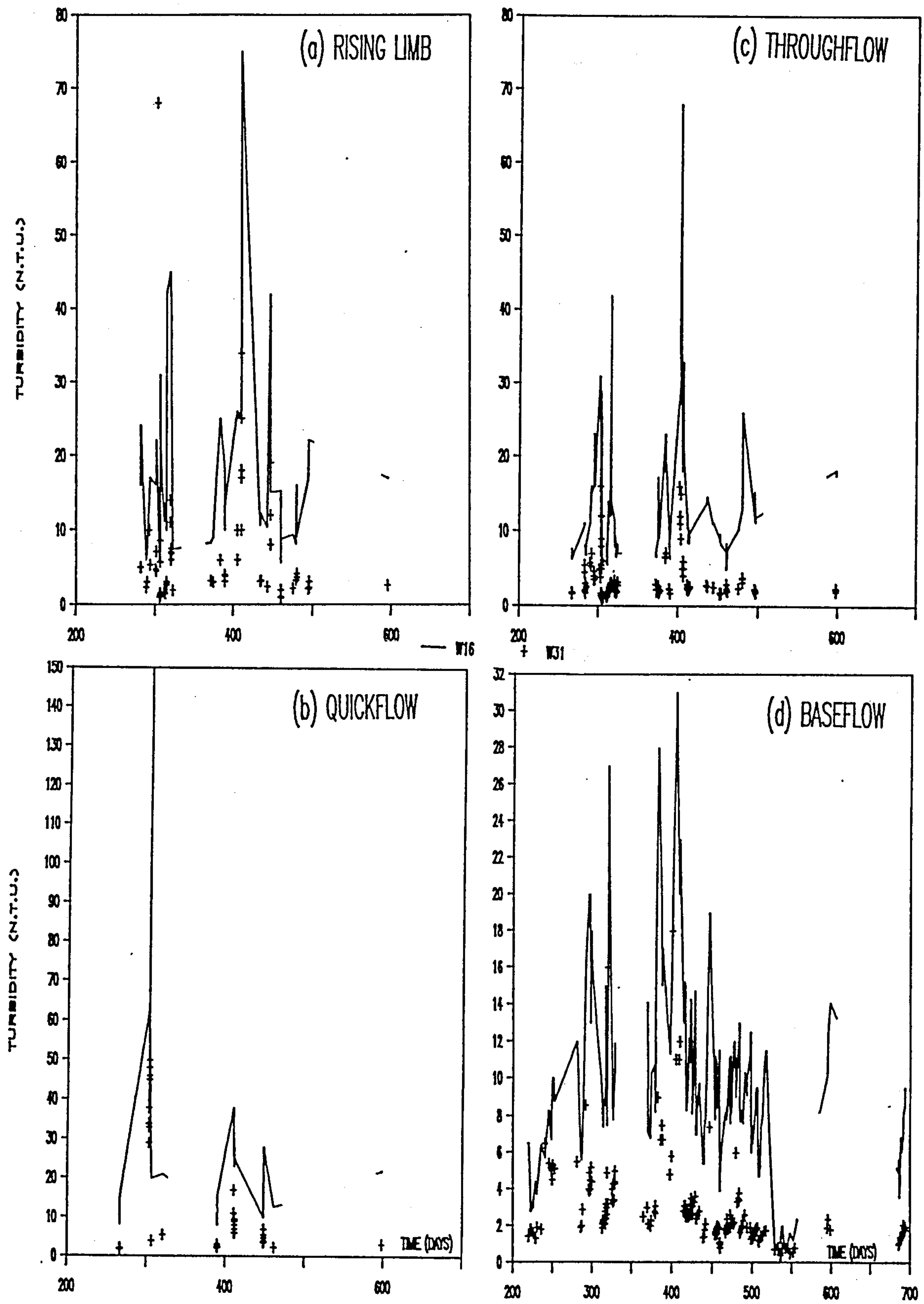


Figure 8.9 Seasonal variation in Turbidity values from both catchments for the various stages of the storm hydrograph

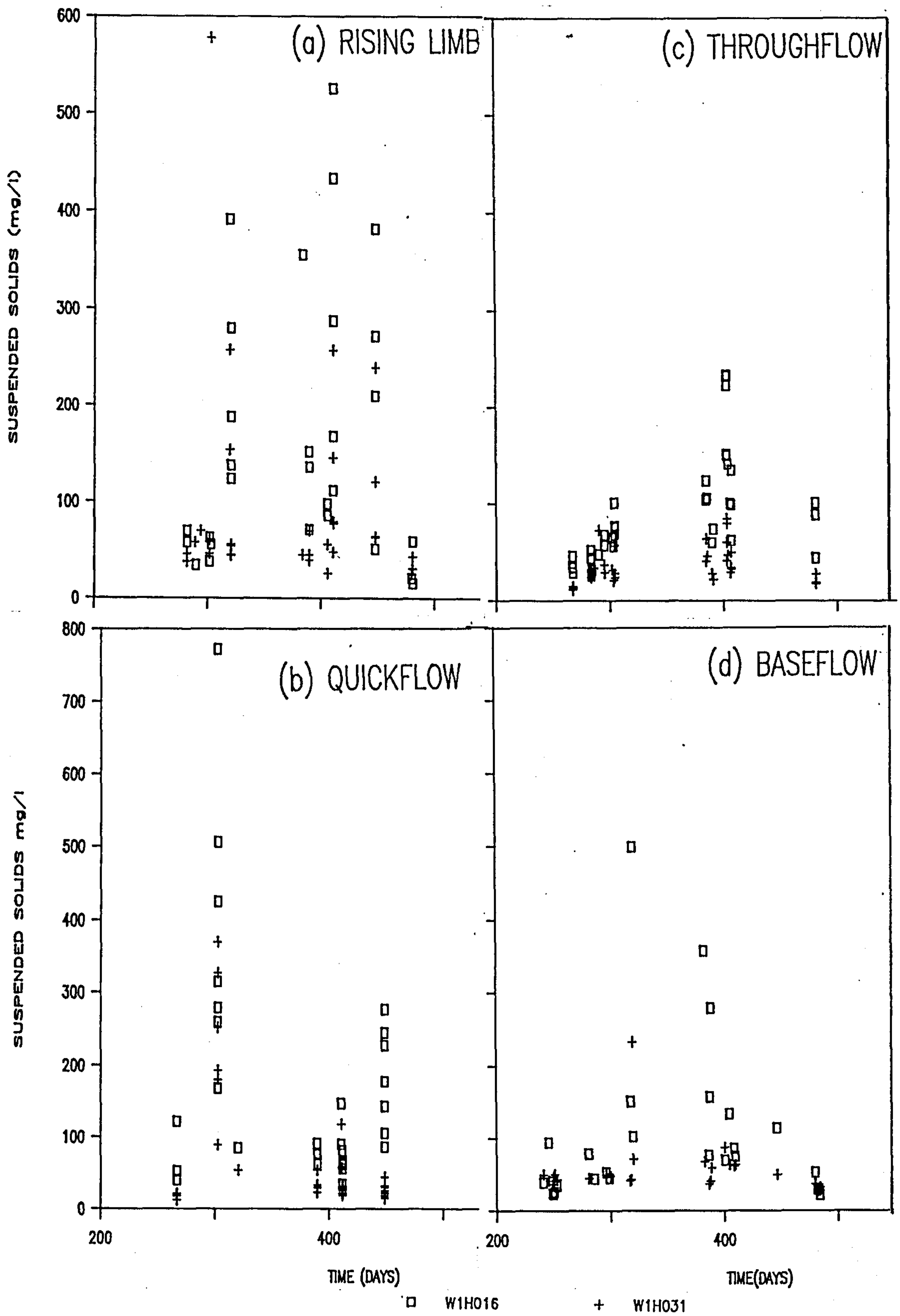


Figure 8.10 Seasonal variation in Suspended solids from both catchments for various stages of the storm hydrograph

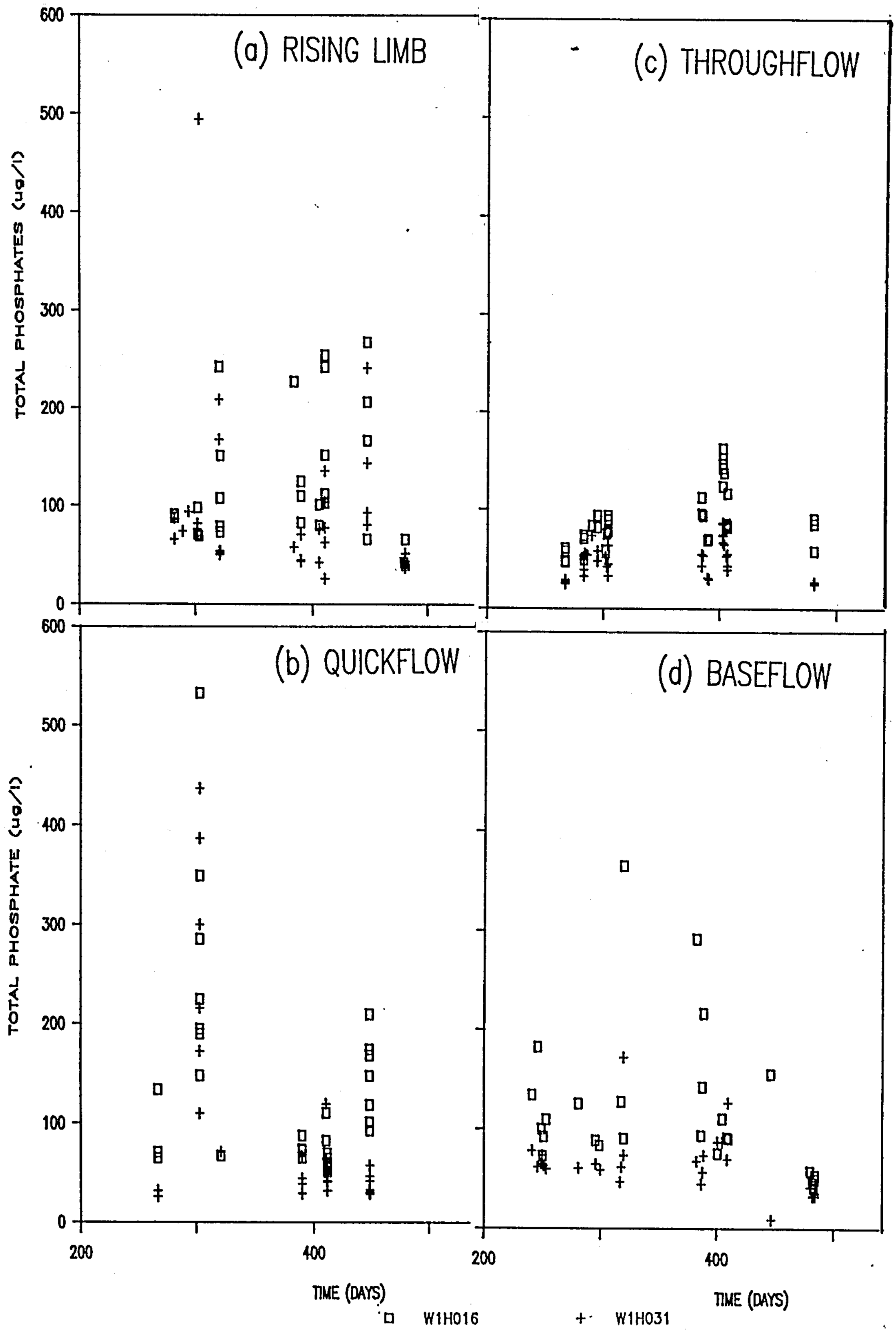


Figure 8.11 **Time series plots of TOTAL PHOSPHATES from both catchments for the different stages of the storm hydrograph.**

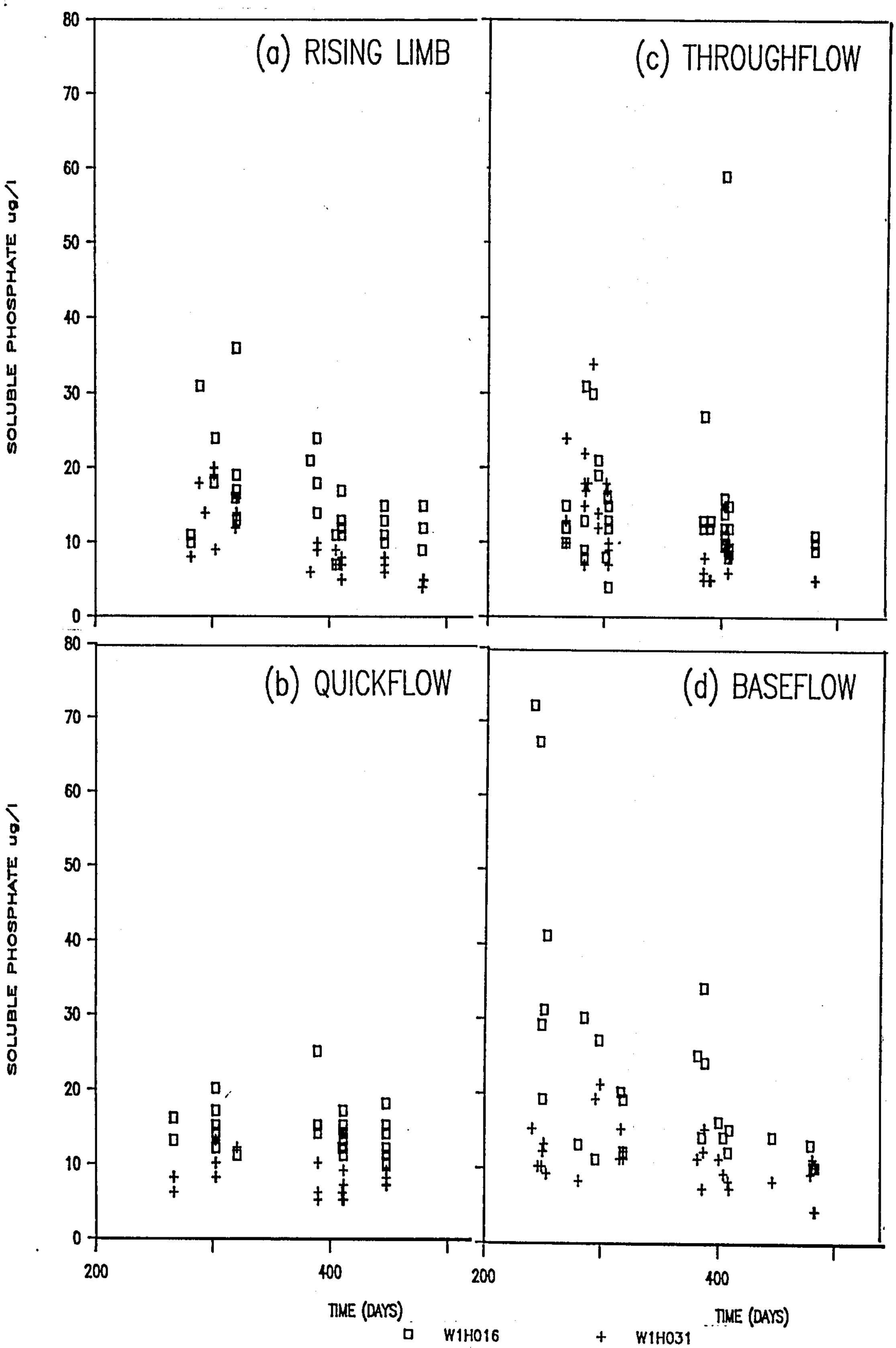


Figure 8.12 **Time series plots of SOLUBLE PHOSPHATES from both catchments for the different stages of the storm hydrograph.**

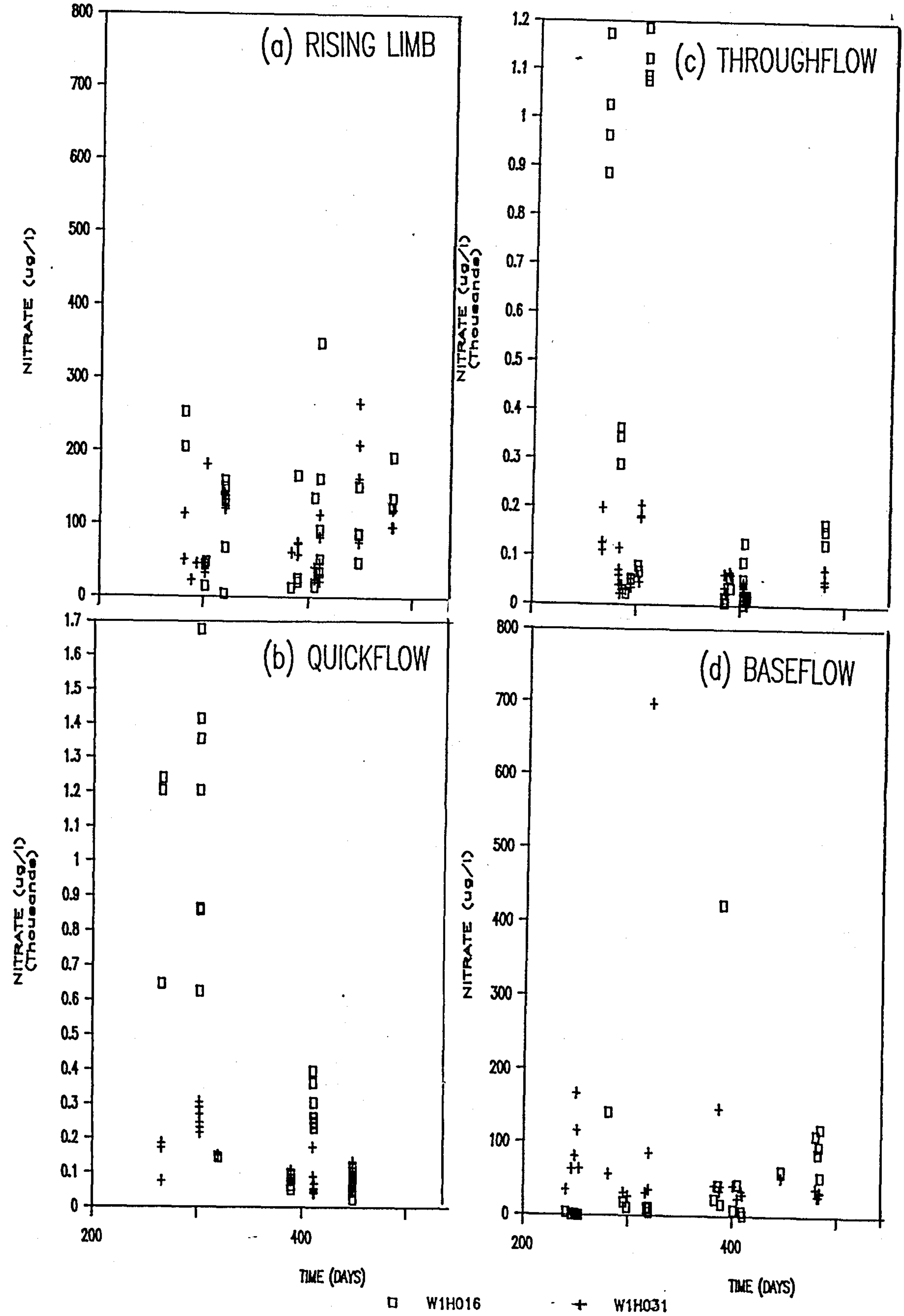


Figure 8.14 Time series plots of NITRATE concentrations from both catchments for the various stages of the storm hydrograph.

approximately $70m^3$ which represents nearly $9m^3$ per month.

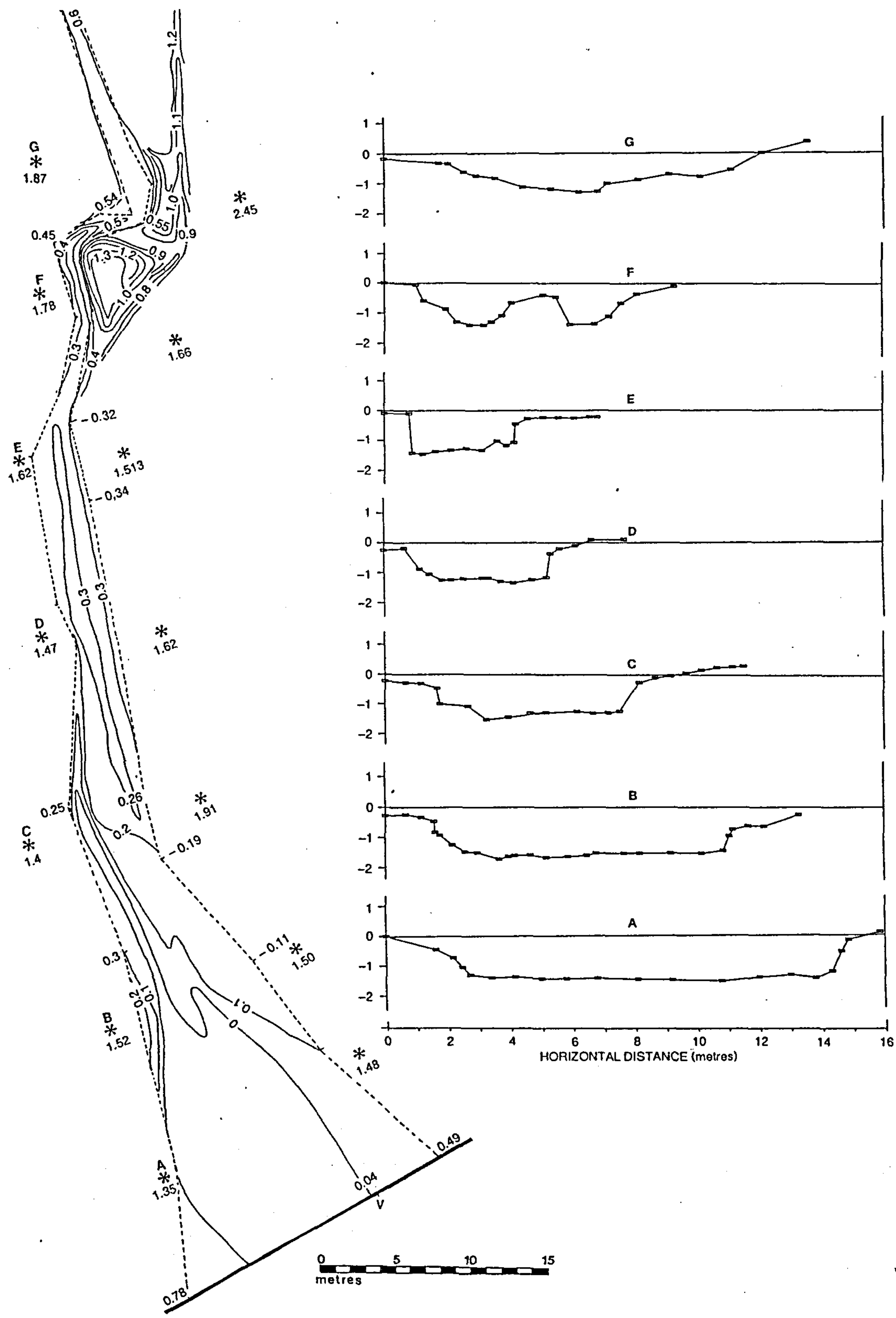


Figure 8,17 Transects across W1H016 used for estimating the bed load component.

STATION LOCATION

In 1988 the weather station on the campus of the University of Zululand was relocated on the campus (Figure II,1) to a position closer to the Department of Hydrology. This was necessary because the original position was being vandalised and was being surrounded by buildings. There was also the probability that the site would be needed for future expansion by sections of the University.

Many of the instruments in the original station were old and in need of major servicing. The instruments were read once a day at 08h00 except on weekends when the field assistant was off duty. Consequently it was decided that an automatic weather station would be installed on the new site with a view to replacing the once daily measurements.

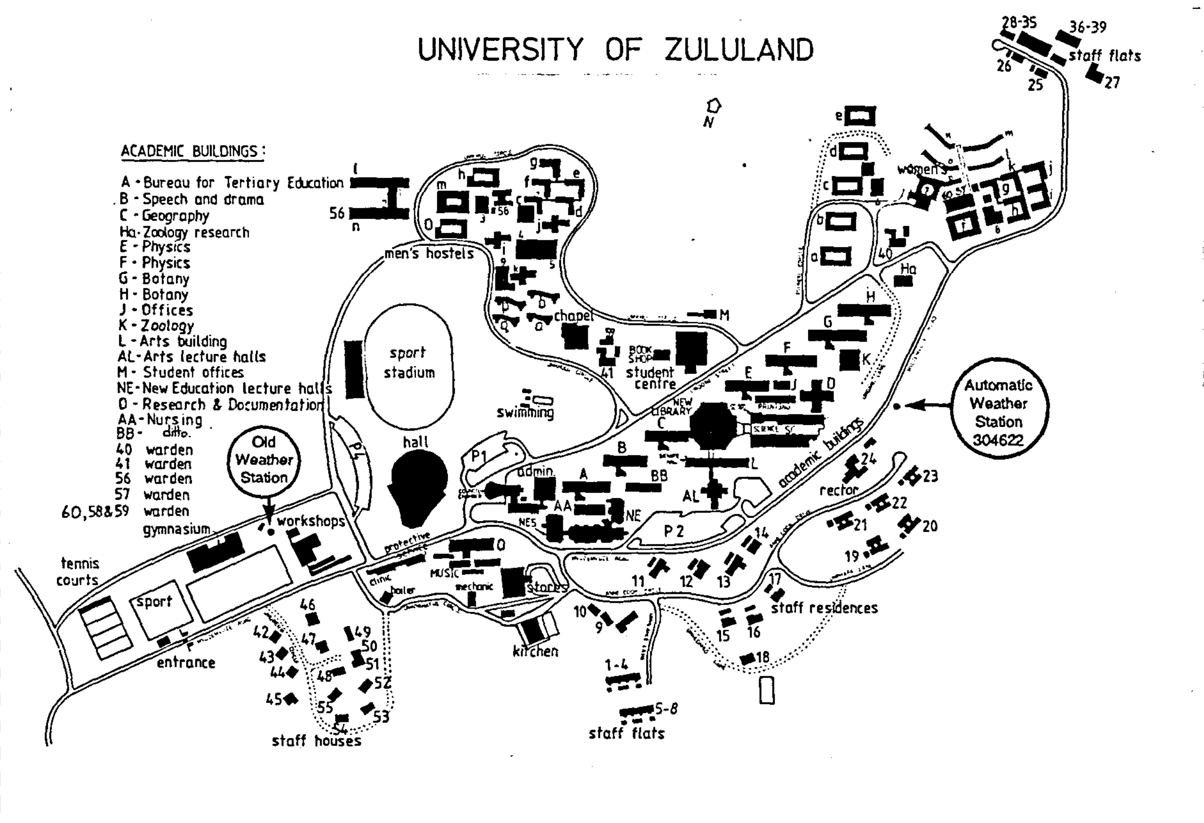


Figure II,1 The locations of Station 304622 on the University of Zululand Campus.

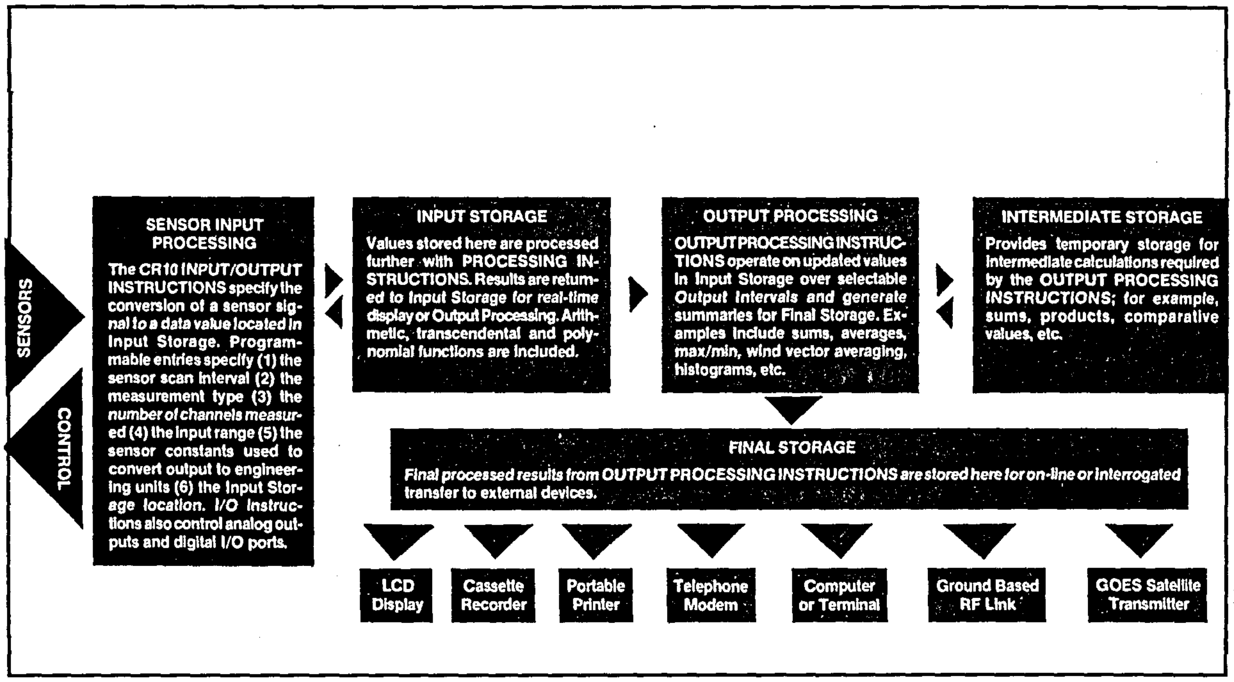


Figure II,4 Diagrammatic representation of the CR10 components

AUTOMATIC WEATHER STATION

The automatic weather station, which is situated on the eastern edge of the University Campus (see Figure II,1) is intended to monitoring atmospheric variables that will provide estimates of potential or reference evapotranspiration for the surrounding area. It is also used to monitor the atmospheric pressure and the rainfall.

SENSORS

The solar radiation is provided by a LICOR pyranometer mounted on the galvanised frame (Figure II,3). The wind speed (and direction) is derived from an ECO anemometer mounted 2 meters above the surface. A thermistor and XNAM hygristor located in the Stevenson screen give measurements of temperature (mean, maximum, and minimum) and vapour pressure (mb).

The data logger is also connected to an ECO tipping bucket raingauge (Figure II,2) and is powered by a 12Volt lead acid battery which is maintained at about 13V by a trickle charge from a local 220VAC mains supply.

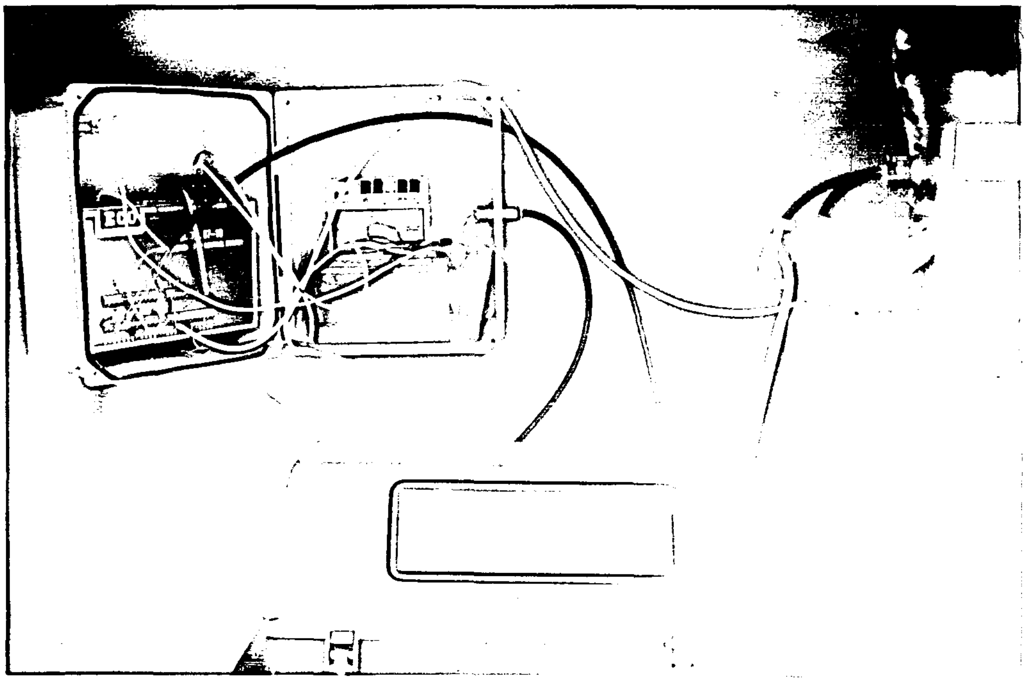


Figure IV,1 CR10 installation at weir W1H031

IV-1 CR10 DATALOGGER

The data logger for the automatic discharge/sampler stations consisted of the basic CR10 unit described in appendix II. The CR10 is housed in a standard electrical fibre box mounted on the wall of the instrument hut at each weir. The box is sealed to reduce the corrosive effect of the coastal environment. The rainfall is monitored by a tipping bucket raingauge which is mounted on the roof of the instrument hut. The piezometer rests on the floor of the stilling well and monitors the pressure and temperature of the water which is than converted to depth relative to the bottom of the V-notch on each weir through appropriate calibrations.

The memory allocations for the two weir stations are given in Table IV,1 while the input locations are shown in Table IV,2. The piezometer at W1H016 was replaced by a one-turn potentiometer half bridge while it was sent for repairs. Input locations 7, 8, and 9 were used to monitor the voltage of the potentiometer and the number of revolutions that it had accumulated in one

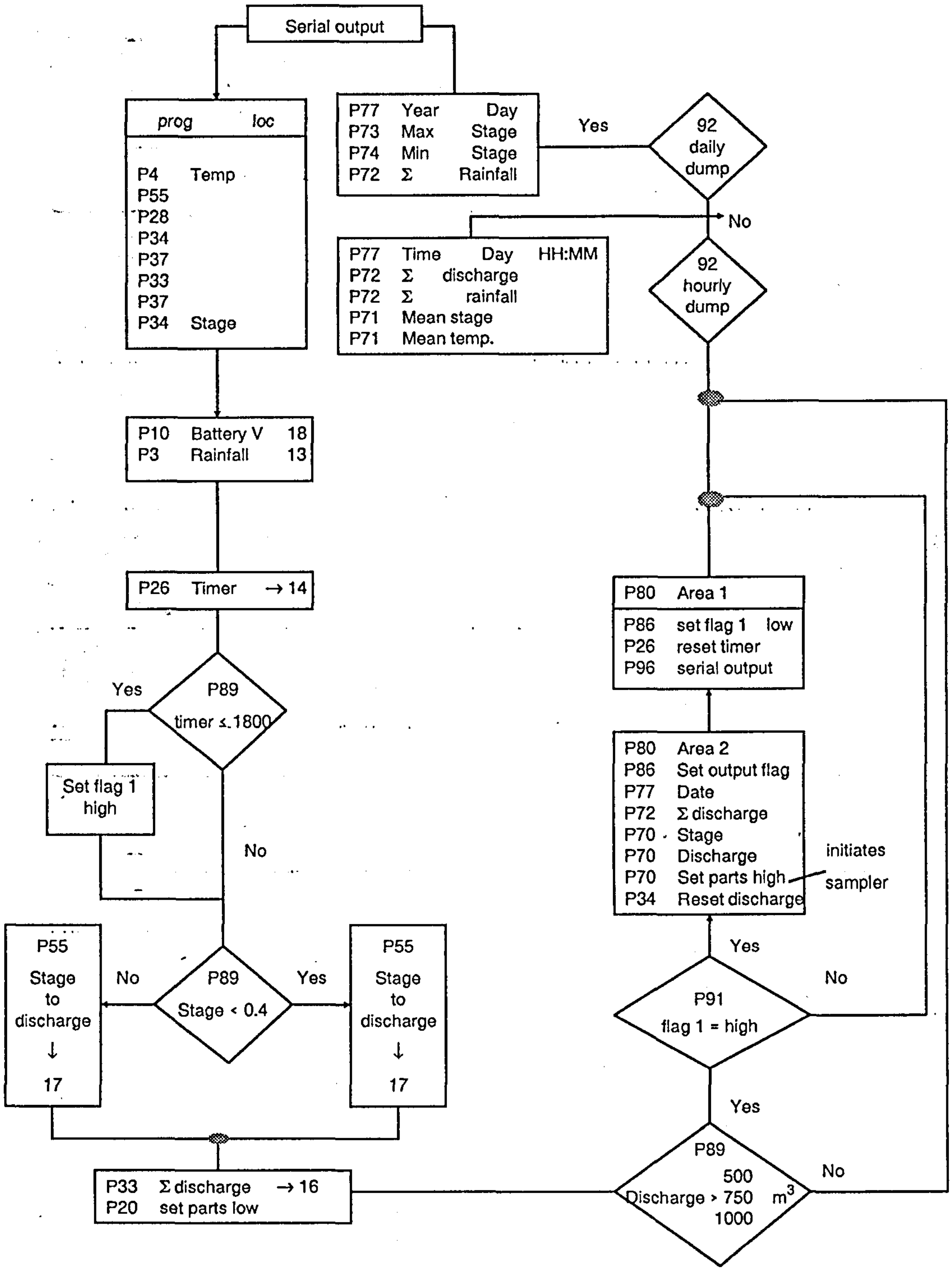


Figure IV,2 Flow diagram of the CR10 program for both weirs.

Table IV,5 Fields for SAMPLING records

Field	Data
01	Program location for initiating dump to final memory.
02	Day of the year (Julian Day)
03	Time (HHMM)
04	Cumulative discharge
05	Stage
06	Discharge

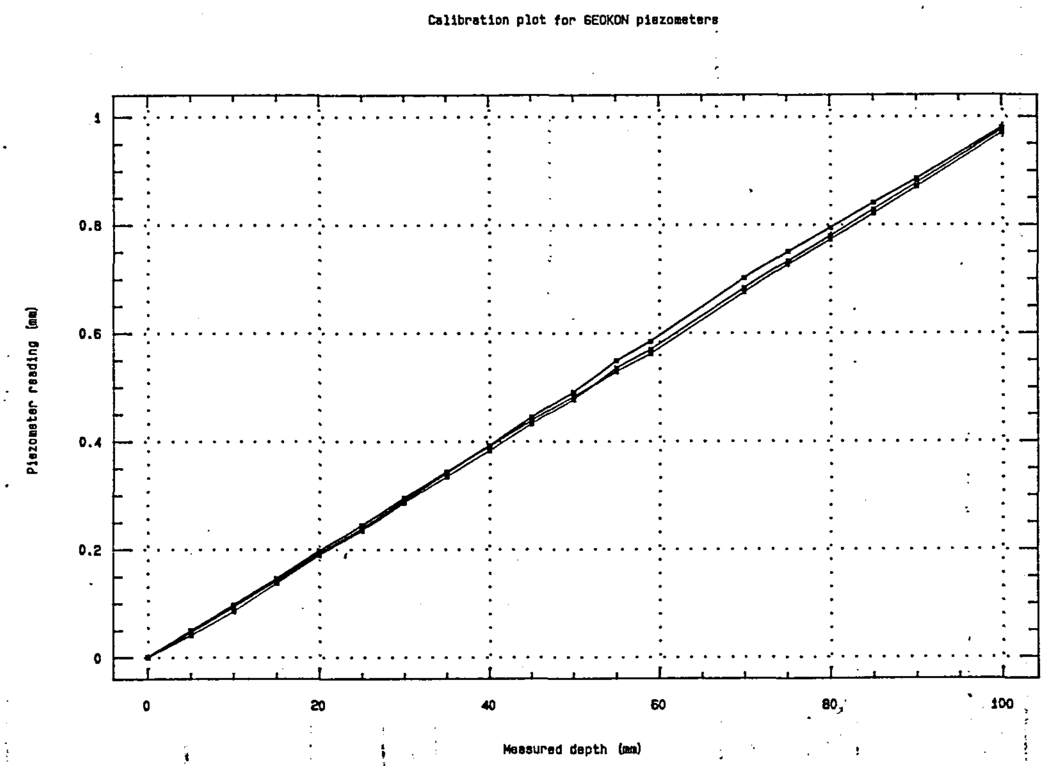


Figure IV,4 Calibration of piezometers

with time and is programmed to activate the ISCO sampler (control port) after a specified volume of water has been recorded. The CR10 program was changed on several occasions to accommodate different size flood events. Unfortunately, no simple flow volume was suitable for the full range of flood hydrographs. Consequently, the CR10 was programmed to activate the ISCO sampler after every $500m^3$ of discharge <u>provided</u> the sample

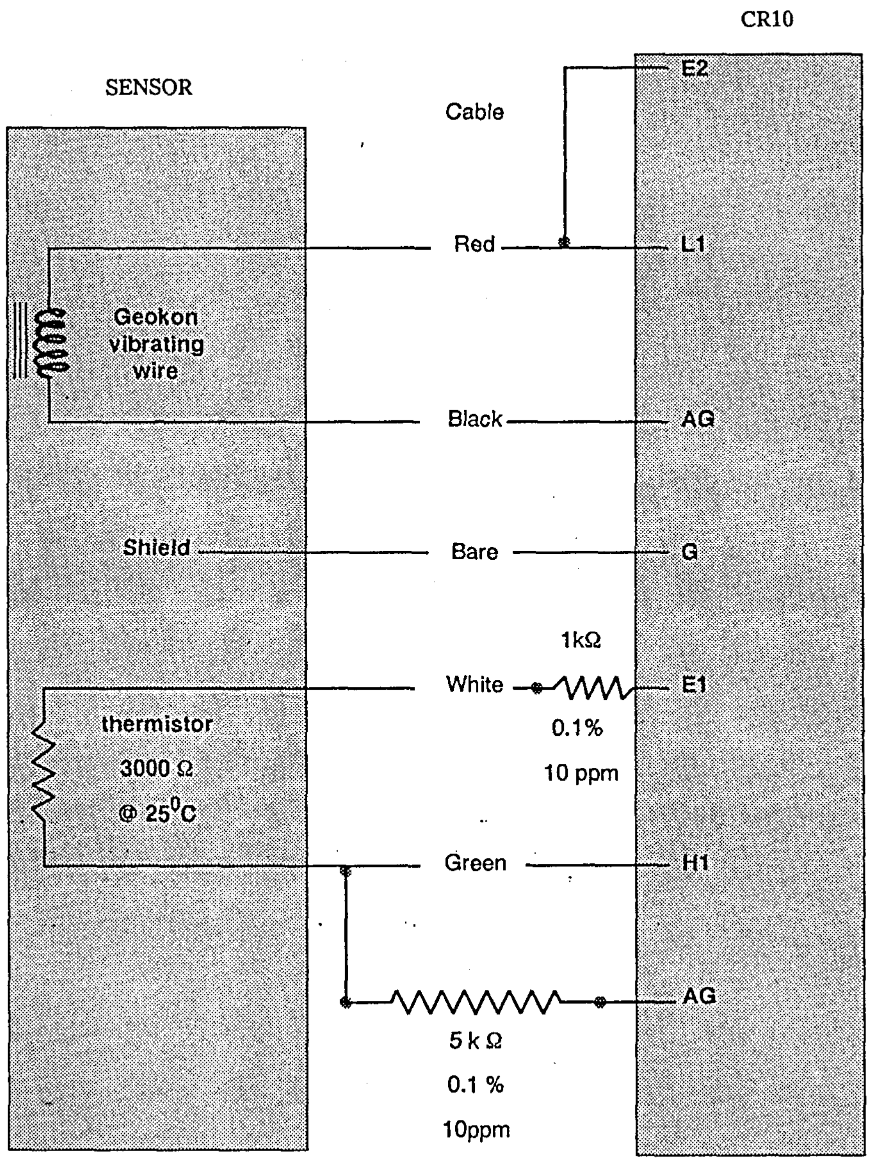


Figure IV,3 Schematic diagram of the piezometer/CR10 connection.

interval did not exceed 30 minutes. This limited the collection of samples to half hourly intervals during large storm events. It also provided sufficient samples to analyze small flood events. The changes to the program are shown in Table IV,6.

The CR10 recorded the time, date, stage and discharge volume of every time the water sampler was activated (even if the sampler did not respond or was full). The sample bottles were collected after each storm event and either analyzed by the HRU_Z or they were sent to the Division of Water Technology, CSIR, Durban.

The stage-discharge relationship (appendix III) was divided into

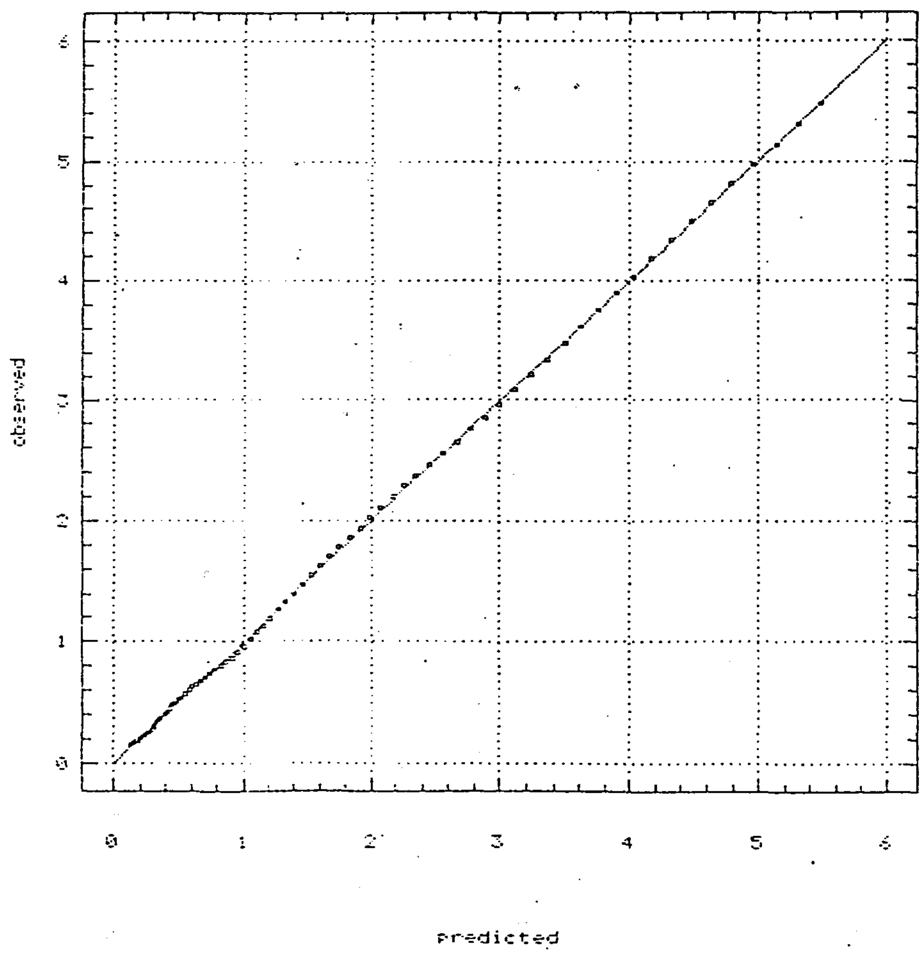


Figure IV,5 Predicted and actual stage-discharge relationship

The dataloggers, connected to a vibrating wire piezometer and tipping bucket raingauge, have now been developed to initiate sampling after a certain discharge has been reached. The system is programmed to record the time and the stage for each sample.

The ISCO programmes were devised to overcome the length of piping to the sample point (weir outlet) and the varying heads during the changing hydrograph. The programme for both stations is shown in Table IV,8.

IV-5 DATA PROCESSING

The CR10 is programmed to dump the data for both memory allocation table to cassette tape at regular intervals. This data is collected when the sample bottles are changed, or at other appropriate times, and transferred to the HRU_Z data bank. All the

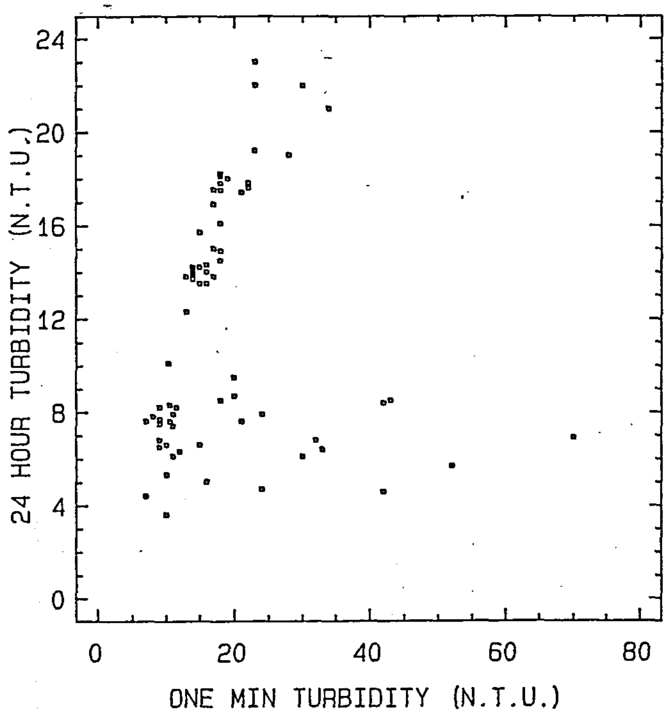


Figure V,1 **A scatterplot of turbidity measurements by HRU_z for two sample preparation methods (for W1H016).**

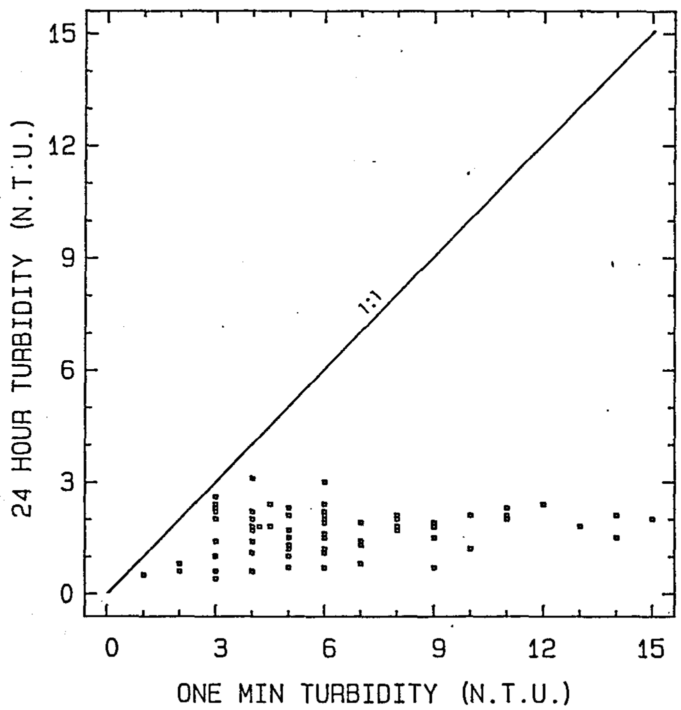


Figure V,2 **A scatterplot of turbidity measurements by HRU_z for two sample preparation methods (for W1H031)**

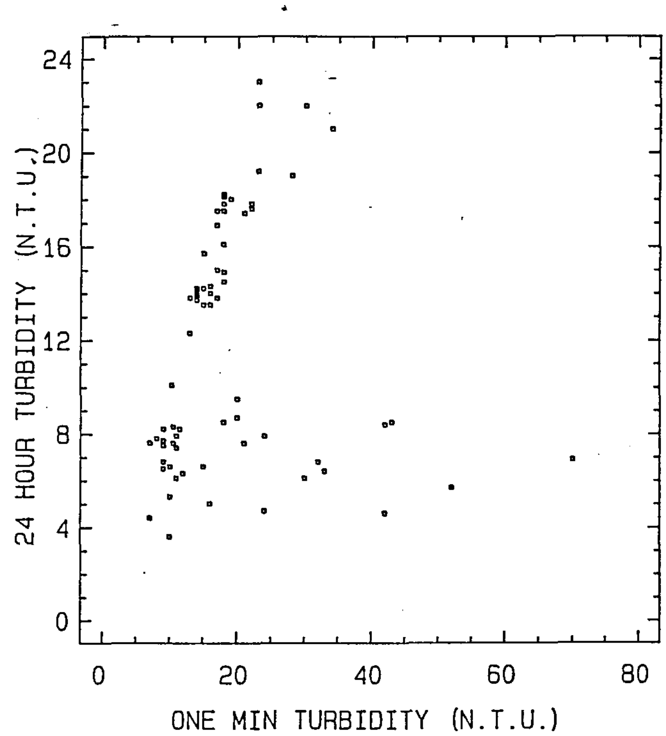


Figure V,1 **A scatterplot of turbidity measurements by HRU_z for two sample preparation methods (for W1H016).**

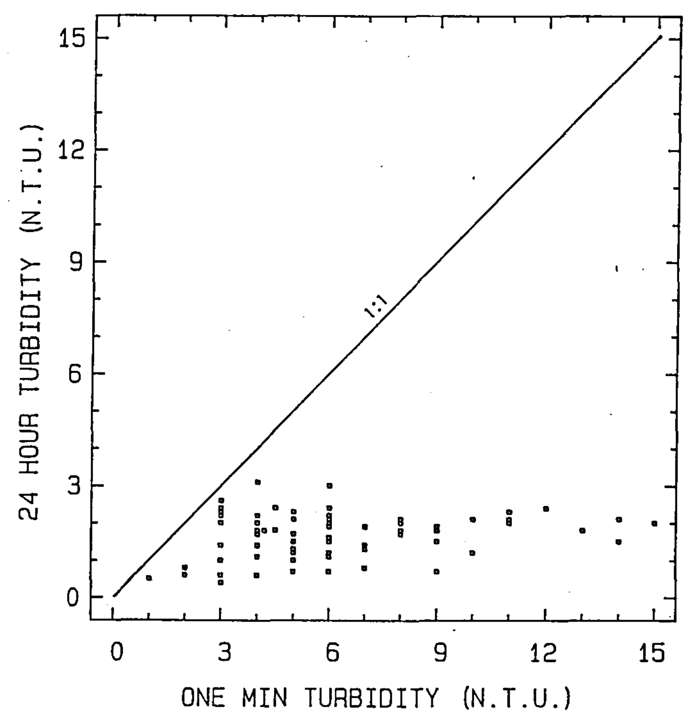


Figure V,2 **A scatterplot of turbidity measurements by HRU_z for two sample preparation methods (for W1H031)**

PREFACE

This report covers a three year project funded jointly by the Water Research Commission and the University of Zululand. The project is part of a collaborative effort by the Department of Agricultural Engineering at the University of Natal, the Division of Water Technology of the CSIR (DWT) and the Department of Hydrology at the University of Zululand (HRUz) to obtain data on water quality for hydrological modelling.

The Department of Water Affairs, who control all monitoring structures on South African rivers have introduced a new identification code for weirs. The old station identification codes (W1Mxx) have been replaced by the new identification codes (W1Hxxx) in this report (where xx refers to station number).

ACKNOWLEDGEMENTS

It is gratefully acknowledged that this project would not have been possible without the considerable financial and moral support of both the University of Zululand and the Water Research Commission.

The authors acknowledge the many people and organisation who have contributed to this project. The Department of Water Affairs has surveyed and rated weir W1H031, they have improved and cleaned W1H012, and have provided charts and assistance for the Ntuze catchment as a whole. Particular thanks are extended to Mr F Wulfe and Mr J Wilkens for their assistance in this regard.

Sincere appreciation is extended to University of Zululand personnel who have played a big part in this project. Mr B K Rawlins and Mr G Moelefe are thanked for their assistance with the digitization of the hydrographic records. Mr G Christopulo and Mr D J Wilkinson are thanked for their technical assistance, particularly in maintaining the autographic raingauges. Mr D E Ntuli, Mr W Nxamalo, Mr S Marule and Mr S Mtshali are all thanked for their assistance in the collection of autographic charts.

The S A Sugar Association Experiment Station (SASAES) provided the soil analyses and the computer model CREAMS. The Hydrological Research Unit (HRU), Department of Geography at Rhodes University and the S A Forestry Research Institute (SAFRI) provided autographic raingauges. Particular thanks are extended to Mr J Meyer and Mr G Platford (SASAES), Professor D Hughes (HRU/IWR) and Mr J Bosch (SAFRI/FORESTEX) for their assistance in providing these facilities.

We wish to extend our sincere thanks to ALUSAF (Mr P Hughes) for providing the particle size analyses, Professor R Schulze, Mr D Simpson, Dr M Dent and their colleagues for their valuable advice during the course of this project. We would also like to thank Ginty Kelbe and Tina Davidson for assisting with the compilation of the data and for typing the manuscripts.

The following people comprised the steering committee for this project and we extend our gratitude to them for their contributions to this project. A special vote of thanks is due to Mr H Maaren for his guidance throughout this project.

Mr H Maaren (Chairman)	:	Water Research Commission
Mr H M du Plessis	:	Water Research Commission
Mr P W Weideman (sec)	:	Water Research Commission
Prof R E Schulze	:	Dept Ageng, University of Natal
Prof P Meiring	:	Dept Ageng, University of Natal
Dr M C Dent	:	CCWR University of Natal
Prof C Breen	:	INR, University of Natal
Mr T Little	:	INR, University of Natal
Mr D E Simpson	:	DWT, CSIR
Mr J M Bosch	:	FORESTEX, CSIR
Dr R D Walmsley	:	FRD, CSIR
Mr M J Underwood	:	Natal Town and Regional Planning
Dr H Furness	:	Umgeni Water
Mr N Hudson	:	Umgeni Water
Mr B K Rawlins	:	University of Zululand
Dr A J Bath	:	Department of Water Affairs
Dr P Ashton	:	DWT, CSIR

EXECUTIVE SUMMARY

World wide concern for environmental denudation and degradation has become an emotional issue because it has such dire consequences for our future. This is compounded by the fact that the degradation of one component of the fragile environment usually has a direct or indirect bearing on many other components of the environmental system. For example the destruction of vegetation in a catchment will lead to erosion and increased sediment production which affects all the water resources downstream and thereby influences all the people using these resources for their domestic, recreational and economic requirements.

One area where serious denudation and degradation of the natural environment is occurring, due to the pressures of human development and migration patterns, is in the large expanding **urban fringe** settlements surrounding the metropolitan centres in South Africa, particularly in the Natal/KwaZulu region. This study was initiated in an attempt to identify the trends and hydrological effects of the urban fringe areas by studying their development and hydrological effects in a small research catchment on the Zululand coastal belt. The University of Zululand research catchments on the Ntuze river were chosen for this study because of their close proximity to the rapidly expanding urban and industrial areas of Richards Bay harbour, the commercial centre of Empangeni and other large industrial concerns at Felixton (sugar mill) and KwaDlangezwa (University of Zululand) as well as the large formal urban settlements at Ngwelezana, Esikhawini, Mtunzini, Gingindlovu and Nseleni. These catchments are situated in a region of the coastal area which is physiographically similar to the urban and urban fringe areas surrounding other Natal coastal centres and consequently the results of this investigation should be directly applicable to many other similarly affected regions.

The principal aim of this study was to determine the hydrological response of small catchments to the expanding third world

settlements. The project adopted two main approaches in pursuing this aim which involved observational analysis and numerical techniques. The observational analysis has been presented in the first volume of this report and has concentrated on three specific objectives

* The identification of temporal changes in the hydrological response characteristics of a disturbed catchment (W1H016) that may be attributed to changes in land use.

* The identification of differences in the hydrological response of a disturbed catchment (W1H016) and an undisturbed, natural catchment (W1H031) that may be related to changes in land use.

* The characterization of the suspended and dissolved load from the two catchments supporting different land uses.

The numerical approach is presented in the second volume of this report and was specifically designed to;

* adapt numerical models for simulating the hydrological processes which could then be used to evaluate the effects of different land uses on the hydrological response.

The application of any numerical model requires suitable data for model verification before predicted changes can be simulated. Consequently the observational analysis presented in Volume I of this report also contributed to the verification of the numerical model presented in Volume II. The continuing development of an observational network in these catchments has produced a large volume of data which is being processed and released in supplementary publications. The processed meteorological data from the automatic weather station on the University of Zululand campus has been published for 1988 and 1989 under separate cover as HRU_z (Hydrological Research Unit, University of Zululand) reports (Kelbe 1989, 1990). The runoff and rainfall together with the water quality measurements from W1H016 and W1H031 have also been released for 1989 and 1990 as HRU_z reports (Kelbe, 1989, Kelbe and Bodenstein, 1990).

VOLUME I Observation Analysis

The University of Zululand research catchments have historical records extending back to their development in 1976. These research catchments, with up to twelve years of historical hydrological data, provided a unique opportunity to compare the disturbed urban fringe areas with an undisturbed natural system (Ngoye Nature Reserve) through the establishment of an observational network (Chapter 3) for monitoring the hydrological response.

Three specific objectives of the observational analysis (Chapter 2) have concentrated on relating the land use changes that have been identified (Chapter 5) with changes observed in the hydrological response. These involved the **temporal** analysis of historical data from a disturbed catchment (W1H016) and the **spatial** comparisons of **runoff** and **water quality** between the undisturbed, natural system (catchment W1H031) and the disturbed catchments (W1H016).

The temporal analysis presented in Chapter 6 showed no consistent trends in the historical record which could be related to land use effects. Problems with missing data, measurement accuracies, and inconsistency in data processing contributed to the limitations of this approach.

The identification of hydrological response relating to land use through a direct comparison of the runoff between two catchments requires a comparison of the physical features of both catchments. This has been presented in Chapter 3 and shows only one physical feature of the catchments which can be identified with a difference in the discharge characteristics. The shape of the disturbed catchment results in two constrictions in the area contributing runoff to sections of the channel network. This is considered to be the cause of three distinct discontinuities in the peak discharge following short duration high intensity storms. There is little observed difference in any of the other physical features of the disturbed and natural catchments which could contribute to a significant difference in the runoff characteristics.

The comparison of the runoff characteristics of the two catchments presented in Chapter 7, shows no differences which could be related to land use effects. However, there were large differences in most of the water quality parameters presented in Chapter 8. The water sampling procedure was identical at both weirs but changed slightly with instrumentation developments during the course of this project. This complicated the direct comparison of the two catchment measurements. The relationship between water quality parameters (mainly turbidity, suspended solids and phosphate measurements) and discharge are presented in Chapter 8. Because of the relationship between these water quality parameters and discharge, it is difficult to make a direct comparison of all the observations as some samples may have been derived from different flow regimes. This is a consequence of the sampling technique which collected composite samples after regular flow volumes and not at fixed time intervals. Consequently, averages of all samples and one to one comparisons of individual samples must be viewed with caution.

Comparisons have been performed on temporal plots for four different storm hydrograph states classified as the rising limb, peak discharge, recession limb and base flow. These have been examined for seasonal trends. The differences between the catchments for these various hydrograph states have been examined. Varying differences between the catchments in the measured pH, conductivity, turbidity, suspended solids, nitrates and phosphates have been observed. Since all the physical features of the two catchments are very similar, these water quality differences are considered to be a response to the differences in land use.

VOLUME II Numerical analysis

Numerical techniques have provided an excellent and relatively cheap means of estimating the effects of various land uses on the hydrological systems but they suffer from the need to be verified before their predictions can be accepted with any confidence. However, numerical models are gross simplification of the real system. Consequently, the choice of a model and its intended role in this study are considered in the introduction (Chapter 1). The specific objectives of Volume II are stated in Chapter 2. The application of numerical models and the approach chosen for a study of this nature within the constraints imposed by the human and computer resources at HRU_z are explained in Chapter 3. After these consideration this project has adapted an existing field scale hydrological model in an effort to determine the anticipated hydrological response to these changing environments.

The model chosen for this study was developed to simulate the **C**hemical, **R**unoff and **E**rosion from **A**gricultural **M**anagement **S**ystems (**CREAMS**) from small agricultural fields. This suite of numerical methods considered the chemical, runoff and erosion components separately and is described very briefly in Chapter 4 where consideration of the scale of application is introduced as an additional long term objective. While the model comprises runoff and water quality components, this report has only achieved the verification and application of the runoff component. Water quality measurements are proceeding and will enable a verification of the other components in subsequent research.

The set of parameters in CREAMS which may be used to examine land use change are described in Chapter 5. This section highlights some of the limitations of this study which are imposed by the available parameters that represent the (desired) features associated with the expected changes in land use. While modern mechanised agricultural management can effectively influence many soil parameters, subsistence type farming may change mainly the vegetational aspects.

The most important aspect of model verification and application is the determination of the model parameter values. Measurement or estimation of these values for small homogeneous areas are not necessarily representative of the entire (lumped) catchment. Consequently, the measurements of catchment characteristics and their utilization in estimating representative catchment parameters form an important component of this study and are described in Chapter 6. Since the scale of application and the degree of representation are also an important part of this study, it may be necessary to continually review this section in extended studies.

Since the model was being considered at a scale of application considerably greater than the original development envisaged and in a region (Zululand) not previously considered in previous evaluations, it was considered necessary to repeat a sensitivity analysis of selective parameters. The sensitivity analysis is presented in Chapter 7 and indicates that several parameters required particularly careful evaluation. These include the SCS curve number, certain soil moisture retention parameters, the leaf area index, and radiation values. These are all revised in Chapter 8.

The hydrological component of CREAMS model has been applied to the smallest catchment of approximately $0.7km^2$ (W1H017) and the verification has been presented for different temporal scales in Chapter 9. The partitioning of the runoff component required further analysis of the storm hydrographs in W1H017 for improved evaluation of the model predictions, which is also presented in this section. The runoff component of the model performed satisfactorily ($0.6 < r < 0.9$) at this catchment scale even though the land use and hydrological response (units) were not particularly homogeneous.

In terms of the stated objectives, the runoff component of the model was then applied to catchment W1H016 which is nearly five times larger than W1H017 (Chapter 10). The lumped model with appropriate representative catchment parameters for W1H016 was compared to actual runoff measurements for model verification. The simulated runoff from four subcatchment, which were comparable in size to W1H017, were integrated to give a spatial (distributed) representation of the runoff from W1H016 for comparison with the lumped simulations. The results have indicated that the lumped model can be applied at the extended catchment scale ($\approx 3\ km^2$) as successfully as the "semi-distributed" simulation.

The model was also applied to the undisturbed catchment (W1H031) and verified against the limited available data. Finally the representative catchment parameters were altered to simulate possible changes in land use and predictions of hydrological response determined which are presented in Chapter 11.

Both volumes have summarized the results of the research in greater detail. They also contain detailed descriptions of selected data, the instrumentation and software development, all of which are presented in separate appendices.

Recommendations for future research. This project has shown the difficulty in identifying differences in the runoff from small catchments with different management strategies. This is due to the nature of the data and the inherent variability of the system under investigation. Since significant difference could **not** be detected in the runoff **volume** which could be attributed to land use, continued research on the runoff characteristics is not recommended for the immediate future. However, the project has shown significant differences in the water quality emanating from catchments under different land uses. This is of considerable importance to water resource managers who need to balance sustainable development with acceptable water quality. Consequently there is a dire need to identify and quantify the processes responsible for deterioration of water quality under specific land use options. This is particularly important in areas of rapid and uncontrolled development.

The project results suggest that the following aspects require further attention;

* This project has shown some relationships between certain water quality variables. It is recommended that some of these relationships should be more fully defined in order to utilize them to reduce the number of sample analysis required to characterize stream loads. This may reduce the number or frequency for expensive water analysis.

* Particular emphasis should be given to identifying the processes responsible for the deterioration in water quality for particular land uses. The contribution of settlements, subsistence cultivation, sugar cane and other developments to the sediment, nitrate, and phosphate loads need to be identified. It is possible that the relationship between water quality and flow may help to trace the path of these components through the hydrological system and thereby contribute to the identification of the source areas.

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1 INTRODUCTION

There is evidence that the sediment yield of many African rivers has increased over the past few decades in response to land use changes (Walling, 1984). This response varies with land use type, the form and extent of precipitation and other controlling factors (soils etc). There has also been suggestion that the sediment load may decrease once the topsoil and other vulnerable deposits have been depleted sufficiently to reduce the material that is available for erosion and transport (Rooseboom and Harmse, 1979). The varying response of catchments to the form and extent of degradation and denudation indicates the need for further information on the precise interactions between land use changes and the hydrological response.

In the river ecosystem, the wetlands act as filters which retain sediment. Where these wetlands are drained and the rivers are canalised, sediment is carried further and deposited elsewhere. One of the major consequences of the degradation and resulting sediment yield is the influence on the fragile ecological and hydrological estuarine systems. The Mhlatuze estuary at Richards Bay is expected to become completely silted with the consequential collapse of the present ecological system (Anon, 1989).

Southern Africa is a region with very limited water resources that are being severely affected by a rapidly increasing population which is migrating toward the industrial areas. This large influx of unskilled rural people is producing rapidly expanding informal urban fringe settlements surrounding all the main metropolitan centres (Simkins, 1985). These areas in Natal and Zululand, such as Embumbulu, Ntuzume, Velindelela and Madadeni (Figure 1,1) still contribute to agricultural production but in most instances comprise uneconomically viable agricultural units (Muller, 1985). They are frequently situated in hilly terrain and are usually managed by family units that are not fully conversant in recognised conservation practices. These settlements are producing considerable denudation and degradation of large areas which are promoting increased erosion (Stocking, 1984) and subsequent pollution of major water resource schemes. While extensive hydrological investigations have been conducted

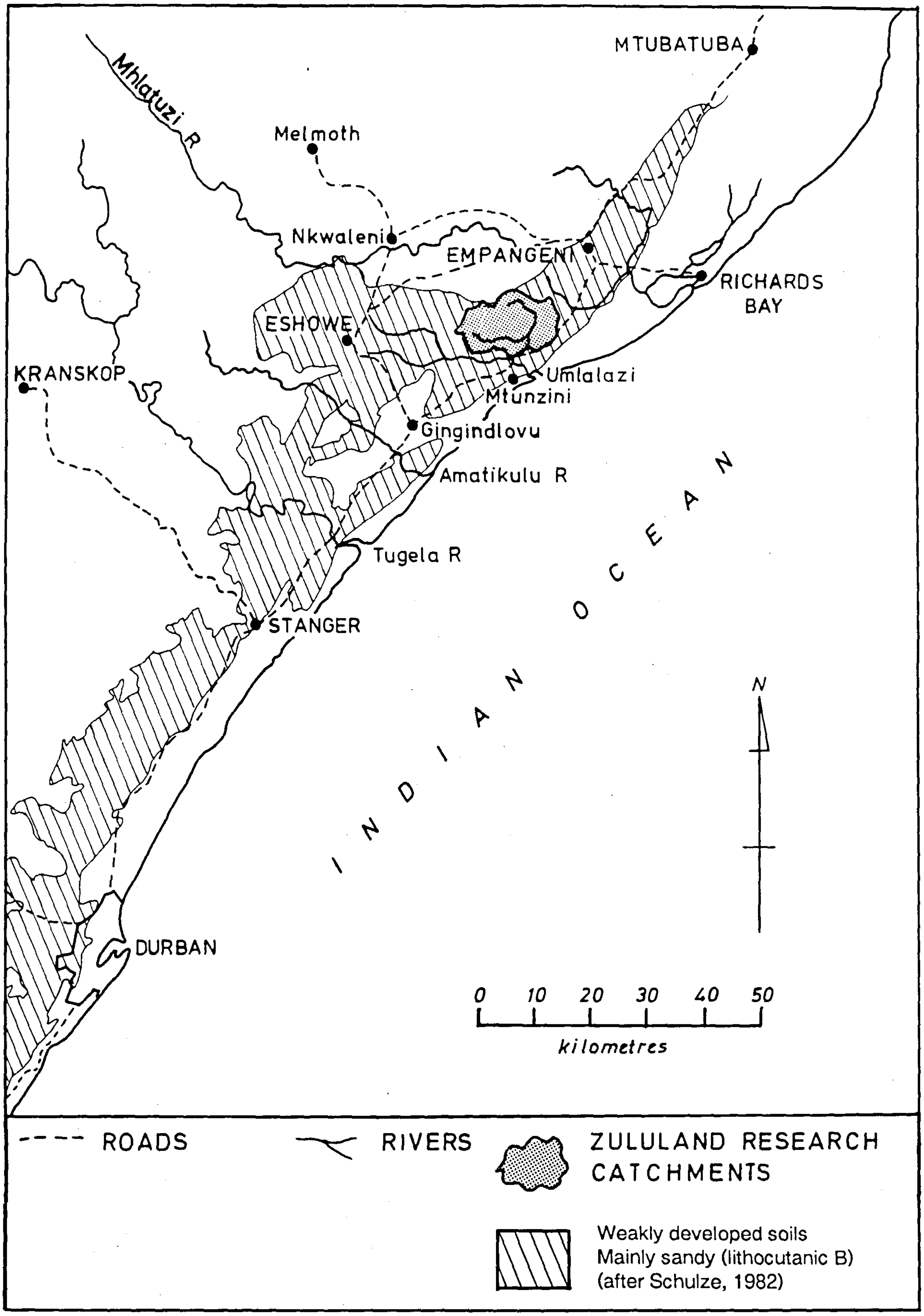


Figure 1.1 **The Zululand research catchments relative to the main coastal metropolitan centres of Natal. The hatched area (from Schulze, 1982) represents similar physiographic areas comprised of weakly developed soils.**

on selected land use type such as forestry, there is little information on the hydrological response to intensive subsistence agriculture in the developing peri-urban areas.

The Hydrological Research Unit, Department of Hydrology at the University of Zululand commenced this three year project in 1988 in collaboration with the Division of Water Technology (DWT) of the CSIR and the Department of Agricultural Engineering, University of Natal (DAE-UN). The project was developed to investigate the hydrological response of the expanding third world settlements in the rapidly developing urban fringe areas surrounding the formal settlements in Natal and KwaZulu. These areas are changing from predominantly pastoral subsistence to more market orientated agriculture. This agricultural cultivation is likely to be poorly managed so that the crops are unlikely to achieve potential development and hence they will provide a poor vegetational cover for soil protection. There are also crude drainage systems on many wetlands where the local inhabitants are cultivating the valley bottoms. These ditches and drainage lines are reducing the filtration effect of the wetlands and sedges and increasing the rate of runoff and sediment production.

The 1980 government census indicates that most of Natal and KwaZulu have experienced a very large population growth, which is mainly attributed to an increase in the Black population. One area which is experiencing exceptional growth (Water Affairs, 1987) is the urban and fringe area surrounding Richards Bay, Empangeni, Ngwelazana, Esikhawini, and Mtunzini (Figure 1,2). Most of the local authorities in this region obtain their water from local impoundments which frequently need to be supplemented from other sources. Many of these sources are polluted and require purification to meet health and industrial standards (Allison, 1987). With the rapid expansion of the unorganised urban fringe areas in this region, and in other areas of Natal/KwaZulu, there is an urgent need to determine the influence of these settlements on the hydrological response of the contributing catchments and to develop management strategies for their control. Knowledge of these influences and their incorporation in hydrological models will be beneficial for water resources planning and management in Natal and KwaZulu.

The study is being conducted in the small research catchments of the Ntuze river, near the University of Zululand (Figure 1,2). These research catchments, in the hilly Ntuze river basin, support both high density third world settlements and a protected natural ecosystem. The existence of the protected nature reserve in the research catchments provided the opportunity to compare two similar catchments with different land uses. The Ngoye Nature Reserve, controlled by the Department of Nature Conservation of KwaZulu, is a small forest reserve that was scheduled for re-fencing and stocking with indigenous fauna during 1988. This has not been achieved and the area is still used for controlled grazing by the local inhabitants surrounding the reserve. The grazing by a limited number of cattle is unlikely to exceed the utilization of fodder by indigenous fauna in a natural ecosystem except in the immediate vicinity of access gates where excessive degradation is likely to occur.

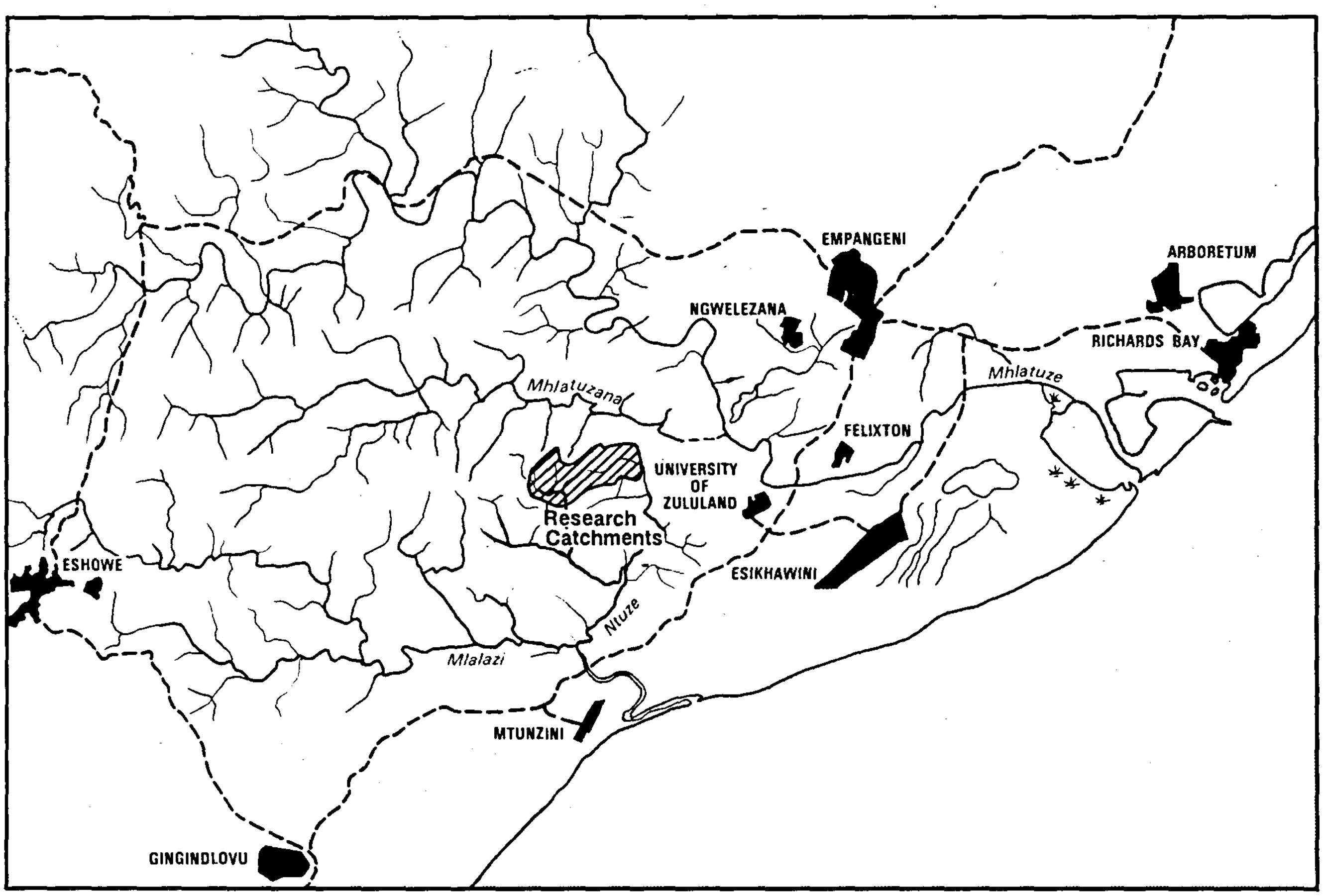


Figure 1.2 **The Ntuze research catchments in relation to urban development.**

2 AIMS and OBJECTIVES

The overall aim of this project is to **identify and model the effects of third world settlements on the hydrological response of small catchments in the rapidly developing urban fringe areas of Natal/KwaZulu.** To achieve these overall aims, several specific objectives are identified :-

a. The identification of temporal changes in the hydrological response characteristics of the disturbed catchments that may be related to changes in the land use.

b The identification of differences in the hydrological response of the disturbed and undisturbed catchments that may be related to differences in their land use.

c The characterisation of the suspended and dissolved loads from the catchments supporting different land uses.

d The adaptation of numerical models for simulating the hydrological processes that will enable an evaluation of the effects of different land uses on hydrological responses.

The first three objectives are examined in this report, which comprises the first of two volumes. The fourth objective is covered in a separate volume by Mulder and Kelbe (1991).

3 RESEARCH CATCHMENTS, INSTRUMENTATION AND DATA COLLECTION

The Ntuze catchment is situated in the physiographic region referred to as the Natal Coastal Belt (Schulze, 1982). This region stretches along the entire coastal strip from the Transkei north to Zululand (Figure 1,1) and generally comprises weakly developed soils (mainly sands). The catchment, therefore, is fairly representative of large sections of the Natal coast including the areas surrounding the large metropolitan centres shown in Figure 1,1.

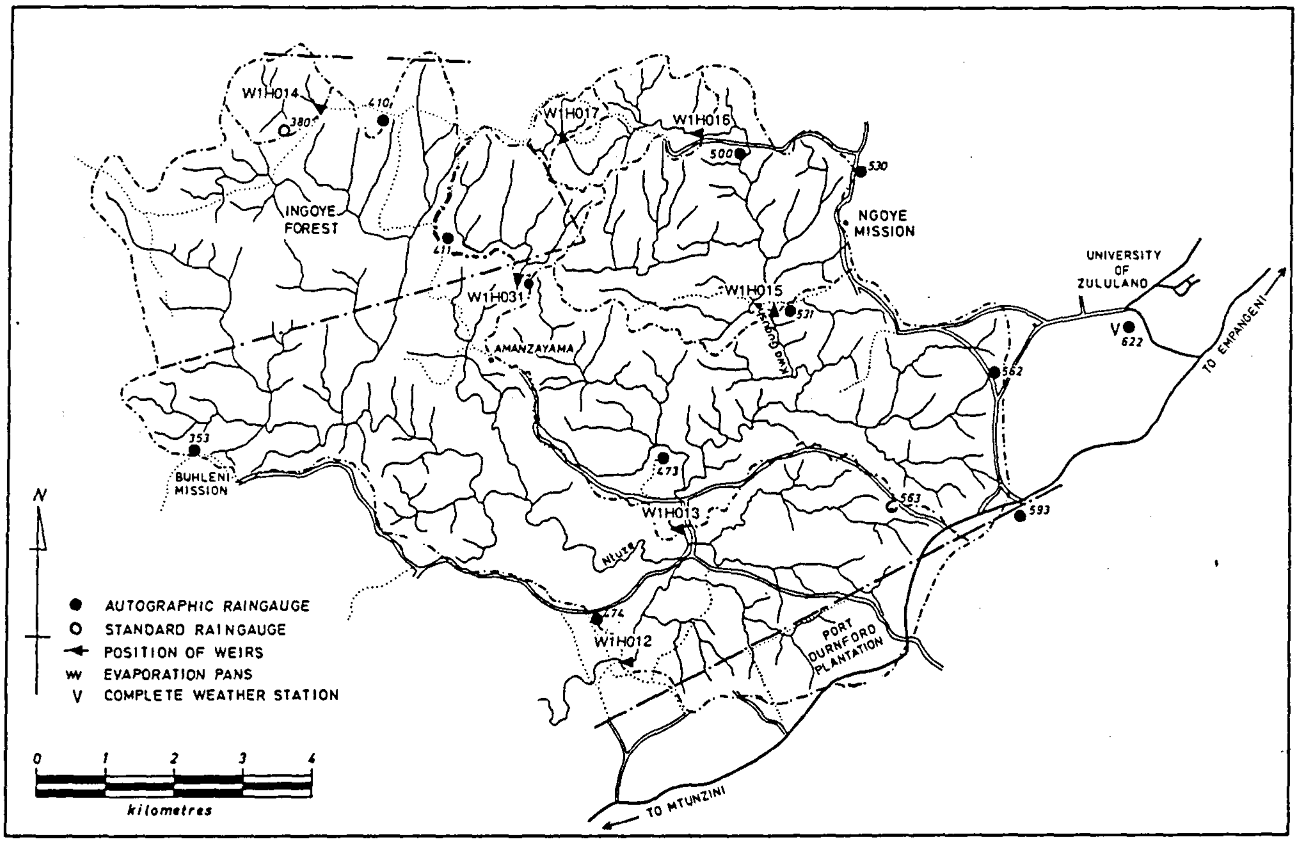


Figure 3,1 **Location of instrumentation and selected topographical features of the Ntuze Research Catchments.**

The Ntuze research area (Figure 3,1) comprised six nested catchments ranging in size from 0,7 to 82 km^2 that had been monitored for rainfall and runoff since 1974. Detailed climatological and geological surveys of the research catchments have been conducted and hydrological response units identified

(Hope and Mulder, 1979; Mulder, 1984).

The settlements in the Ntuze catchment are concentrated along the access roads and have their greatest density in the south-eastern areas (Figure 3,2) which are closest to KwaDlangezwa (University of Zululand) and the main arterial roads leading to the industrial centres at Empangeni and Richards Bay. The more developed south-eastern area comprise small fields of sugar cane and cash crops. However, sugar cane has now been established in the northern areas (W1H016) and is expected to increase markedly with the allocation of quotas to Homeland areas and the shortage of cane at the new Felixton mill. This development is leading to improved roads and other communication facilities which will promote further settlements in the area.

In 1977, five weirs were designed and built by the Department of Water Affairs along the Ntuze river (Figure 3,1), a tributary of the Umlalazi river. These structures were designed to record

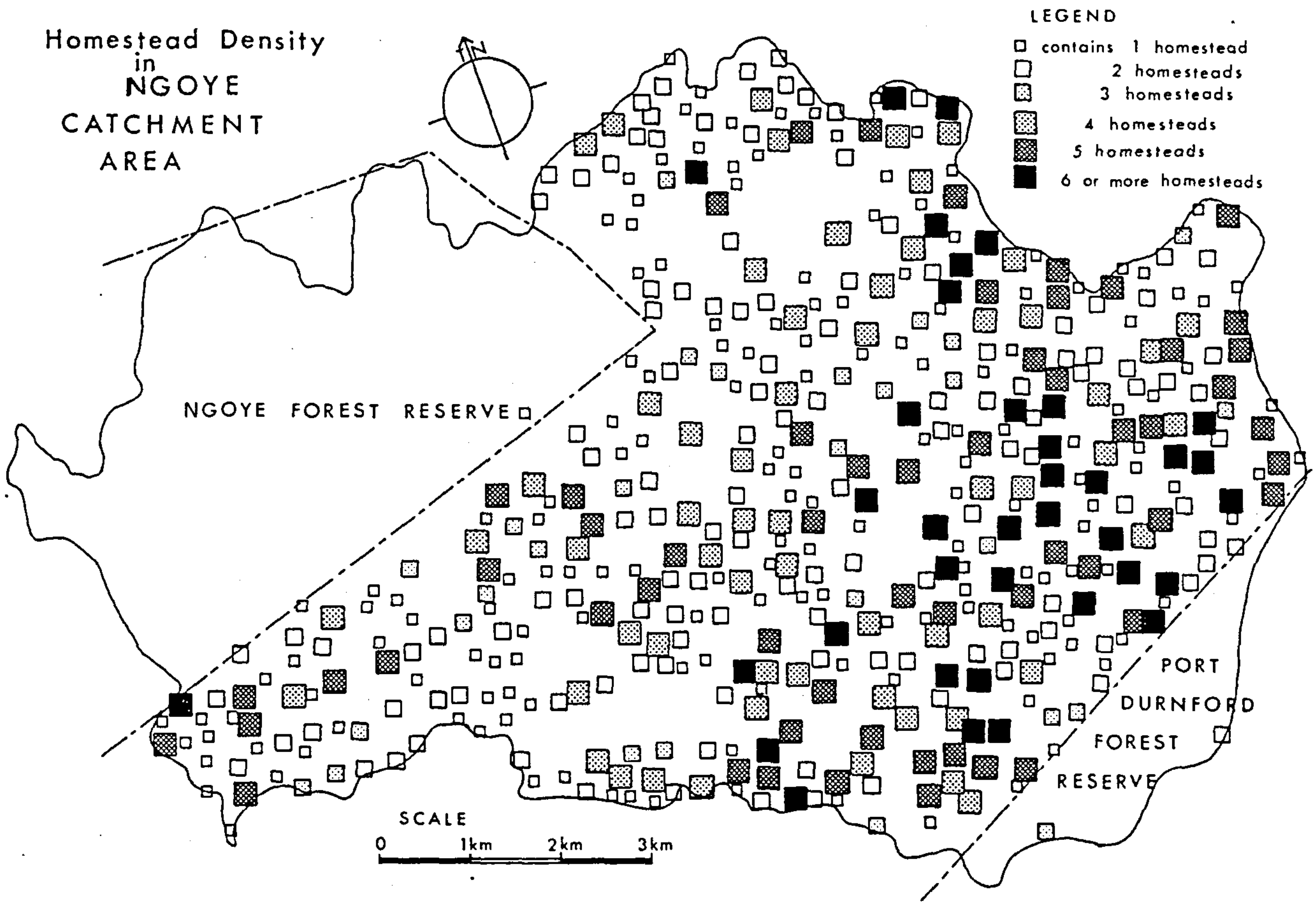


Figure 3,2 **Spatial density of dwellings in the Ntuze catchment (after Townsend, 1988).**

up to and including the one in 20 year flood with an accuracy of better than 5% of discharge. A sixth weir was constructed in 1979 by the Department of Geography, University of Zululand to monitor the indigenous forest of the Ngoye Nature Reserve. These six weirs, were intended primarily for the collection of accurate data for hydrological modelling, and have been described in detail by Hope & Mulder (1979) and Hope (1984). An additional weir was constructed in 1988 at W1H031 (Figure 3,1) for the specific purpose of this study.

From the inception of the original Water Research Commission program in 1974 until the middle of 1983, the data collection was undertaken by the HRU_Z at University of Zululand and sent to the Department of Agricultural Engineering, University of Natal, for digitising. Subsequent collection of the data and the digitisation was undertaken by the HRU_Z. The digitisation and error checking of all rainfall and runoff data have been completed up to the end of 1989. Much of the data for 1990 has been digitised and is presently being processed for errors. All of this data is currently being installed on the data bank in the Department of Hydrology, University of Zululand and will be made available through the Computing Centre for Water Research (CCWR) at the University of Natal, Pietermaritzburg, or through direct link to the Local Area Network (LAN).

In the process of utilising this historical information, it became evident that changes in the collection and processing of the data were not well documented and posed a serious threat to any hydrological analyses. This is particularly relevant to the discharge measurements where structural changes and the cleaning of weirs has not been documented. An effort is being made to document a calendar of events for each weir (Appendix I) and to document missing data.

Major problems were encountered following the devastating floods in September 1987 and heavy rainfall in January 1989. Some gauge plates were damaged and heavy siltation of the weirs occurred. Some of the more serious problems include the temporary closure of Weir W1H014 (indigenous forest catchment) since January 1989 as a result of damage to the plates and problems with accessibility. This weir has been cleaned and will be re-opened when repairs have been completed. Weir W1H016 has been cleaned frequently since February 1989 and has been surveyed (September 1990) as part of an effort to determine the rate of siltation occurring in this catchment. W1H012 was cleaned and upgraded by the Department of Water Affairs in 1990. The hut housing the overhead cables at weir W1H013 was damaged and the cable was lost in the floods of 1987.

3.1 THE METEOROLOGICAL STATION

The Department of Hydrology maintained a meteorological site (622) on the university campus which was situated within 10km of the research catchments (Figure 3,1). The weather station at 622 had deteriorated badly and was being vandalised. Consequently it was considered necessary to move the station to another site on the campus and to upgrade the instrumentation (Appendix II). The new station instruments comprise standard (Casella) and autographic (Theis) raingauges, Symons tank, A-pan, wet & dry bulb thermometers, and maximum and minimum thermometers. An automatic weather station was installed during 1988 to monitor, on a continuous basis, the atmospheric pressure, solar radiation, temperature, specific humidity, wind speed, wind direction, and rainfall. A water level recorder is being designed and constructed to monitor the Symons tank on a continuous basis. The instrumentation for the automatic weather station is described in detail in Appendix II.

One of the primary objectives of establishing the automatic weather station was to obtain estimates of potential evaporation through the application of the Penman equation (appendix II), particularly for modelling purposes. In this study the radiation and temperature have been used directly in the model simulations presented in Volume II (Mulder and Kelbe, 1991). A computer program was developed to process the data from the automatic weather station. This program was designed to provide estimates of the potential evapotranspiration based on the Penman equation (Campbell, 1986) and is explained in detail in appendix II. The processed data for 1988 and 1989 has been published under separate cover (Kelbe, 1989,1990)

3.2 RAINGAUGE NETWORK

Problems have been encountered with the Casella raingauges and many clocks have had to be scrapped for spare parts. This has necessitated the closure of several rainfall stations in the Ntuze catchment and the establishment of others in the immediate vicinity of the catchments which are directly relevant to this project (W1H016 and W1H031).

Detailed analysis of the rainfall regime in the Ntuze catchment has been presented by Hope & Mulder (1979). Their results indicated that monthly rainfall at any ungauged point within the relevant catchments (W1H016 & W1H031) was generally correlated with station 441 at better than 0.990. However, it was considered appropriate to increase the aerial coverage by upgrading stations 500 and 411 to autographic stations and to establish an additional rainfall station at 441, near the new weir. With the deployment of dataloggers at the weirs, two additional raingauges (tipping bucket) have been installed on the instrument hut at W1H016 and W1H031 (see plate IV-1 in Appendix IV). After the rainfall station at 470 was severely vandalised in 1990 it was moved 200m from its original location. The present network of raingauges is shown in Figure 3,1. With the loan of the autographic raingauges by the Institute for Water Research (previously HRU), Rhodes University and FORESTEK (previously SAFRI), it is intended that several more raingauge sites will be established in the near future.

3.3 WEIRS

Investigation of the hydrological effects of the third world settlements in the Ntuze catchment requires either direct measurements of appropriate variable or a comparison with the natural system of hydrological responses. The relatively undisturbed Ngoye Nature Reserve, within the Ntuze catchment, provides an ideal opportunity to make direct comparisons with a similar area. Several hundred meters outside the south-eastern boundary of the reserve, an abandoned dam formed the outlet to a catchment situated almost entirely within the Ngoye Nature Reserve (Figure 3,3). This catchment shares a common divide with W1H016 and is situated in the same geological structure (Hope and Mulder, 1979). Situated at the same altitude and in such close proximity, these two catchments (W1H016 & W1H031) must also share a similar climate. Consequently, this control structure was adapted (Appendix III) to monitor discharge from the predominantly natural grassland system for direct comparison with the disturbed catchment W1H016.

The weir structure, rating table and other relevant information is given in appendix III. Hourly and daily discharge, rainfall and stilling well temperature have been obtained and published under separate cover (Kelbe, 1990).

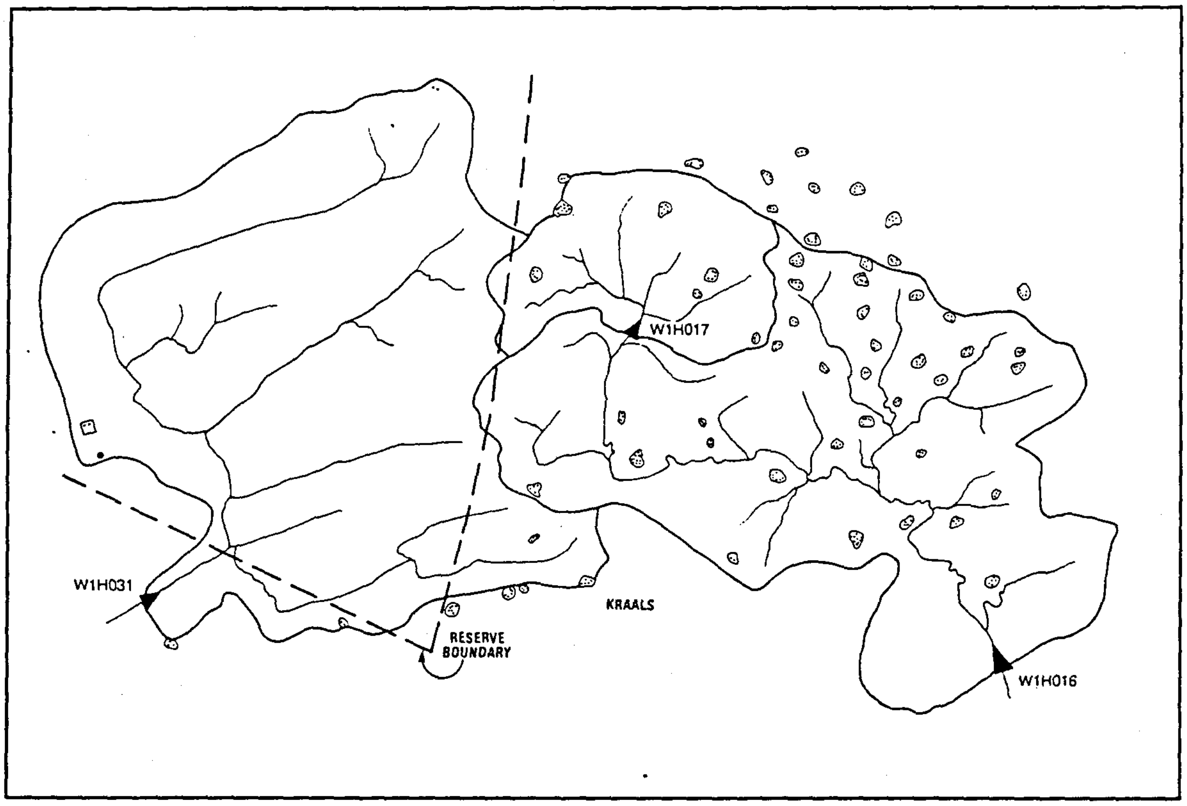


Figure 3.3. Stream network and location of dwellings in W1H016 & W1H031. Data from aerial photographs in 1976.

A summary of the daily discharge, the mean, maximum and minimum stage, daily rainfall and mean daily temperature are given in appendix IV. The computer program (appendix IV) for processing the weir data also provides mean hourly values for each month of the discharge, stage and temperature together with the total rainfalL.

3.4 WATER SAMPLERS & CONTROL INSTRUMENTATION

OTT water level recorders are installed at all the weirs in the Ntuze catchments. The pen release arm within these OTT recorders was used as a trigger mechanism to switch on the ISCO water samplers which were installed at weirs W1H016 and W1H031. An interface was constructed to maintain contact closure so that the water samplers would continue to function when the microswitch was released after the pen arm had moved past the contact point. This method for the collection of water samples commenced in August 1988 and was operational until January 1989. Unfortunately this method was not entirely reliable and it was difficult to link the time of sample to the stage since it was not possible to accurately determine the exact point of contact closure by the micro switch.

This method could only provide time related samples which were then related to the discharge hydrograph. However, the DWT collaborative project was more concerned with continuous flow related samples. Consequently, Campbell Scientific CR10 dataloggers coupled to Geokon piezometers (appendix IV) were obtained to monitor discharge continuously and to activate the ISCO water samplers after a specified volume of discharge had occurred in order to provide flow related samples.

The dataloggers, with some accessories were acquired during 1988. Unfortunately severe problems with the initial equipment (faulty piezometers and interface cards) and service delayed the development of this system until June 1989. The dataloggers, connected to a vibrating wire piezometer and tipping bucket raingauge, have now been developed to initiate sampling after a specified discharge has been reached. The system is programmed to record the time and the stage for each sample, together with the total discharge since the previous sample. This system worked well until July 1990 when the piezometer at W1H016 became erratic and gave erroneous readings. A similar problem at two other stations established at St Lucia indicates a problem with the system which requires further development. Excessive delays by the local agent in determining and rectifying the problem has caused unnecessary loss of time and data. After consultation with DWT a potentiometer has been obtained and incorporate into the OTT float cables system in an effort to replace or supplement the piezometer system. This is described in detail in Appendix IV.

The times of both dataloggers were synchronised on several occasions during the project although they seldom varied by more than a few minutes. Several program changes were also made during the course of this project and are shown in appendix IV. These program changes usually produce different formats in the data record which have to be corrected by further processing. The computer program for processing the data (appendix IV) incorporates all these changes during processing. This program still requires adaptation to restore the raw data in a form which shares only one format that is more suitable for all users. The most suitable format for this datalogger or any other continuous recording system is not clearly defined and is a topic for further investigation.

3.5 SOFTWARE DEVELOPMENT AND ALTERATIONS

A tremendous amount of software development and alteration has been necessary to implement the datalogger systems and to use the processed runoff and rainfall data. Most of this has been described in the relevant appendices. Computer programmes for analyzing the rainfall (RAINX) and runoff (RUNOFF), which were developed by Schulze and Arnold (1980) for the mainframe environment, were altered to run on the PC-AT system environment with an 80 column printer.

4 CLIMATOLOGICAL AND PHYSICAL CATCHMENT CHARACTERISTICS

A comparison of the hydrological response of two catchments will reflect differences in many factors of the catchment physiography and land use. Consequently it is necessary to quantify any significant differences in the physical features of the two catchments if their responses are to be compared and related to land use. The two catchments of direct interest to this project are W1H031, (undisturbed natural grassland) and W1H016 (third world settlements)

4.1 CLIMATOLOGICAL CHARACTERISTICS

The general rainfall characteristics of the research area are derived from both free and forced convective activity. In winter the rainfall is almost certainly dominated by widespread forced convection (frontal and orographic), while in summer numerous thunderstorms do occur. These two systems produce rainfall from opposing directions. Along the east coast of southern Africa, the summer cumulonimbus generally tend to move under the influence of the upper level winds toward the east-northeast (Kelbe 1983) while the forced convection is derived mainly from a low level south-southeasterly flow due to invading synoptic systems moving along the east coast (Kelbe 1988; Garstang et al, 1987). Since the height contours of the research catchments tend to be orientated in a SW-NE direction, these opposing systems will either move parallel or perpendicular to the topography. The two catchments being compared also lie at similar altitudes and in the same orientation, consequently their rainfall regimes should be very similar.

4.1.1 SEASONAL AND ANNUAL RAINFALL

Total monthly rainfall since 1938 has been derived for station 622. These values together with selected statistical parameters are given in Table 4,1. The 52 year mean monthly values show a definite annual cycle (Figure 4,1) with the wettest period occurring during February. Significant rainfalls generally do occur throughout the year, but the winter mean values are

Table 4,1 MONTHLY RAINFALL FOR STATION 622 : UNIZULU CAMPUS

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1938				83.1	56.0	146.7	276.8	78.2	11.1	109.9	65.7	121.7	
1939	77.9	368.6	200.1	75.2	181.7	143.0	127.8	73.2	321.8	110.2	332.1	102.6	2114.2
1940	88.6	34.9	222.3	120.9	333.1	171.7	38.7	137.0	72.3	74.3	229.2	185.8	1703.8
1941	98.4	64.3	151.4	77.5	79.8	38.1	44.9	14.5	100.4	40.9	154.3	121.2	985.7
1942	236.3	33.8	247.9	81.0	121.4	31.3	53.1	68.3	105.9	65.4	176.5	268.9	1489.8
1943	23.6	158.2	240.8	231.3	35.8	66.0	144.0	123.7	64.6	161.3	97.5	117.7	1464.5
1944	34.0	181.5	177.5	61.3	38.6	189.3	58.9	25.4	197.7	104.8	150.7	84.9	1304.6
1945	124.5	215.2	302.3	73.6	33.3	28.5	15.3	59.9	20.3	80.0	88.8	150.8	1192.0
1946	127.2	98.6	119.2	170.2	52.5	0.0	12.7	53.3	48.0	137.1	51.9	140.3	1011.0
1947	87.9	217.9	201.0	107.1	64.8	90.4	101.9	59.5	118.4	145.0	203.9	104.2	1502.0
1948	164.6	164.7	141.8	136.0	53.5	16.5	10.4	57.5	33.0	95.3	157.2	85.5	1116.0
1949	127.3	219.7	77.5	224.8	22.8	70.4	32.2	43.3	100.9	177.7	162.2	278.7	1537.5
1950	100.0	224.2	201.0	62.3	40.6	80.0	31.3	71.3	16.3	71.5	34.5	160.9	1093.4
1951	102.2	79.4	143.1	42.4	40.4	77.7	74.1	194.5	119.2	164.6	18.0	164.2	1219.8
1952	135.7	92.0	115.9	67.7	115.6	19.3	74.7	17.2	40.6	45.5	127.8	110.4	962.4
1953	67.0	114.3	135.1	30.1	26.0	15.4	55.4	31.0	167.5	125.0	243.4	118.9	1129.1
1954	116.5	280.5	106.7	175.0	98.4	67.5	44.5	46.1	206.1	298.1	40.0	110.7	1590.1
1955	243.8	113.9	260.4	102.3	84.7	32.4	3.0	66.0	116.0	170.0	168.0	142.0	1502.5
1956	59.0	370.0	160.1	50.6	99.0	92.0	3.5	118.0	121.0	116.5	155.0	609.0	1953.7
1957	101.0	168.5	177.0	269.0	36.5	14.5	92.5	57.5	272.5	274.0	89.5	112.5	1665.0
1958	347.0	200.5	67.4	199.0	24.5	46.0	67.5	27.0	258.5	130.5	71.5	118.5	1157.9
1959	115.0	100.0	42.0	55.5	108.5	24.5	24.5	190.0	103.0	202.0	95.6	196.0	1256.6
1960	73.5	336.0	102.0	201.6	100.0	22.0	51.0	52.5	103.1	68.0	344.6	591.3	2043.1
1961	89.4	148.3	134.3	351.0	48.5	287.4	90.0	35.5	116.5	172.5	178.0	108.0	1765.6
1962	120.9	98.7	120.7	109.7	70.6	1.3	32.8	91.1	48.3	123.9	195.3	8.7	1022.0
1963	206.9	93.0	154.3	132.6	1.9	229.2	292.6	25.4	13.7	119.1	102.8	86.4	1457.9
1964	193.8	93.5	121.6	185.3	5.1	21.5	79.0	71.5	84.4	207.7	115.6	111.0	1290.0
1965	75.5	51.0	72.0	101.0	44.3	218.8	50.5	126.0	140.3	202.0	124.3	48.0	1253.7
1966	232.5	137.5	30.5	62.0	67.5	56.5	40.0	114.0	43.0	73.3	76.5	56.5	989.8
1967	169.0	76.0	278.0	281.0	13.0	15.5	136.0	27.5	24.0	108.5	112.0	51.5	1292.0
1968	90.0	187.0	187.0	36.0	16.0	59.0	28.0	109.0	64.5	86.5	160.0	108.0	1131.0
1969	81.0	83.5	443.5	63.5	89.0	50.5	36.5	0.0	124.5	123.5	95.5	7.5	1198.5
1970	62.5	51.5	90.4	73.0	131.5	36.5	25.0	13.3	103.5	264.0	160.0	83.0	1094.2
1971	160.5	198.5	133.5	95.5	466.5	23.5	156.5	12.5	117.5	154.0	93.5	80.0	1692.0
1972	34.2	676.0	124.5	93.0	244.0	47.5	49.5	52.0	19.0	49.5	153.0	147.5	1689.7
1973	107.2	183.0	102.5	302.5	73.5	17.0	43.5	305.5	241.5	79.5	186.5	53.0	1695.2
1974	211.0	103.0	119.5	61.0	102.0	74.0	40.5	32.0	25.5	75.5	114.0	187.5	1145.5
1975	167.0	221.0	133.0	110.0	51.5	14.0	58.5	84.5	179.1	126.3	117.2	165.0	1427.1
1976	307.9	144.5	461.6	215.7	126.1	23.3	36.3	66.2	70.1	202.0	148.1	146.7	1948.7
1977	169.7	534.5	213.8	24.8	45.0	29.2	49.6	43.3	103.6	115.0	174.7	117.5	1620.7
1978	389.3	147.8	128.3	211.9	32.3	88.8	52.4	60.6	111.3	183.6	144.0	57.8	1608.1
1979	206.0	32.1	72.9	52.0	94.4	38.0	43.6	47.7	95.4	86.8	94.9	125.5	989.3
1980	141.5	56.6	33.9	66.9	28.6	30.0	12.7	19.7	223.1	36.0	99.2	51.5	799.7
1981	263.7	171.5	66.0	103.7	317.4	96.9	21.5	102.1	135.5	110.9	188.6	78.4	1656.2
1982	94.6	87.9	158.0	69.4	86.9	0.0	21.9	11.8	103.0	128.1	77.2	49.8	888.6
1983	68.8	63.5	30.8	4.0	39.6	60.8	80.2	131.6	32.4	85.6	168.1	92.4	857.8
1984	426.7	406.6	135.6	144.8	29.1	61.3	159.7	71.2	6.5	72.6	132.7	96.2	1743.0
1985	140.6	350.4	39.1	2.7	12.3	107.2	84.4	52.8	124.5	272.6	62.2	79.9	1328.7
1986	190.3	48.3	136.7	95.5	21.4	54.0	4.5	17.4	115.8	84.6	85.7	132.2	986.4
1987	221.4	20.0	228.6	54.1	80.5	212.9	43.7	159.8	602.8	113.8	130.5	131.9	2000.0
1988	58.6	289.8	212.8	21.9	37.1	77.5	32.8	37.3	80.9	180.3	215.0	402.7	1646.9
1989	139.4	317.8	61.4	81.4	91.0	76.3	83.5	5.5	180.3	125.8	451.6	167.2	1781.2
1990	133.8	179.6	281.8	76.2	82.8	36.6	25.4	141.0	26.0	62.8	43.2	34.6	1123.8
1991													
NUMBER	52.0	52.0	52.0	53.0	53.0	53.0	53.0	53.0	53.0	53.0	53.0	53.0	52.0
MEAN	**146.2**	**174.8**	**155.8**	**113.4**	**83.5**	**67.0**	**59.1**	**70.3**	**116.6**	**128.5**	**142.2**	**137.3**	**1386.9**
ST.DEV	86.6	130.2	90.0	78.9	85.8	63.3	50.0	56.8	98.2	61.8	77.9	114.0	336.8
MIN	23.6	20.0	30.5	2.7	1.9	0.0	3.0	0.0	6.5	36.0	18.0	7.5	799.7
MAX	426.7	676.0	461.6	351.0	466.5	287.4	292.6	305.5	602.8	298.1	451.6	609.0	2114.2
CV	59.0	74.0	57.0	69.0	102.0	94.0	84.0	80.0	84.0	48.0	54.0	83.0	24.0

approximately one third of the peak summer amounts.

The annual total rainfall series for station 622 since 1938 and the coefficients of variation (CV) are shown in Figure 4,2. Spectral analyses of this annual and corresponding monthly rainfall series confirms the cyclical nature of the rainfall along the east coast found in other South African series by Tyson (1986) and Kelbe et al (1982). The annual cycle dominates but there is a strong indication that the 18 year cycle is also significant.

4.1.2 HOURLY RAINFALL

The total rainfall for each **hour** of the day, accumulated over each calendar month, have been plotted for each month since September 1989 when the tipping bucket raingauges were installed at weirs

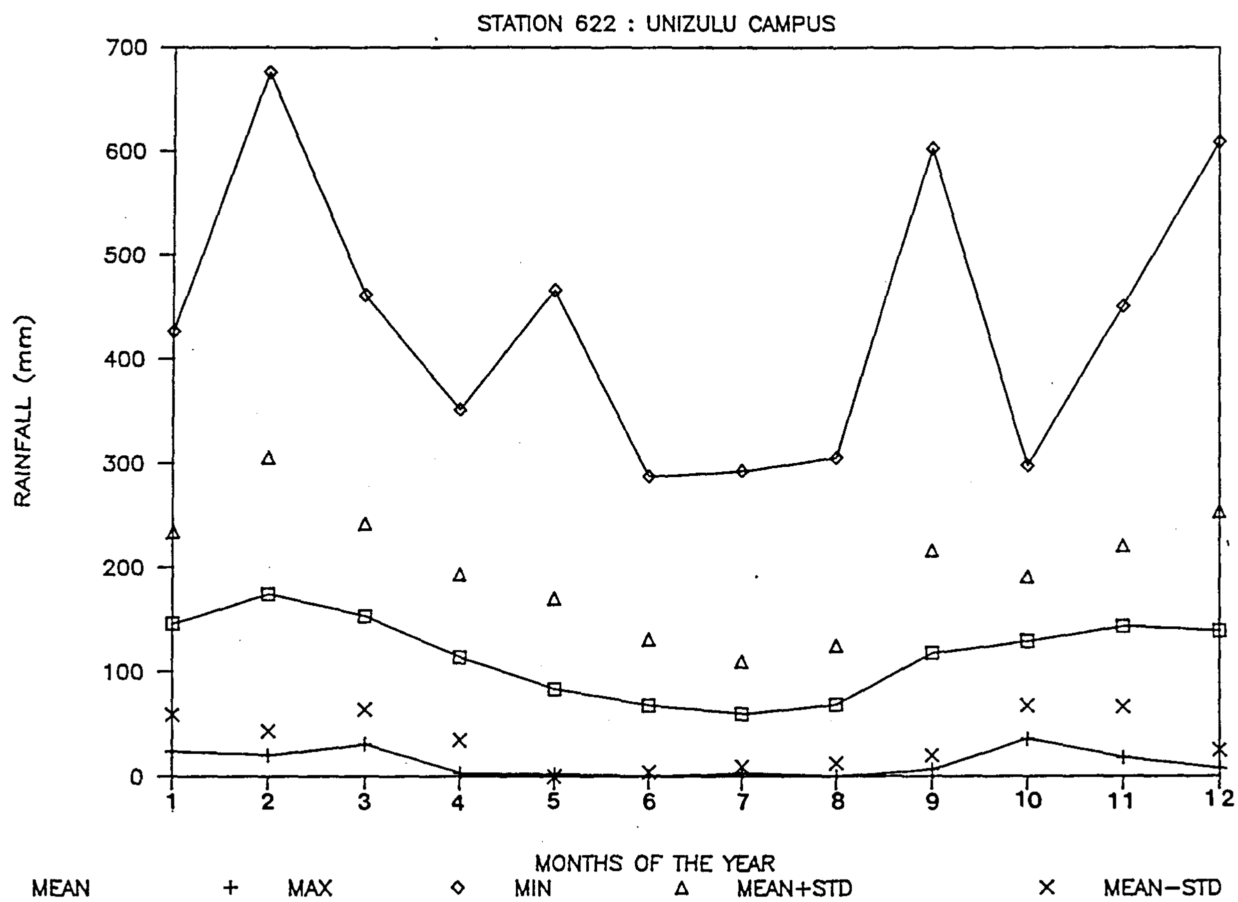


Figure 4,1 **Seasonal variation in monthly rainfall at station 622, University of Zululand campus.**

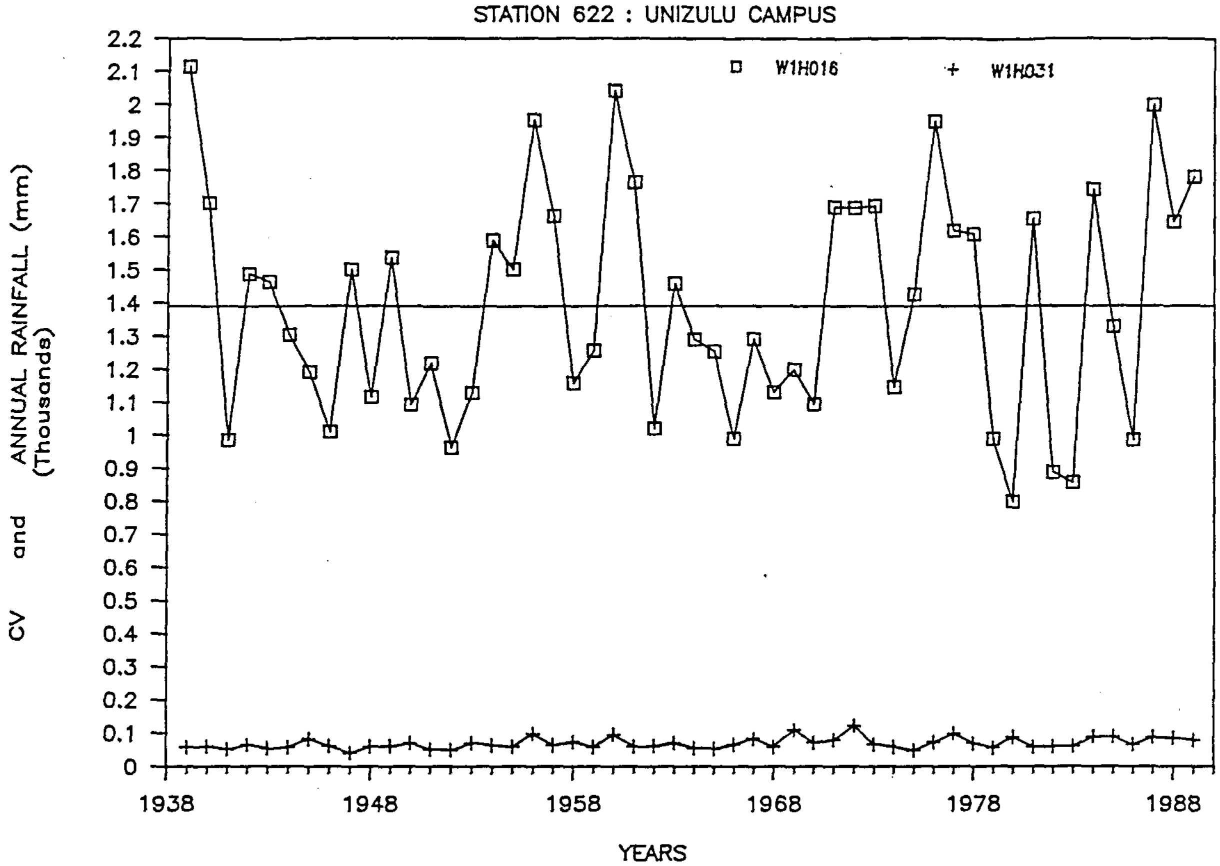


Figure 4,2 Annual total rainfall and coefficients of variation series since 1938.

W1H016 and W1H031 untill the end of 1989 (Figure 4,3 to Figure 4,6). A comparison of the hourly rainfall for the two stations show several large differences between the rainfall at the outlets to the two catchments, particularly during October and December. Despite the large differences between the two stations, the diurnal nature of the rainfall is evident in several months, particularly the late summer months (January to April) when the tropical influence is dominant in this region. In winter the low rainfall is evenly distributed throughout the day reflecting widespread frontal activity.

In the early summer months (October to December) the weather is influenced by the middle latitude frontal systems which often are preceded by intense cumulonimbus activity. However, Kelbe (1982) and Garstang et al (1986) have shown that the intensity of

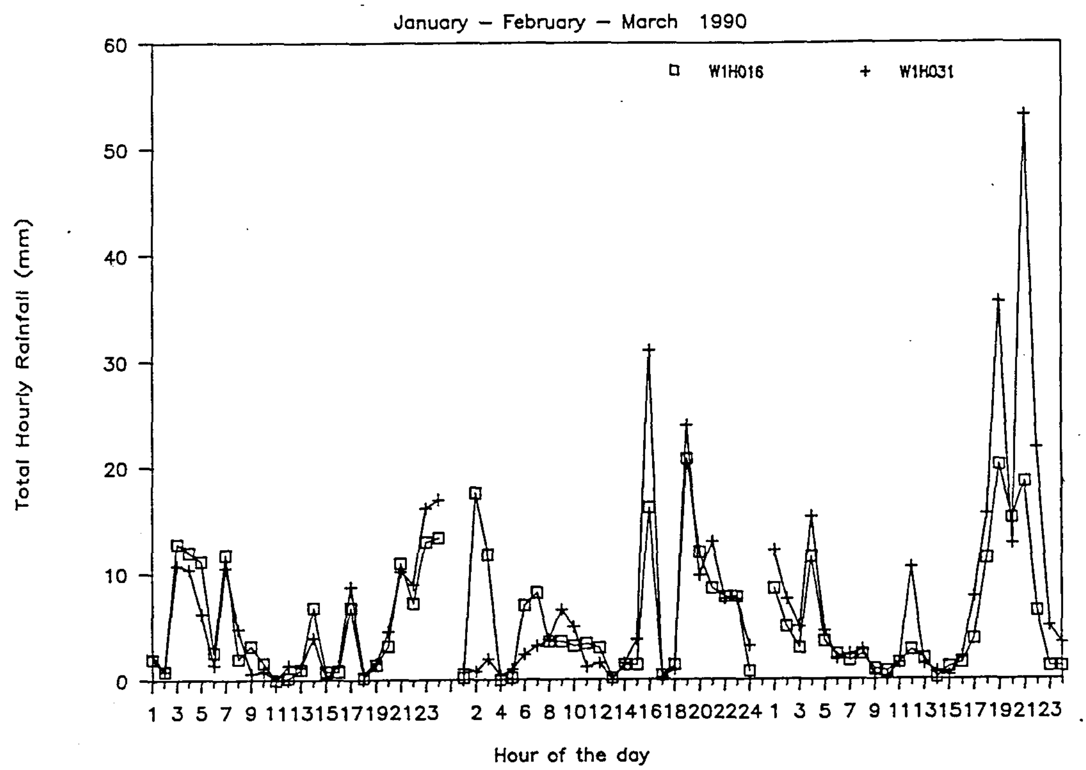


Figure 4,3 **Diurnal variation in total hourly rainfall at W1H016 and W1H031 for January, February and March.**

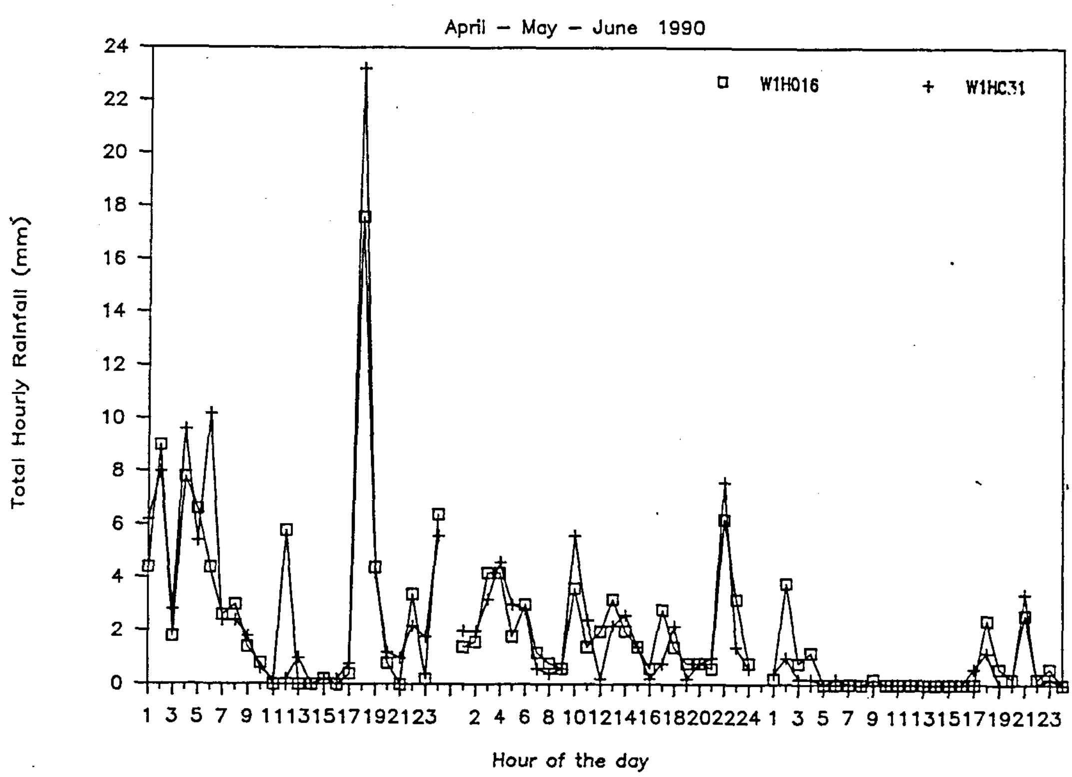


Figure 4,4 **Diurnal variation in total hourly rainfall at W1H016 and W1H031 for April, May and June.**

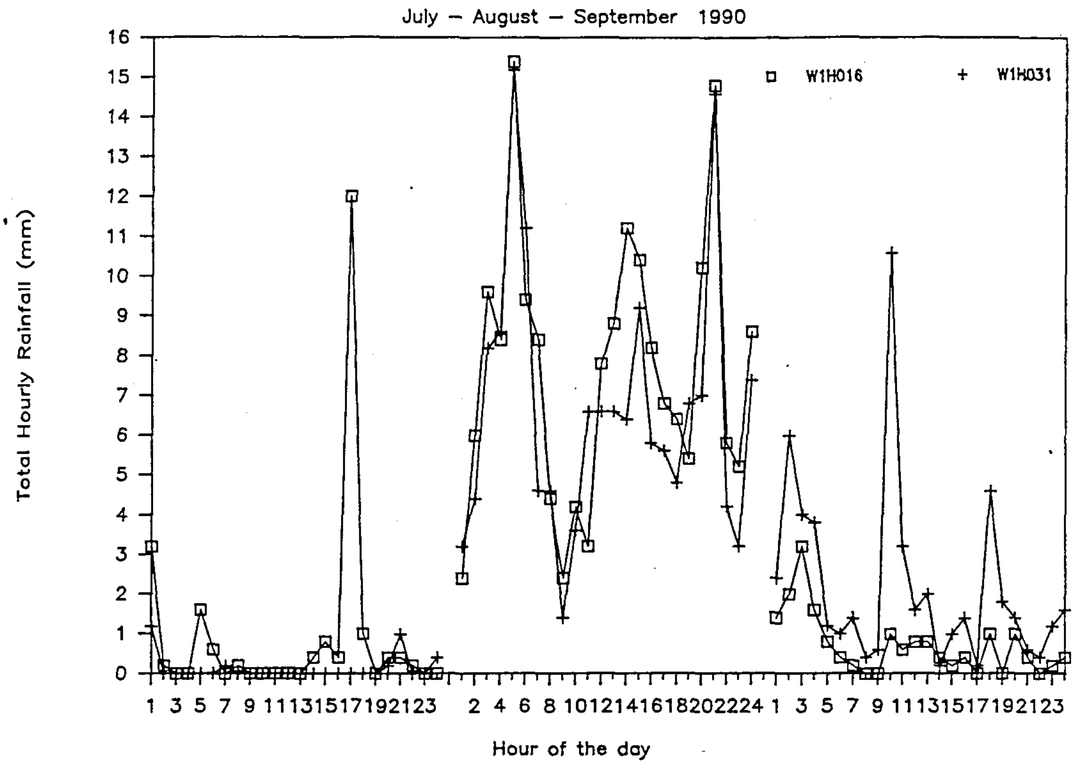


Figure 4,5 **Diurnal variation in total hourly rainfall at W1H016 and W1H031 for July, August and September.**

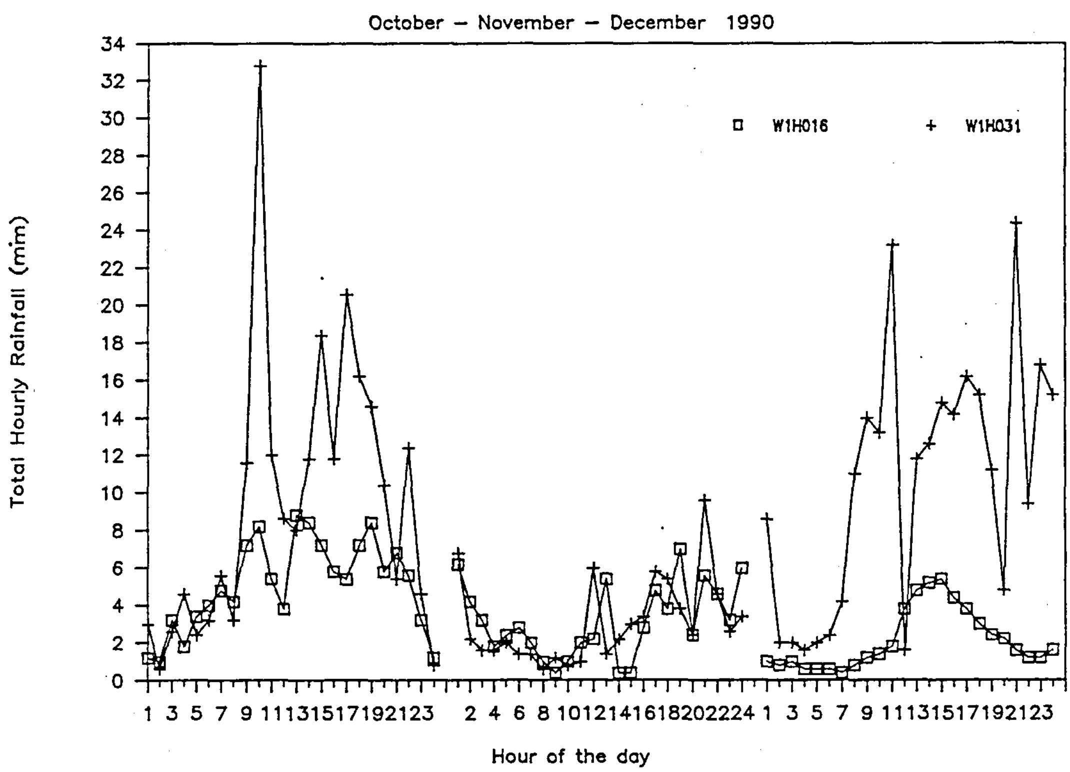


Figure 4,6 **Diurnal variation in total hourly rainfall at W1H016 and W1H031 for October, November and December.**

convection along the east coast is also influenced by the interaction between the approaching front (trough) and the diurnal surface heating. The results (Figure 4.3 to Figure 4.6) show that although heavy falls do occur in the morning, the rainfall for the early summer months generally peaks in the afternoon and early evening (Figure 4,3 to Figure 4,6). This is due to the time required for the storms to propagate eastward from their usual breeding grounds over the escarpment regions (Kelbe, 1982).

4.1.3 RAINFALL RATES

The frequency of rainfall rates exceeding 5mm per hour at both weirs since September 1989 have been plotted in Figure 4,7. With the exception of two large events recorded at W1H031 both stations have similar rainfall rates for this short period of observation.

4.2 TOPOGRAPHICAL FEATURES

One of the prime factors in soil loss from a catchment is the velocity of the water movement which must be related to the topographical gradients. A general indication of the relief or physiography of both catchments can be gauged from a plot of the area of the catchment at selected height intervals (Figure 4,8). Although W1H031 extends over a greater elevation range (180-350m above sea level), both regions have very similar gradients over most of the catchment. However, W1H031 descends much more rapidly in the lower regions near the outlet of the catchment. If both curves in Figure 4,8 were transposed to a common peak elevation then there would be good agreement between both catchments except for the lowest 50 meters.

A topographical map of the catchments was used to derive detailed slope profiles using a technique described by Young (1975). The catchment was divided into subcatchments and midpoint lines (bisectors) were drawn between each stream and its divide. A number of slope lines perpendicular to the bisector were spaced equidistant along

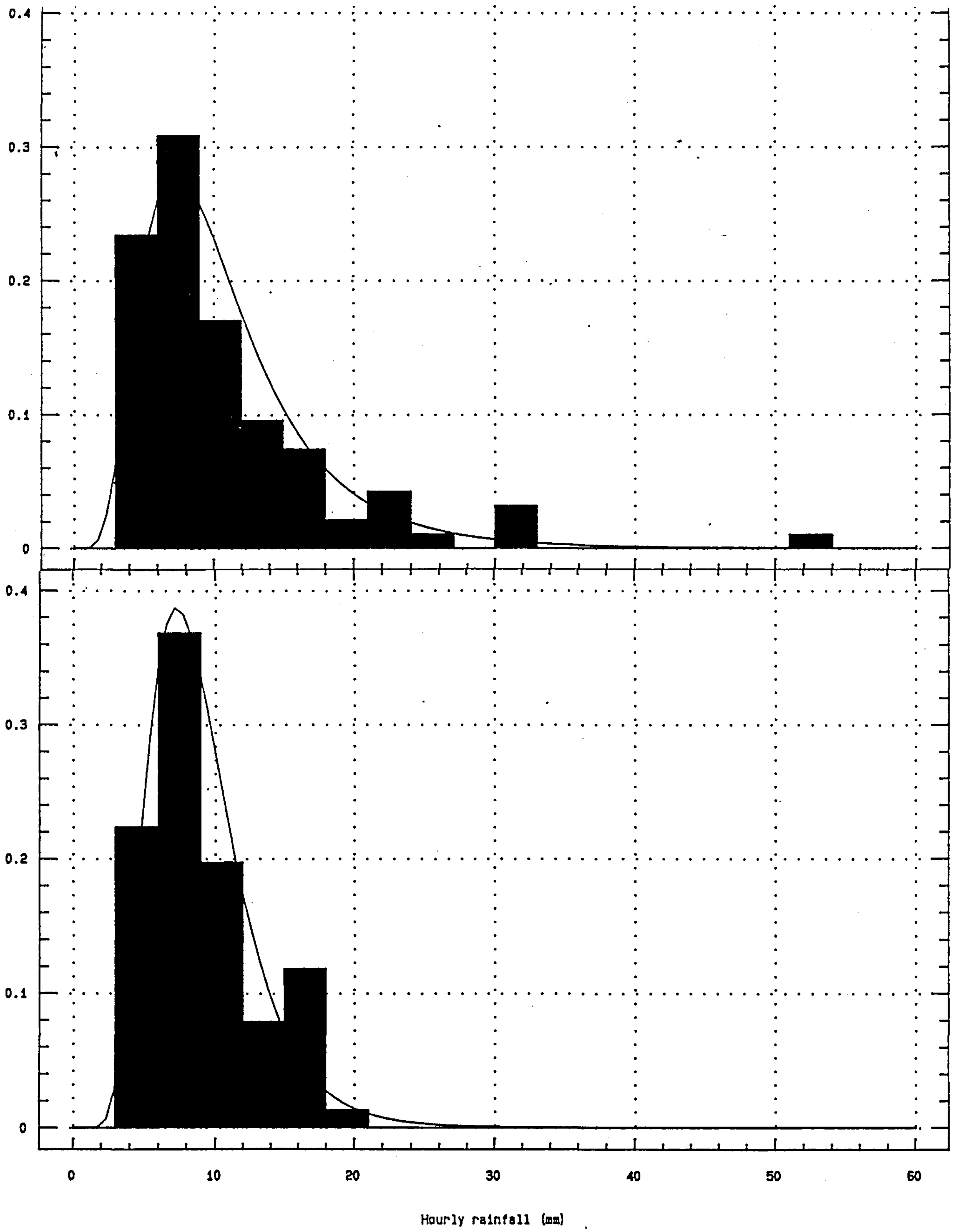


Figure 4,7 Frequency analysis of hourly rainfall rates exceeding 5mm/hr for W1H016 and W1H031.

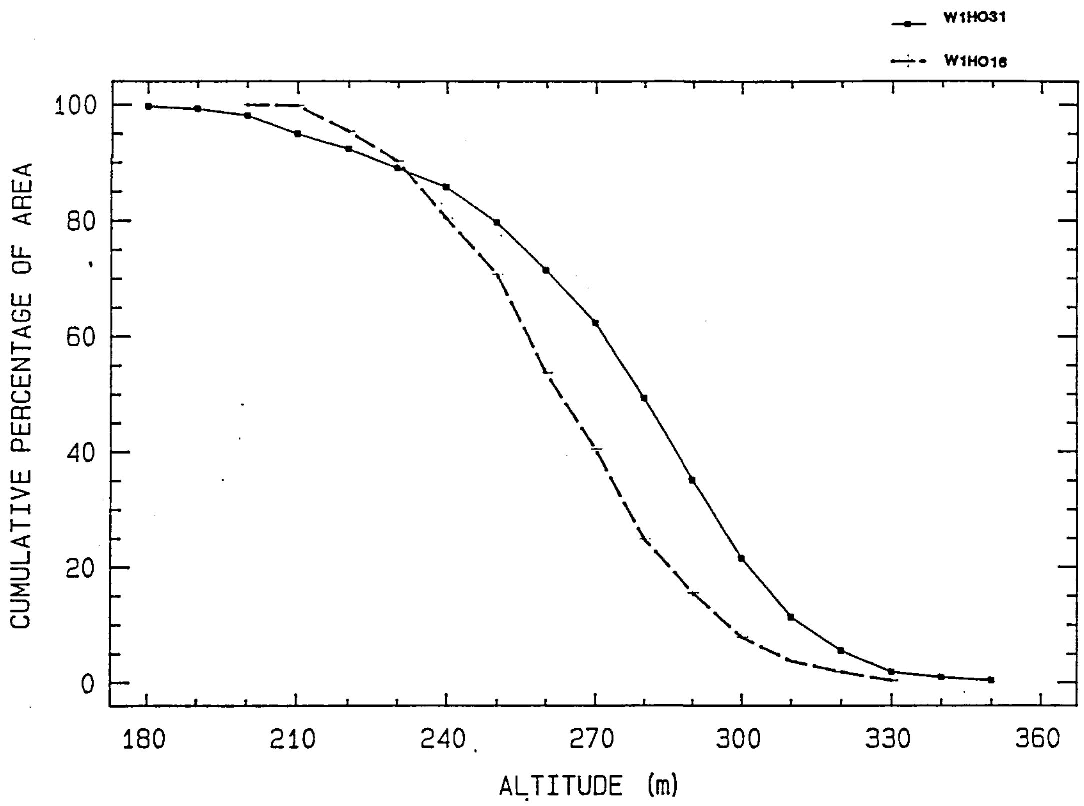


Figure 4,8 **The relative area of contour heights for catchments W1H031 (solid line) and W1H016 (dashed line).**

the bisector. The slope lengths were estimated along the slope lines and the average value determined. An estimate of the area representing each slope profile was then derived for specified classes of slope along the stream course (Figure 4,9). The relative area of each class of slope for both the catchments shows almost identical distribution (Figure 4,10). The disturbed catchment, W1H016, has approximately 10% more area with slopes of between 10° and 20° with a correspondingly lower frequency of slopes of below 10°. However, the relative areas of slopes steeper than 15° are almost identical for both catchments.

4.3 SOILS

Soils also have a significant role in the hydrological response of a catchment. Deep sandy soils with a high infiltration rate will tend to induce greater attenuation

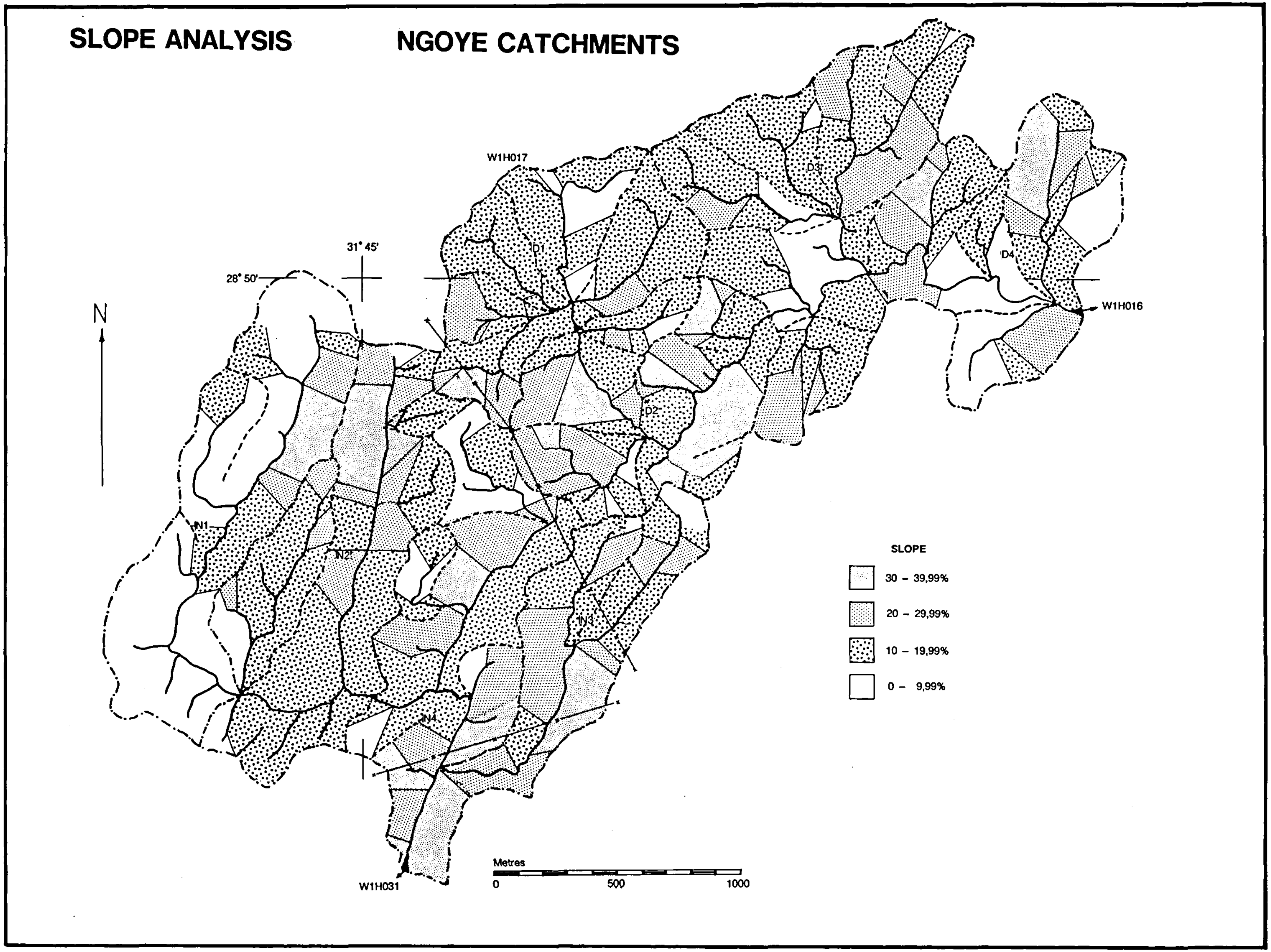


Figure 4,9 A slope analysis of catchments W1H016 and W1H031

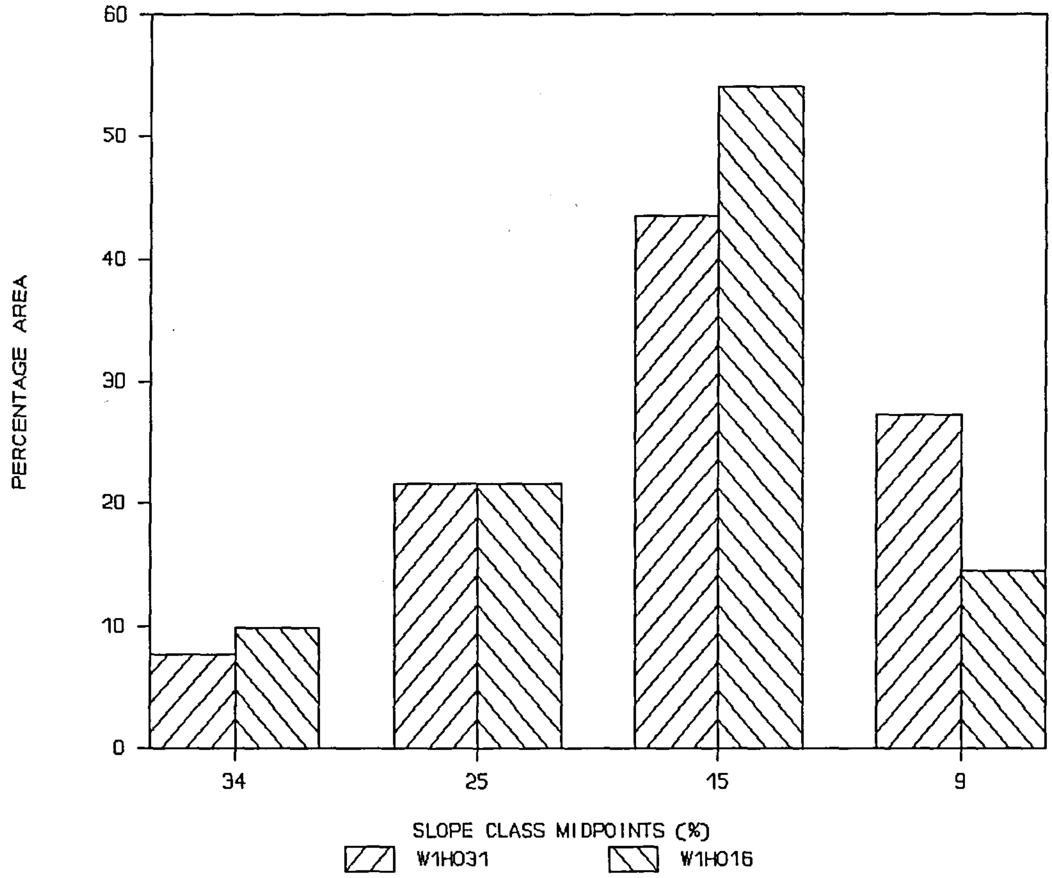


Figure 4,10 The relative differences in the area of the classes of slopes for both catchments.

of catchment peak discharge rates than the less permeable clay soils. Soil types will also have a influence on the sediment load and suspended solids derived from the catchments. Soil characteristics are needed also for deriving specific parameters in hydrological modelling (Mulder and Kelbe, 1991). Consequently a detailed soils map was derived for both catchments from core and pit profiles at strategic locations. Soil samples, from the locations shown in Figure 4,11, where analyzed by the South African Sugar Association Experiment Station (SASAES) at Mount Edgecombe. The soil samples were analyzed for bulk density, total and air filled porosity, moisture content at saturated capacity, field capacity, and wilting point. These values are given in an appendix of Volume II of this report.

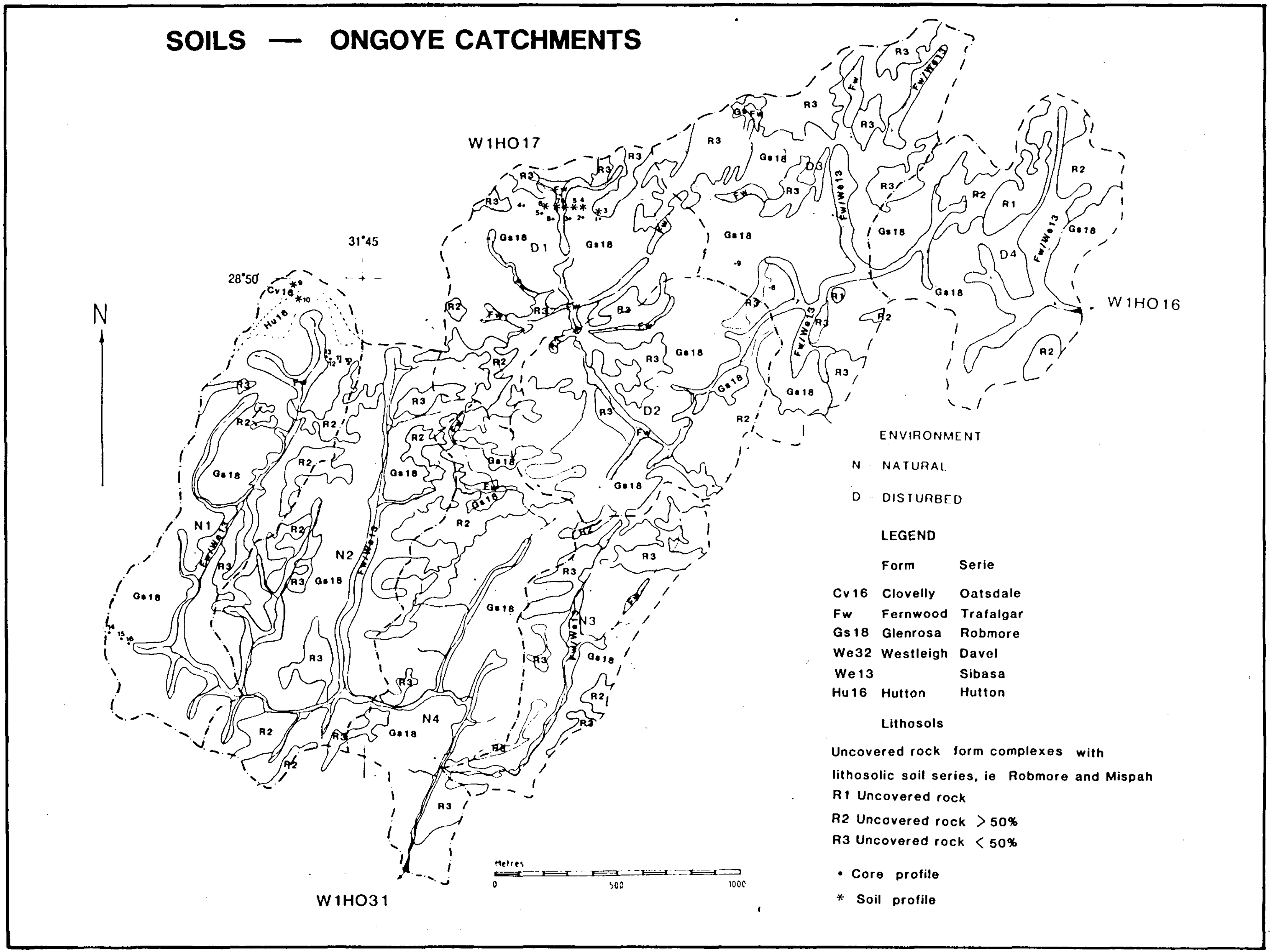


Figure 4,11 The distribution of soil series and lithosolic complexes in catchments W1H016 and W1H031

The relative area of all the main soil types for both catchments is shown in Figure 4,12. With the exception of very small areas of Clovelly (Oatsdale) and Hutton forms in W1H031, both catchments have remarkable similar soils and approximately the same percentage of rock outcrops. Nearly 70% of both catchments are covered by fairly deep Glenrosa form (Robmore series). Consequently the Robmore soil series should have the most significant effect on selected characteristics of the water quality.

Studies by Mulder (1988) on deep, midslope, Glenrosa soils with grass cover on a runoff plot at the University of Zululand campus have shown that there is little or no significant surface flow on the mid-slopes. Nearly all the storm flow component from these plots was derived from surface runoff associated with bottom land variable source areas.

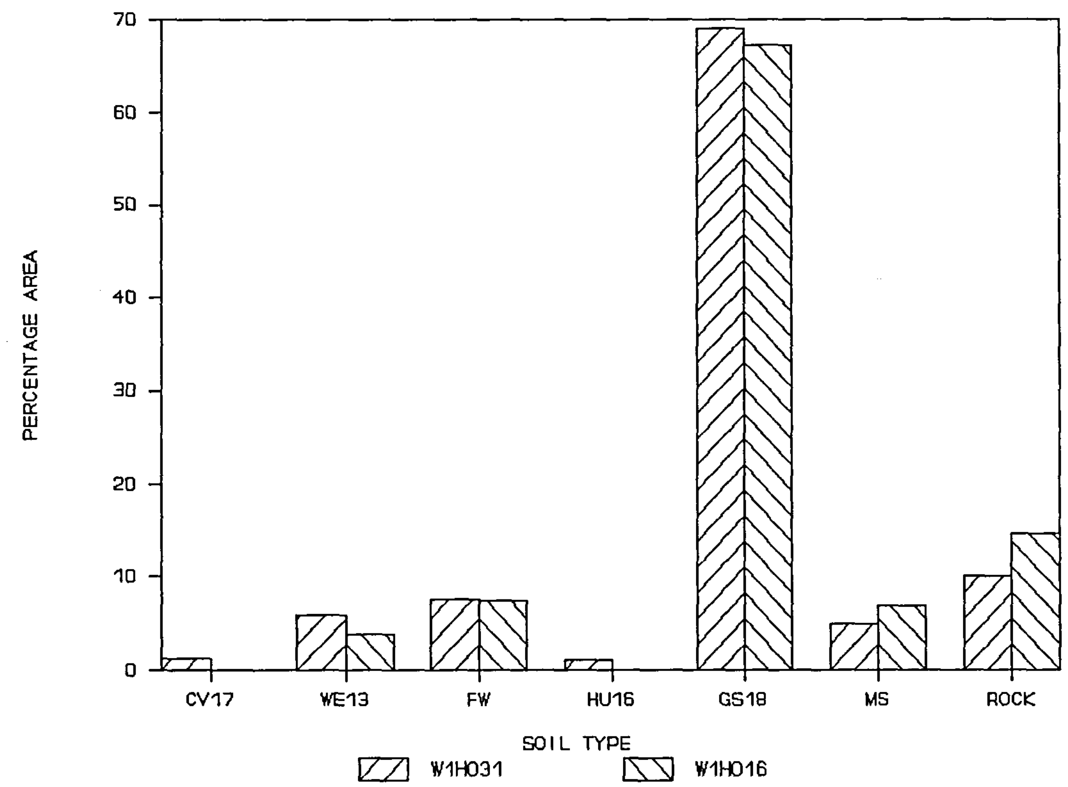


Figure 4,12 The relative difference in areas of the various soil classifications for W1H016 and W1H031.

4.4 GEOMORPHOLOGY

Recently, methodologies have been proposed to relate catchment response to basic geomorphic features which are useful in the estimation of the hydrologic behaviour of catchments without adequate data (Gupta, Rodriquez-Iturbe and Wood, 1986). These methodologies are also useful in comparative studies of different catchments. Rodriquez-Iturbe, Devoto and Valdés, (1979) claim that the most representative feature of the behaviour of a system is its response function, and that any attempt to compare the discharge behaviour of different catchments should be based on the structure of the response function.

Water and sediment arrive at the catchment outlet (weirs) through a network of streams to produce the characteristic response hydrograph for that catchment. Rodriquez-Iturbe and Valdés (1979) present a synthesis of the hydrologic response of a catchment by linking the instantaneous unit hydrograph (IUH) with the geomorphologic parameters of the catchment. The IUH can be seen as the conditional expectation of actual catchment response given the fundamental geomorphological characteristics (called the GUH). The GUH can be interpreted as the theoretical frequency distribution of the time of arrival (at the outlet) of water particles following the instantaneous application of a unit volume of excess rainfall uniformly spread over the catchment. Under these assumptions the differences in the theoretical GUH for the natural (W1H031) and disturbed (W1H016) catchments would then infer EXPECTED differences in the derived IUH for each catchment that are attributed to the morphology of the catchments.

The derivation of the GUH relies on the link between drainage network and the hydrological response of a catchment. Rodriquez-Iturbe and Valdés (1979) suggest a link between the hydrologic response (GUH) and the channel network as described by the Horton geomorphologic laws.

$N(w)/N(w+1) = R_B$ = Law of stream numbers

$L(w)/L(w+1) = R_L$ = Law of stream lengths

$A(w)/A(w+1) = R_A$ = Law of stream areas where N(w) is the number of streams of order w, L(w) is the mean length of order w, and A(w) is the mean area of the basin order w. R_B, R_L, and R_A represent the bifurcation ratio, the length ratio, and the area ratio.

Rodriquez-Iturbe and Valdes (1979) derive a dimensionless product $g = 0.58(R_B/R_A)^{0.55} * R_L^{0.05} = Q_p \cdot t_p$ which can describe the GIUH in terms of Q_p (the peak discharge) and t_p (the time to peak). They claim that g is a dimensionless ratio which is independent of the storm characteristics and which is intimately linked to the geomorphology of the watershed and to its hydrologic response structure. Consequently, the geomorphologic and physiographic parameters were derived for both catchments to enable a direct comparison in order to identify any hydrological response which could be attributed to factors other than land use.

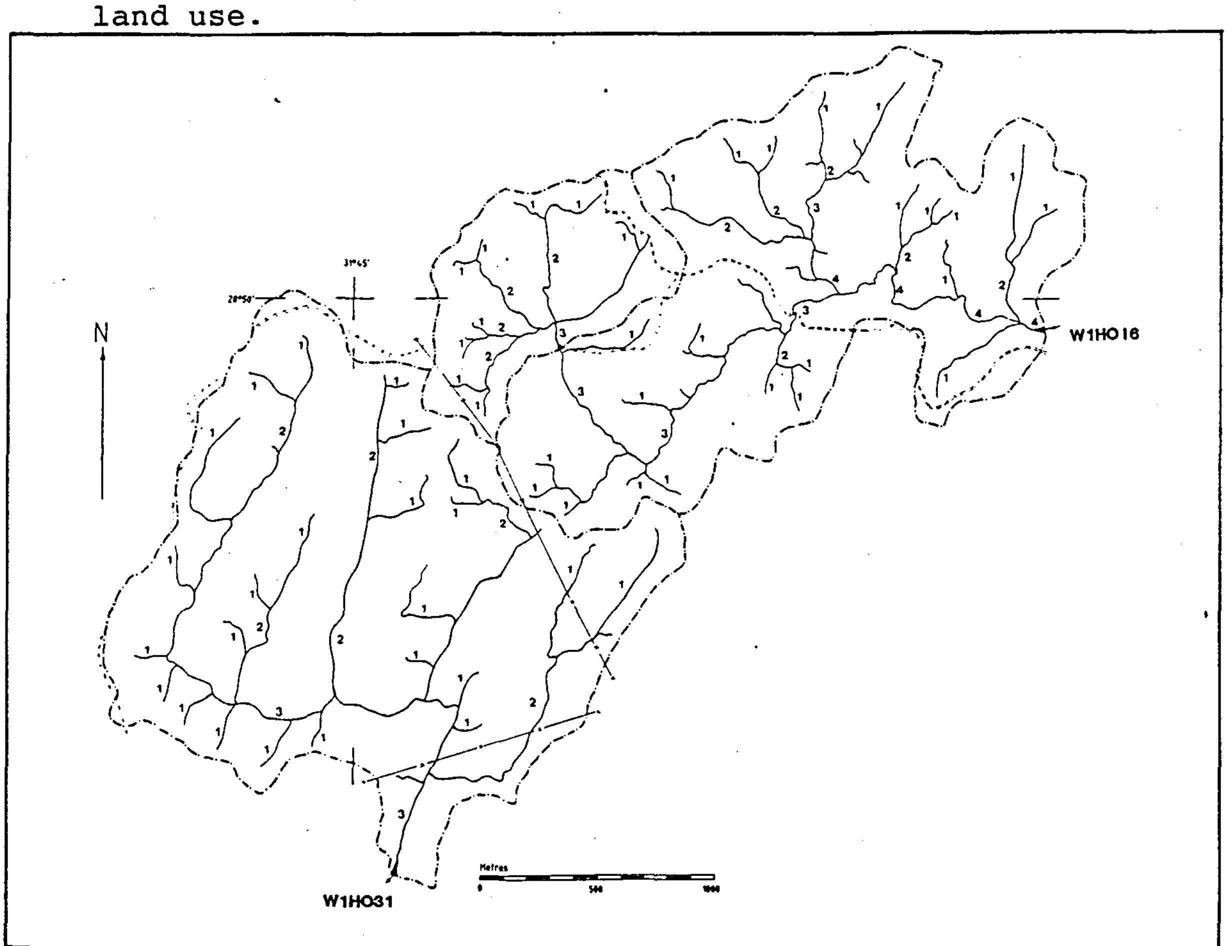


Figure 4,13 Strahler ordered stream network

The Strahler ordering scheme (Doornkamp and King, 1971) was used to define the stream network (Figure 4.14) which was derived from aerial photographs taken in August 1988. Having defined the catchment order (w), the other morphometric properties (Doornkamp and King,1971) were determined and are presented in Table 4,2.

The geomorphologic parameters for both catchments displayed as Horton diagrams have been plotted in Figure 4,15 to Figure 4.17. All Horton numbers (Figure 4.15-4.17 & Table 4.3) fall within limits usually found in nature. There is very little difference between the two catchment in all the parameters shown in Table 4.4. The identification of a further first order stream on the central tributary in W1H031 would have made this catchment a fourth order stream network with almost identical Horton parameters.

Table 4,2 Geomorphic parameters for W1H031 and W1H016 catchments.

Sym	Drainage network variables	W1H 016	W1H 031
w	Catchment order	4	3
R_B	N(w)/N(w+1) = Bifurcation	3.6	4.9
R_l	L(w)/L(w+1)	2.0	1.8
R_A	A(w)/A(w+1)	1.3	1.2
g	$0.58(R_B/R_A)^{.55} * r_L^{.05}$	1.1	1.3

4.5 TRAVEL TIMES

Equidistant points along the streams of both catchments were derived to estimate the isochrones.These are shown in Figure 4,17. Both catchments have almost identical main tributary length, total catchment area (Table 4,4) and very similar stream gradients. Consequently one would expect very similar hydrographs. However, the one morphological factor which could produce a different response is the shape of the catchment. The distribution of area contributing to the different travel times shows a significant difference between the two catchments (Figure 4,18). The contributing area for different isochrones shows a single peaked distribution for W1H031

Table 4,3 HORTONIAN NUMBERS FOR BOTH CATCHMENTS

	W1H016			:	W1H031		
ORDER	1	2	3	4	1	2	3
N(w)	22	6	2	1	19	4	1
L(w)	8.10	11.38	14.23	15.55	7.37	12.88	13.91
A(w)	2.06	2.90	3.03	3.23	1.78	2.80	3.19

(natural catchment) but three distinct peaks for W1H016 (disturbed catchment). This morphological difference is shown, in section 8, to produce clear differences between catchments in their peak discharges for certain rainfall events.

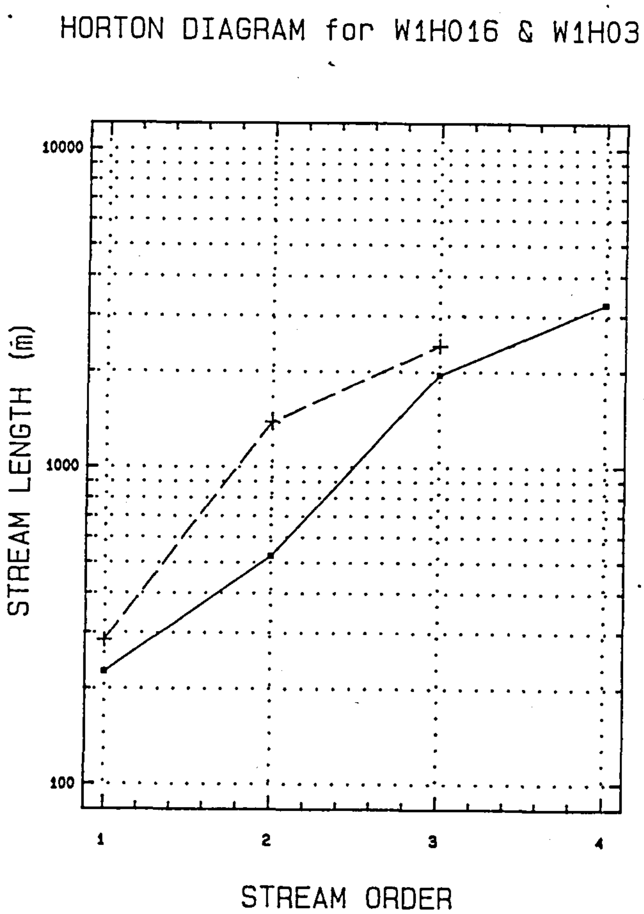


Figure 4,14 Stream length Horton diagram for catchments W1H016 and W1H031

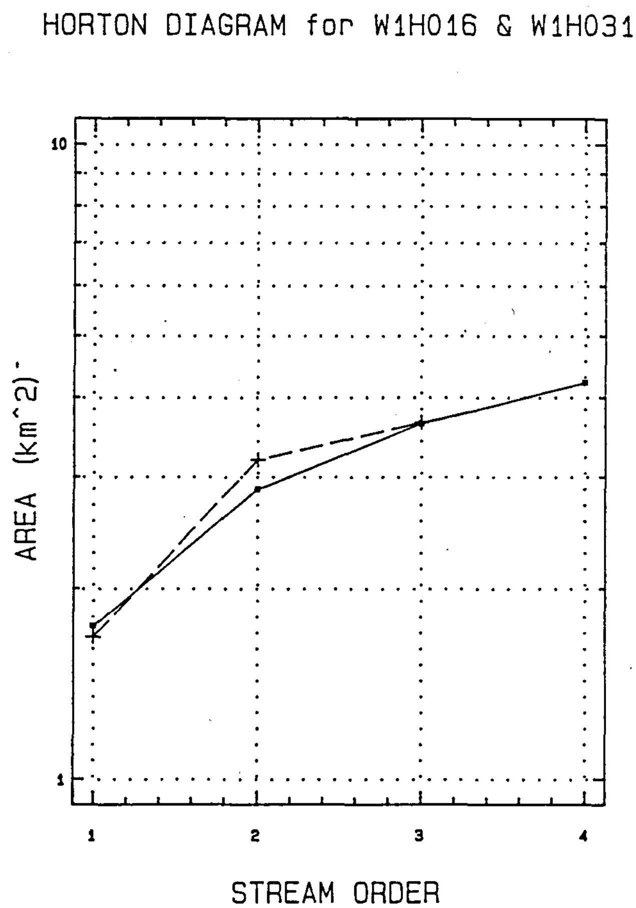


Figure 4,15 Stream area Horton diagram for catchments W1H016 and W1H031

Table 4,4 PROPERTIES OF THE CATCHMENT GEOMETRY

CATCHMENT		W1H016	W1H031
A	Area of catchment (km^2)	3.23	3.19
L_b	Length main tributary (km)	4.25	4.00
P	Perimeter (km)	9.55	8.57

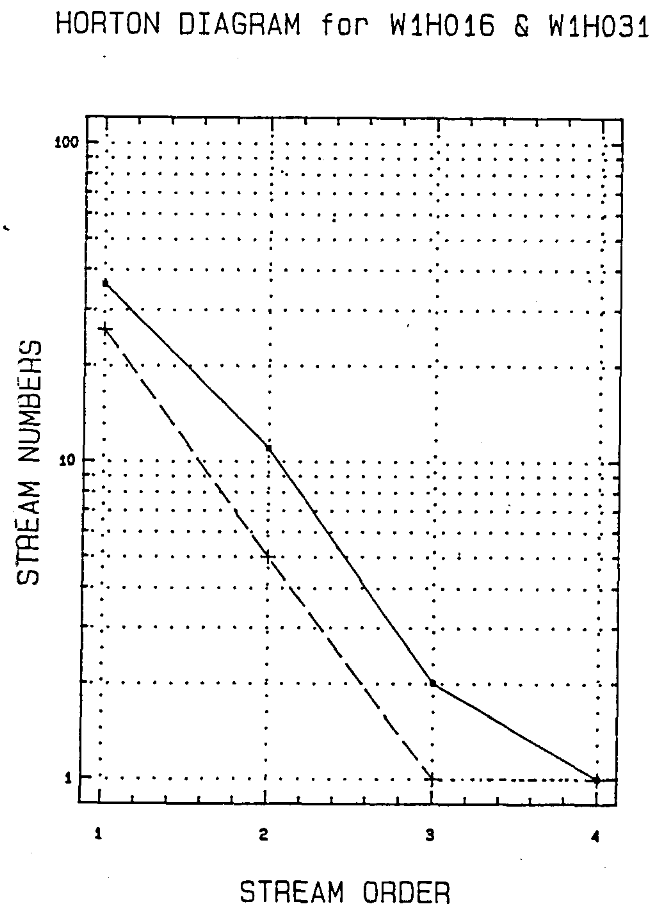


Figure 4,16 Stream numbers Horton diagram for catchments W1H016 and W1H031

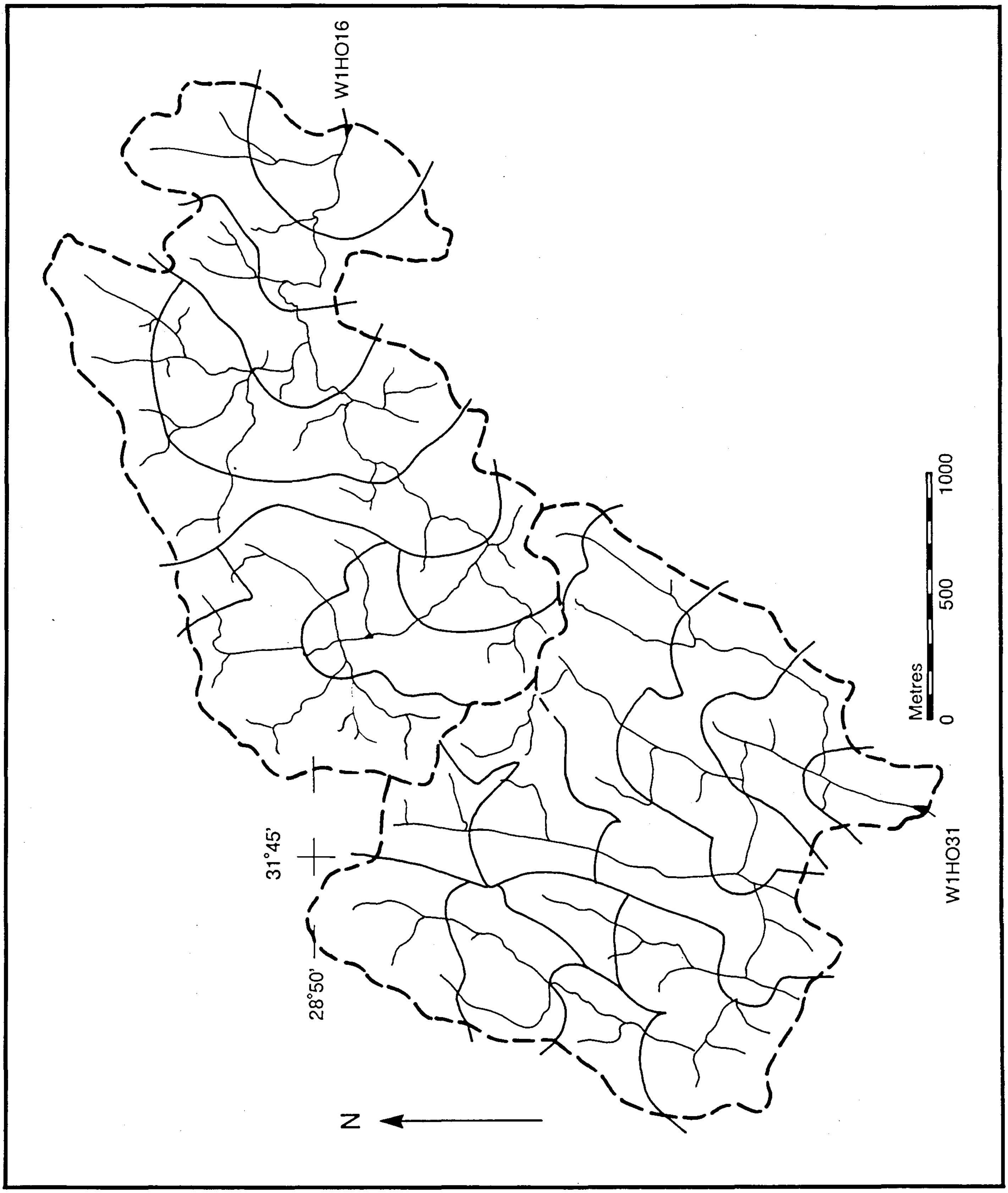


Figure 4,17 Areal map showing streams and isochrones.

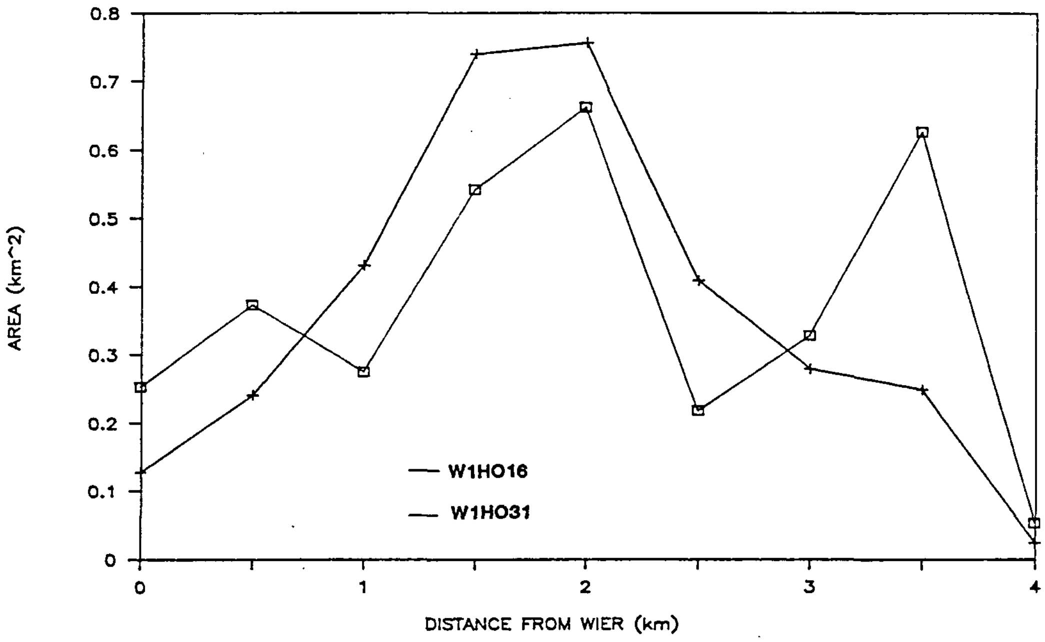


Figure 4,18 Area contained within selected isochrones.

5 LAND USE CHARACTERISTICS OF THE CATCHMENTS

The primary consideration of this project is to determine the influence of the changing land use. In order to achieve this it is necessary to determine the extent of any land use change that has occurred. Consequently a demographic survey of the permanent inhabitants of the region by Mathonsi (1990) was financed through this project. Twenty kraals were petitioned within catchment W1H016 to obtain information on the population development and agricultural preferences.

5.1 DEMOGRAPHIC FEATURES

Table 5,1 Absolute frequency of petition

Class	Hut	P/K	P/H	Wives
0-2	1	0	12	17
3-4	6	2	6	2
5-6	8	2	1	1
7-8	3	8	1	0
9-10	1	1	0	0
>10	1	7	0	0
Mean	6	11	3	2

The petition revealed that all of the respondents had resided in the area for the past 15 years and that 50% worked in the surrounding metropolitan centres. All of the respondents believed that there had been a drastic increase in settlement patterns which they attributed to increase in family size. The family structure is shown in Table 5,1, Table 5,3. The size of the kraal varied from 1 to more than ten huts with a similar spread in the number of occupants per kraal (P/K) and occupant per hut (P/H). 40% of the respondents had more than one wife, with two respondents boasting more than five wives. The survey indicated that the **average** kraal comprised six huts with three people in each hut.

Seventy five percent of the inhabitants obtained their water supply from springs while the remaining 25% used river water. 45% of the kraals had no cattle (Table 5,2, Table 5,3) while none of the kraals exceeded 20 cows. A government dipping program at (Gugushe - 705) just upstream of weir W1H016 shows that the area has over 2380 cattle (356 owners) which are treated on two days per week. This implies an average of 6.7 cows per owner, which is close to the value obtained by the survey. Efforts to obtain cattle numbers from previous years have not been fruitful. Stock farming was generally restricted to pastures along the slopes and was used for commercial, subsistence and traditional purposes.

5.2 POPULATION & DWELLINGS

Since no population register is available for this catchment the hut count was considered a suitable alternative indicator of the temporal trend in population development. Unfortunately the mode of dwelling construction is changing rapidly with the introduction of brick and mortar homes (Table 5,3) as opposed to the more traditional collection of thatched huts. Twenty percent of the kraals have a combination of both types of construction. These modern structures generally have several rooms and consequently accommodate more people. Based on an assumed occupancy of two people per brick/mortar house for every person in a hut (ie one house is equivalent to two huts), the change in population density for W1H016 can be gauged from the hut count for the three years shown in Figure 4,31, Figure 5,1. The dwellings within catchment W1H016 have risen three fold from approximately 100 in 1970, to nearly 300 in 1988. The increase has been almost as large in W1H017 (Figure 4,31, Figure 5,2) and is even greater (4 fold) in the areas outside the Ngoye Nature Reserve (W1H031) (Figure 4,31, Figure 5,3).

Table 5,2 Frequency of Cattle/Kraal

class (#cows)	% freq
0	45
1 - 5	20
6 - 10	10
11 - 15	20
16 - 20	5
over 20	0

Table 5.3 Kraal construction.

Kraal	Freq
Mud-thatch	50
Mortar-thatch	5
Mortar-tin	20
Combination	25

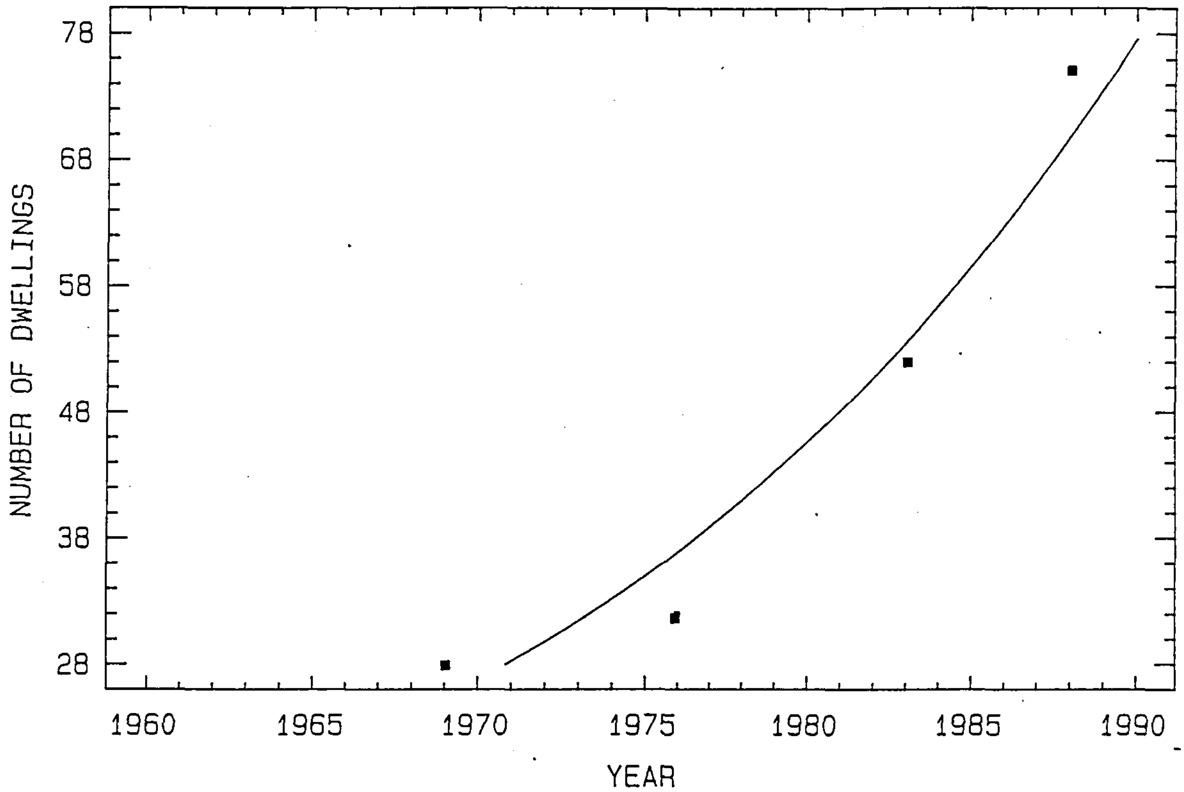


Figure 5,1 Temporal changes in the number of dwellings in W1H016.

The huts are generally located (Table 5,4) on the slopes (85%) although several (15%) were located on the crests of the hills. None of the respondents resided in the valley bottoms.

Table 5,4 Kraal locations

Kraal location	Freq %
Crest	15
Upper slope	50
Lower slope	35
Foot slope	0
Bottom lands	0

With an average of three people per hut this indicates that there are estimated to be approximately 3*300 people (300 people/km^2) in this catchment (W1H016). If the hut count continues to treble every 15 to 20 years, then the population in this catchment at the turn of the century is expected to be approximately 3*900 people (900 people/km^2). This increase is considered to be due to the natural birth rate of the present inhabitants. With the expected influx of people to the urban fringe areas around the metropolitan areas in this region, this catchment is expected to witness

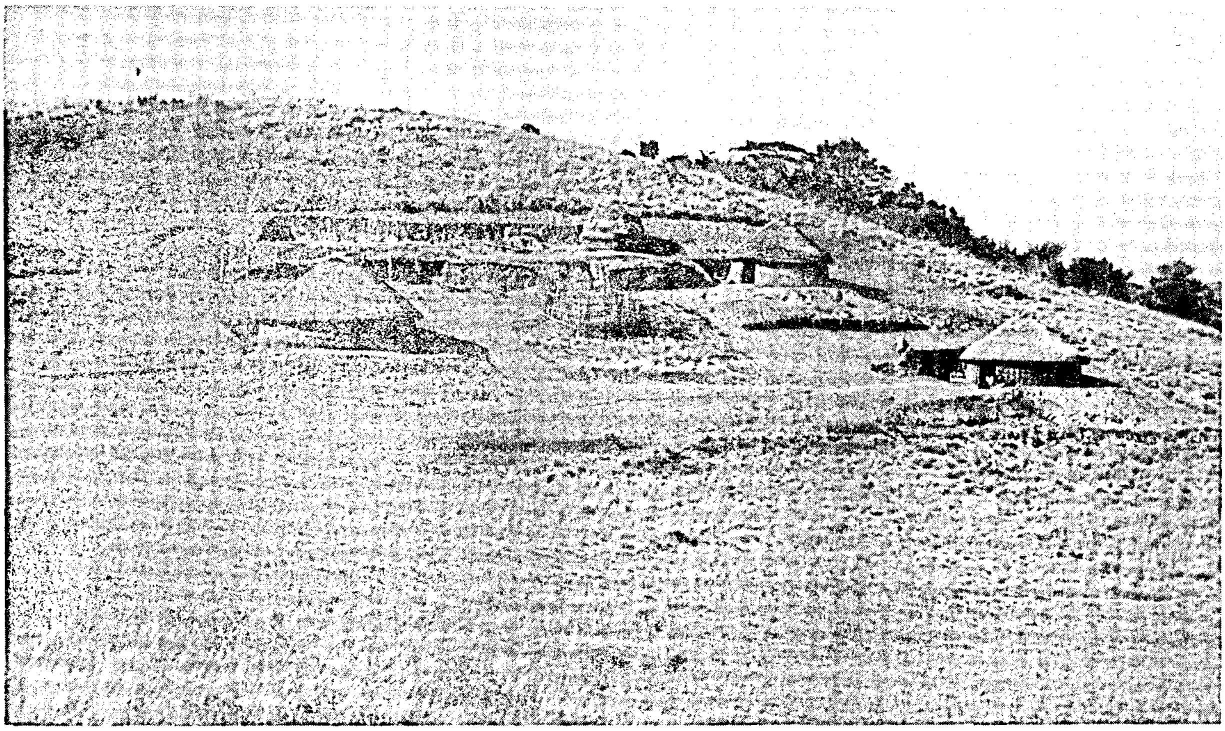


Plate 5.1 Photograph of the typical settlement structure.

considerable changes over the next few years.

The tendency in the establishment of kraals is to build huts of approximately 5m diameter and then clear all the vegetation around the immediate vicinity of the dwelling. The huts are generally developed (one for each wife) in a circular fashion around the cattle stockade centred in the middle of the kraal (Plate 5.1). If each hut occupies $20m^2$ and its direct area of influence (bare soil) extends to about $100m^2$ it will directly influence an area of 10^4m^2 (100 huts * $100m^2$). With the inclusion of outhouses (grain and fowl) and cattle stockades, this could be as high as $2*10^4m^2$ per km^2. This amounts to about 2% of the surface area of catchment W1H016. Assuming an equivalent area of paths and roads leading to and from each kraal, then the total bare surface amounts to about 4% at present. If the population continues to increase at the rate shown in Figure 4,31, Figure 5,1 to Figure 4,31, Figure 5,3, then the direct influence (urbanisation) will double in the next 10 years. With the perennial streams and numerous springs providing ample water together with improvements in the formal road infrastructure and public transport, this is likely to be a very conservative estimate.

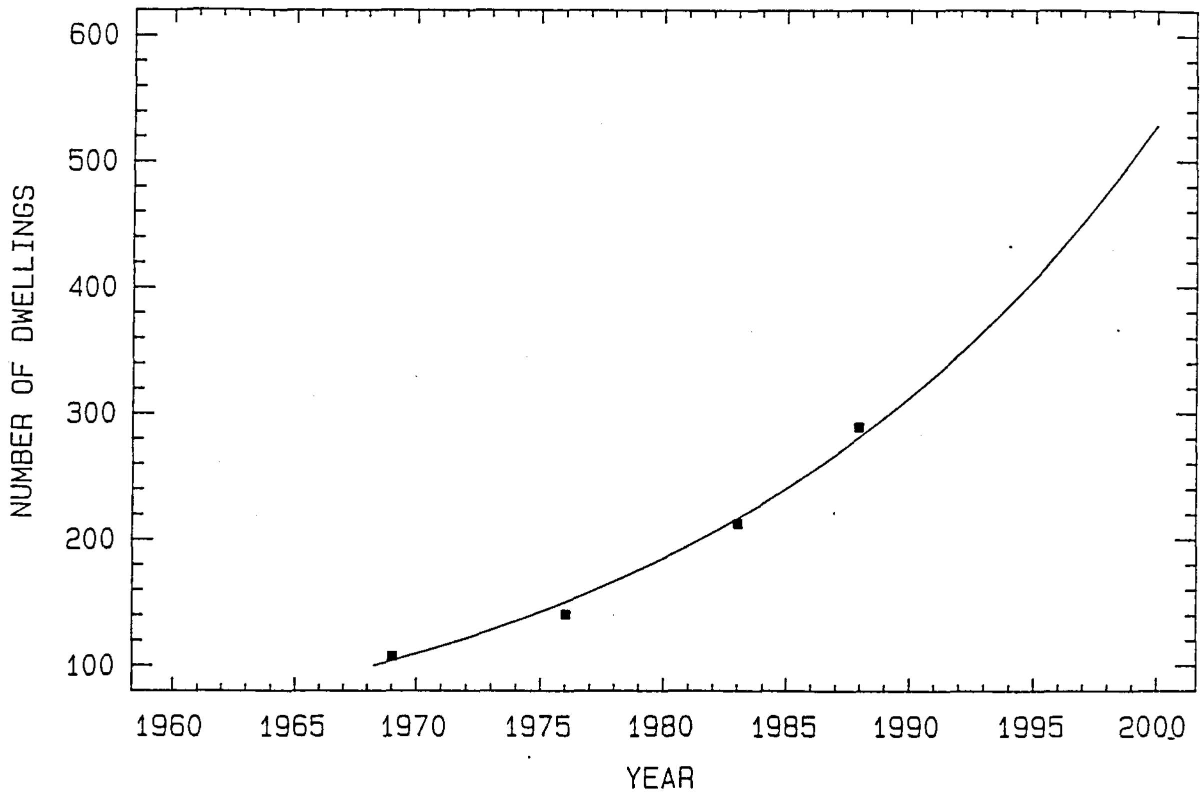


Figure 5,2 **Temporal changes in the number of dwellings in W1H017.**

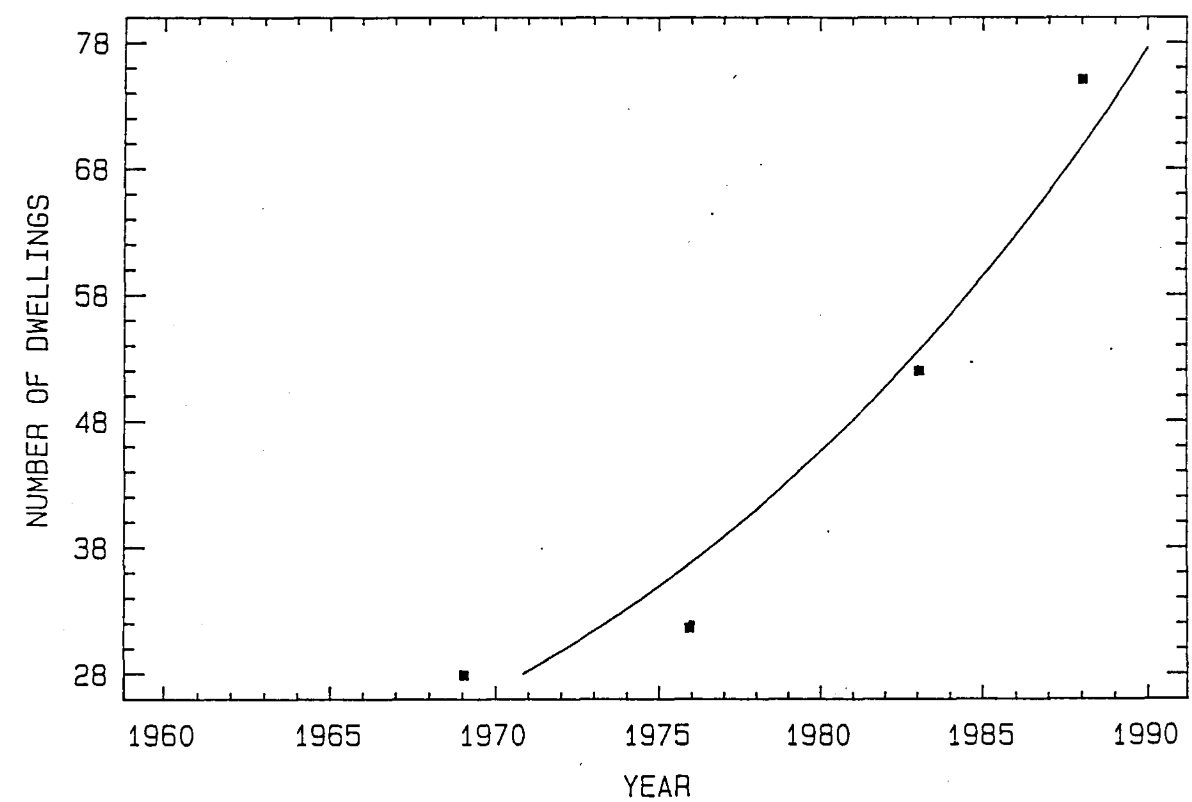


Figure 5,3 **Temporal changes in the number of dwellings in W1H031.**

5.3 CULTIVATION

Aerial photographs taken in 1978 and 1988 were obtained for the research catchments. The areas under different cultivation practices were identified and plotted in Figure 5.5. These maps were then digitised in order to derive the area associated with each cultivation practice (Figure 5.6). There was no detectable change in the land use pattern for W1H031 since the increase in hut count has occurred along the catchment boundary (crest) and shows an insignificant impact of land use changes for this catchment. Between 1978 and 1988, in W1H016, the percentage of the catchment area under exotic timber plantations has increase by 75% from 3.7% of the catchment to over 6.5%. Sugar cane was not cultivated in W1H016 during 1978 but know accounts for nearly 2% of the area. No significant change has occurred between 1978 and 1988 for the indigenous forest and the subsistence cultivation.

All these land use features are sufficiently concentrated to be identified on aerial photographs. Features which can be seen but are difficult to quantify (digitize) are foot paths and roadways. These have already been estimated to occupy 2% of the catchment surface. Since the inhabitants of many kraals obtain their water supply from the streams and rivers, many paths will lead directly down steep gradient toward the waterways, thereby enhancing the erosion process.

The survey indicates that most inhabitants preferred to cultivate areas close to their dwellings, however, people are starting to drain the wetlands and sedges to cultivate crops, particularly bananas. Nearly all the respondents to the demographic survey cultivated a combination of crops (sugar cane, maize, madumbe and sweet potatoes). 65% implied that their crops were for commercial purposes rather than immediate consumption.

All the estimates of land use and their associated surface area of influence are summarised in Table 5,5.

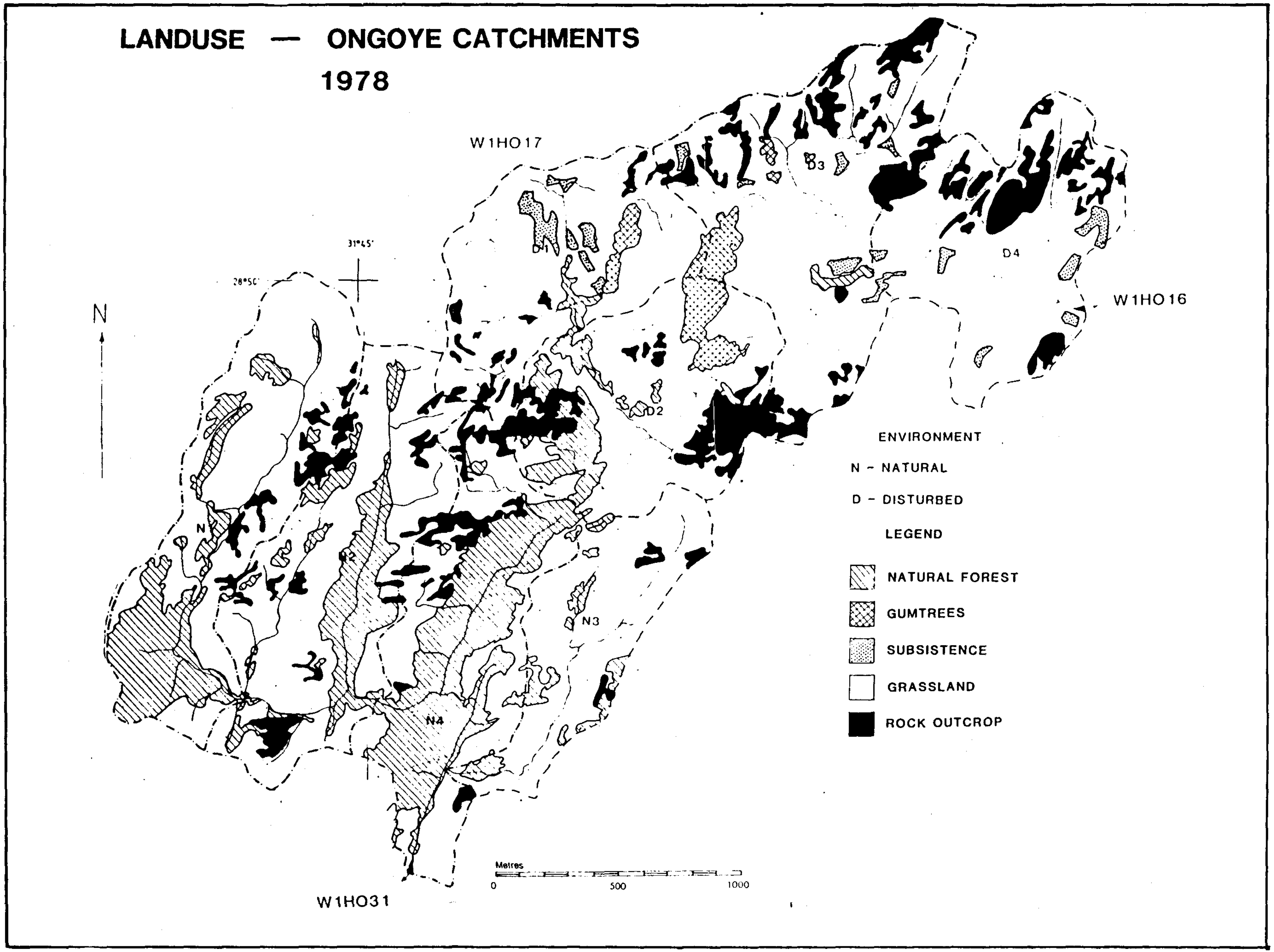


Figure 5,4 The landuse distribution in catchments W1H016 and W1H031 in 1978

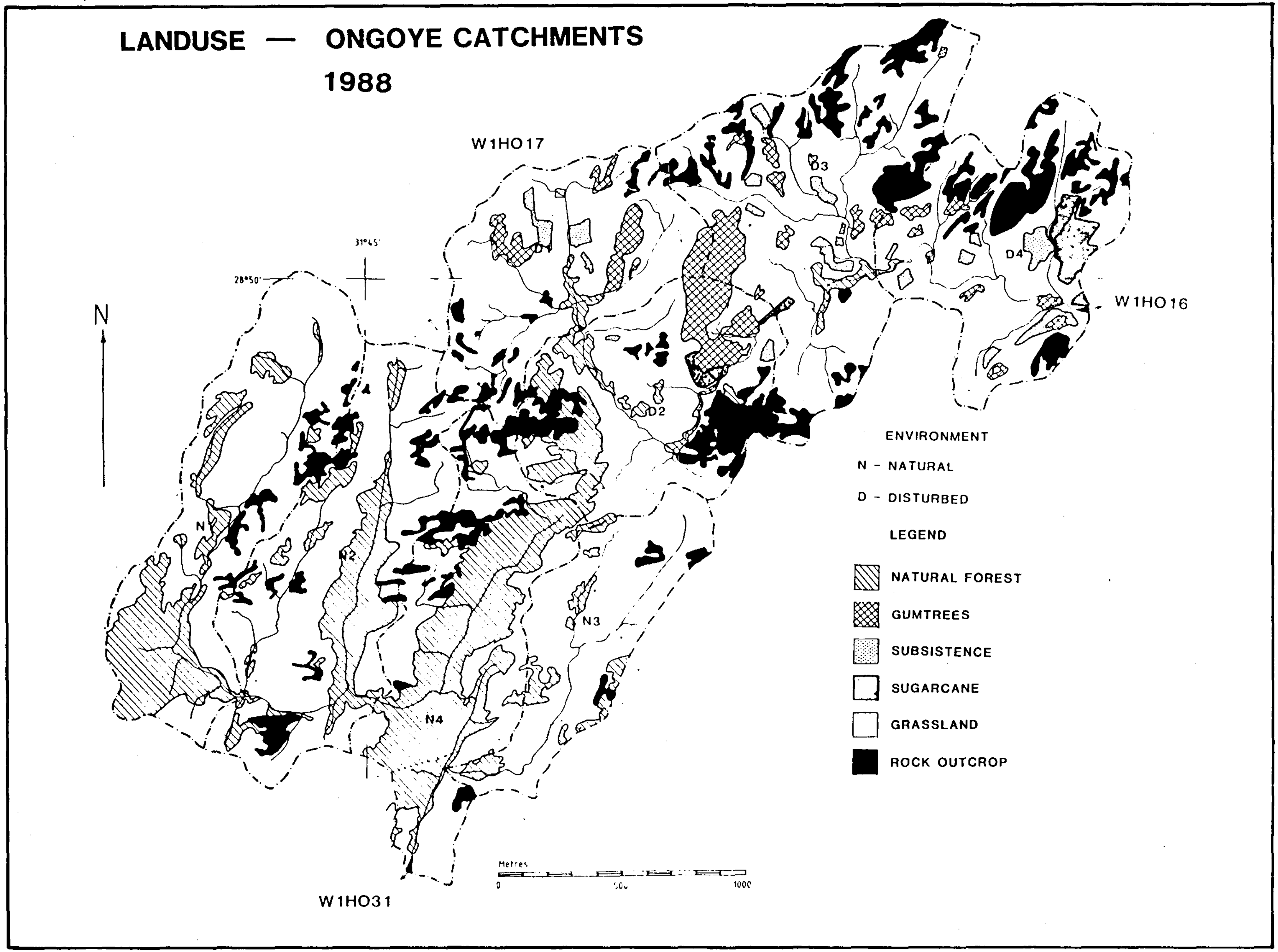


Figure 5,5 The landuse distribution in catchments W1H 016 and W1h031 in 1988

Table 5,5 Catchment area (km^2) of associated land use.

FEATURE	W1H016 1978	W1H016 1988	W1H031
Forest	0.15	0.16	0.88
Plantation	0.12	0.22	0.00
Subsistence	0.09	0.09	0.00
Sugar cane	0.0	0.06	0.00
Grass land	2.51	2.35	2.06
Rock	0.46	0.46	0.19

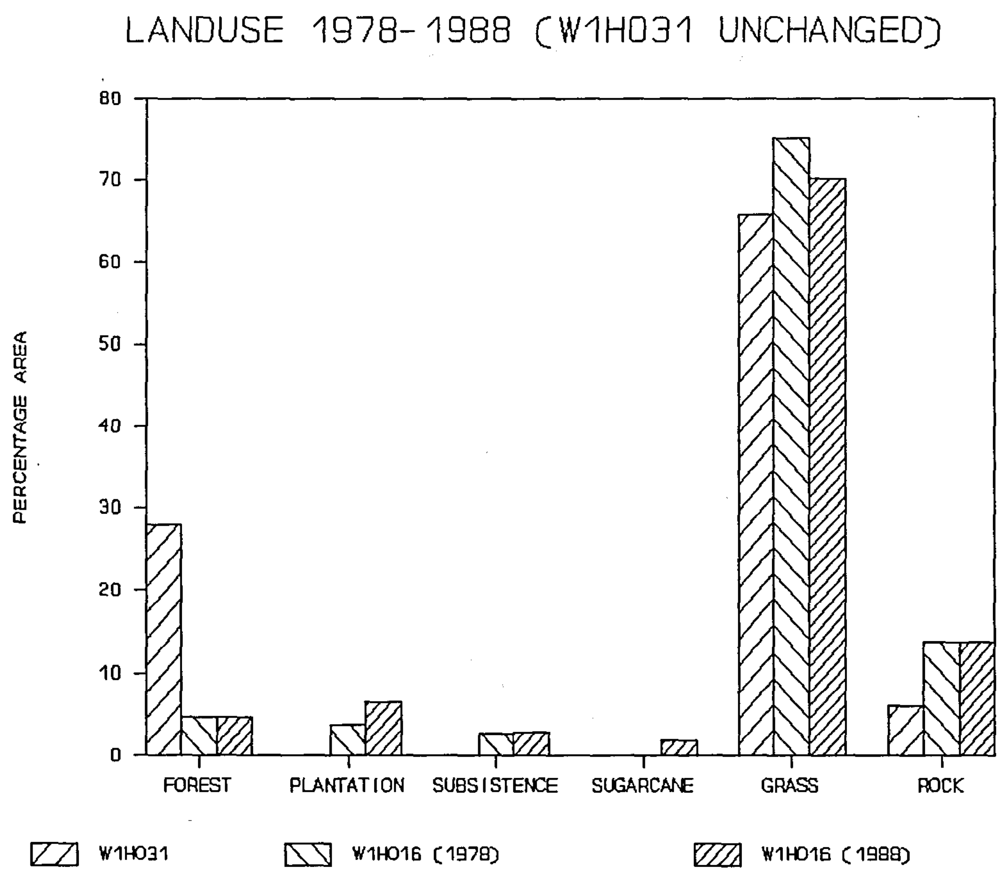


Figure 5.6 The relative area of the different land uses for both catchment W1H016 and W1H031.

6 IDENTIFICATION OF TEMPORAL CHANGES IN THE HYDROLOGICAL RESPONSE CHARACTERISTICS OF THE DISTURBED CATCHMENTS.

One of the primary objectives of this project was to identify any temporal changes in the hydrological response once any temporal changes in the land use had been identified. The identification of a temporal response will depend on the magnitude of the response as well as the suitability and consistency of the historical record.

6.1 DATA CONSISTENCY

The hydrological data from the Ntuze catchments has been obtained and processed by different people and organisations. Consequently, any inconsistencies in the data must be identified before any temporal analyses can be undertaken. The usual procedure for investigating inconsistencies is through the use of double mass plots. These are considered together with the difference in the actual time of occurrence of selected events. Time consistency is important since certain temporal parameters were considered for comparison (response time).

The one historical autographic raingauge within the catchments of concern in this study is 470 (Figure 3,1). This station shows a correlation in monthly rainfall of 0,990 with autographic station 501 (Hope and Mulder, 1979). Consequently, the digitised records of these two station records were compared for differences in storm **depth** and **duration**. Also considered was the difference between the stations in the time at which 5 mm of rainfall (T_5) had accumulated for each storm event at each station. All storm events for which T_5 exceeded 100 minutes (1.5 hours) where assumed to be different storm events and were discarded. After station 501 was relocated in 1987 due to its inaccessibility the comparison was based on a comparison between stations 470 and 411.

Figure 6,1 shows the variability of the difference between 470 and 501 (411 after 1987) of the total amount of rainfall per storm event for each year. With the possible

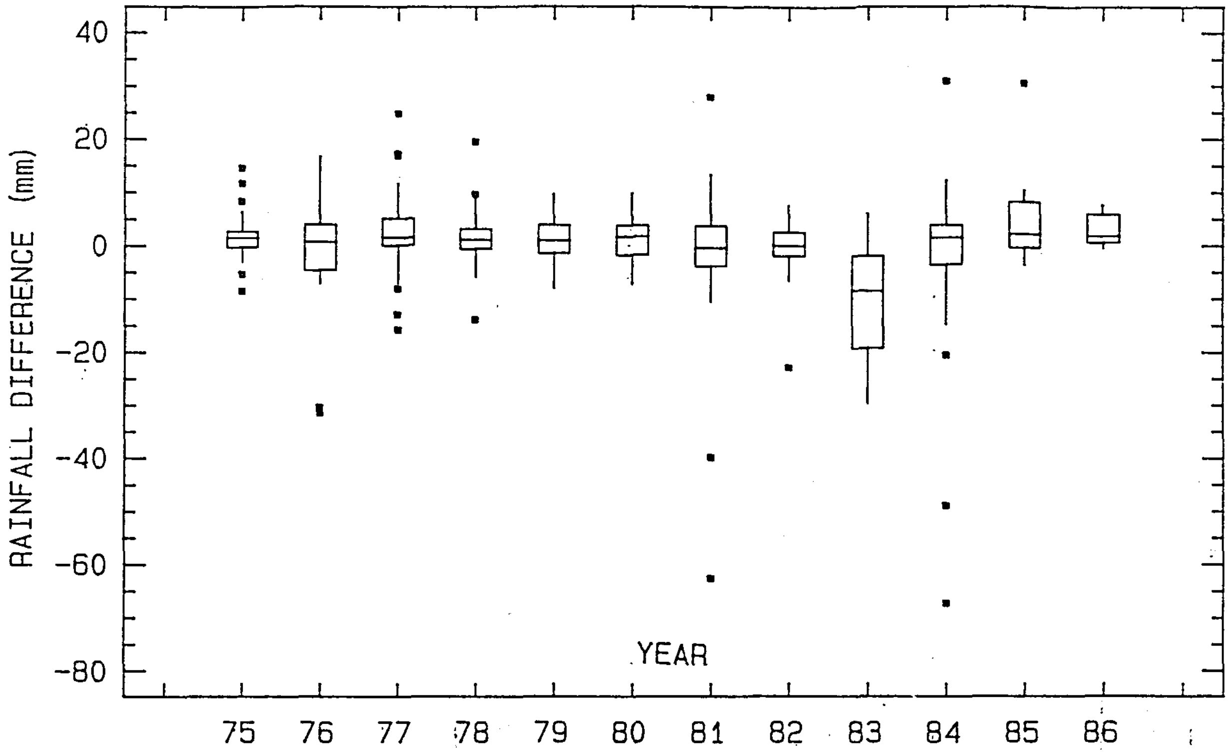


Figure 6,1 **Box and whisker plot of the difference between total rainfall accumulated per storm event at raingauges 470 and 501.**

exception of 1983, these two stations show similar depth of rainfall (per storm) over the period of measurement. The mean difference is close to zero with the upper and lower quartiles generally within 5mm. From this comparison it appears that station 470 has more rainfall per events than 501 since the mean difference is nearly always positive.

The difference in the storm duration (Figure 6,2) shows considerable variability over the years particularly after 1982. However, the mean difference is close to zero except in 1982 and 1983.

The variability in T_5, the chronological order of rainfall accumulation of 5 mm, is shown in Figure 6,3. The data after 1983 shows considerably more variability than the data prior to 1983. The mean differences in accumulation time in 1983, 1985, 1986 and 1988 appear to be approximately 60 minutes as opposed to a mean of less than 30 minutes in all other years. Consequently, temporal analyses utilising the time of a specific event is questionable. [NB any similarity in duration and depth

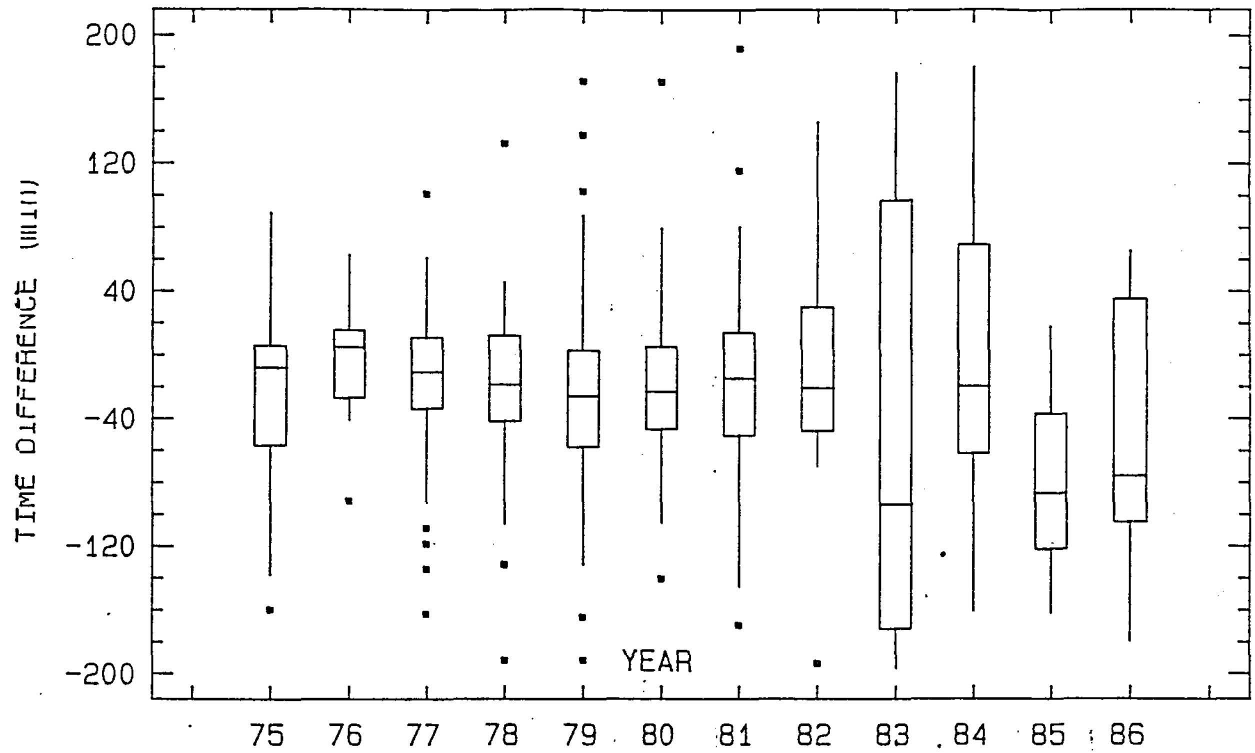


Figure 6,2 **Box and whisker plot of the annual variability in the difference between duration of each storm at raingauges 470 and 501.**

reflects accuracy in clock settings. Poor accuracy in accumulation time reflects difference in the time of clocks (synchronization)] Since there is such a poor correlation in the time factors of this data, it is considered inappropriate to examine, in detail, procedures that rely on the synchronization of the autographic instruments.

6.2 DOUBLE MASS PLOTS

Double mass plots have frequently been used to test rainfall and runoff records for nonhomogenuity (Schulz, 1976). They have also been used to identify the effects of land use (Braune and Wessels, 1980). This method plots the cumulative record of one station against the cumulative record of one (or more) other station(s). The record being tested should , if possible, be compared to at least 4-5 base station records of either rainfall or runoff. Because of the very limited length of record in this study and problems associated with missing data, it was decided to consider runoff from W1H014, an indigenous forest catchment in close proximity to W1H016 (Figure 1,2) as the base station. Only runoff was considered and not rainfall because of the problem associated with missing data and other recognized inherent errors in point source measurement of spatially variable fields. For the case of missing discharge data, the entire daily flow for both stations could be discarded from BOTH records under comparison. This assumes that the response of the two catchments are the same and are less than 24 hours. This is clearly the case for the small catchments under investigation in this project.

Cumulative DAILY total runoff and the cumulative DAILY quickflow component, as generated by the program RUNOFF (Schulze and Arnold, 1980), were used for catchments W1H016 and W1H014. The accumulated daily runoff and the accumulated daily quickflow series from W1H014 was plotted against the corresponding accumulations series from W1H016 for two separate periods (Figures 6.4 & 6.5). Since W1H014

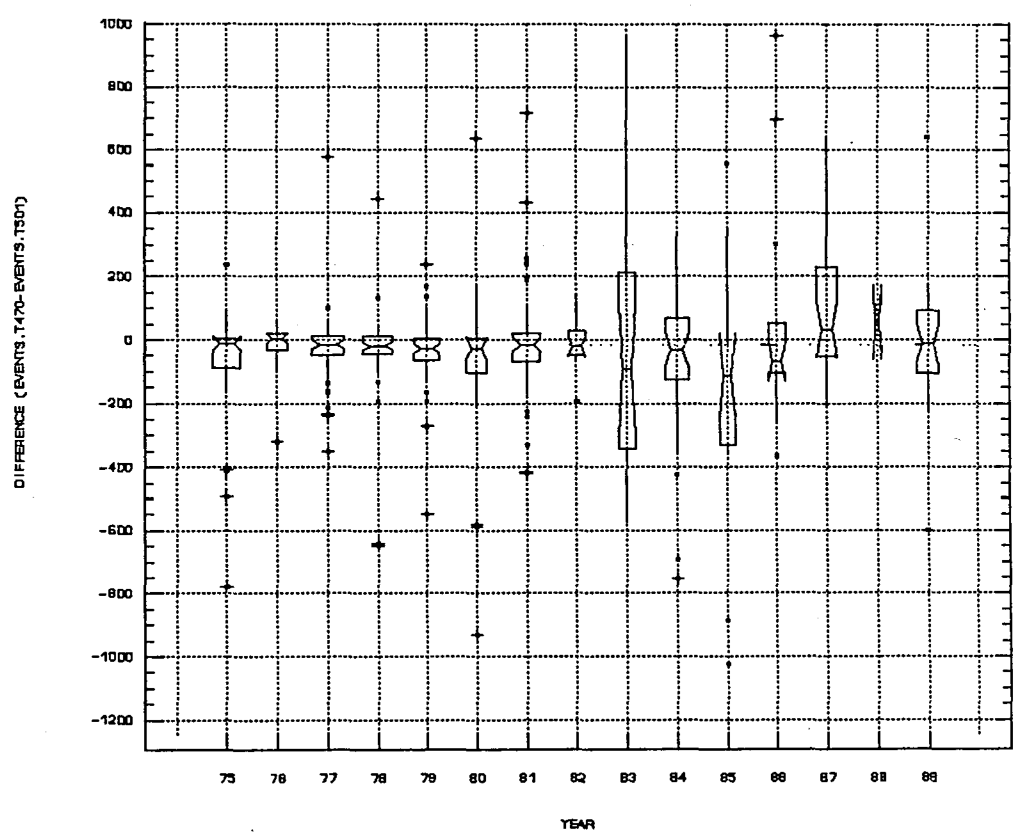


Figure 6,3 **Box and whisker plot of the annual variability in the difference between the time when 5 mm of rainfall had accumulated at raingauges 470 and 501 (stations 470 & 411 after 1987).**

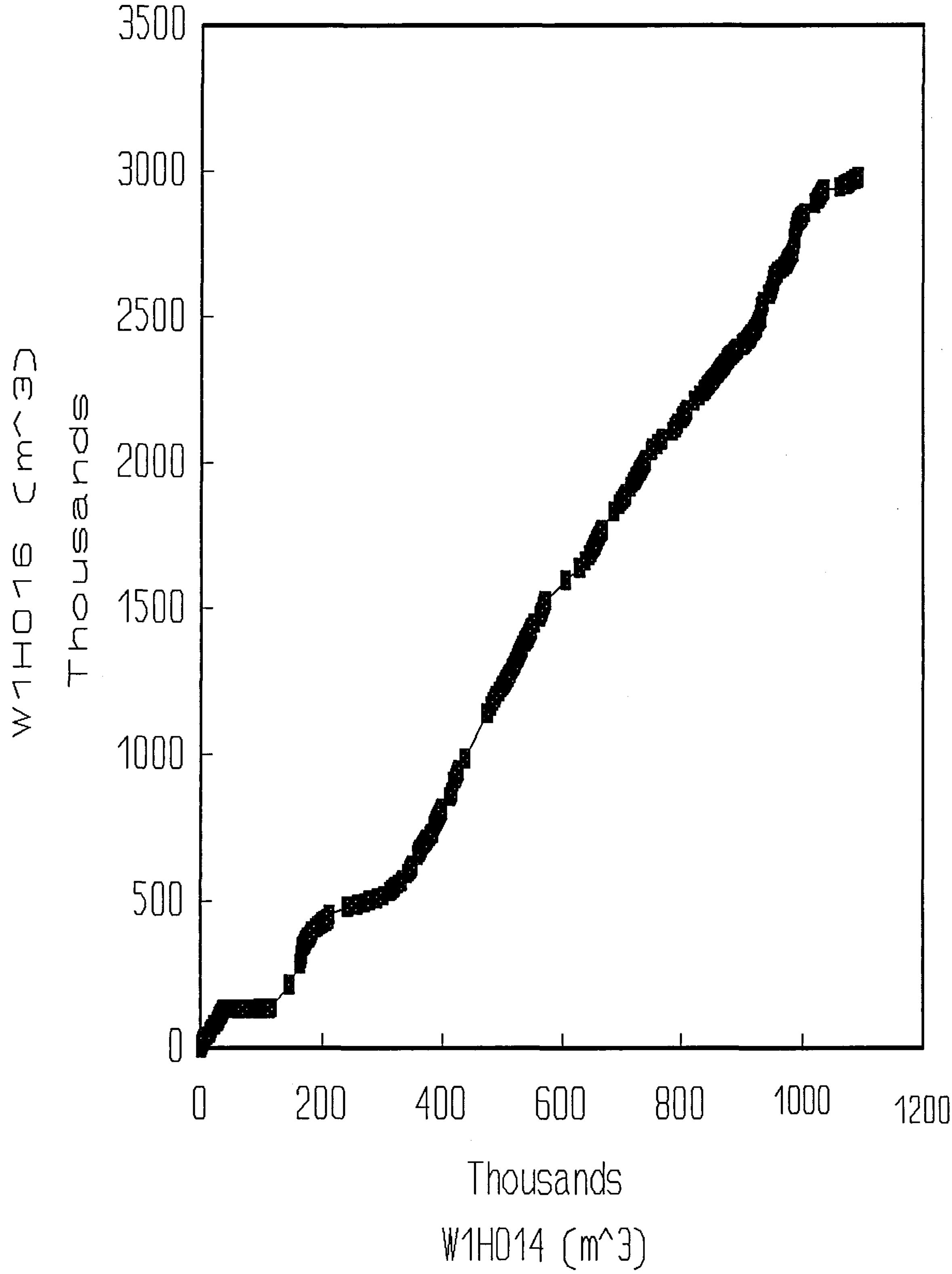


Figure 6,4(a) Double mass plots of accumulated runoff for W1H014 (Ngoye Nature Reserve) and W1H016 (disturbed catchment) for 1979-1983.

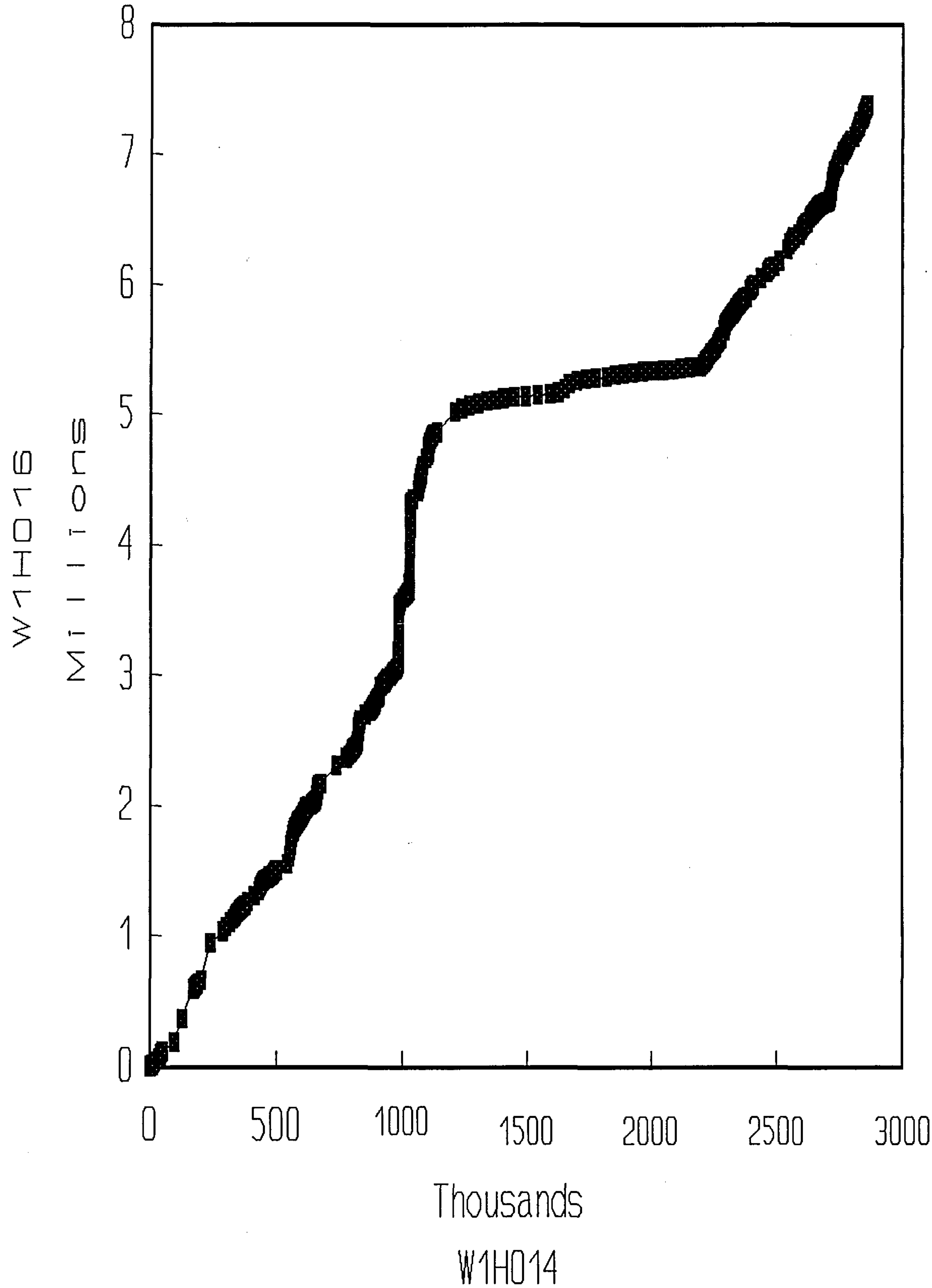


Figure 6.4(b) Double mass plots of accumulated runoff for W1H014 (Ngoye Nature Reserve) and W1H016 (disturbed catchment).or 1984-1989

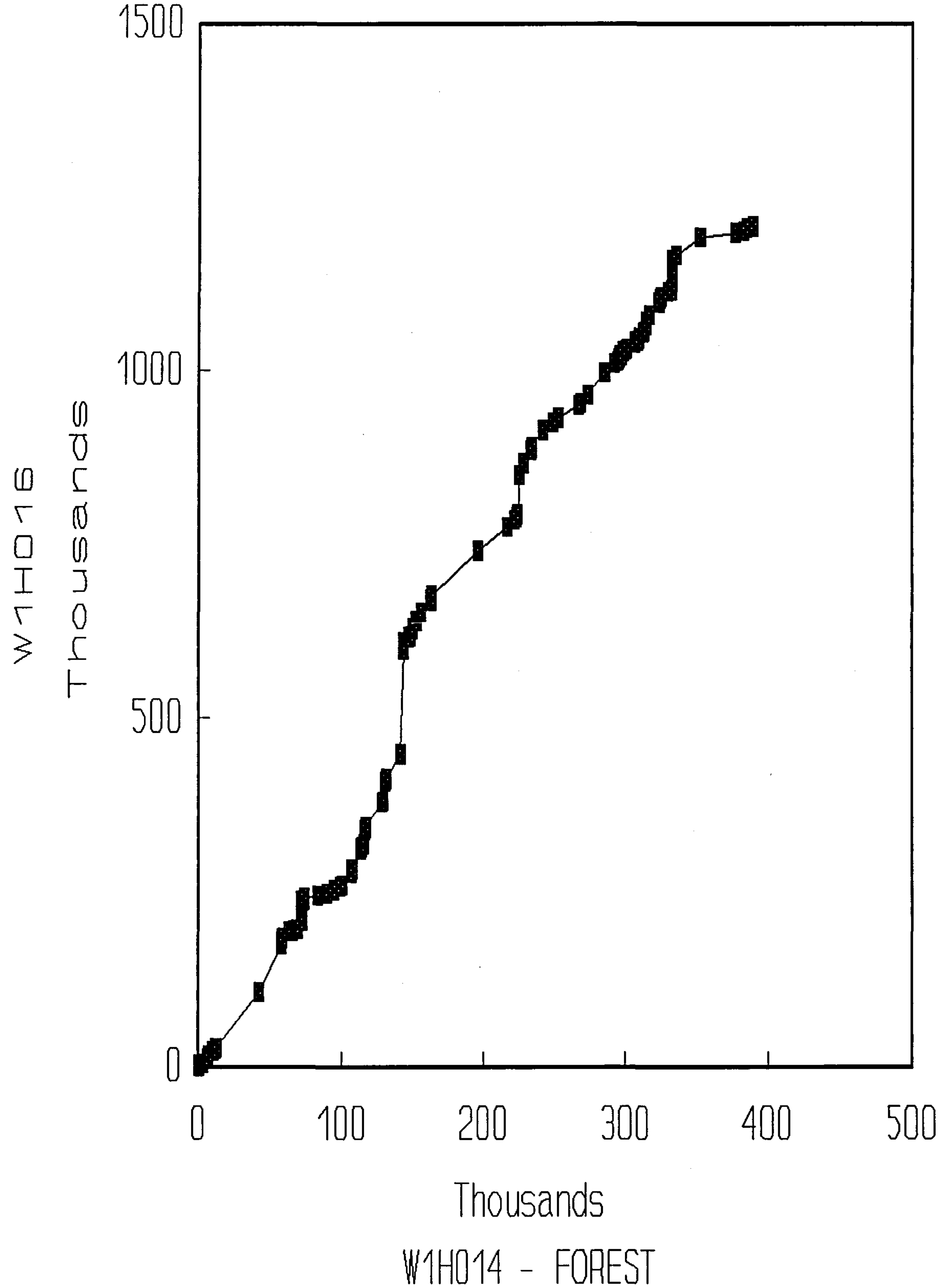


Figure 6.5(a) **Double mass plots of QUICKFLOW runoff for W1H014 (Ngoye Nature Reserve) and W1H017 (disturbed catchment) for 1979-1983.**

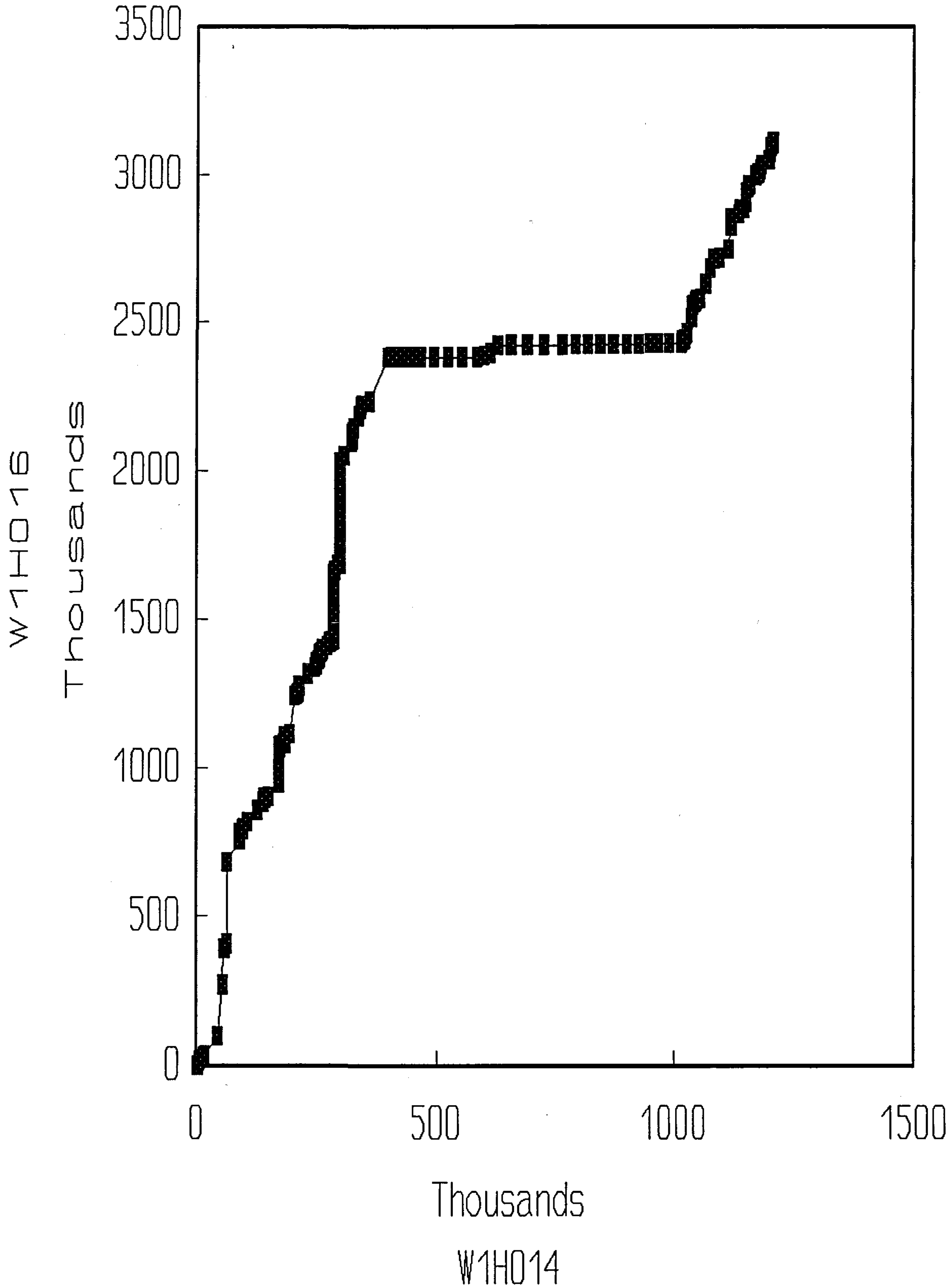


Figure 6.5(b) Double mass plots of QUICKFLOW runoff for W1H014 (Ngoye Nature Reserve) and W1H017 (disturbed catchment) for 1984-1989.

was only commissioned in 1979, the comparison for the first series starts from 1979. Much of 1983 data are missing so the second period comparison commenced in 1984.

Table 6,1 Slope of double mass plot for three selected periods,

PERIODS	COMPONENT	SLOPE
1979-1983	TOTAL FLOW	0.335
1984-1989		0.319
1984-1989		0.391
1979-1983	QUICKFLOW	0.320
1984-1989		0.281
1984-1989		0.296

Figure 6.4a shows the double mass plot for the accumulated total runoff from 1979 to 1983 for W1H014 against W1H016. The plot shows considerable differences between the discharge from both catchments which is even more variable in the plot for the second period (1984 - 1989) shown in Figure 6.4b. Both catchments display periods when one catchment continued to sustain runoff while the other had a very much reduced flow. However, there are periods when the plot exhibits linear characteristics. For these periods a straight line was fitted by eye and used for comparison. The slope of the straight lines from Figure 6.4 were extracted and are given in Table 6,1. Similar comparisons were done for the accumulated quickflow component and are presented in Figure 6.5 and Table 6,1. The regression slopes for the runoff plots show no recognizable trends and are sufficiently similar, with one exception, to discard any suggestion of a significant change in the runoff characteristics of the catchments.

6.3 RECESSION RATES

The discharge hydrograph is directly related to catchment characteristics. All else being equal, changes in the land use of a catchment will result in changes in the response hydrograph, particularly if such characteristics as the infiltration rates and composition of the wetland areas are significantly altered by the changing land use. Temporal analyses of such characteristics as the response time (time from rainfall to runoff) of the catchment were not considered in view of the uncertainty in the quality of the data from 1983. However, changes in the shape of the discharge hydrograph could reflect changes in the physiography of the catchment if the geomorphology is assumed to remain the same during the period of analysis.

The recession coefficients relating to surface flow, interflow, and baseflow were derived for W1H017 using the method described by Schulz (1976). Using the logarithmic transformation of discharge, the recession curves can be divided into three linear components (Figure 6.6). The recession curves for all the storms during each season were digitized from the autographic charts, logarithmically transformed and analyzed for the different hydrographic components. The **recession rates** of the three hydrographic components of surface runoff (quickflow, interflow and baseflow) were obtained for all short duration single peak storms from 1976. These coefficients are also used in the partitioning of the infiltration component in the modelling section (Volume II of this report). Box and whisker plot of the three recession coefficients for each year are shown in Figure 6.7. An inspection of these plots indicate no clear temporal trends which could be related to changes in catchment characteristics such as landuse. There is a suggestion that the recession rates of base flow prior to 1983 may have declined steadily since 1976. For the 10 year period there are only three mean rates above the line joining the 1976 and 1986 mean values - one of which is a single value (1983).

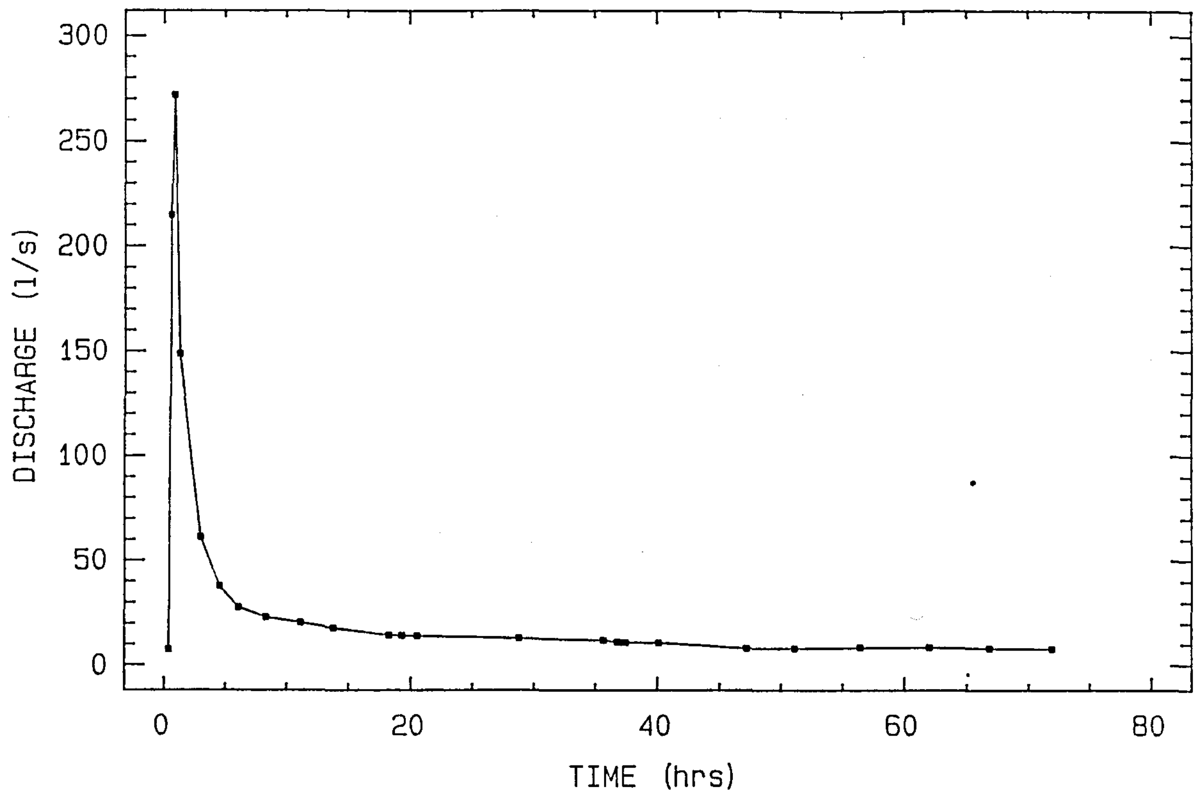
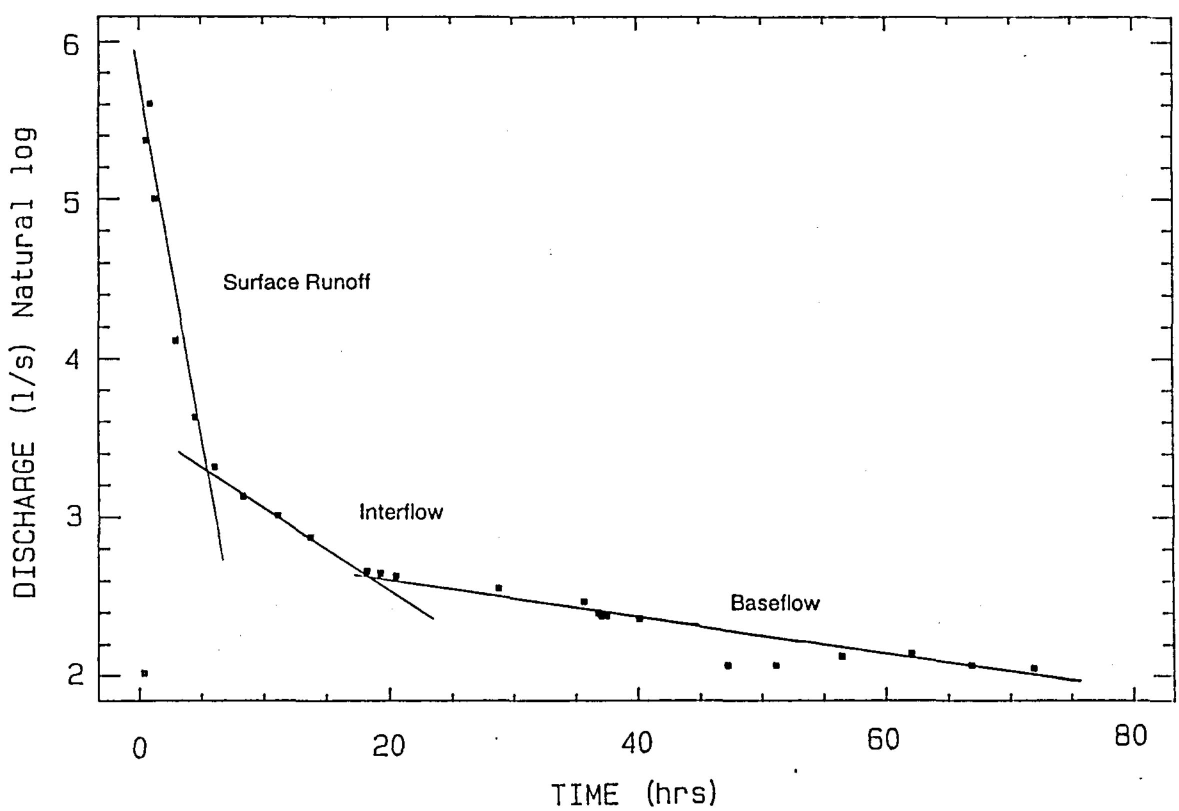


Figure 6.6 **An example of the logarithmic separation of the three components of a hydrograph.**



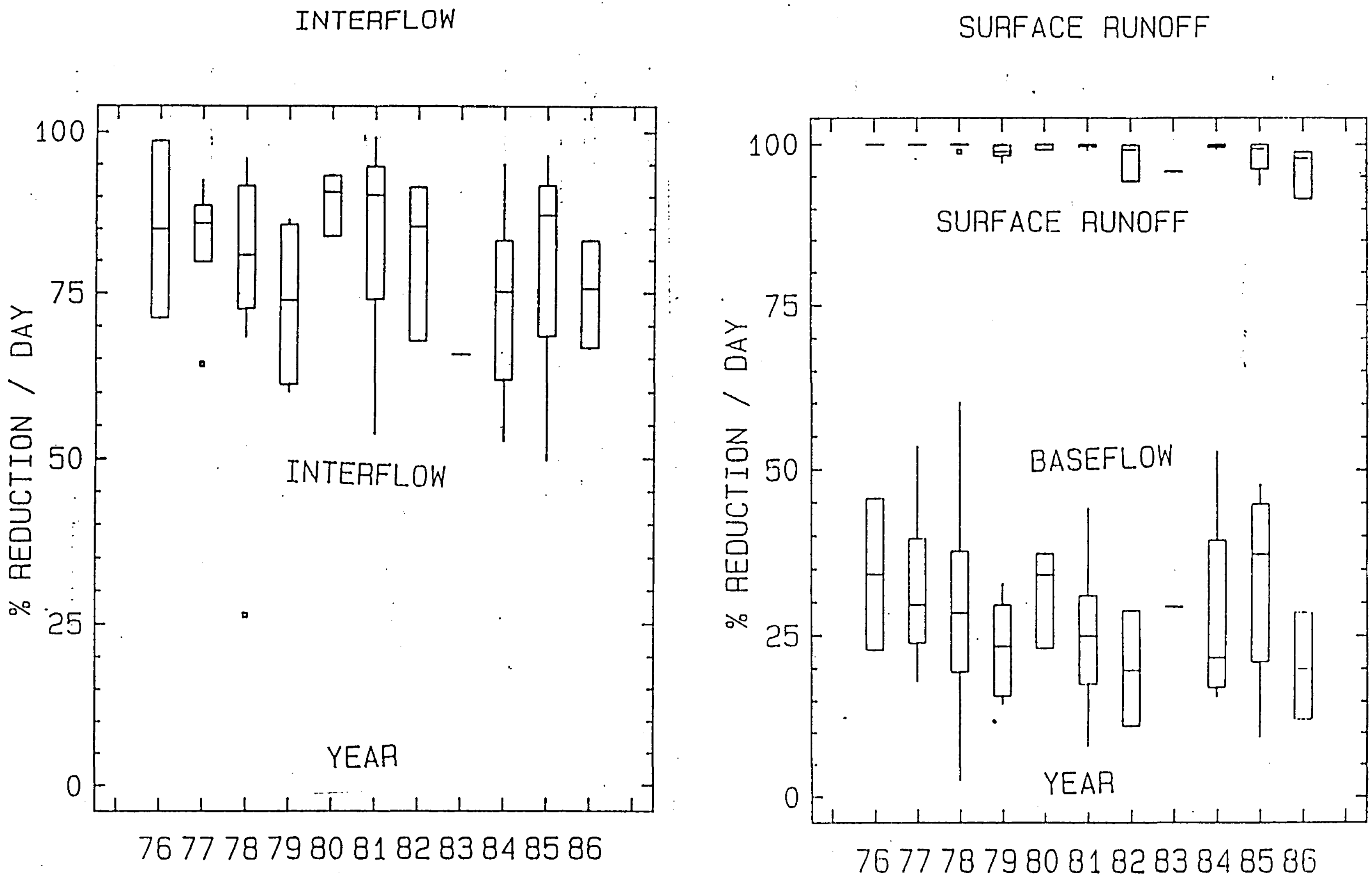


Figure 6.7 Annual variation in the recession coefficients.

7 IDENTIFICATION OF DIFFERENCES IN THE HYDROLOGICAL RESPONSE CHARACTERISTICS OF THE DISTURBED (W1H016) AND UNDISTURBED (W1H031) CATCHMENTS.

It is the intention of this section to compare the hydrological response of two catchments with substantially different land uses, one comprising third world subsistence farming communities, and one situated almost entirely within a protected nature reserve. Since catchment physiography and land use are recognised as playing an important role in the rainfall-runoff process, meaningful comparisons of the hydrological responses of these two catchments which can be attributed to the different land uses must identify and quantify all the significant differences between the two regions.

7.1 HYDROGRAPH CHARACTERISTICS

A comparison of the autographic charts revealed several distinct differences between the hydrographs of weirs W1H016 and W1H031. In nearly all cases, the initial response (increase in stage) and the recession rate were very similar (Figure 7.1). However, the peak stage for W1H016 seldom reached the same elevation as the stage for W1H031. This does not appear to be a result of the weir construction since the rating curves for both weirs are identical up to 0,4m and very similar above this stage (see appendix III). According to the rating curves, W1H016 must have a slightly higher stage (approx 0,05m) for the same discharge when the water elevations is higher than 0,8m. However, for stages between 0,4 and 0,8m W1H016 should be approximately 0,05m lower for comparable discharges. Since many of the difference in peak stage are greater then 0,1m, the difference must be due to other factors.

The digitised data from both catchments was processed using the program RUNOFF (Schulze and Arnold, 1980) to obtain estimates of hydrographic characteristics for individual storms. Those events which where the result of significantly different rainfall conditions were ignored in the following comparisons. For several storm events there were missing data during short periods which affect only

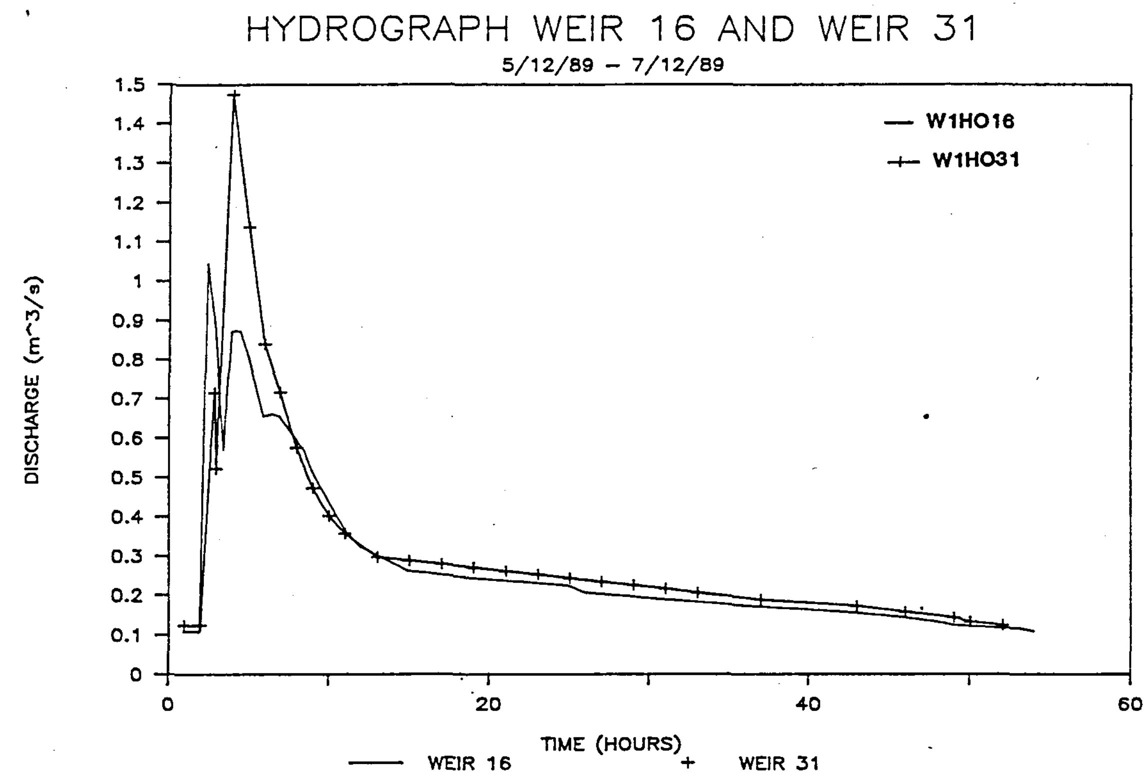


Figure 7.1 **An example of the discharge from W1H016 and W1H031 for very similar rainfall events at both weirs.**

certain comparisons. Consequently these events were included in the overall analysis because some comparisons would not be affected by the missing data. For example, missing data during the recession stage would not influence the peak discharge or time to peak estimates. However, these events have been identified where they influence the comparisons.

The total storm flow, the peak discharge rate and components of the quickflow were estimated for all storms that had similar rainfall. These estimates were then compared for W1H016 and W1H031. The **total stormflow** for both catchments (Figure 7.2) shows a good 1:1 relationship with the exception of three points. Two of these points have subsequently been found to include missing data during short periods of the hydrograph.

The scatterplot of **total quickflow** for both catchments (Figure 7.3) shows a similar relationship to the total stormflow. The two outlier events are the same as the two large outlier in Figure 7.2, one of which had some missing data.

A comparison of the **peak quickflow** rates is shown in Figure 7.4. Also shown are the 1:1 and 2:1 relationships. Nearly all the points fall within these two lines. With the exception of two points, most of the larger events are closer to the 2:1 line. This confirms the suggestion that the undisturbed catchment has a much higher peak discharge rate than the disturbed catchment. The quickflow is partitioned into the rising limb and recession limb and compared for both catchments. The scatterplots for the rising limb (Figure 7.5) shows that most points fall close to the 1:1 relationship. Of the two events that fall well below the 1:1 line, the large one has missing data for one peak. The other outlier ($40m^3$ for W1H016) is also an

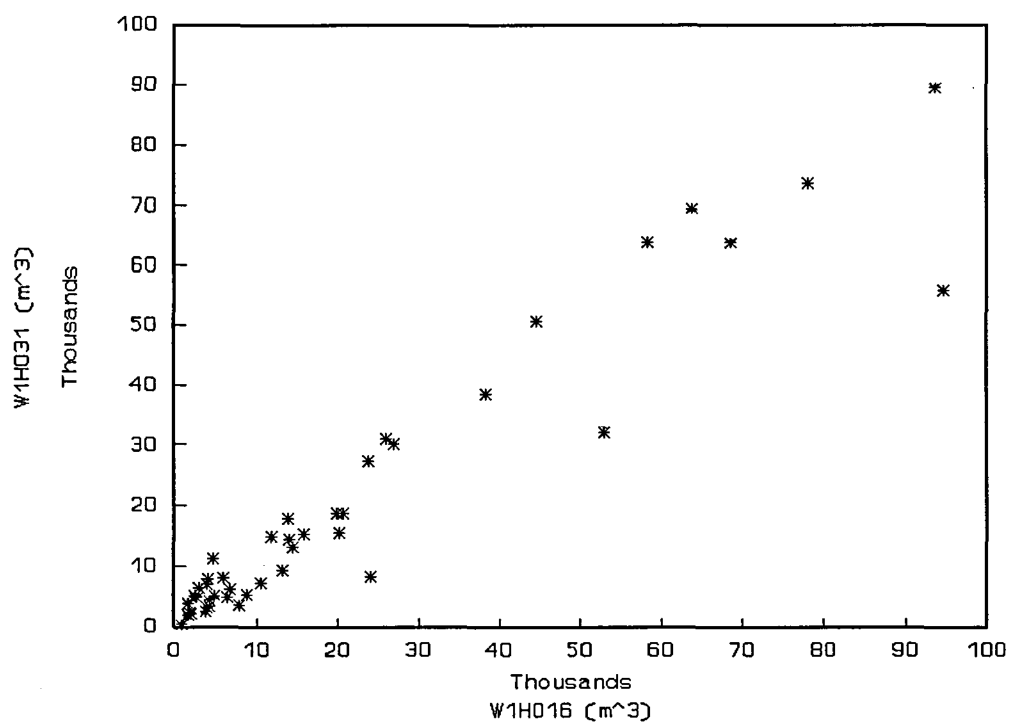


Figure 7.2 Relationship in total storm flow between W1H016 and W1H031. (■ contains missing data)

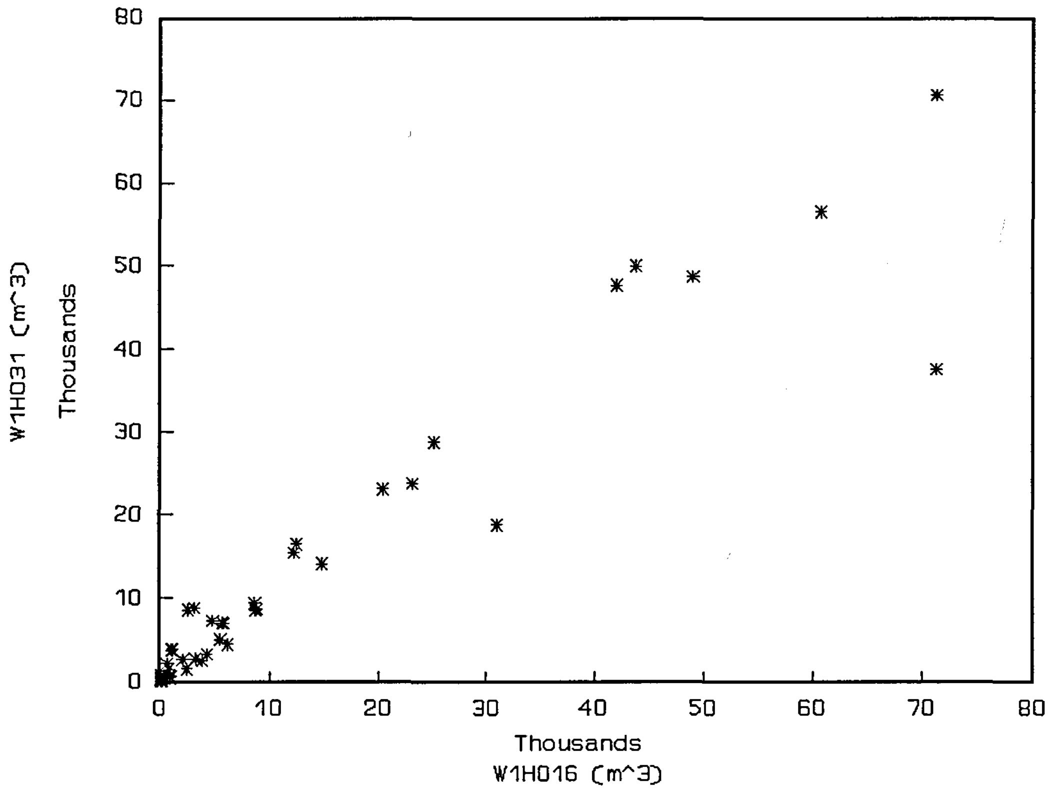


Figure 7.3 **Relationship in total quickflow between W1H016 and W1H031 (■ contains missing data).**

anomalous event in the plot of the recession component of quickflow (Figure 7.6) which indicates that the partitioning may be incorrect for W1H031 for this event. The apparent deficit in quickflow for this event during the rising limb is approximately the same as the excess quickflow for the recession component.

There is a good correspondence between the **duration** estimates of the storm events from both catchments (Figure 7.7) and the **time to peak** (Figure 7.8). The one anomalous time to peak value (1800 mins for W1H016) is the same event that was considered to be incorrectly partitioned in Figures 7.5 and 7.6.

The **baseflow** (Figure 7.9) and the ratio **{recession time}/{time to peak}**, as well as other hydrograph characteristics examined showed no discernable difference between the two catchments which could be attributed to any land use effects.

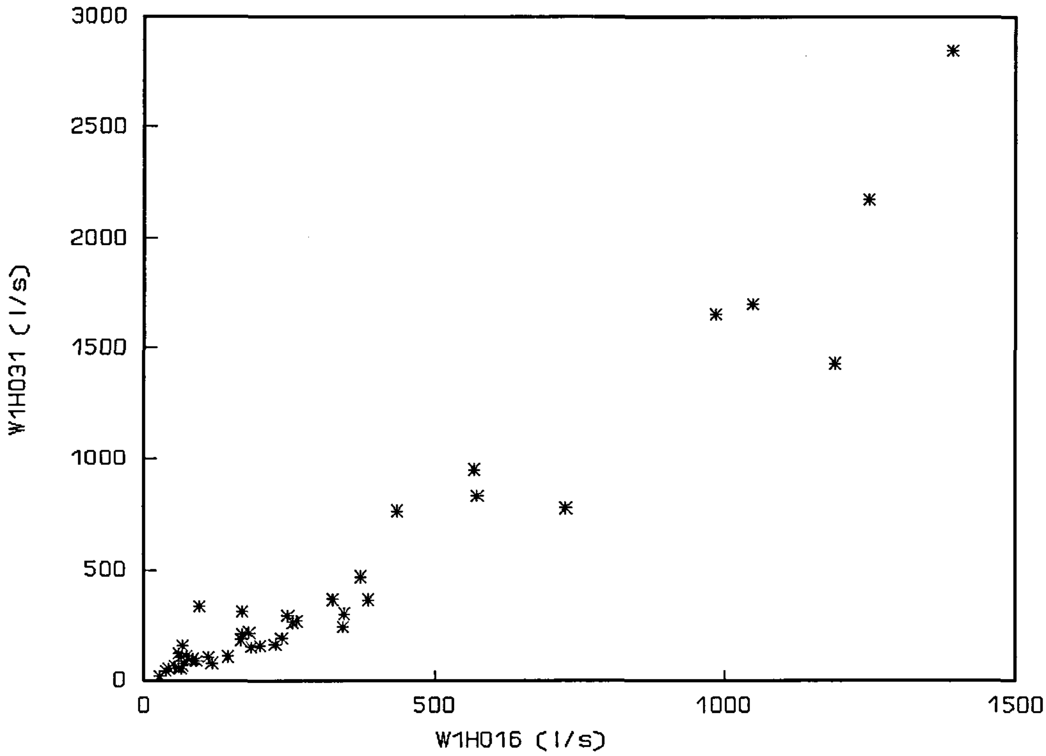


Figure 7.4 **Relationship in peak discharge between W1H016 and W1H031**

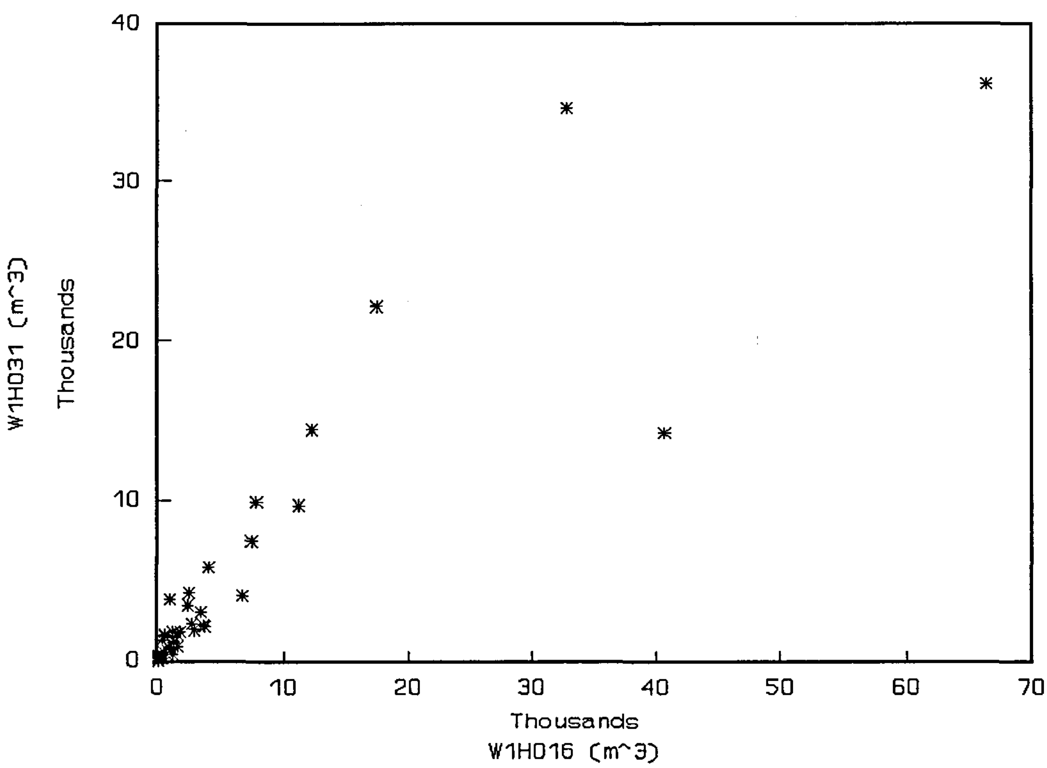


Figure 7.5 **Relationship in rising limb component of quickflow between W1H016 and W1H031.**

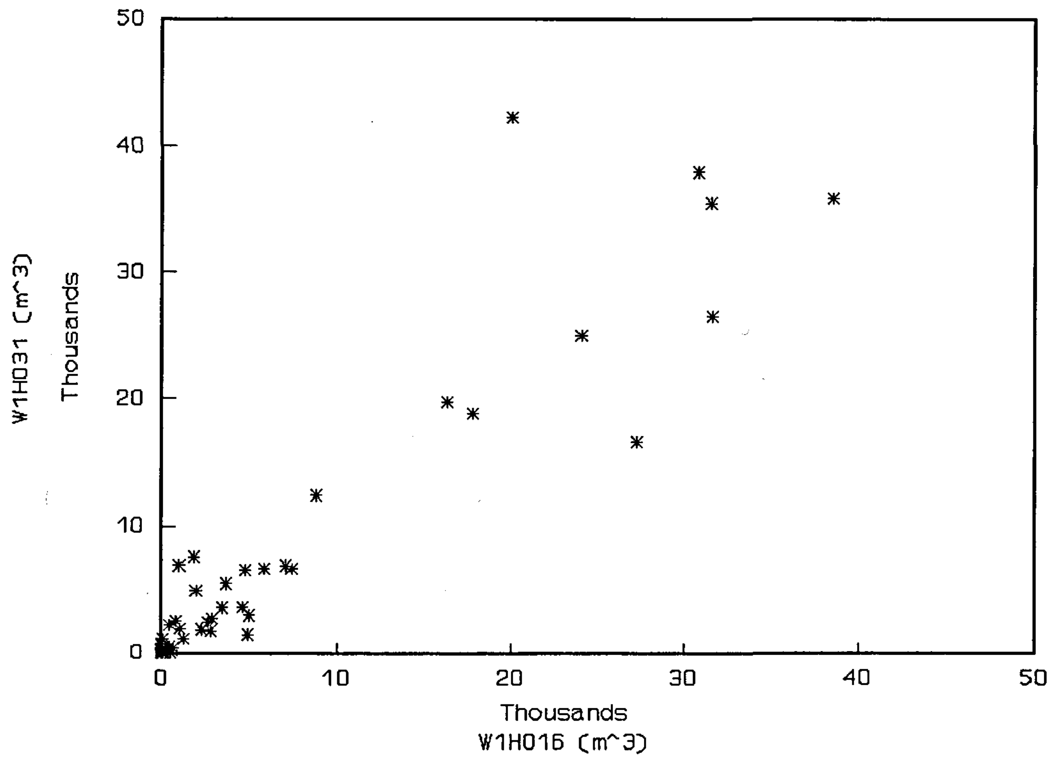


Figure 7.6 **Relationship in recession component of quickflow between W1H016 and W1H031.**

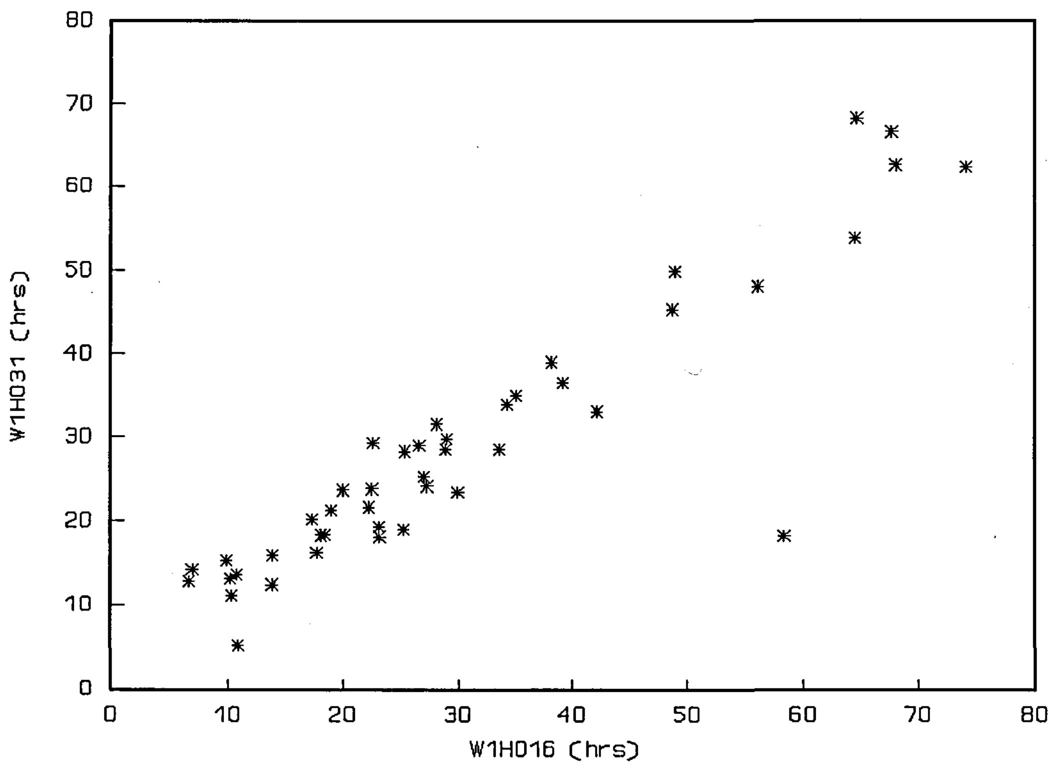


Figure 7.7 **Relationship in the duration of storm events between W1H016 and W1H031.**

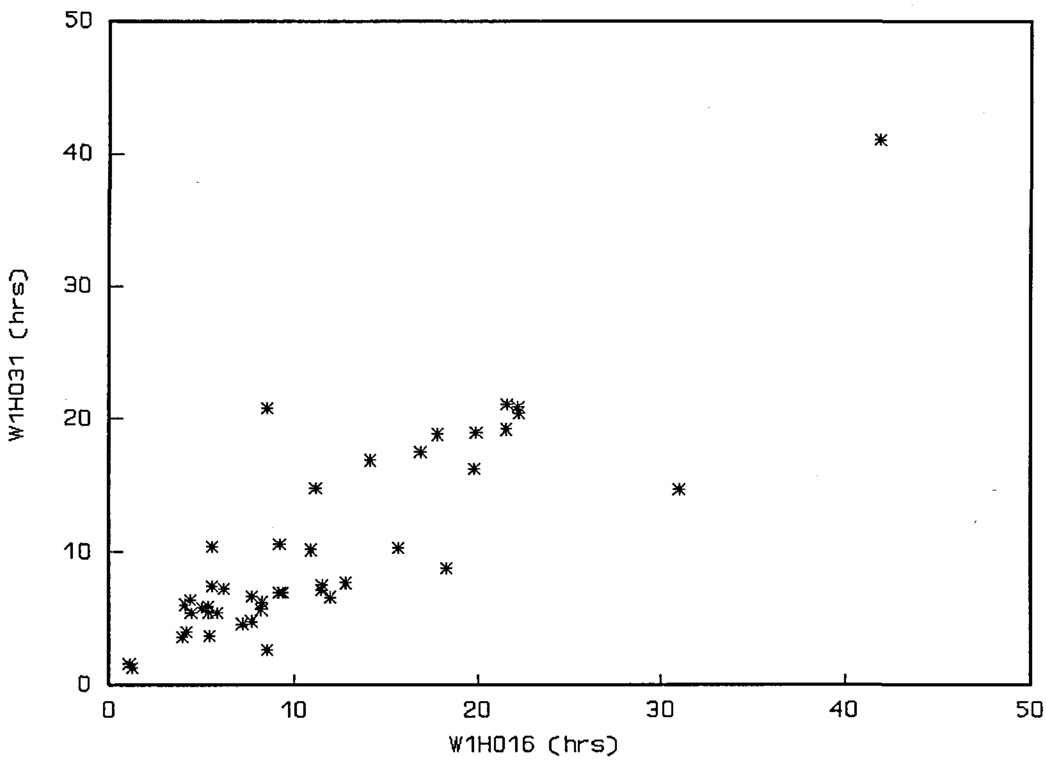


Figure 7,8 **Relationship between the Time to Peak of storm events at W1H016 and W1H031.**

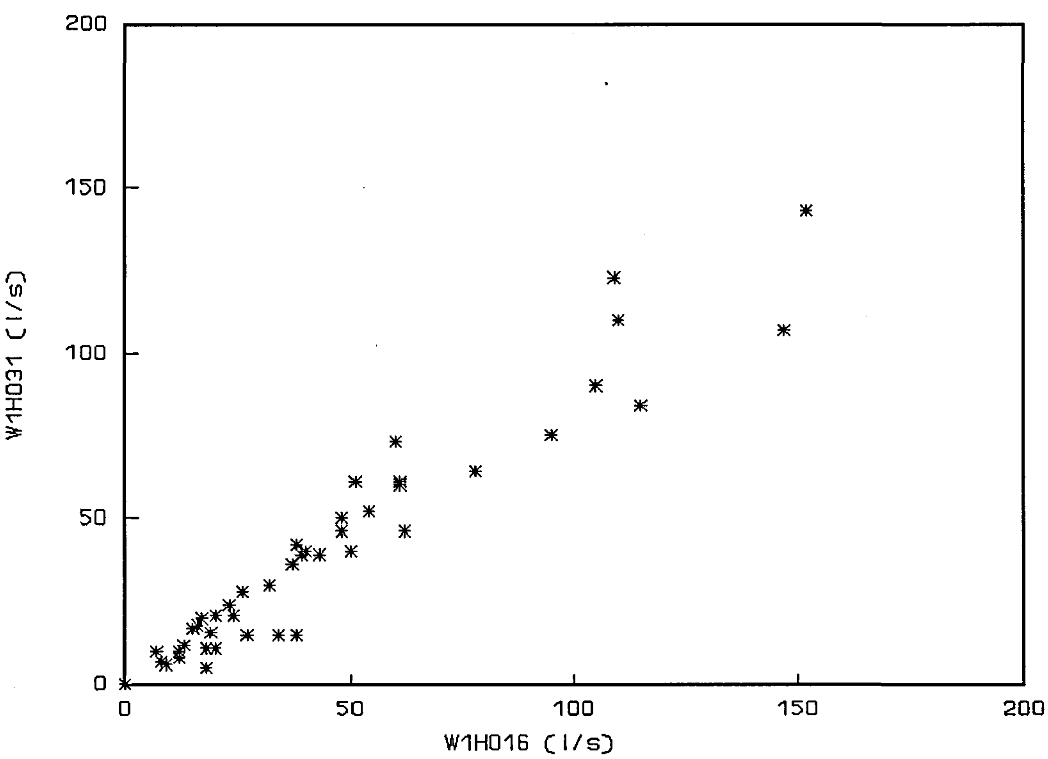


Figure 7,9 **Relationship between the Baseflow for storms at W1H016 and W1H031.**

7.2 DIURNAL VARIATION IN DISCHARGE

The mean hourly discharge for each hour of the day from W1H016 and W1H031 have been derived from the CR10 data (appendix IV and Kelbe 1990) and plotted in Figure 7.10 and Figure 11. The data since July 1990 has not been included because the piezometer at W1H016 became erratic at this time and had to be sent for repairs.

During winter (May & June) when no convective storms occurred, the mean hourly discharge from both weirs (Figure 7.11) is very similar but shows considerably greater variations for the disturbed catchment which possibly reflects the diurnal variation consistent with evaporation losses from within the catchment. This diurnal trend is also evident for W1H016 during April (Figure 11). In all three winter months the discharge reaches a minimum in the early morning (08h00) and a peak rate around 16h00. If the water loss was due to evaporation from the river channels and weir dam then the minimum discharge should correspond to peak evaporation times near solar noon (around 14h00) which is at least four hours after the minimum discharge rate. Consequently it is unlikely that this minimum discharge rate is a response to evaporation within the river channel.

Evaporative losses within the catchment should peak with the potential evapotranspiration rates which also occur around solar noon. If the minimum discharge is due to the evapotranspiration losses within the catchment then the base flow conditions during winter indicate a baseflow response time of about 20 hours between the peak evapotranspiration time and the time of minimum flow at the outlet to the catchment. If this diurnal cycle in baseflow was due to evapotranspiration then one would certainly expect to see it in the baseflow for the undisturbed catchment. Since it is not evident in the discharge from both catchments it is probably not due to evapotranspiration.

A examination of the times of peak (storm) rainfall in

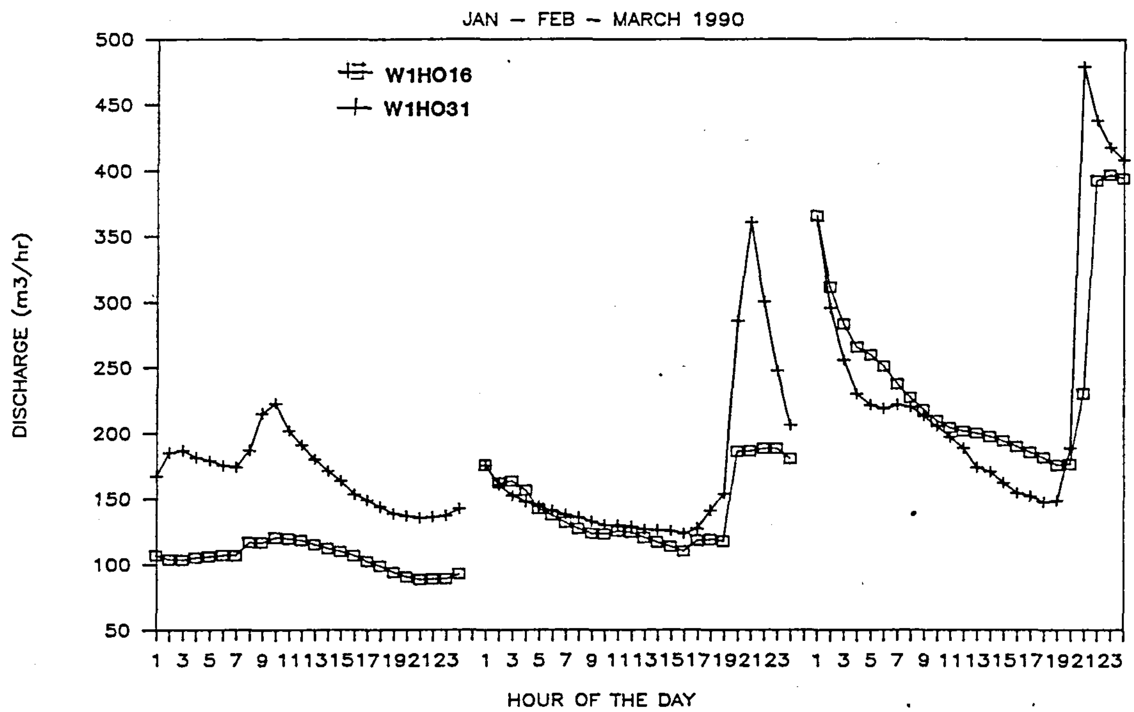


Figure 7.10 Mean hourly values of discharge from W1H016 and W1H031 from January to March, 1990.

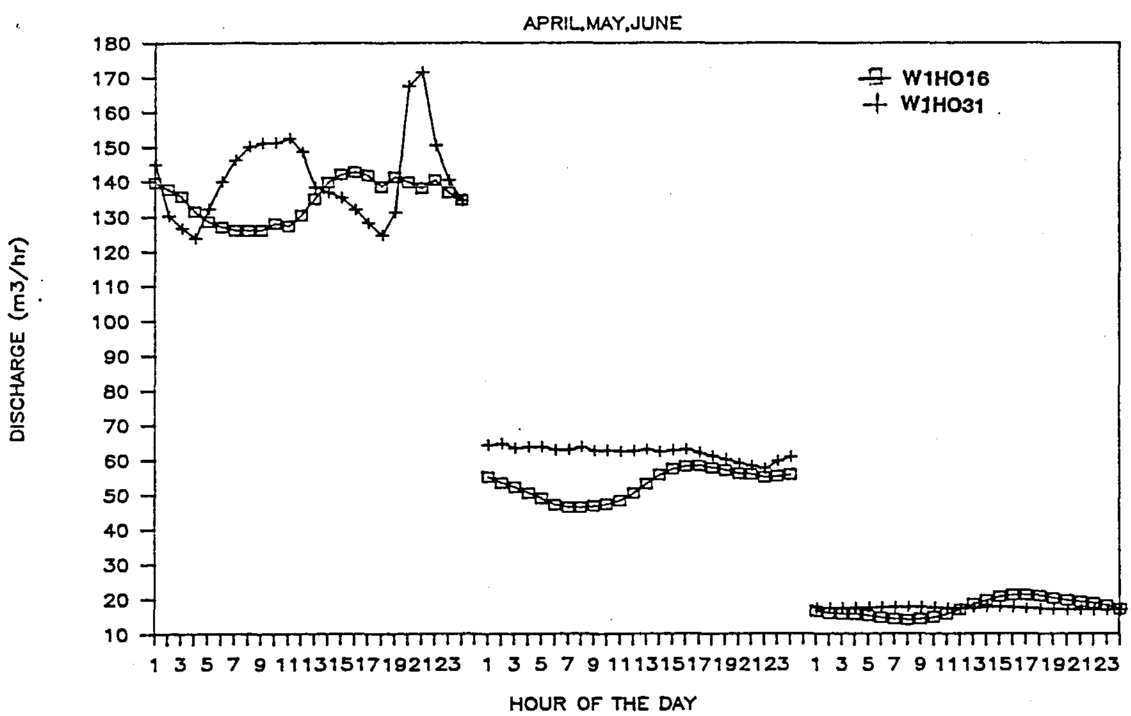


Figure 7.11 Mean hourly values of discharge from W1H016 and W1H031 from April to June, 1990.

February (Figure 4.3a) and April (Figure 4.3b) and their corresponding discharge response (Figures 7.10 & 11) shows that both catchments respond to storms in approximately 2 hours. The peak rainfall in March is a composite of several storms and masks the individual responses.

There are significant differences between the hydrographs from W1H016 and W1H031. In January 1990, the discharge from W1H031 is substantially higher than the corresponding discharge from W1H016 despite the similarities in the rainfall measurements (Figure 4.3). It is not clear why this month shows such a large discrepancy, but it could be due to an unrecorded change in piezometer program offset (gauge plate correction). Except for January, all months show very similar discharge characteristics particularly when the rainfall depths are similar. In February the peak discharge is considerably higher from W1H031 which can be attributed directly to a much higher rainfall at 16h00 (Figure 4.3).

7.3 HYDROGRAPH SHAPE and TRAVEL TIMES

An examination of the hydrographs from W1H016 on many occasions revealed that the peak discharge consisted of several distinct peaks (Figure 7.1). There were no corresponding peaks for the hydrographs from W1H031. It was also evident that in nearly all these situations the peak discharge (stage) for W1H016 was always lower than the peak discharge from W1H031 (Figure 7,4) despite the fact that the rising and recession limbs of the hydrographs were almost identical for both catchments (Figures 7.5 & 7.6).

Table 7,1 Average time and stage of discontinuity in hydrograph W1H016.

Break point	time	stage
base	0	0
peak-1	155	578
trough-1	325	430
peak-2	405	520
trough-2	598	491
peak-3	699	512

All the hydrographs for W1H016 since 1976 which showed peak seperation were identified and the points of inflection were digitised. These are summarised in Figure 7,12 & Table 7,1. In all cases these hydrographs were derived from short duration, high intensity storms. The three peaks in the hydrograph appear to correspond to the three peaks in the catchment areas contributing to the travel times derived from the isochromes (Figure 5.6).

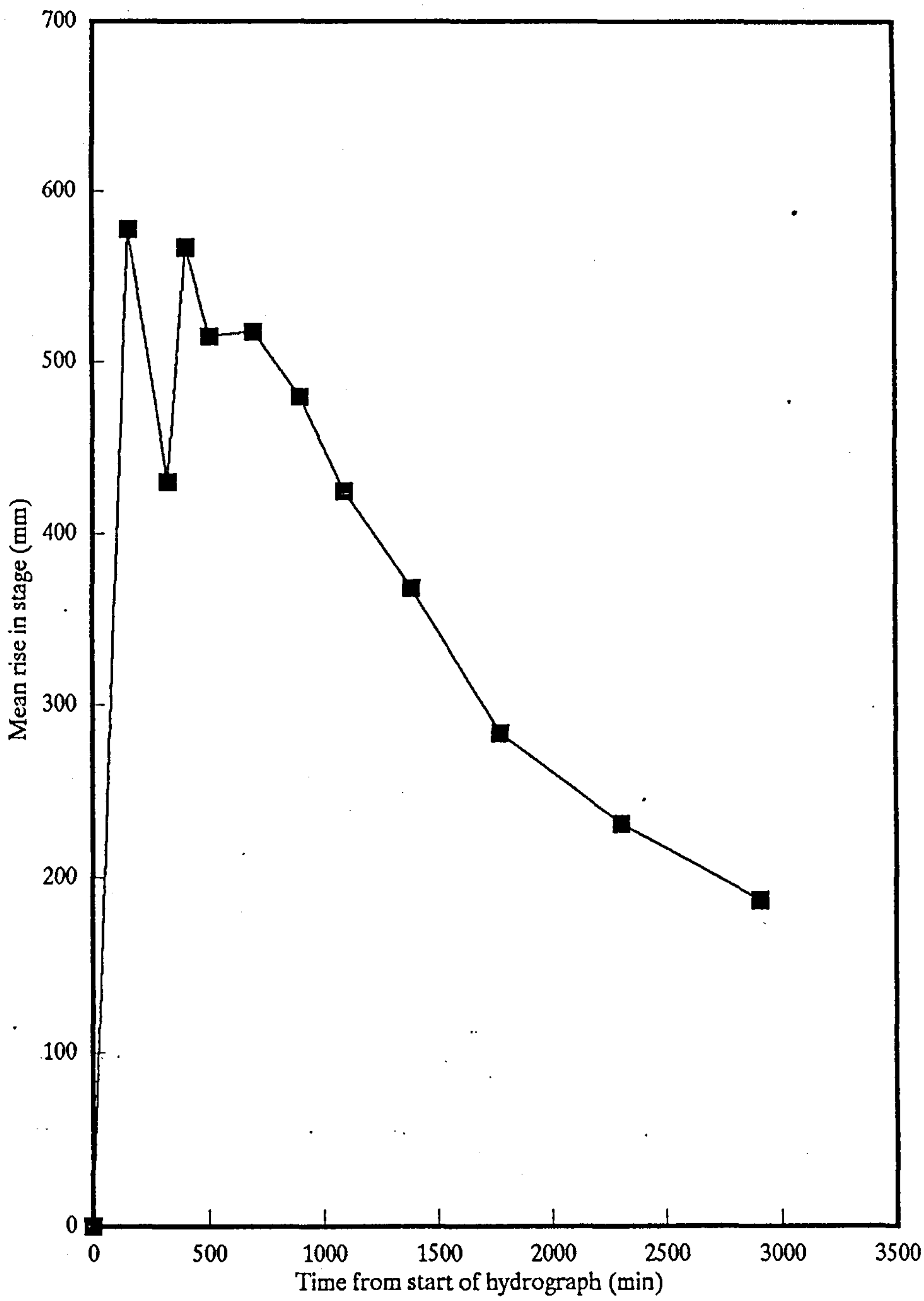


Figure 7.12 **Plot of the time of the points of infection at the three peaks in the stage of selected storms for W1H016.**

8 CHARACTERISATION OF THE SUSPENDED AND DISSOLVED LOADS FROM THE CATCHMENTS SUPPORTING DIFFERENT LAND USES.

Increasing demands on water supplies and the growing concern for water quality require water resources managers to know more about the impact of land use on water resources. It is essential, if we are to utilise the catchments more intensively through sustainable development and at the same time maintain water quality at desired levels, that we understand the impact of landuse on water quality. Due to water's particular solvent characteristics and chemical reactivity together with its general mobility and fundamental involvement in all life processes, pollutants are easily transported along hydrological pathways. Consequently water quality deterioration is reflected in the ecological effects on flora and fauna. Many organisations have finally accepted that the whole catchment is of fundamental importance in the management of water resources. This is becoming abundantly clear in the utilization and management of the estuaries along the Natal coast where sediment deposition is causing considerable problems and adversely affecting the fragile ecological systems.

The influence of third world farming methods have produced significantly greater runoff and erosion than natural (bush fallow) management controls in an area with similar soils under a slightly more arid environment (Lal,1989). The implementation of ploughing techniques were also found by Lal (1989) to influence the sediment density in runoff. With demographic changes and poor management practices it has been estimated that the erosion rate in Natal has increased by a factor of 12-20 compared to average geological erosion rates (Martin, 1987). This is considered to be the cause of the prograding beach along the Zululand coast which has been estimated by Weisser and Baeker (1983) to be over 5m per year at Mtunzini (Figure 1.1). The estimated mean sediment damage in South Africa is close to R94m (Braune and Looser, 1989).

The agricultural management practice in the Siyaya catchment at Mtunzini (Figure 1,1) has been acknowledged as the principle cause of the deterioration of the lagoon. Similar trends in agricultural practice and urbanization in the Umlalazi and Ntuze catchments are causing concern for the Umlalazi lagoon (NPB)

This project was established in collaboration with water quality studies being undertaken by the Division of Water Technology (DWT), CSIR as part of the Mgeni Systems Model Project at Natal University. Many of the water samples collected were sent to DWT for analyses and used by them for their investigation. In order to avoid unnecessary duplication of results and conclusion, some of those characteristics of the water quality that are analyzed by the DWT and presented in a separate report to the WRC by Simpson (1991) are not included here. However, where there were additional samples and analyses conducted by the HRU_z, these have been included.

Simpson (1988) conducted a survey of various catchments in Natal/KwaZulu to obtain base values of water quality parameters under different management systems and showed significant differences between the water quality of the Ntuze catchments and those at other locations in Natal (Cedara). He also identified several significant differences between the subcatchments of the Ntuze basin which has led to further in-depth studies of these catchments using more intensive (continuous) sampling procedures. This project has provided further water samples from the natural grassland catchment (W1H031) and the disturbed catchment for the extended DWT project. It also used these and other measurements to investigate those characteristics of the suspended and dissolved loads emanating from these two catchments in an effort to relate them to the different land use practices.

8.1 SAMPLE COLLECTION SITE AND PROCEDURE

The water quality of a stream can be defined in terms of its physical, chemical or biological features. While the biological features of the two streams may show considerable differences they were not considered in this project. However, selected physical and chemical properties of the stream discharge have been investigated in order to determine the effects of the different management practices. One of the primary parameters being investigated in this study is the sediment loads emanating from catchments under different landuse management strategies.

The sediment load comprises two components which vary in direct response to the carrying capacity of the river (velocity). When the terminal velocity of a suspended particle exceeds the turbulent velocity of the streamflow, then the particle will tend to precipitate to the stream bed. Only the suspended component has been investigated throughout this project. However, an effort is now being made to investigate the bed load and tentative results are included.

The initial study by Simpson (1988), based on weekly grab samples from both catchments, provided the mean values of selected water quality variables (Table 8,1) as well as the ratio of the means and an indication of their significance (95%). Based on these results and the cost of analyses, it was decided to limit the water quality evaluation during the initial phase of this study to those parameters indicated by an asterix in Table 8,1

The rate of sediment settling in a fluid is dependent upon the particle size distribution and the settling time. Hence large storage compartments (dams/weirs) will increase the deposition rate as a result of longer settling times. In a direct comparison of two catchments, if the settling times vary immediately upstream of a sampling point, there will be different deposition rates and hence a difference in sample load which may be due to the sampling technique. In this study, the weirs at the outlet to both catchments have very similar storage capacities and hence should exhibit similar deposition rates. Consequently, the weir notches were chosen as the most suitable sampling location. The 8mm plastic pipes from the ISCO samplers for sample collection, were housed in 25mm pipes (galvanised/rubber) which were attached to the weir structure. The inlet was housed in a perforated (10mm holes) steel pipe which was fixed to the weir wall at approximately 20cm below the bottom of the V-notch.

While the DWT study preferred flow related samples, the facilities were not available at the commencement of this study. Equipment was ordered in 1988 to develop the

Table 8,1 Mean water quality measurements, ratio of means and their significance for W1H016 & W1H031 (after Simpson, 1988)

PARAMETERS	Sign 95%	W1H016 mean	W1H031 mean	RATIO 16/31
pH (HRU_7) *	yes	7.06	6.85	1.0
Conductivity * (mSm^{-1})	no	14.7	14.9	1.0
Suspended solids* (mg/l)	yes	13.5	3.6	3.8
Turbidity * (NTU)	yes	19.3	8.5	2.3
SRP	no	1.12	0.8	1.4
Soluble phosphorus*(µg/l)	no	6.5	7.1	0.9
Partcle phosphorus*(µg/l)	yes	25.2	44.9	1.7
NH_3 (µg/l)		20.6	13.5	1.5
Inorganic Nitrogen*(µg/l)	yes	270	34	8.0
Soluble Organic Nitrogen	no	514	486	1.1
Partcle Nitrogen (µg/l)	yes	351	392	0.9
DOC	yes	4.5	6.1	0.7
COD	no	23.6	25.7	0.9
Chloride (mg/l)	yes	38.0	41.6	0.9

facilities for using the ISCO water samplers in a flow related mode. However, the initial equipment was faulty and had to be returned to USA. In the interim, the automatic water samplers were interfaced to the Ott water level recorders through a movable microswitch which initiated each set of samples. The microswitch was set just above the stage at regular interval during the hydrograph recession. The rise in stage which activated the microswitch could only be estimated audibly and consequently it was difficult to determine the exact time that the sampler was activated. However, once activated this system was programmed to sample at regular, fixed time intervals (usually every half hour). Once the time and stage at which the microswitch was activated had been estimated from the autographic charts the remaining sample conditions could be read directly off the autographic charts at the selected regular time intervals.

Because it was not always possible to link the first sample to the stage with suitable accuracy the system was upgraded by incorporating a datalogger. The datalogger could determine and record the stage, convert it to discharge, integrate it over time, and then initiate the water sampler after a specified discharge volume. The system is described in detail in appendix IV. The record of sample times and discharge were generally downloaded to magnetic tape when the water samples were collected, transferred to computer and sent with the samples for analyses.

Only selected samples were sent to DWT for analyses. These were all the major storm event for which a good set of samples were obtained. Once the HRU_Z water analyses laboratory had been established (appendix V), all the remaining samples were analyzed by the HRU_Z for pH, conductivity, turbidity, and occasionally nitrates. Several samples were also analyzed by Alusaf Laboratories for particle size and particle area distribution.

For some of the more expensive analytical procedures, DWT used composite samples in the initial stages of this project. This was not entirely suitable for our analysis so subsequent samples were discarded in preference to compositing. Nearly all the analytical results of the sample analyses together with their corresponding discharge and antecedent rainfall have been tabulated with the hourly data and these have been published under separate cover (Kelbe, 1990).

8.2 RAINFALL

Since rainfall can act as a source for many of the chemical constituents in the discharge, sample analyses were conducted on rainfall samples in order to ascertain the concentration of selected water quality parameters. Several rainfall samples were collected at irregular intervals on the University Campus during this project and analyzed by DWT for the same constituents as the runoff. The results are given in Table 8,2 for comparison with water quality conditions emanating from the two catchments under different flow regimes.

Table 8,2 Analytical results of rainfall samples

DATE	pH	COND mS/m	TOT-PO_4 µg/l	NO_3 µg/l	NH_3 µg/l	KNF µg/l
6-12-88	6.3	4.7	3	45	62	
29-08-89		1.7	4	19		83
11-01-90	6.2	3.5	12	208	292	503
12-01-90	5.8		13	219	280	600
12-01-90	5.5	2.7	5	246	184	523
22-01-90	6.0	1.9	6	94	205	478
25-02-90	5.3	2.7	5	168	116	224
27-03-90	6.6	2.8	7	26	26	306
29-03-90	6.2	2.4	12	39	39	217
10-04-90	6.2	3.3	14	153	153	573
MEAN	6.0	3.0	11	122	151	390

The mean pH value of rainfall (6.0) is close to the minimum value for the runoff from either catchment (see Table 8,5). Similarly the conductivity and total phosphate concentration are both much lower than the corresponding runoff values. However, the nitrate concentration is similar to the concentration of NO_3 measurements for the runoff (Table 8.5)

8.3 INTER-PARAMETER RELATIONSHIPS

Water quality is known to vary considerably during the rise, at the peak, and in the recession stage of a storm hydrograph. The relationship between variables also changes during the various stages of a storm hydrograph as material is released and stored in the channel. Consequently, all the water samples were classified broadly according to the stage of the hydrograph at the time of the sample collection. The stage was determined subjectively by visually examining the slope of the recession curve on autographic charts and using the points of inflection to separate the hydrograph into the rising limb, peak flow, recession stage and base flow (Figure 6.6). The recession limb was subdivided further into a quick-flow and through-flow component for some analyses.

8.3.1 Relationship between turbidity and suspended solids.

Since suspended solids in solution will reflect and scatter incident radiation, the concentration of particles and their size distribution will have a direct influence on the turbidity measurements which are determined from the transmission of light through the solution. Particle size analysis presented in section 8.5 shows contrasting variations between the disturbed and undisturbed catchments in both the median size and area of the suspended sediment during the passage of a storm hydrograph. The median particle size for the disturbed catchment (W1H016) decreases during the receding stage of the storm hydrograph while the samples from the undisturbed catchment (W1H031) show the opposite trend. Consequently, any relationship between suspended solids and turbidity could be different for both catchments particularly during the recession stages of storm hydrographs. Some of the relationships between turbidity and suspended solids have been plotted in Figure 8.1 for individual storm events. In these plots of turbidity against suspended solids, sequential sample values are joined

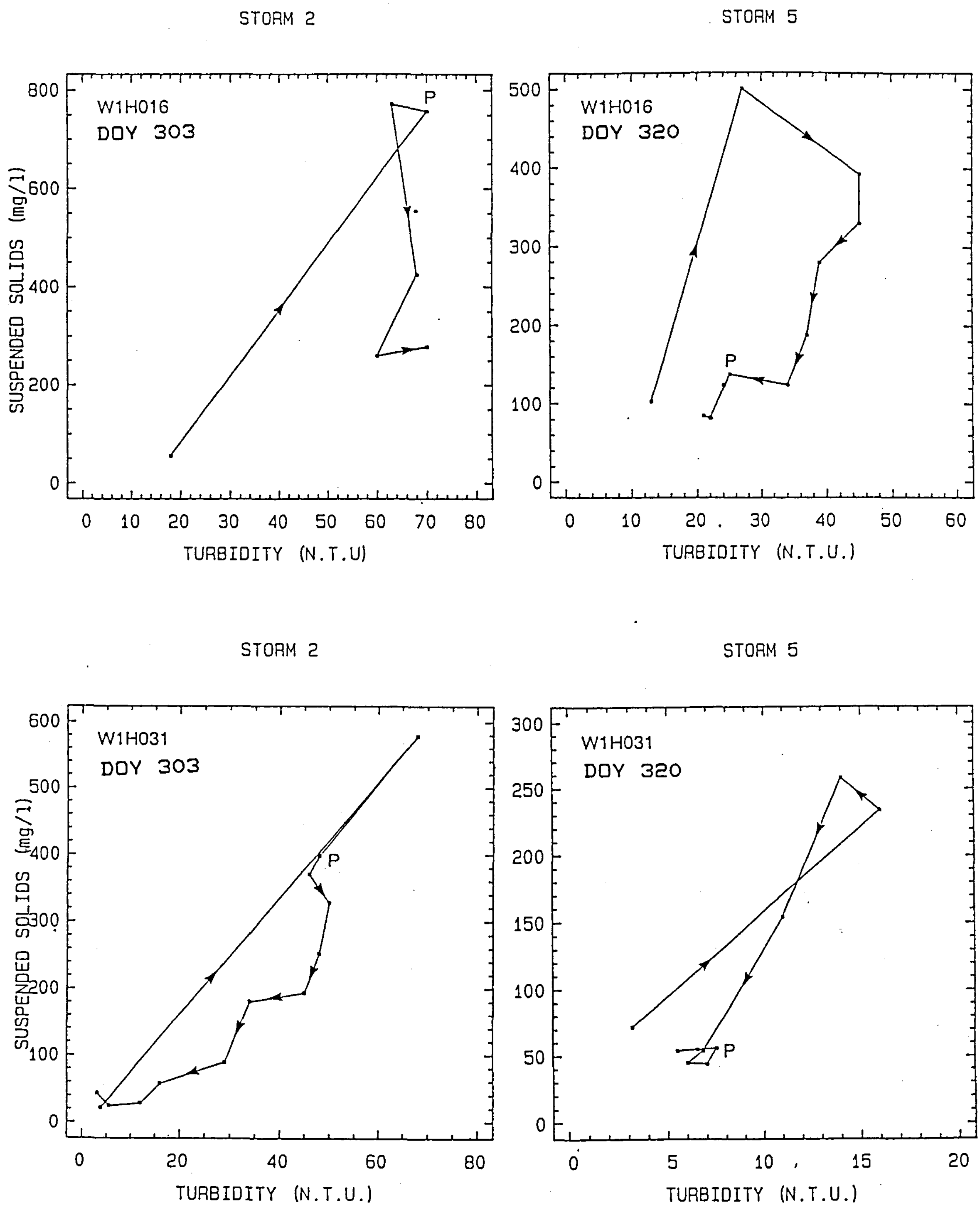


FIGURE 8.1 **Sequential plot of Suspended Solids Concentration (mg/l) against Turbidity (NTU) for selected storm events.**

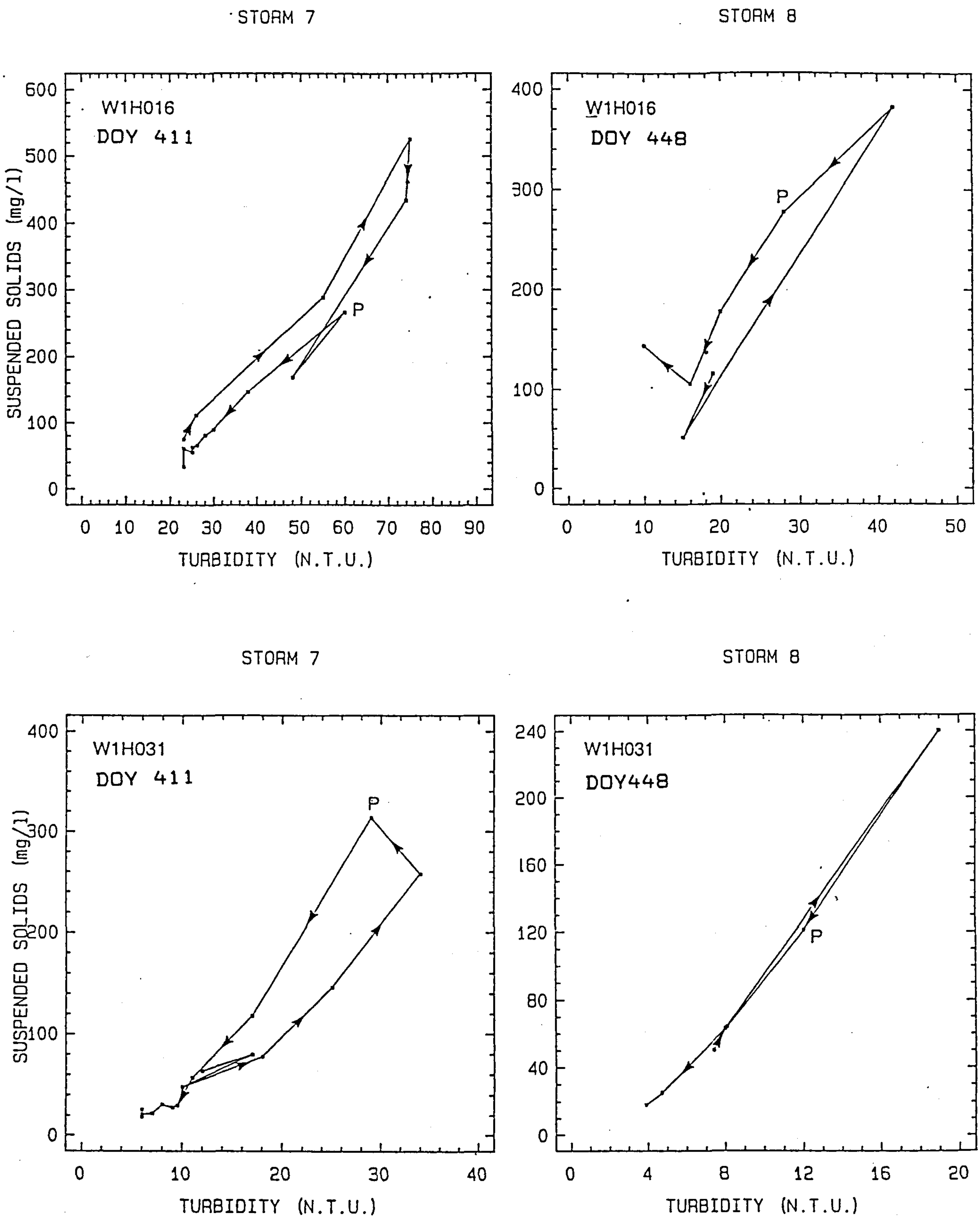


FIGURE 8.1 **Continued.**

to show the change in values with the rising limb and receding stages of the storm hydrograph. The peak flow values are indicated by a letter P in each plot. The plots in Figure 8.1 represent storms which produced peak values of suspended solids which ranged from 200 mg/l to over 800 mg/l.

For the storms which produced high levels of suspended solids there was a good relationship with the changing turbidity for selected storm events (Figure 8.1). For Storm 2 there was a second peak immediately after the relationship shown in Figure 8.1 which showed a different relationship. This suggests that antecedent conditions may significantly affect the relationship. For those storms which produced only small or moderate increase in the suspended solids there was not such a good relationship with turbidity (Figure 8.1).

The peak values in both suspended solids and turbidity seldom coincided with the peak flow rates. The peak flow rates generally occurred after the highest values in suspended solids and turbidity. The suspended solids relationship with turbidity for **all** the samples which were classified according to the hydrograph stage are investigated for both catchments separately in Figure 8,2. Regression analysis for each stage of the hydrograph are presented in Table 8,3 and shows a good correlation for certain hydrograph stages.

The relationship between suspended solids and turbidity is almost identical for both catchments during the rising limb of the hydrograph (Figure 8.2a). The relationship for the quickflow component would be almost as good with the exclusion of the one outlier shown for the W1H016 plot in Figure 8.2b. With the considerably lower range of suspended solids and turbidity during the other stages of the hydrograph the relationships are not as well defined.

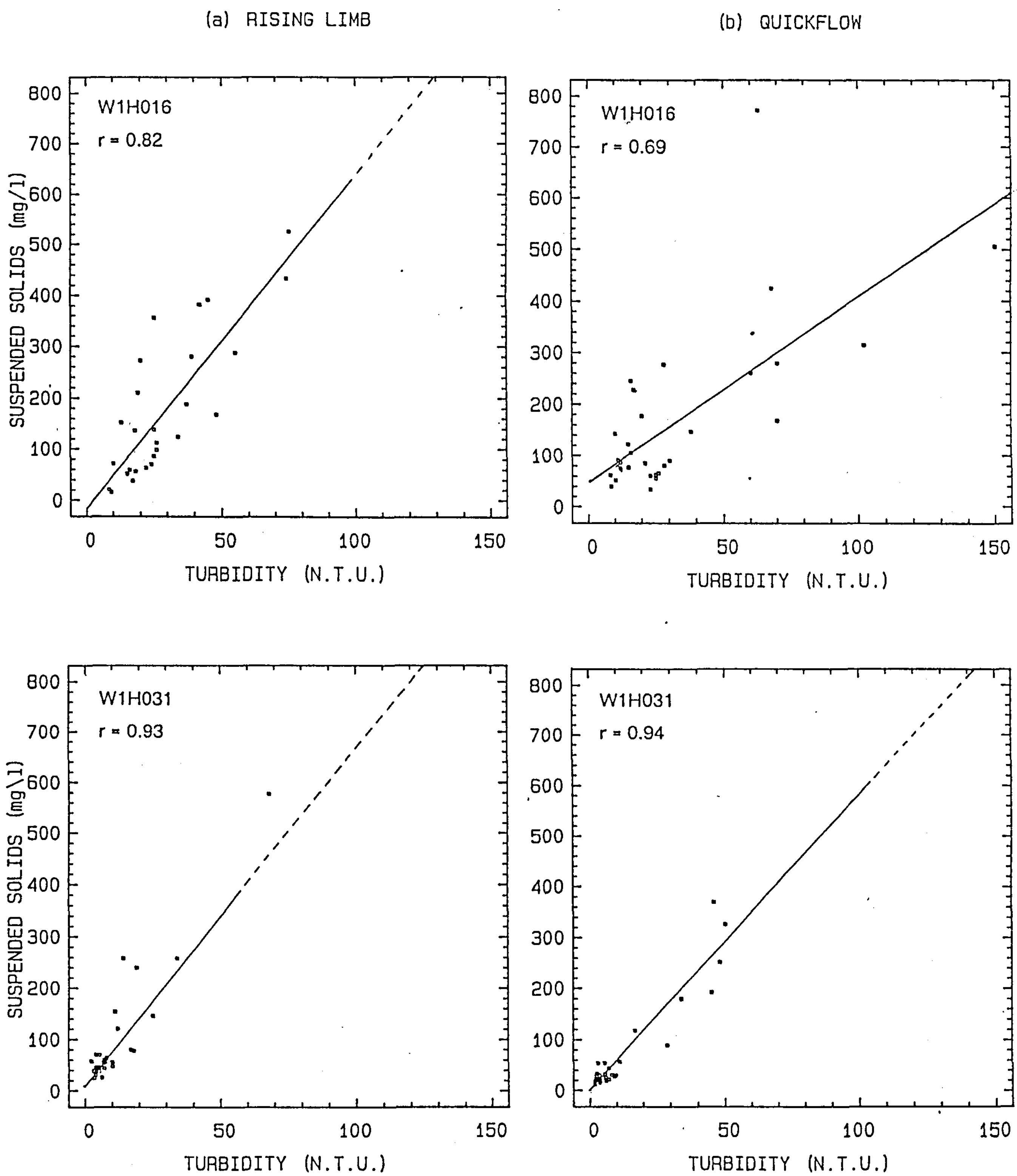


Figure 8.2 Scatterplot of the suspended solids (mg/l) against Turbidity (NTU) for different stages of the storm hydrograph.

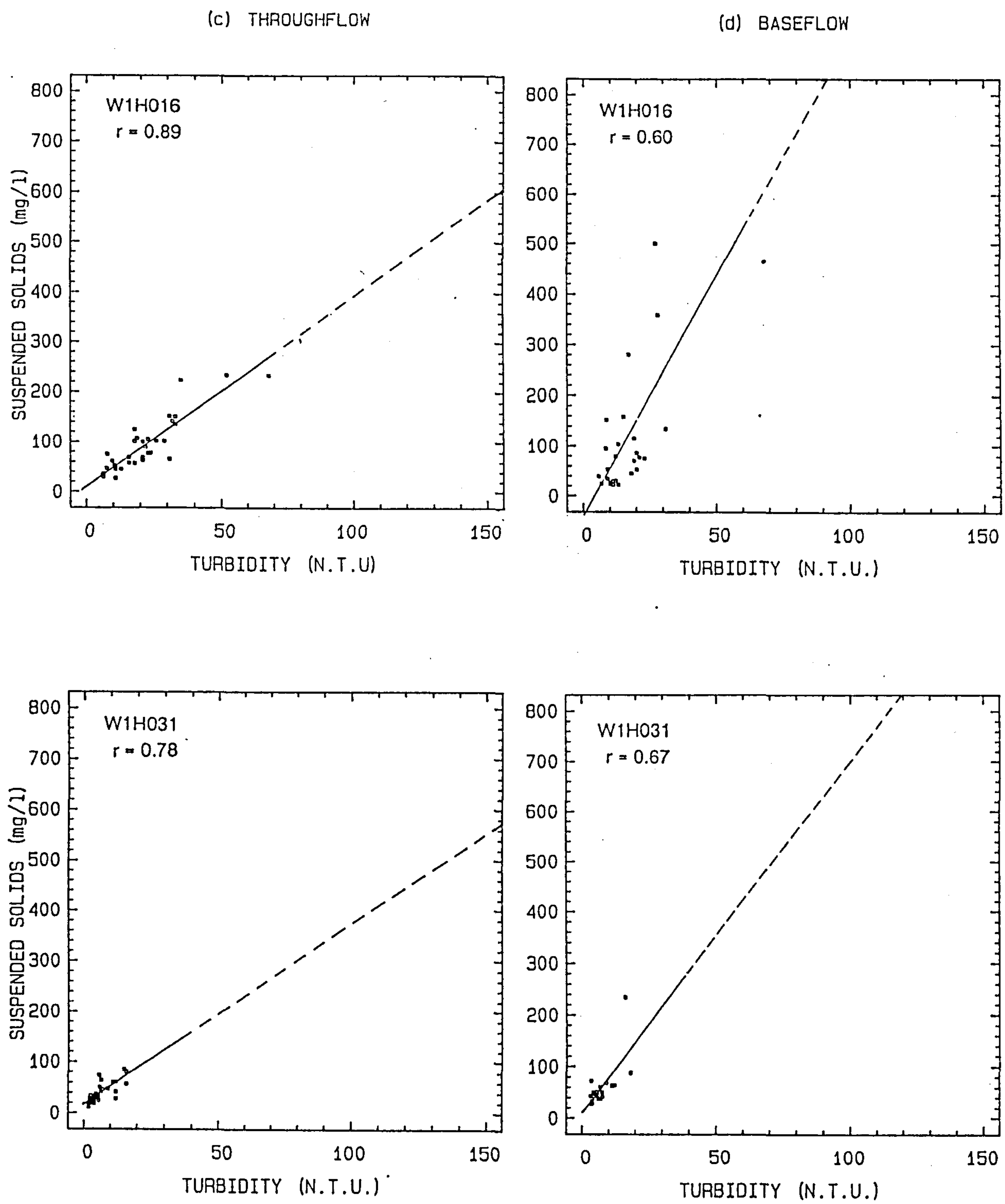


Figure 8.2 **Continued.**

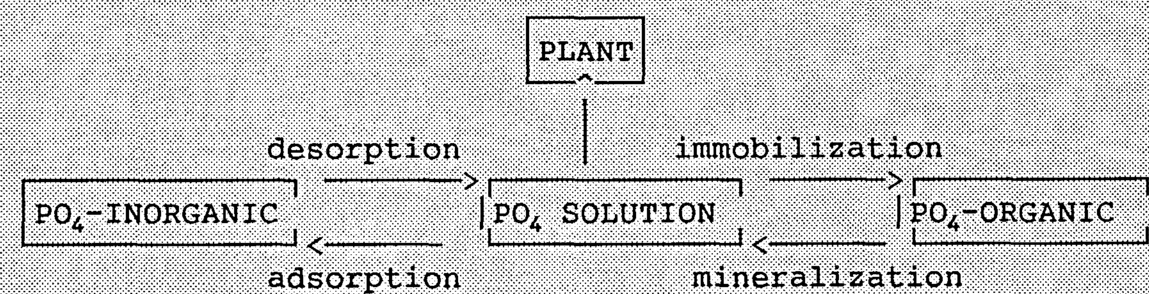
Table 8,3 Regression coefficient and correlations between suspended solids and turbidity for each catchment under different flow regimes.

WEIR	FLOW	SLOPE	INTERCEPT	r
W1H031	RISING	6.6	8.1	0.93
W1H016		6.3	-11.8	0.82
W1H031	QUICK	5.8	0.6	0.94
W1H016		3.5	50.6	0.69
W1H031	THROUGH	3.5	15.3	0.78
W1H016		3.8	10.5	0.89
W1H031	BASE	6.8	10.1	0.67
W1H016		9.5	-60.1	0.60

8.3.2 Relationship between suspended solids and total phosphate.

A simplified pathway for phosphate reactions in the field (Figure 8.3) shows that phosphorus can be found in three basic states (Caussade and Prat, 1990). Phosphorus in solution can be removed as insoluble inorganic phosphates of calcium, magnesium, iron or aluminium, or through heavy adsorption by charged clay particles. It can also be immobilised as organic compounds. Since the adsorption potential of phosphate

Figure 8.3 Simplified model of Phosphorus pathway (after Caussade and Prat, 1990).



ion is relatively high, a considerable proportion of the total phosphate is held on the surface of soil particles. Consequently there is a good relationship between the total phosphate ion concentration and suspended solids (Figure 8.4). The regression coefficients given in Table 8,4 indicate the strong relationship for both catchments under all flow regimes. The relationships for all flow regimes from both catchments indicate similar gradients with one significant exception.

For the rising limb the relationships are highly significant and very similar for both catchments. Both catchments also show similar relationships for the base flow. However, there is a significant difference in the relationship between the two catchments under quickflow conditions (Figure 8.4). For the disturbed catchment (W1H016) the total phosphate adsorption is almost half the corresponding rate for the undisturbed catchment. The higher concentration of phosphate ions for the natural catchment per unit load of suspended solids is discussed in section 8.4.5 where the variations in concentration are analyzed relative to hydrograph stage.

Table 8,4 Regression coefficient and correlations between suspended solids and total phosphate concentration for each catchment under different flow regimes.

WEIR	FLOW	SLOPE	INTERCEPT	r
W1H031	Rising Limb	0.73	26.6	0.90
W1H016		0.66	45.3	0.94
W1H031	Quick flow	1.12	7.7	0.99
W1H016		0.64	26.4	0.99
W1H031	Through flow	0.86	17.9	0.90
W1H016		0.50	42.6	0.94
W1H031	Base flow	0.67	27.7	0.82
W1H016		0.60	55.5	0.93

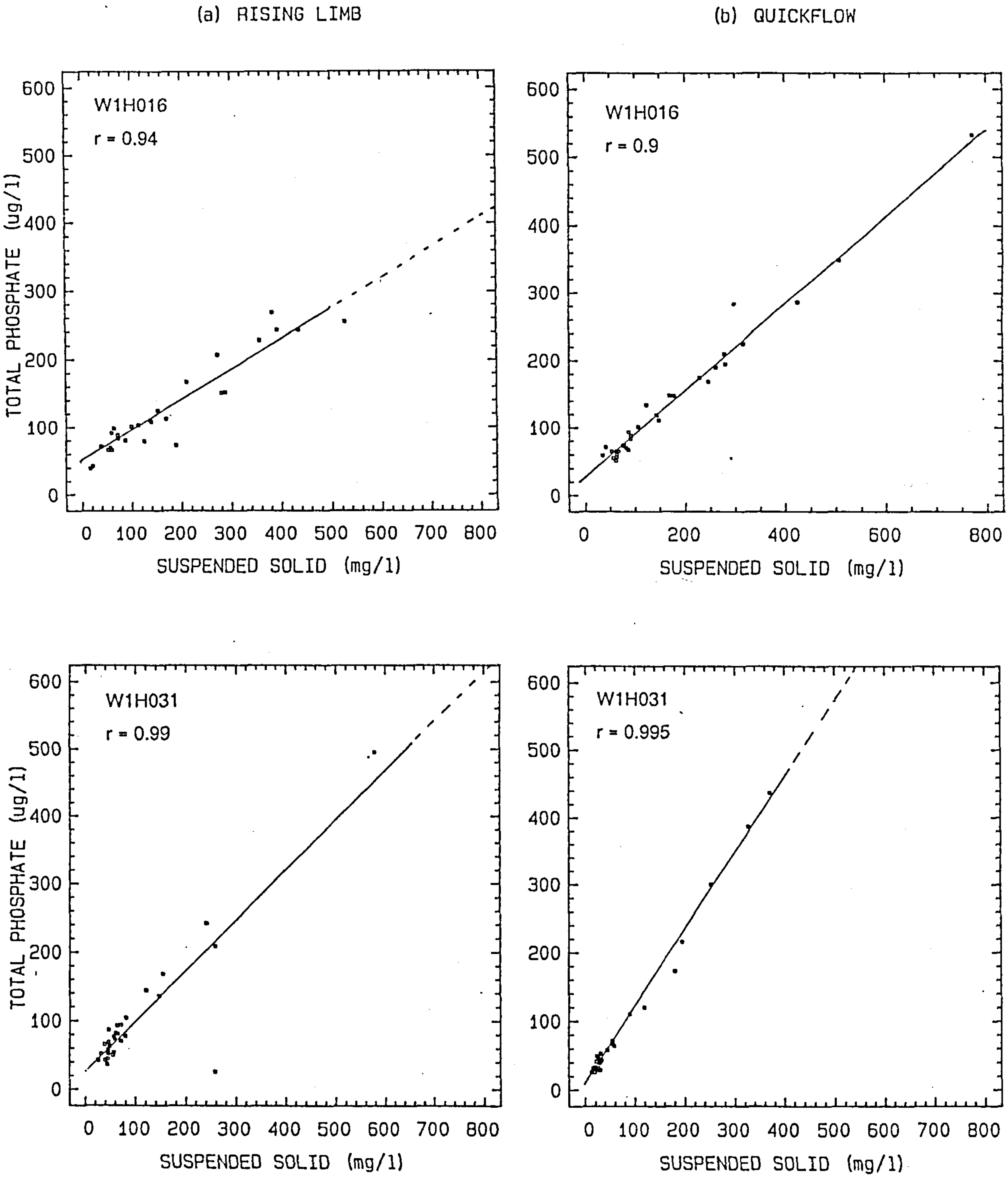


Figure 8.4 **Scatterplot of Total Phosphate concentration(ug/l) against Suspended solids (mg/l) for different stages of the storm hydrograph.**

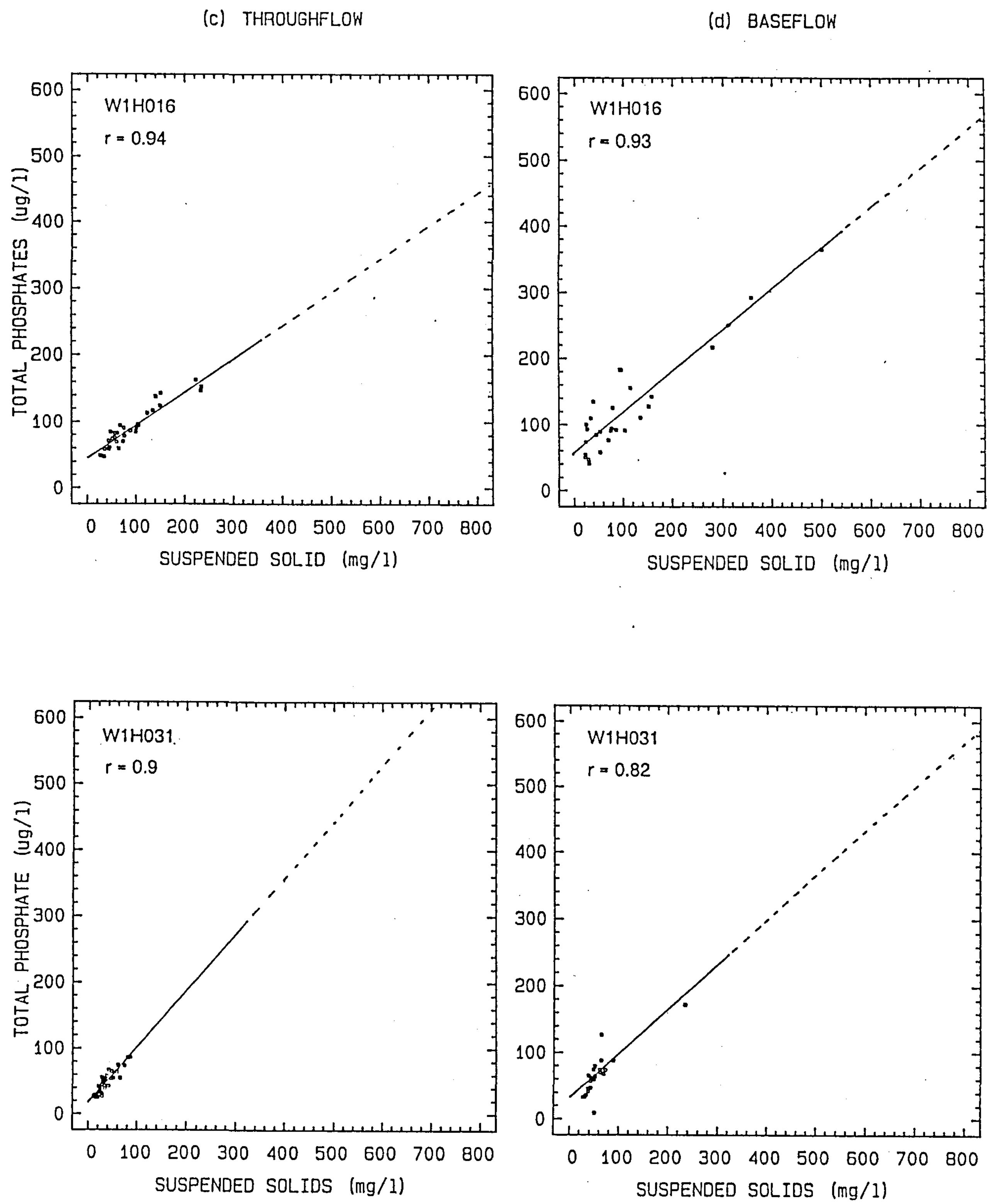


Figure 8.4 Continued.

8.4 SEASONALITY IN WATER QUALITY CHARACTERISTICS

Physical features of the catchment as well as hydrological processes will play a major role in defining the variability of water quality characteristics from a catchment. The sediment composition of a stream is generally a function of the erodability of the soils and the ability of the precipitation to dislodge the soil particles and transport them to the stream channel. Consequently one expects certain parameters of the water quality to vary during the season according to the discharge volume or rainfall intensity and the type of landuse/preparation (harvest, fallow, cultivation, etc). Hence the different water quality characteristics have been analyzed in relation to the different components of the annual and storm hydrographs.

Regular measurements of all the water quality parameters were not always available because only the significant storm events were sent to DWT for full analyses, while HRU_Z conducted only some analyses on most of the remaining samples. Because of the nature of the sampling procedure, many more samples of base flow conditions were obtained and analyzed by HRU_Z during the season. There were relatively few samples at peak flow conditions or for the rising limb of the storm hydrograph because the sampler was programmed to sample at a maximum rate of once every half hour in an effort to extend the sampling range. Since the sampler also composited every second sample (ie two samples per bottle) there were occasions when the sample was derived from two different flow regimes. This frequently occurred at the start of the hydrograph where the baseflow and the rising limb were combined. Consequently the seasonal analysis has been restricted to those storm hydrograph components with a sufficient numbers of samples.

8.4.1 General observations

General observations during the course of this investigation have revealed that the discharge from the Natural grassland catchment (W1H031) has a reddish-brown coloration during the late winter months when the discharge is very low. This could be attributed to a high organic content. However, measurements were not made and these observation must be considered speculative. Similar coloration of the discharge from the Mfabeni swamp on the Eastern shores of Lake St Lucia have been observed. The discharge from this area was found to be high in tannin which may be attributed to decaying vegetation (Kelbe and Rawlins 1989). The discharge from W1H031 was generally found to be very clear at the beginning of winter during low flow situations. This was evident by the fact that the sample pipe was clearly visible during this period but could not be seen during the summer when more frequent storms occurred. The water discharge from the disturbed catchment was not sufficiently clear during any season for the sampler pipe to be visible.

8.4.2 Hydrogen Ion Activity (pH)

Seasonal variation in the relationship between pH and discharge have been observed by Kuncle and Meiman (1967). Although their results varied considerably from year to year, they indicated that pH often drops to a minimum at peak flow rates. In the case of both W1H016 and W1H031, there is a slight drop in pH during the recession stage of the hydrograph (Table 8,5). There is also a slight difference between the mean values of both catchments. The pH of the natural catchment is between 0.1 and 0.3 lower than the corresponding pH values of disturbed catchment (Table 8,5).

The pH values of all samples from both catchments (Figure 8.5) show considerable variability over a range of values from 5.7 to 7.4. There is some indication (Figure 8.5) that the peak values during the winter months may decrease during the summer when discharges are greater following increased rainfall.

Table 8,5 Mean sample characteristics for different flow regimes

Flow	Rising limb		Peakflow		Recession		Baseflow	
Catchment	31	16	31	16	31	16	31	16
Flow #1	1.94	1.20	7.64	5.55	5.22	4.58	0.19	0.18
Flow #2	2.00	1.63	7.17	5.47	4.84	4.26	0.18	0.17
pH	6.41	6.66	*	*	6.19	6.51	6.68	6.79
Conductivity	15.5	15.4	15.1	12.1	12.2	12.9	16.3	16.3
Turbidity	9.5	21.4	14.0	36.0	11.7	33.0	5.1	11.6
Sus Solid	112.	144.	137.	325.	70.	156.	51.	98.
Sol PO_4	9.5	17.3	11.5	16.5	8.5	13.2	9.9	25.2
Tot PO_4	105.	116.	131.	223.	84.	125.	64.	115.
Nitrate	92.	360.	179.	166.	162.	663.	74.	68.
min # samples	34	34	6	6	9	9	17	17

* indicates insufficient samples

For the few samples that were taken during the **rising limb** of the storm hydrograph, the pH measurements of the disturbed catchment (shown as lines in Figure 8.6a) are generally higher than the corresponding measurements from the undisturbed catchment (shown as + in Figure 8.6a). However, there was no clear seasonal variation associated with these differences except that suggested in Figure 8.5. There is also a distinct difference in the pH of **throughflow** samples between the two catchments which shows little seasonal trend (Figure 8.6b). Although the distinction between catchments in pH measurements for the **baseflow** is much less than shown in other stages (Figure 8.6c), there is a tendency for the measurements of the undisturbed catchment to be consistently lower than the corresponding values for the disturbed catchment.

8.4.3 Conductivity

Seasonal plots of all the conductivity measurements (Figure 8.7) indicate high peak values at the end of the 1989 winter. Missing data (instrument failure) for the same period of 1990 (DOY 365+250) may also have shown the same high trend in conductivity when the discharge volume was low. Since no measurements were

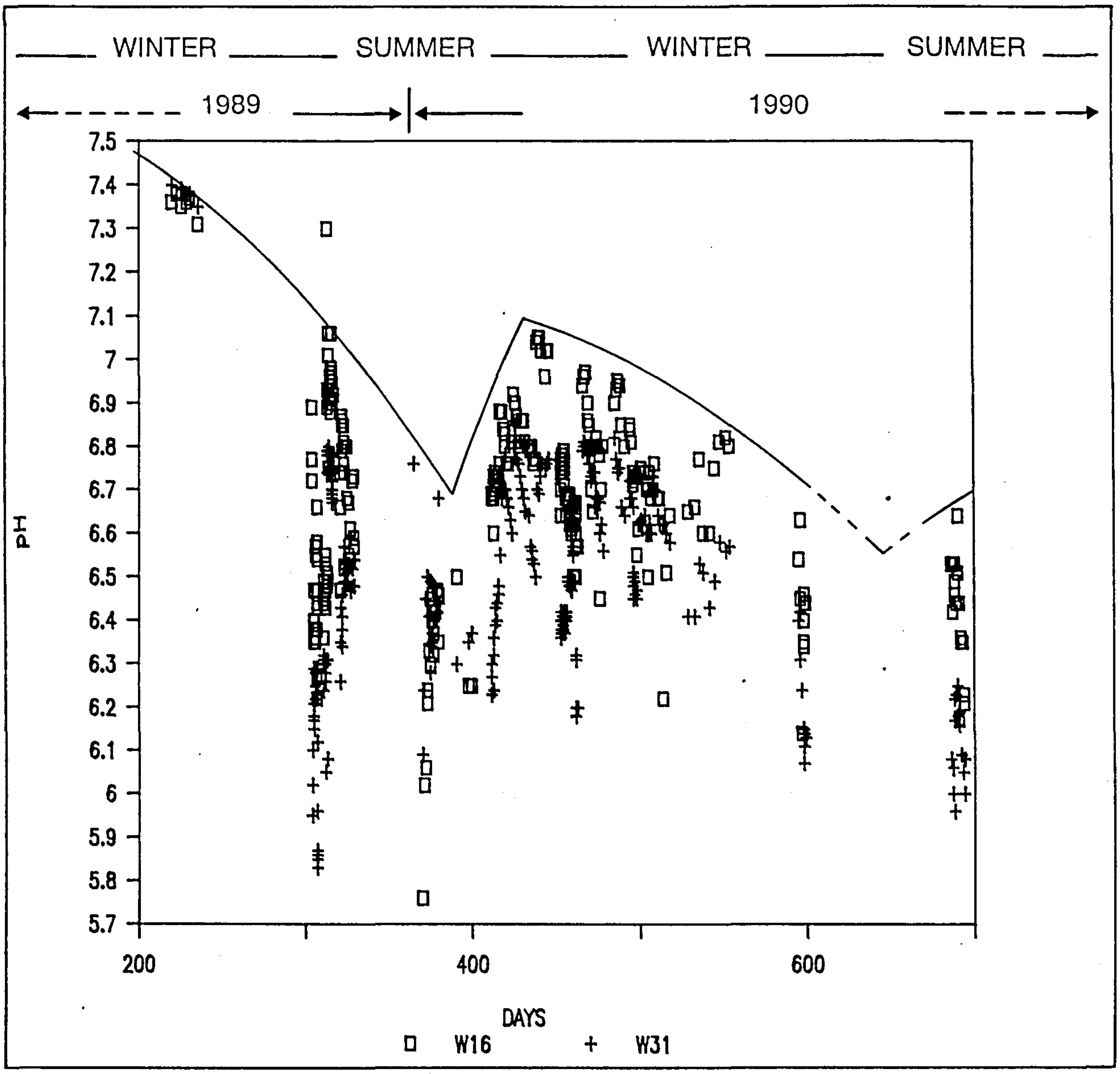


Figure 8.5 **Plots of pH for the whole season.**

available, this is speculative. However, there does appear to be a seasonal trend with a minimum value of conductivity during March when discharge volume was the highest.

There is little difference between the mean conductivities of the two catchments for the **rising limb**, **recession limb** and **baseflow** conditions (Table 8,5). There is, however, a small difference (3.0 mS/m) between the conductivities of the two

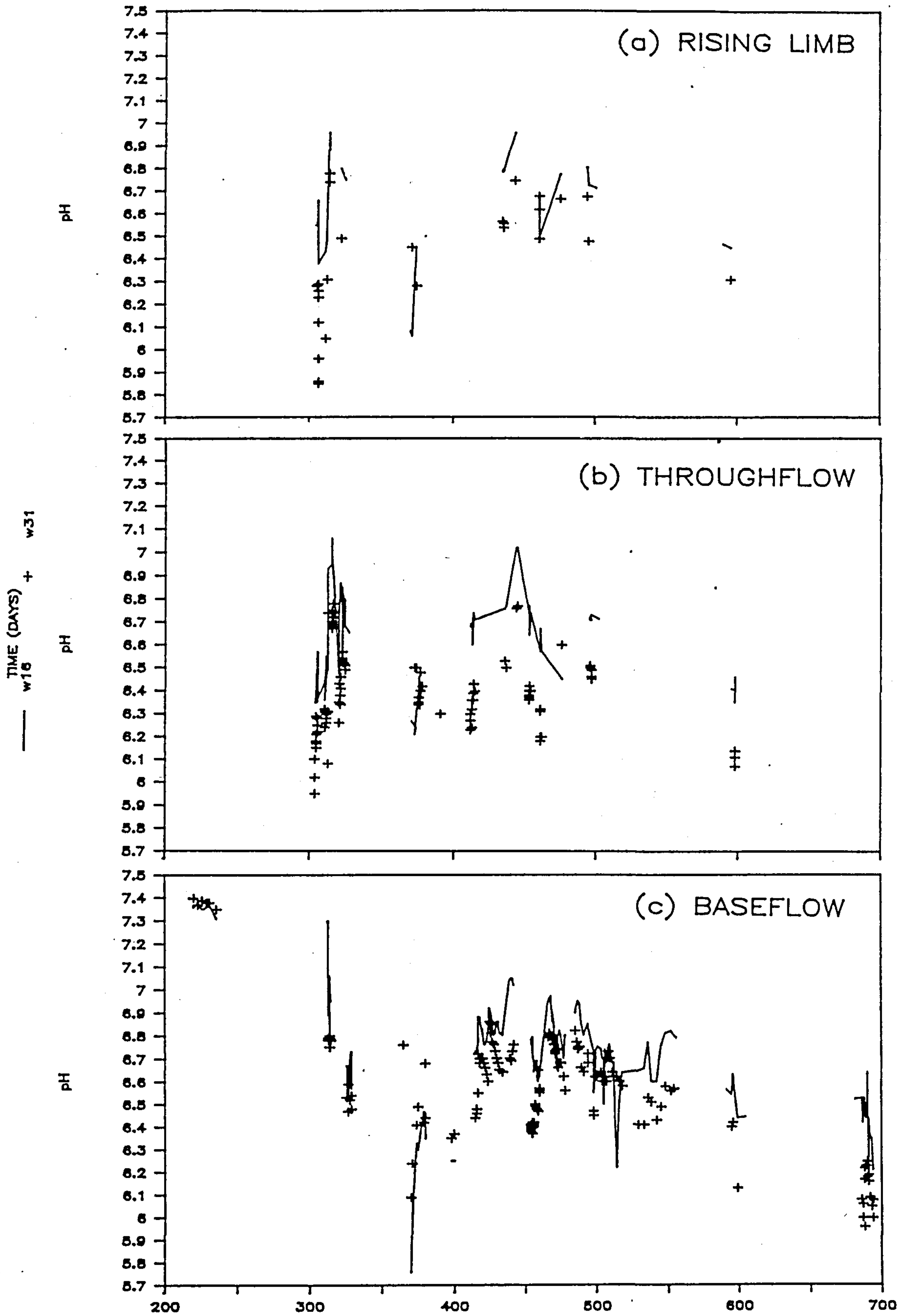


Figure 8.6 Seasonal variation in pH from both catchments for different stages of the hydrograph.

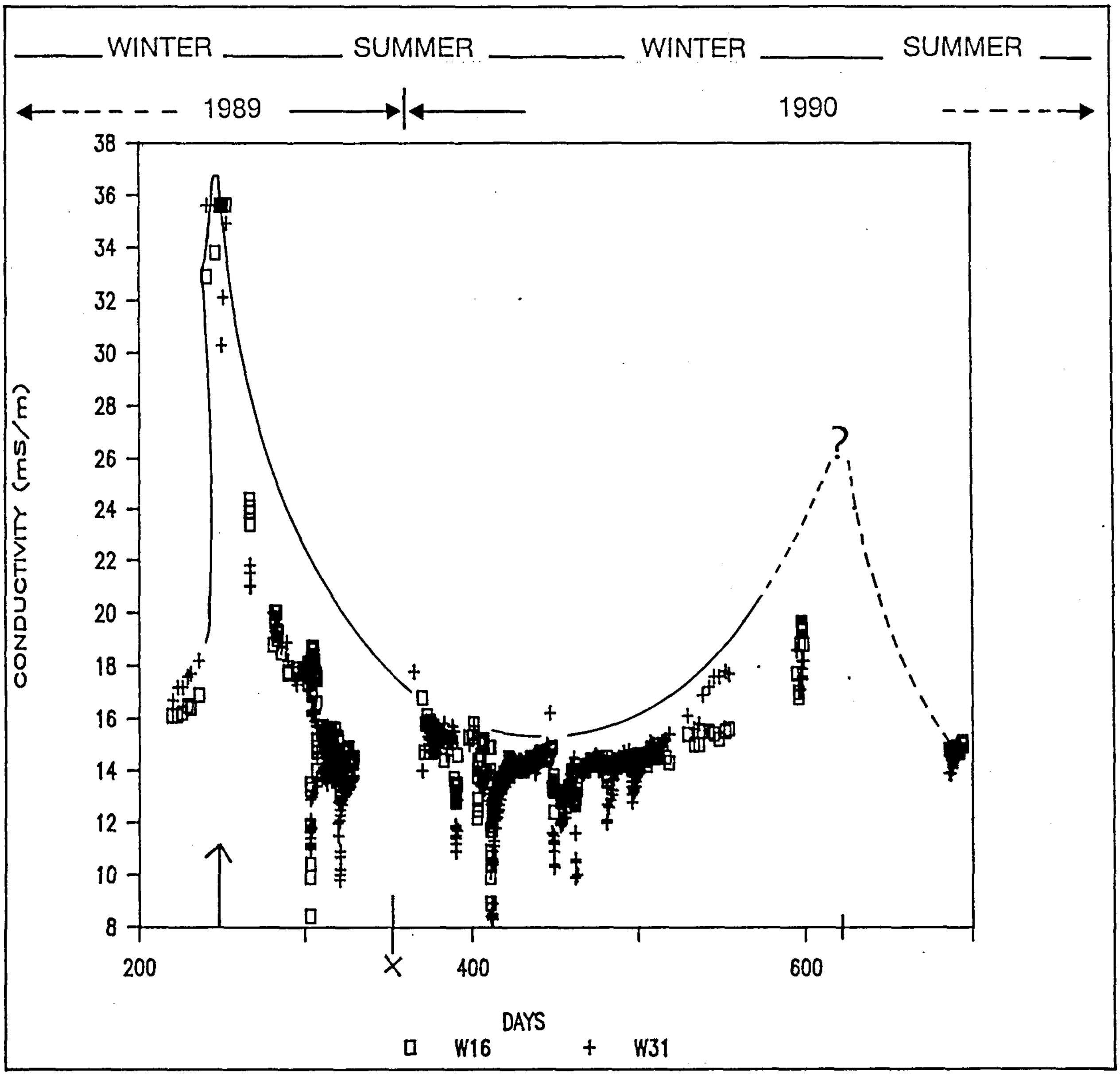


Figure 8.7 Seasonal variation in Conductivity values

catchments during the **peak** discharge stages of the storm hydrograph.

The samples for the separate components of the storm hydrograph are shown in Figure 8.8. For the **rising limb** there is little difference between the catchments although W1H031 generally has a lower conductivity value than W1H016. The **quickflow** conductivity plot shown in Figure 8.8b indicates that in most cases the sample values are generally lower for W1H031 compared

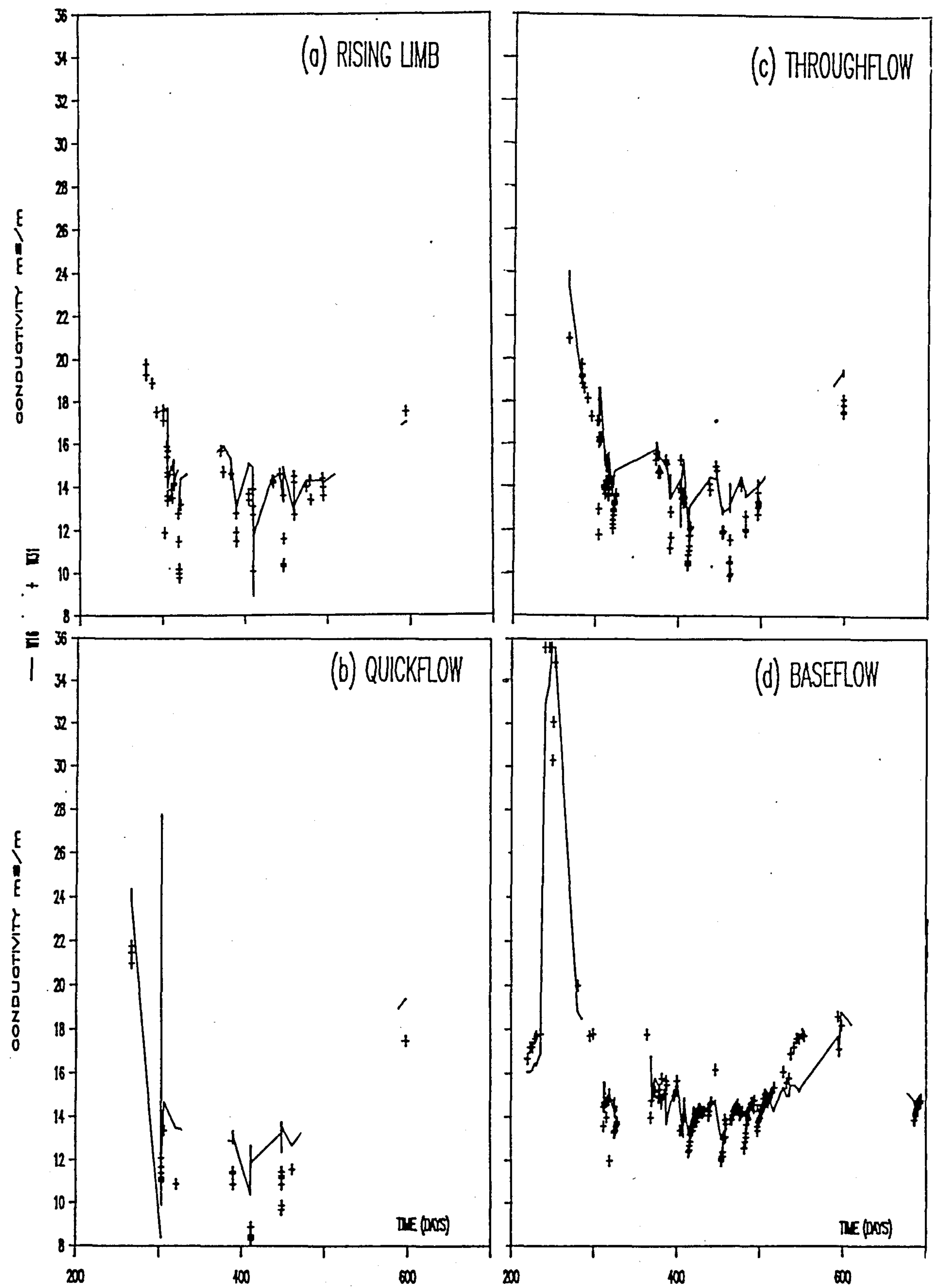


Figure 8.8 **Seasonal variation in Conductivity values for the different stages of the storm hydrograph.**

to the corresponding values for W1H016. This is not as clear for the **throughflow** components (Figure 8.8c) where there are several instances when W1H031 values were higher than the corresponding values of W1H016. Similarly, there are no consistent differences between corresponding catchment values for the **baseflow** samples although there are periods when W1H031 is considerably higher than W1H016, particularly during the drier winter months (DOY 210 & DOY 550=365+185 in Figure 8.7 & 8.8d).

8.4.4 Turbidity and suspended solids

The most noticeable difference in water quality between the two catchments throughout the season is exhibited in the turbidity and suspended solids measurements (Table 8,5). Since suspended solids analyses were only conducted for storm events which were sent to DWT for analyses, few base flow measurements were available for ascertaining seasonal trends. In view of the relationship between suspended solids and turbidity during certain stages of large storm hydrographs (section 8.3.1 & Figures 8.1 & 8.2) the general trends observed in turbidity may reflect the general variations in suspended solids for the rising limb and quickflow conditions. However, in the case of baseflow where there are few suspended solids measurements and a poor relationship with turbidity, no inferences can be derived.

The plot of turbidity values for the different flow regimes (Figure 8.9) show no clear **seasonal** trends with the exception of the baseflow values for W1H016 and possibly W1H031.

The turbidity measurements for the undisturbed catchment are consistently lower for all the flow regimes during all seasons despite of the large variability in measurements (Table 8,5). The turbidity measurements of the disturbed catchment are generally twice the value of the measurements from the undisturbed catchment (Table 8,5). For the undisturbed catchment, the mean turbidity values for the **rising limb** are approximately twice as high as the **baseflow** (seldom do baseflow turbidities reach the level of the rising limb average value of 10NTU). The mean values for the **recession limb** components are double the **baseflow** component values. In the case of the disturbed catchment there is exactly the same trend but the turbidity in the **recession** stage is now three times higher than the **baseflow** component. The turbidity measurements for **baseflow** from the disturbed catchment (W1H016) show considerably higher turbidity values during the summer when high flows prevail. This seasonality, however, is not as apparent for the undisturbed catchment or the other flow regimes (Figure 8.9).

Because there are much fewer measurements, the trends and differences found for turbidity are not as clear for suspended solids (Figure 8.10). The suspended solids for the **rising limb** stages are frequently lower for the undisturbed catchment (Figure 8.10) (NB with the exception of one very high value for the undisturbed catchment). The difference between the catchments is more obvious for the **quickflow** and **throughflow** conditions but not for the base flow regime where there are occasions when the undisturbed catchment has slightly higher suspended solids measurements.

The suspended solids measurements from the disturbed catchment are generally about twice the corresponding value from the undisturbed catchment (Table 8,5). The values for both catchments are generally higher for the **rising limb** and **quickflow** states than for the **throughflow** and **baseflow** states. With the possible exception of the **baseflow**, there is no clear seasonality or temporal trends in suspended solids.

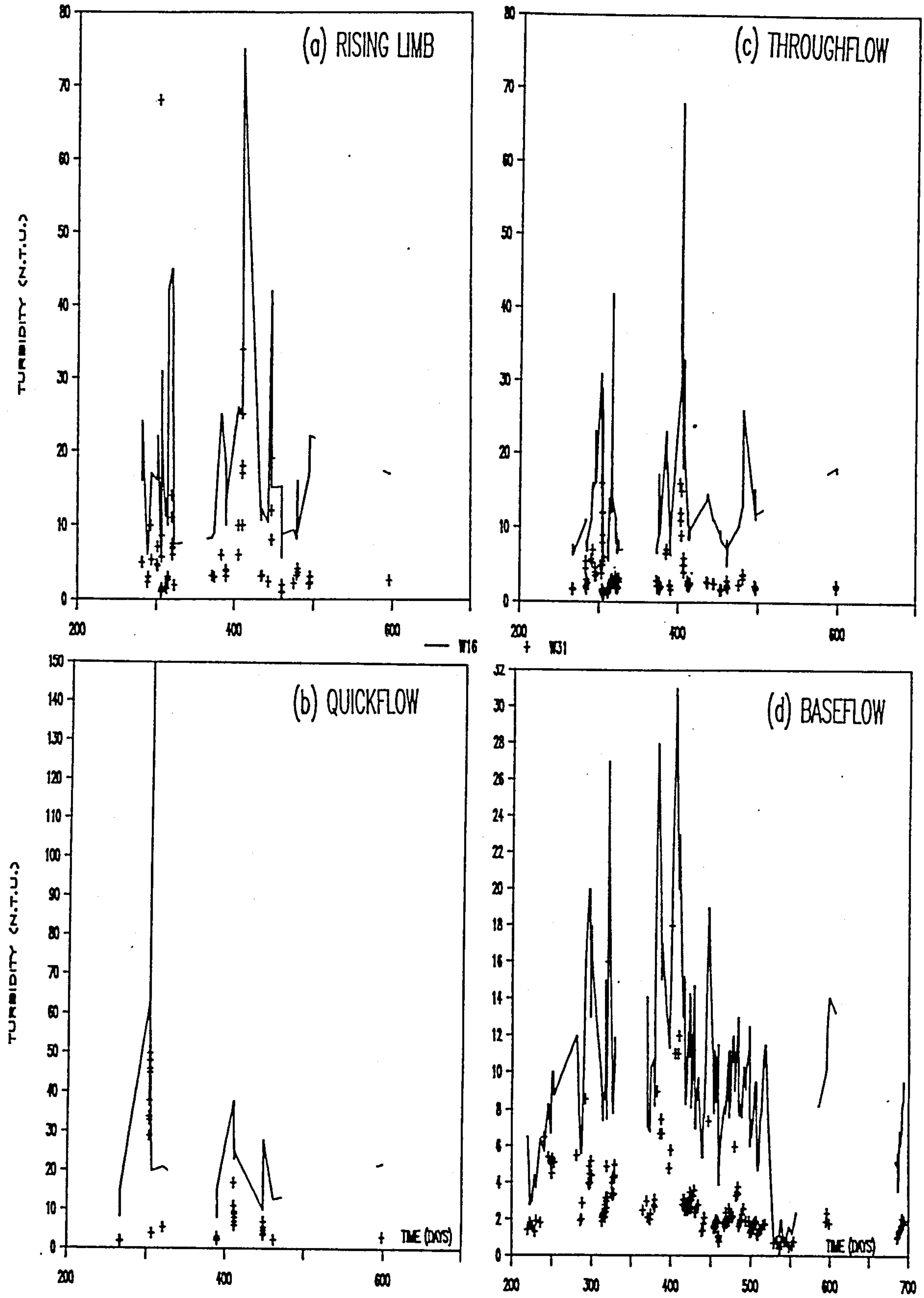


Figure 8.9 Seasonal variation in Turbidity values from both catchments for the various stages of the storm hydrograph

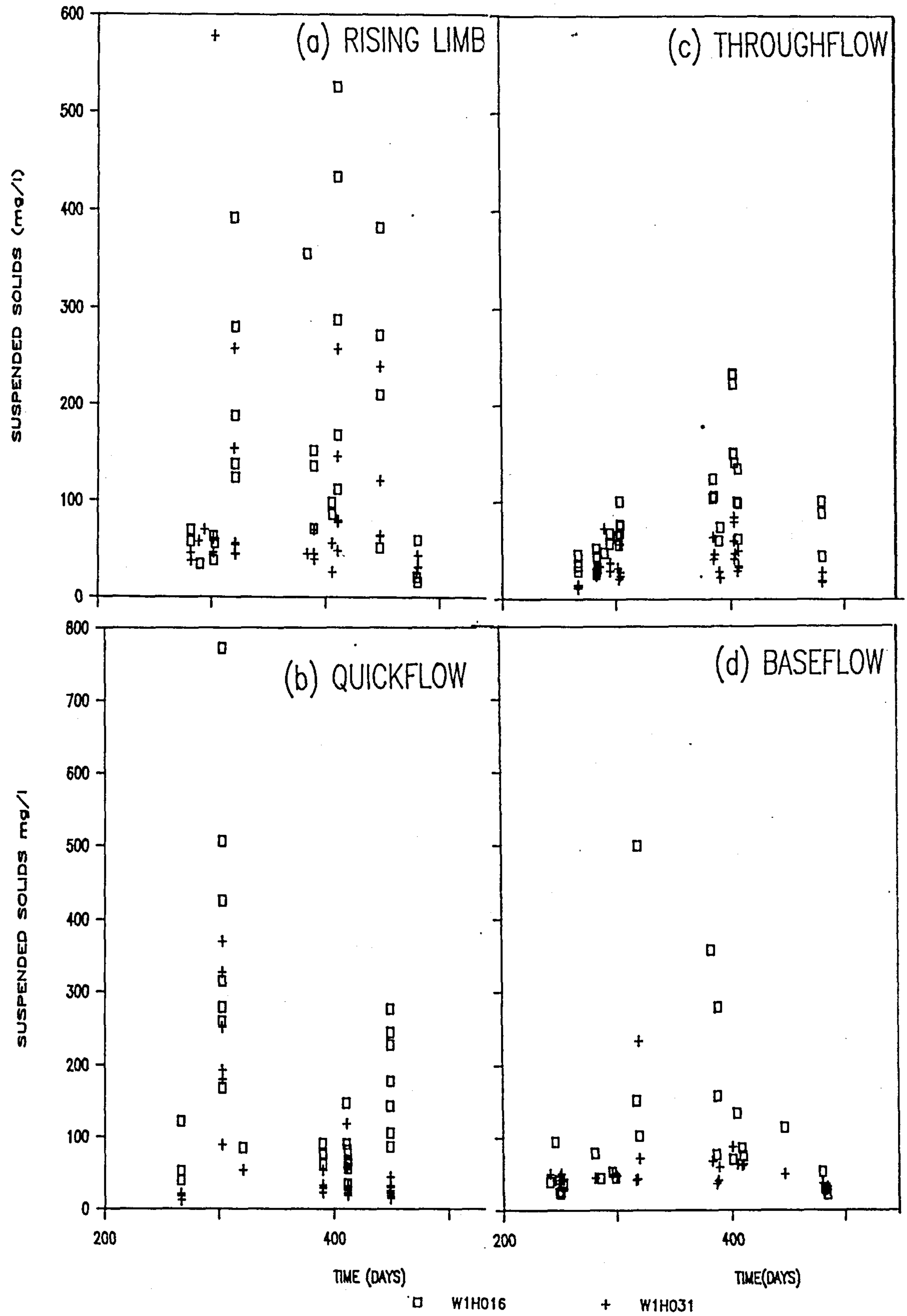


Figure 8.10 **Seasonal variation in Suspended solids from both catchments for various stages of the storm hydrograph**

8.4.5 Phosphorus

The total and soluble phosphorus concentrations for the different flow regimes is shown in Table 8.5. The soluble phosphate concentration is nearly an order of magnitude less than the total phosphate which is derived mainly from the particulate matter in suspension (Figure 8.4).

8.4.5.1 Total phosphorus

Total phosphate concentration is strongly correlated with suspended solids and should therefore show the same seasonal trends and storm hydrograph relationships as suspended solids. The time sequence plots for base flow (Figure 8.11) is very similar to the corresponding plot for suspended solids (Figure 8.10) except for periods during winter when there was a significantly bigger difference in the concentrations between the two catchments. For the **rising limb** the difference between catchments is not very distinct, showing similar mean values (Table 8,5) (which could be due to the one very high outlier on DOY 303 when much greater discharge occurred in W1H031). For the recession stages (quick- and through- flow) the plots are very similar to Suspended solids. The difference between the phosphate discharge from W1H016 associated with throughflow conditions is highly significant (Figure 8.11) when the concentration is almost double the corresponding value from the undisturbed catchment.

8.4.5.2 Soluble phosphate

With the exception of a couple of samples during the early summer rains in 1989 (DOY 280-303) the disturbed catchment produced consistently higher values of soluble phosphate than the undisturbed catchment for the **rising limb** components (Figure

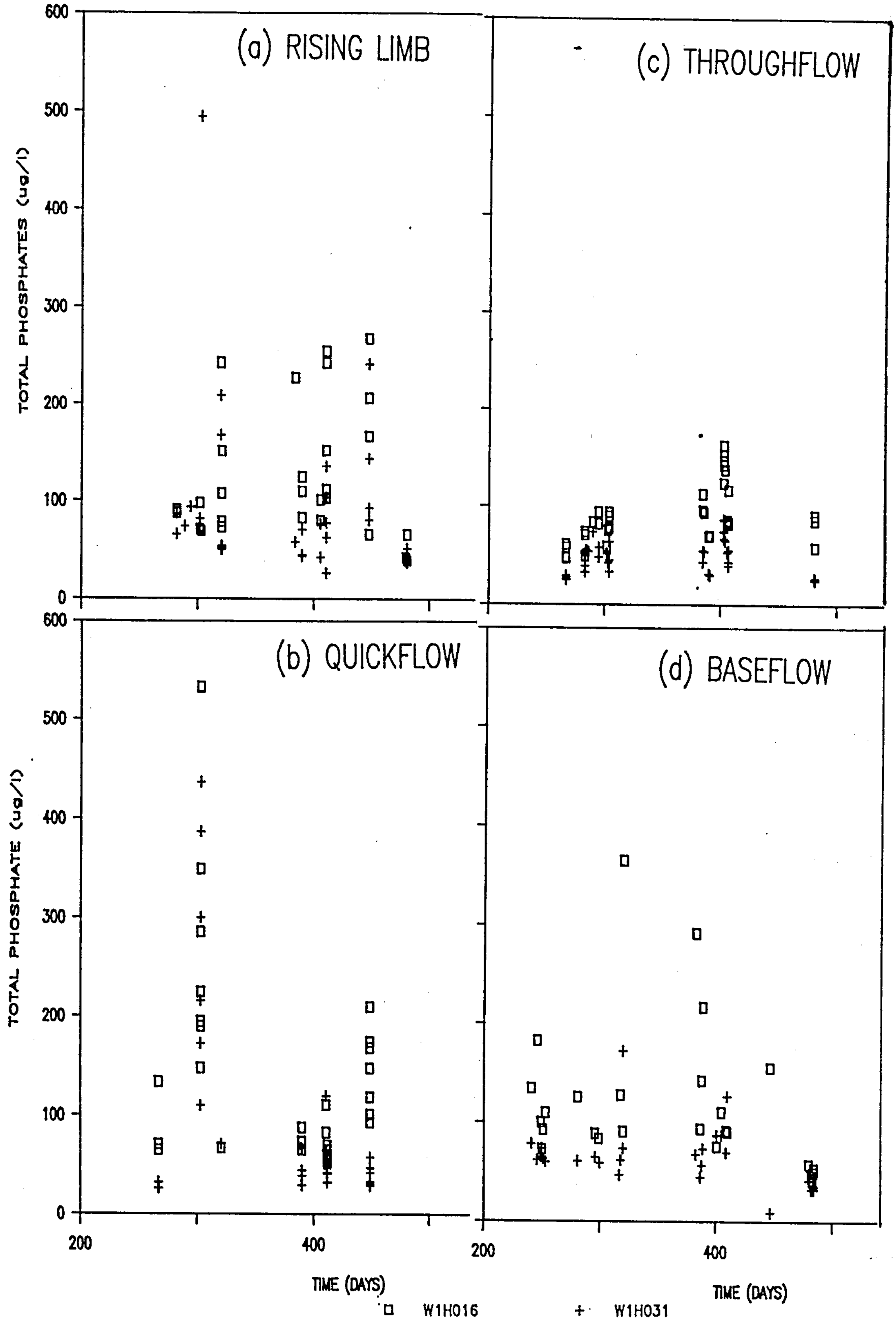


Figure 8.11 **Time series plots of TOTAL PHOSPHATES from both catchments for the different stages of the storm hydrograph.**

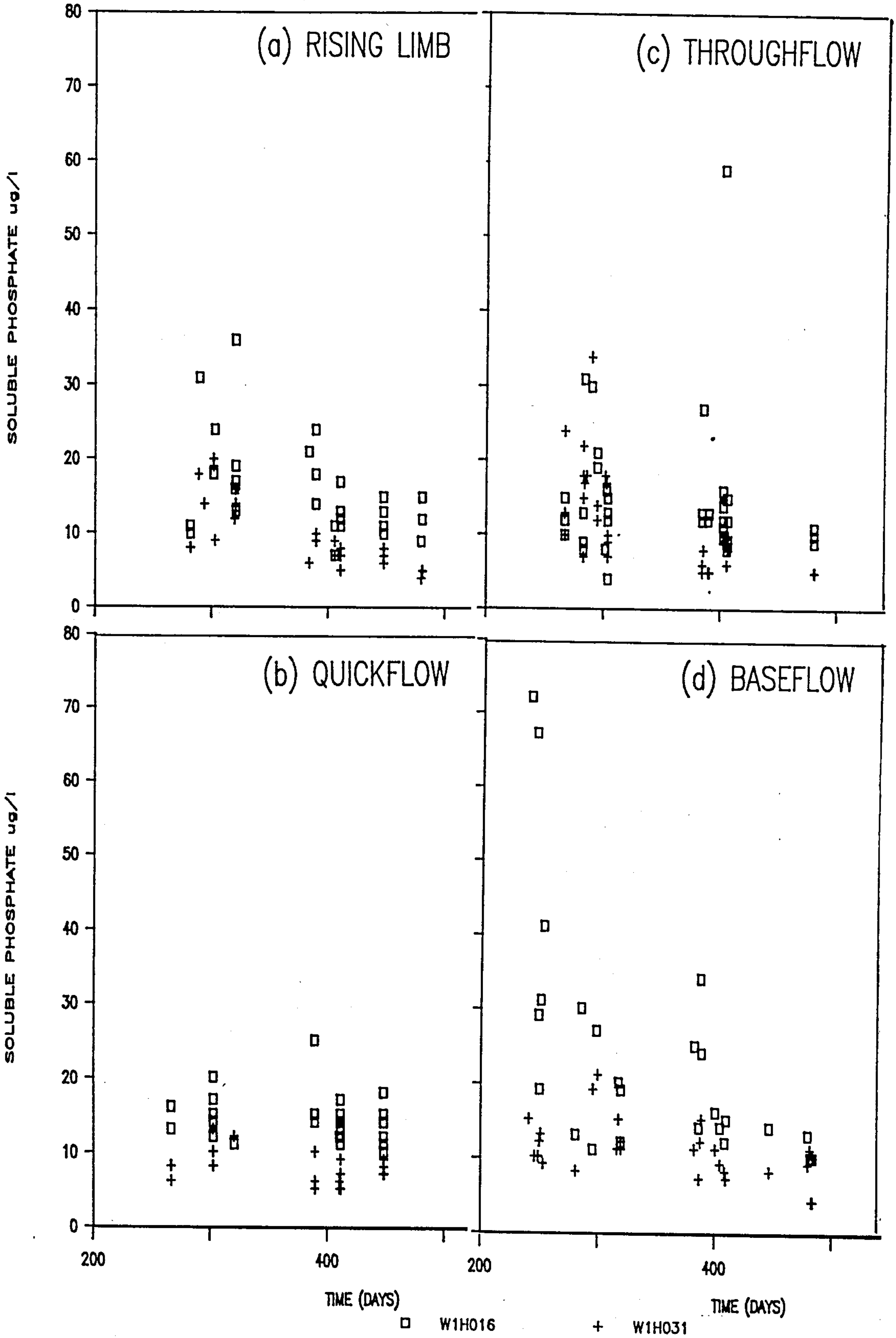


Figure 8.12 **Time series plots of SOLUBLE PHOSPHATES from both catchments for the different stages of the storm hydrograph.**

8,12). This is reflected in the mean values in Table 8,5. A very similar difference is observed for the **quickflow** (Figure 8.12) but not for the **throughflow** where the early summer values (coinciding with the onset of rainfall) of 1989 show considerable overlap in the time series plot of Figure 8.12. A better separation between the catchments can be observed in the **baseflow** in Figure 8.12.

8.4.6 Nitrates

The atmosphere constitutes the main reservoir of nitrogen used by the biosphere. The nitrogen uptake, however, is complicated by the fact that nitrogen cannot be used directly in its gaseous state by plants but it must pass through the nitrogen cycle. A simplified nitrogen model, idealised in Figure 8.13, shows that nitrogen can exist in several forms which influence the concentration of nitrogen in the discharge from catchments.

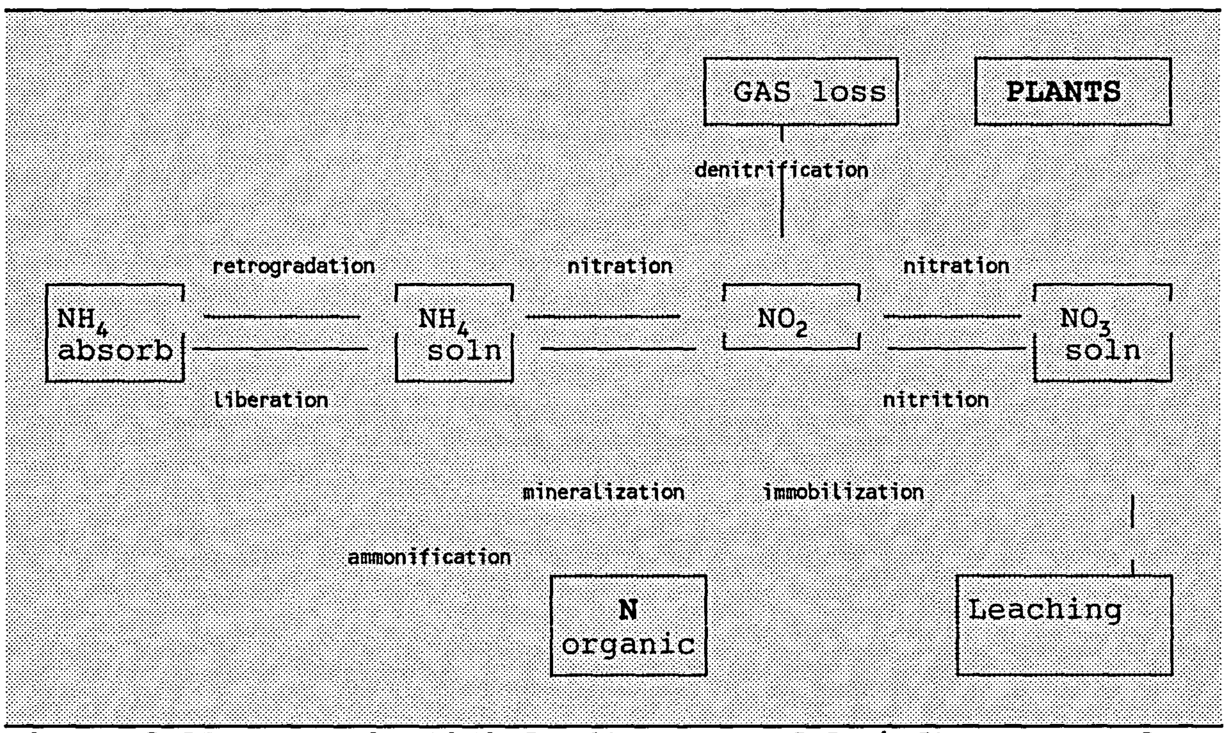


Figure 8.13 A simplified nitrogen model (after Caussade & Prat, 1990)

Mineral nitrogen enrichment is made up of two stages - ammonification and nitrification. Plants and microorganisms immobilize the mineral nitrogen in the soil which can then be released through nitration making it available for release as N_2 and NO_2 through denitrification. These biological processes are superimposed on the non-biological processes of enrichment (rainfall, irrigation,and fertilization) and deterioration (volatilization, chemical reaction, harvesting, leaching and erosion). Consequently, land use can have a considerable influence on the nitrogen balance in a catchment which will then be reflected in the quality of the discharge.

The different response in nitrate concentration for the various hydrograph components is evident in Table 8,5. For the **rising limb**, the disturbed catchment produced a mean nitrate concentration that was four times higher than the undisturbed catchment (360:92 mg/l). The mean nitrate concentration for the **recession** stages of the storms shows the same difference between the two catchments (663:162 mg/l) but the mean concentrations are nearly double those of the **rising limb**. However, the concentrations for both catchments near the **peak discharge** and for the **baseflow** are slightly higher for the undisturbed catchment (Table 8,5).

While the mean concentrations given in Table 8,5 show very large differences between the catchments, individual samples plotted in Figure 8.14 suggest a more complicated relationship. There is a consistent difference in [NO_3] between the catchments for both components of the **recession** stage (quick- and through-flow) except when the concentrations are very low at low discharges (Figure 8.14). There is no consistent difference between catchment concentrations for **baseflow** conditions (Figure 8.14), or for the rising limb component.

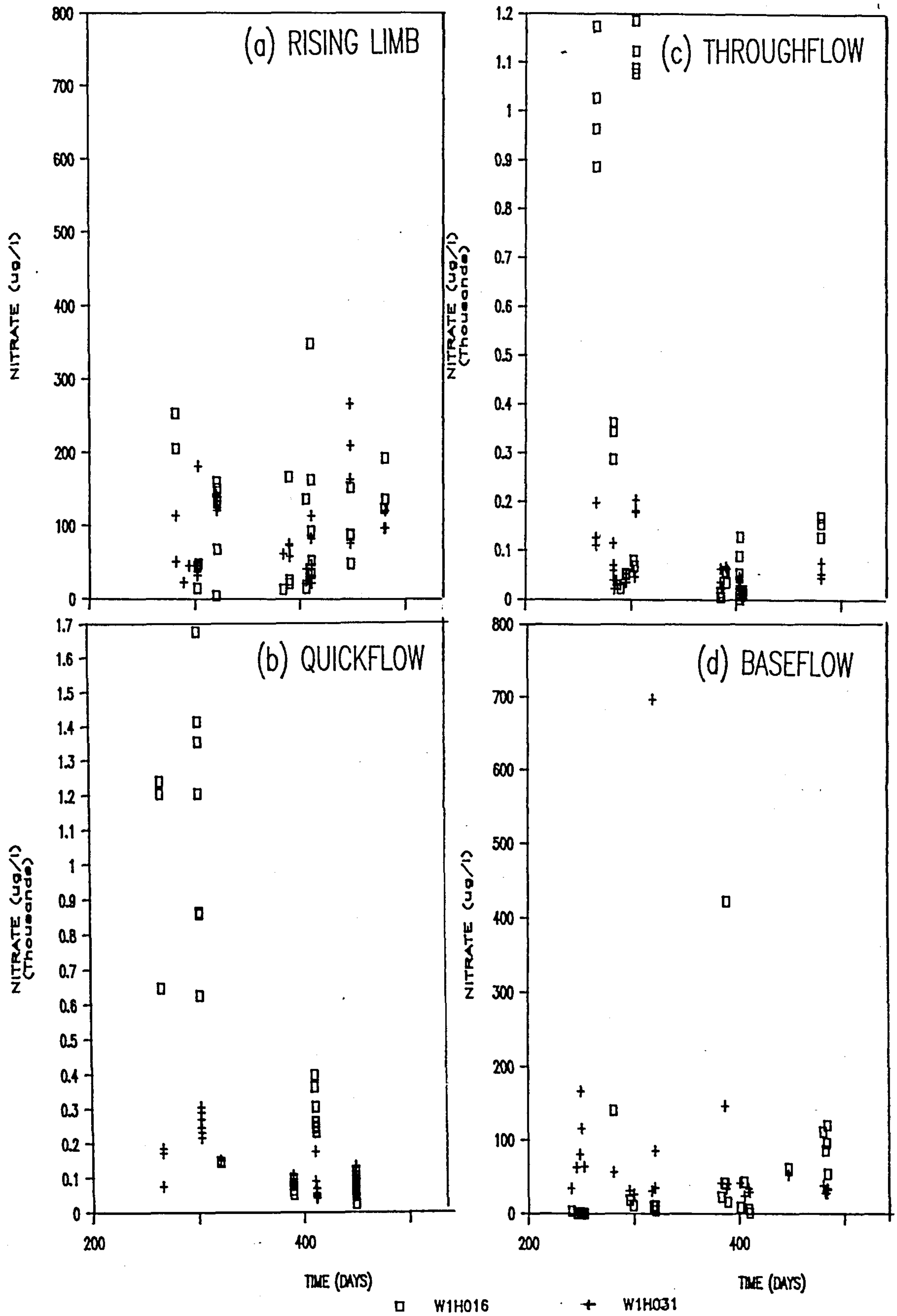


Figure 8.14 Time series plots of NITRATE concentrations from both catchments for the various stages of the storm hydrograph.

8.5 PARTICLE SIZE ANALYSIS

A series of samples from both weirs were analyzed by ALUSAF, Richards Bay, for variations in the size of the suspended particles. The analytical instrument (GALAI-CIS-1) uses laser technology to count and measure the cross-sectional diameter of particles in the water sample as it is pumped continuous through an optical lens. The computerized system provided a frequency analyses of the size, area and volume of each sample from which statistical parameters were derived (Table 8,6). The number concentration of particles for the sequence of samples from both catchments is presented in Figure 8.15. For this sequence of samples, W1H016 had a much higher concentration of smaller particles during the storm event than W1H031.

The surface area of the particulate matter is considerably higher for the undisturbed catchment (Table 8.6). Since the surface area of the suspended solids affects the adsorption of phosphates, this could account for the difference in the relationship between suspended solids and phosphate observed in the regression analysis during peak flow conditions in Table 8.6.

Table 8,6 Concentration and median values of particle size analysis for W1H016 and W1H031 for / /90

Disch (m^3/s)	conc ( )		size micron		area micron	
	W1H16	W1H31	W1H16	W1H31	W1H16	W1H31
0.134	58400	100000	3.48	3.67	25.14	21.18
0.165	39000	89000	3.16	3.89	21.62	20.69
0.714	370000	77000	2.71	4.05	11.38	20.70
0.893	230000	38700	2.70	4.23	16.80	25.07
0.575	84000	42000	3.63	4.39	18.22	22.14
0.282	56000	58000	3.55	4.07	19.39	21.89
0.169	9500	32000	3.37	3.72	18.16	19.00

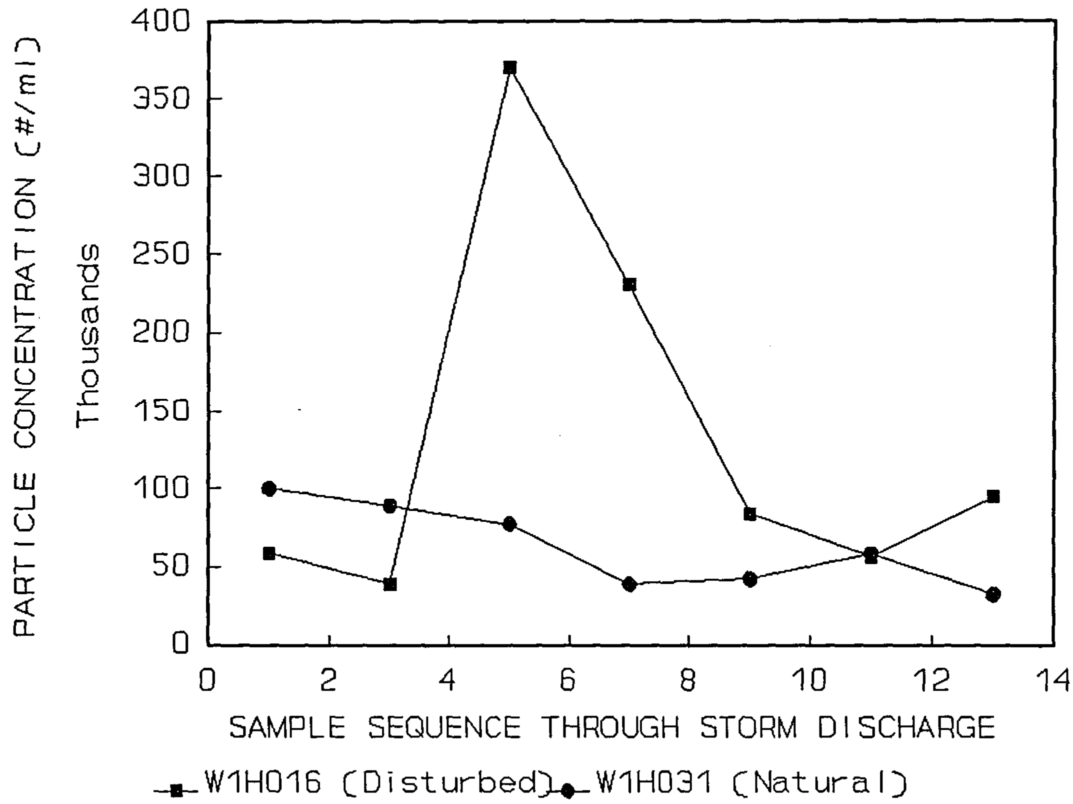


Figure 8,15 Particle size analysis.

8.6 BED LOAD

The bed load of any stream does not move relatively fast as it is stored and released by depressions and reservoirs within the river reach in accordance with an equilibrium involving the sediment capacity, discharge rate and other morphological factors. If the river has an excess sediment transport capacity adjustment occurs by erosion of the bed and banks. If the entrained sediment volume exceeds the carrying capacity, the excess is deposited. Therefore it is difficult to identify a particular bed load sample with a hydrological process responding to a specific storm event. Elaborate devices are usually required to sample bed load. Consequently this component of water quality was not considered in the initial phase of the project. However, since this information is also required for model verification, an effort is now being made to estimate the bed load component of W1H016 and W1H031 by regular surveys of the same transects across the weir dams.

Fourteen permanent survey points have been establish along the banks of the weir dams for both W1H016 and W1H031 and these are used to measure the depth of the surface topography at regular intervals between any two survey pegs. The initial survey of W1H016 was conducted in August 1990 after the stilling basin had been cleaned (Figure 8.16). A second survey was conducted in October 1990 after a particularly heavy rainfall event on the 19-20/10/90 (>130mm rainfall recorded). The third survey was conducted on January 8, 1991 when the initial survey at W1H031 was also done. This covered a period when several large storms occurred.

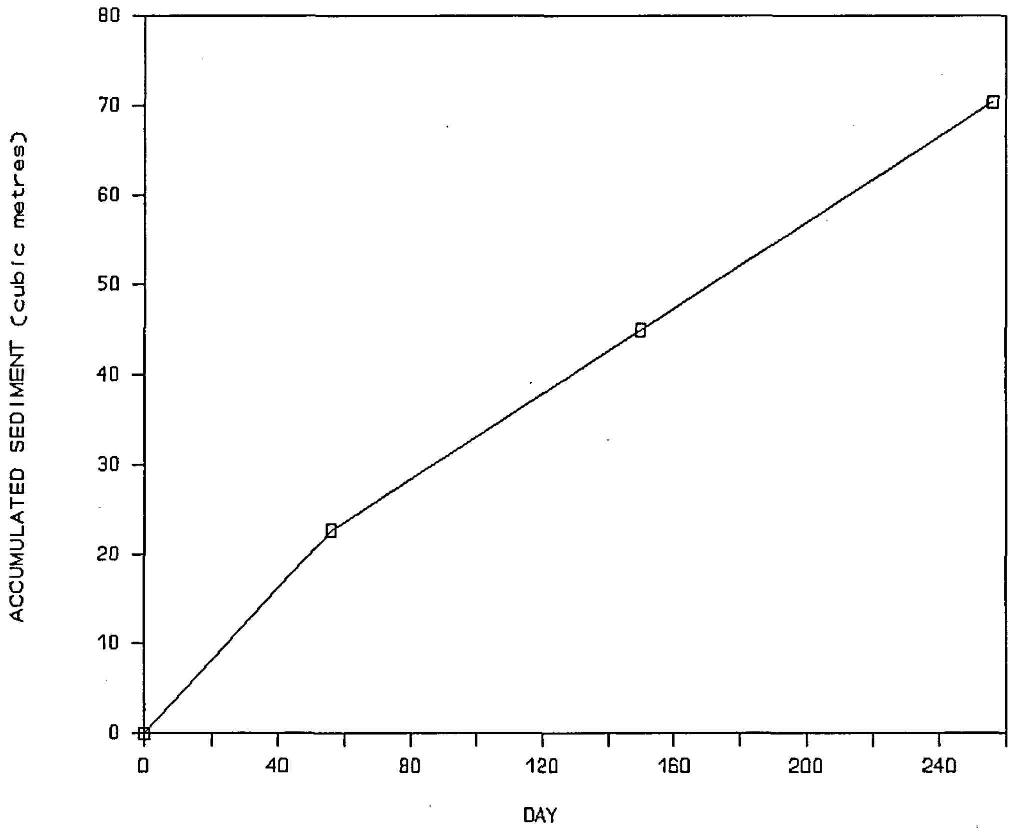


Figure 8,16 Accumulated bed load in weir W1H016.

From the distance between transects and the change in depth along the transect, the volume of sediment was estimated. The estimated volume from these surveys indicated that the first storm deposited (moved) approximately 22.68m^3 of sediment in the upper reaches of the stilling basin of the disturbed catchment (Figure 8.17). Subsequent measurements of the bed load show a steady increase over eight months of approximately 70m^3 which represents nearly 9m^3 per month.

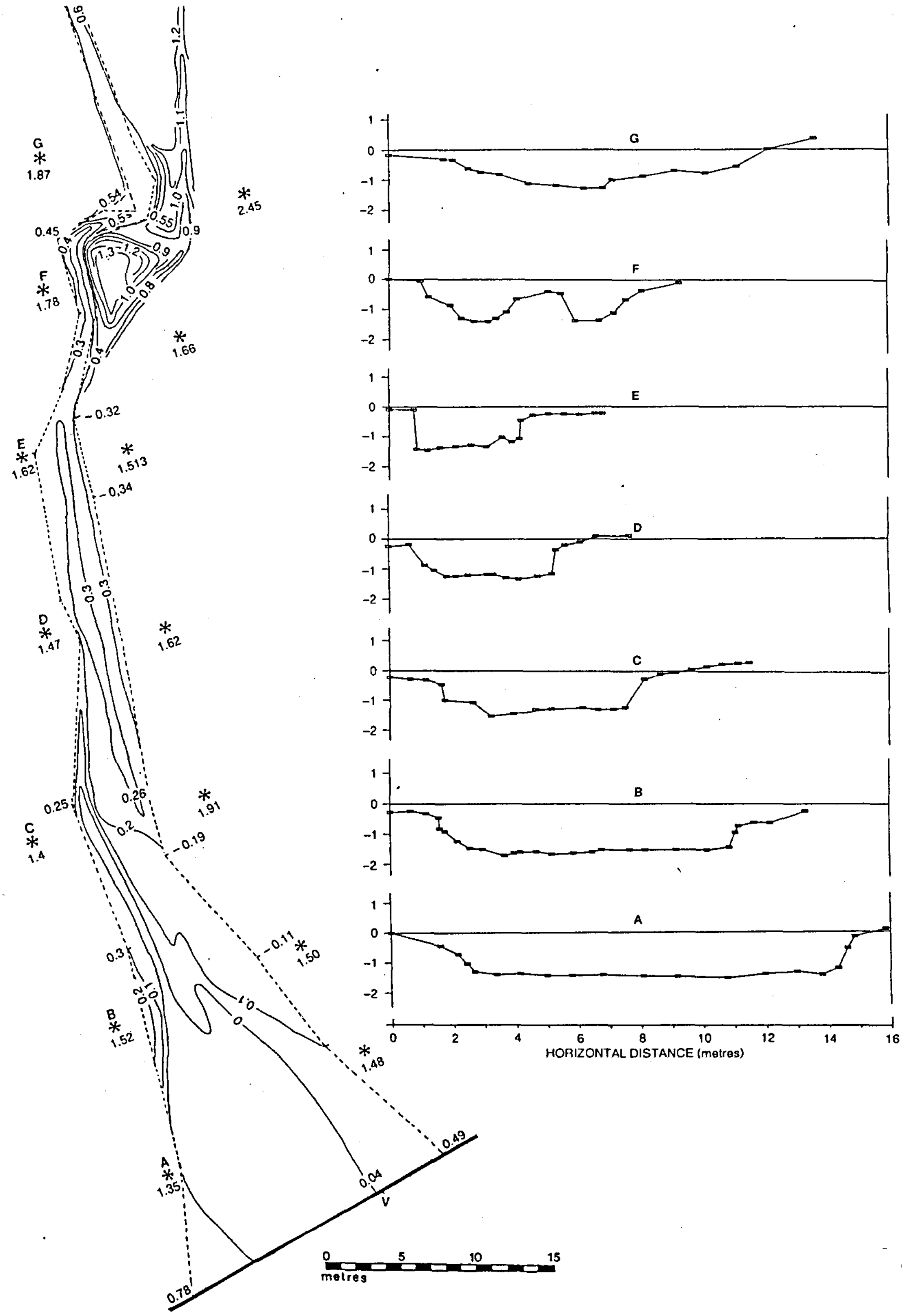


Figure 8,17 **Transects across W1H016 used for estimating the bed load component.**

9 CONCLUSIONS

This volume of the report has presented the observational analysis of an investigation of the hydrological response of a small urban fringe catchment to changing land use patterns. The numerical analysis presented in Volume II utilized some of these observations and includes more details of some analysis, mainly soils.

This investigation has shown that there has been a significant change in the development of the urban fringe region in the Ntuze catchments over the last few decades. The housing density, and by direct implication the population density, is increasing at about 13% per year. This rise in population is expected to increase with the development and improvement of the roads and other communication infrastructures.

The disturbed catchment has shown an 83% increase in the development of exotic timber plantations. This form of silviculture however utilizes a continuous form of harvesting (removal of small branches mainly for housing construction) which leaves a fairly mature stand cover and which therefore should have less effects than the commercial exploitations. The disturbed catchment has experienced no detectable change in the area under cultivation of the traditional subsistence crops such as maize, madumbi and sweet potatoes. However, there are small pockets of bananas being planted in the wetlands and sedges which require drainage. These drained wetlands could become the most serious development since they will remove the natural filtration process offered by these natural systems.

The other important development in the disturbed catchment is the introduction of sugar cane over the last few years. This form of agriculture now occupies 2% of the catchment but is expected to increase rapidly with accessability to regions within the catchment, the recent development of loading zones in close proximity to the catchment and the severe cane shortage being experienced by the large mill at Felixton.

While the disturbed catchment shows significant trends in land use, the undisturbed catchment which is used for direct comparison, has been maintained as a nature reserve with limited and controlled grazing by local cattle since there is very little indigenous fauna. The controlled grazing is assumed to have the same environmental impact as grazing indigenous fauna.

A comparison of the disturbed and natural systems shows that the natural catchment has significantly more indigenous forest and approximately half the area of exposed rock. Since all other physical aspects of the two catchments such as soils and slope are identical, it is possible that these difference in the vegetational cover are a long term result of the degradation by the local settlements using the indigenous forests for wood (fuel and construction) and overgrazing the grasslands. However, the destruction of the forest may be decreasing with the introduction of more modern fuels such as paraffin and electricity.

This project has attempted to identify temporal trends in both the land use and hydrological characteristics with a specific objective of relating the observed changes in land use with identified changes in hydrological parameters. Because of the complicated non-linear hydrological processes which define and characterize the hydrological response of a catchment it is difficult to anticipate the exact nature of any changes in the hydrological parameters which could be attributed to the changes in land use except through the use of numerical procedures. Numerical procedures are being used but they also need physical measurements and observations for parameter specification and model verification before they can be utilized in this role. Consequently this analytical study proceeded in conjunction with the numerical study but has not yet been able to draw on any numerical results for guidance on analytical methods or hydrological characteristics to investigate in an effort to determine a land use response. The numerical study is described in Volume II of this report. This analytical study adopted several objectives to investigate any relationship between the observed changes in land use and the hydrological response of the catchment. The first approach was to utilize the historical data collected since 1976 in a temporal analysis. However the double mass plots of runoff components and hydrographic characteristics did not identify any significant temporal trends which could be linked to land use effects. The other approaches involved the direct comparison with an undisturbed catchment.

To relate differences in the hydrological response of two catchments to their differences in land use it is necessary to quantify all other factors contributing to the hydrological response. Consequently a detailed comparison of the two catchments was undertaken before their hydrological responses were compared. No significant differences were detected in the climatological aspect of the two catchments, although there were differences in the rainfall which required consideration in further comparisons of catchment runoff. The topographical features were extremely similar showing minor differences in the slopes of flattish areas (0 - 20% slopes). The soils of both catchments were almost identical and are unlikely to influence the hydrological response disproportionately. There is slightly more exposed rock in the disturbed catchment which is expected to promote a more rapid hydrological response leading to higher peak flows. This was not detected in the hydrographs where the disturbed catchment had much lower peak discharge rates. The disturbed catchment also exhibited multiple peaks for short duration high intensity storms which were attributed directly to the shape of the catchment and not to any land use effect. All geomorphological parameters, which are recognized as influencing the hydrograph shape, were very similar for both catchments and indicated that the hydrographs should be very similar.

While the discharge volume and intensity does not appear to be significantly affected by the differences in land use between the disturbed and undisturbed catchments, the water quality shows large differences which are attributed to land use differences. The physical and chemical nature of the runoff reflects the pathways and processes of the journey from precipitation to discharge at the point of sampling. While some processes lead to accumulation of constituents culminating in a state of equilibrium, others act as sources or sinks as they progress from one equilibrium state to another. Consequently it is difficult to attribute the observed character of the water quality to any specific effect at this stage of the investigation. However, this study has observed several differences between catchments in certain water quality parameters. Since the samples from both catchments were not always taken at exactly the same time or stage of discharge it is difficult to attribute a significance level to the comparison because there is a definite relationship between discharge and certain variables. Turbidity and total phosphate are linearly related to suspended solids which tends to increase with increasing discharge. However, the other water quality measurements do not show such a good relationship with either suspended solids or discharge. Nevertheless, all water quality measurements were considered to vary with discharge and were therefore classified according to the hydrographic stage of the discharge during the sample collection. Four flow regimes were subjectively defined as the rising limb, peak flow, recession limb, and base flow. In some cases the recession limb was subdivided into a quickflow and through flow component. The water quality measurements from both catchments for each flow state were then compared during the sample period.

The results suggest that there may be some seasonality in the pH, conductivity, and suspended solids which could be related to the seasonal trends in discharge (rainfall) volume which is considered to promote a dilution of dissolved solids and an enhanced detachment and transport of soil particles. The seasonality, however, was not always clear because of the number of samples, but it could be inferred from relationships with either the dissolved or suspended loads. The comparison between the catchments of water quality measurements for the various storm hydrograph stages showed large differences for most variables, although the magnitude of the difference varied with parameter.

Water quality, as opposed to water quantity, appears to be a better indicator of land use degradation. Significant differences are evident in the dissolved and suspended loads from the natural and disturbed catchments. However, these differences need to be quantified more precisely, particularly with regard to discharge and antecedent conditions. Only then can an attempt be made to link these differences with management strategies.

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APPENDIX I

Calendar of events for hydrometeorlogical measurements

During the period of this project many events occurred which have a bearing on the analysis and utilization of the hydrometeorological data that has been collected and processed. Consequently, a calendar of events has been compiled and presented.

The raingauge network which was first established in 1974 has been altered over the past 16 years in accordance with the aims and objectives of the various research project that have been undertaken on the Ntuze Catchments. Table I-1 lists all the raingauges, the date they were installed and periods during their operation when any significant event occurred which may have introduced inconsistencies in the data set.

Table I-2 summarises the missing runoff data for the weirs on the Ntuze by giving the start date (Day of the year or DOY) and end date when missing data was recorded. When the missing data only occurred on one day only, then that DOY is given as a single value. In the individual tables, those years without any indicated missing values (first column has ?) are still being investigated. The same notation is used in the rainfall stations given in Table I-3.

TABLE I-1 Raingauges, Date of first record and instrumentation.

Stn	Start	Make	Closed	Event
320	5/ 6/75	Cassella		2/7/87
353	3/ 6/75	Cassella		
380	23/ 8/79	Cassella		1/10/88
410	5/ 6/75	Cassella	12/08/88	
411	13/ 7/88	Cassella		
412	1/ 1/77	Cassella	01/07/88	
441	13/ 7/88	Cassella		
470	5/ 6/75	Cassella		Moved 200m
473	4/ 6/75	Cassella		
474	4/ 6/75	Cassella		6/ 7/89
500	1/ 1/89	Cassella		
501	4/ 6/75	Cassella		2/ 3/88
530	1/ 1/76	Cassella		
531	1/ 1/89	Cassella		
562	1/ 1/76	Cassella		
564	1/ 9/75	Cassella		17/ 3/88
593	5/ 6/75	Cassella		
622	2/ 9/75	Cassella		
W1H16		tip-bucket		
W1H31		tip-bucket		

TABLE I-2

Missing runoff data for Ntuze weirs. Each set of dates indicates the start and end of missing data periods.

STATION ; W1H012

Year	DAY OF YEAR to DAY OF YEAR					
1977	?					
1978	320-328					
1979	354-365					
1980	001-003					
1981	043-059	060-064	ENDS IN	MARCH		
1982	?					
1983	?					
1984	?					
1985	004-008	134-136				
1986	014-017	301-318				
1987	013-014	203-210	279-280			
1988	039-040	041-042	057-058	069-072		
1989	?					
1990	?					
1991	?					
1992						

STATION ; W1H013

Year	DAY OF YEAR to DAY OF YEAR					
1976	001-NOV					
1977	?					
1978	001-027					
1979	354-365					
1980	001-003					
1981	?					
1982	?					
1983	?					
1984	026-030	074-075	312-320	324-327		
1985	093-100					
1986	300-314					
1987	?					
1988	167-173	204-217	218-234			
1989	029-032	JUL-365				
1990	?					
1991	?					
1992						

STATION ; W1H014

Year	DAY OF YEAR	to	DAY OF YEAR			
1976	?					
1977	?					
1978	?					
1979	270-273	274	305-312	313-317	354-365	
1980	001-003	227	-555 &	-666	RECORDS	????
1981	078-079	204-205	216-218			
1982	112-120	121-126				
1983	?					
1984	39	76	JUN-365			
1985	124					
1986	282-304	308-315	317-322			
1987	271-272	285	305-307			
1988	41	096-103	124-131	294	298-300	300-305
	306-307	315	DEC-365			
1989	011-365	CLOSED				
1990	no data					
1991	no data					
1992	no data					

STATION ; W1H015

Year	DAY OF YEAR	to	DAY OF YEAR			
1976	001-NOV					
1977	?					
1978	?					
1979	354-365					
1980	001-003	122				
1981	194-212	213-218	281-288			
1982	?					
1983	001-MAY					
1984	JUN-365					
1985	093-106	169-181	182-193	DEC-365		
1986	025-029	058-063	302-308			
1987	196-205	236-237	325-328	334-335		
1988	002	003	004	040-041	062	161
	242-245	DEC-365				
1989	JUL-365					
1990	?					
1991	?					
1992						

STATION ; W1H016

Year	DAY OF YEAR		to	DAY OF	YEAR	
1976	001-NOV					
1977	083-084					
1978	?					
1979	312-326	354-365				
1980	001-003					
1981	183-190					
1982	119-120	121-133	201-203	221-243	244-245	OCT-365
1983	001-MAY	MAY-JUL				
1984	033-039	075-082	192-212	JUL-365		
1985	002-003	014-018	018-024	038-047	048-052	052-059
	060-090	091-120	121-136	137-147		
1986	081-084	308				
1987	?					
1988	169-174	174-181	181-182	183-187	187-192	202-204
	251-258	286-287				
1989	037-045	157-169	194-195			
1990	?					
1991	?					
1992						

STATION ; W1H031

Year	DAY OF YEAR to DAY OF YEAR				
1988	001-OCT	314-315	320-321	334-335	335	336-337
	344	365				
1989	007	025-026				
1990	?					
1991	?					
1992						

TABLE I-3

Missing rainfall data for select stations. Each set of dates indicates the start and end of missing data periods.

STATION 410

Year	DAY OF YEAR to DAY OF YEAR					
1975	001-JUN	331-334	335-338	345-352	358-365	
1976	022-031	032-036	078-085	092-305	306-310	359-366
1977	049-055	139-146	224-230	350-362		
1978	019-031	032-040	081-090	355-362		
1979	250-251	277-288	360			
1980	235-241	252-255	318-335	336-346		
1981	029-031	032-036	120	121-127	244	246-253
	323-334					
1982	113	203-210	AUG-			
1983	?					
1984	?					
1985	?					
1986	?					
1987	?					
1988	?					
1989	?					
1990	?					
1991	?					
1992						

STATION 412

Year	DAY OF YEAR		to	DAY OF	YEAR	
1976	050-057	078-085	092-099	105-108	122-305	306-310
1977	006-013	335-342				
1978	096-103	250-257	348-355			
1979	060-067	250-251	277-288	305	333-334	335
	347-354	359-365				
1980	253-255	258	263	267-268	273	282
	290-297	333-335				
1981	005-006	022-024	028-029	137-141	225-232	240-243
	244					
1982	021-028	048	098-105	112-119	140-147	151
1983	?					
1984	?					
1985	?					
1986	?					
1987	?					
1988	?					
1989	?					
1990	?					
1991	?					
1992						

STATION 470

Year	DAY OF YEAR		to	DAY OF YEAR		
1975	001-JUN					
1976	008-015	078-086	092-305	306-310		
1977	?					
1978	007-013	215-222	264-271			
1980	029-031	032				
1980	213	214-227	252-255	364		
1981	019-021	025-027	033	039-040	042	045-048
	120	121-127	137-141	197-204	239-243	244
1982	014-021	035-042	203-205	AUG-		
1983	?					
1984	?					
1985	015-018	080-088	150-157	262-276	304-310	
1986	029	035	063-070	076-077	084-091	111-112
	230-231	249-252	293-296	358-364		
1987	001-006	154-???	209-216	270-274	314	
1988	001-002	089-096	096-103	103-110	124-131	138-145
	145-153	157-167	167-174	174-181	181-187	187-195
	195-202	217-224	230-251	253-2576	315	321-322
	334-335	351	360	363-366		
1989	012-013	023-026	040	040-061	067-088	118-125
	147-148	152-179				
1990	?					
1991	?					
1992						

STATION 530

Year	DAY OF YEAR		to	DAY OF YEAR		
1975	001-JUN	254-261				
1976	078-085	092-305	306-310			
1977	258-265					
1978	152-159	166-173				
1979	347-361					
1980	024	030-031	101-108	213-220	241-283	346-353
1981	036-043	057-059	060-064	113-120	136-141	183-190
1982	102-105	JUL-				
1983	?					
1984	?					
1985	?					
1986	?					
1987	?					
1988	?					
1989	?					
1990	?					
1991	?					
1992						

STATION 562

Year	DAY OF YEAR	to		DAY OF	YEAR	
1975	001-JUN	?				
1976	008-015	022-031	032-036	078-085	092-305	306-310
	359-365					
1977	307-315	335-353	350-356			
1978	113-147	252-255	278-285			
1979	067-074	081-090	091-109	284-291	347-354	
1980	038-045	227-231	254-260	282-303		
1981	064	068-071	075-078	099-106	136-141	218-225
	242-243	244	255-260			
1982	056-069	080-084	126-147	196-210	AUG-???	
1983	?					
1984	?					
1985	?					
1986	?					
1987	?					
1988	?					
1989	?					
1990	?					
1991	?					
1992						

STATION 593

Year	DAY OF YEAR		to	DAY OF YEAR		
1975	001-JUN	254-261	275-282	345-352		
1976	008-015	036-043	306-310	351-358		
1977	005-065	097-104	125-132			
1978	271-279	334-335	346-355	360-362		
1979	002-004	008-011	172-173	277-291		
1980	010-018	029-031	066-073	101-122	220-235	240
	253-258	268	276-303	334	351-353	
1981	001	007-008	021-022	022-028	052-054	075-079
	133-134	136-141	239-246			
1982	063-070	210	217-???			
1983	?					
1984	?					
1985	?					
1986	?					
1987	005	071-076	176-178	236-237	238-243	287-294
	352-357					
1988	013-020	025-031	032-055	074-083	089-091	092-110
	124-152	153-182	183-202	217-224	339-340	351-358
	360-365					
1989	007-011	020-025	047-053	54	103-120	121-123
	152-159	182	183-187			
1990	?					
1991						

APPENDIX II

Automatic weather station 0304622 : University campus

The automatic weather station installed on the University of Zululand campus is described in detail in this appendix as the datalogger utilised in the system is the central monitoring and processing unit employed at other sites in the catchment. The programs for generating and processing the data as well as the data format, however will be different for the different applications and will be referenced in the appropriate appendices.

This meteorological station forms part of the raingauge network covering the research catchments. It also provides additional meteorological data which is used in the modelling of the hydrological processes presented in Volume II (Mulder and Kelbe, 1991)

STANDARDS

There has been very rapid development of reliable data loggers and atmospheric sensors over the last decade. Many loggers which are programmable and can process the measurements to provide different options on the format and frequency of the data have become available. This has resulted in a proliferation of information from these programmable loggers with processing capabilities, which does not conform to any specific standard. In contrast to the standard meteorological measurements, where the standard day for most observations is from 08h00 to 08h00, the deployment of a datalogger with programming capabilities provides many different options on the processing of the data, including the selection of the fundamental period of measurement. The CR10 datalogger was programmed to process the data on a hourly and daily basis commencing at midnight and not at 08h00. Consequently the data (particularly rainfall) is not entirely compatible with standard observation. In order to alleviate any misconceptions the data is being made available in processed form and will be provided on flex-disc for further application when completed.

STATION LOCATION

In 1988 the weather station on the campus of the University of Zululand was relocated on the campus (Figure II,1) to a position closer to the Department of Hydrology. This was necessary because the original position was being vandalised and was being surrounded by buildings. There was also the probability that the site would be needed for future expansion by sections of the University.

Many of the instruments in the original station were old and in need of major servicing. The instruments were read once a day at 08h00 except on weekends when the field assistant was off duty. Consequently it was decided that an automatic weather station would be installed on the new site with a view to replacing the once daily measurements.

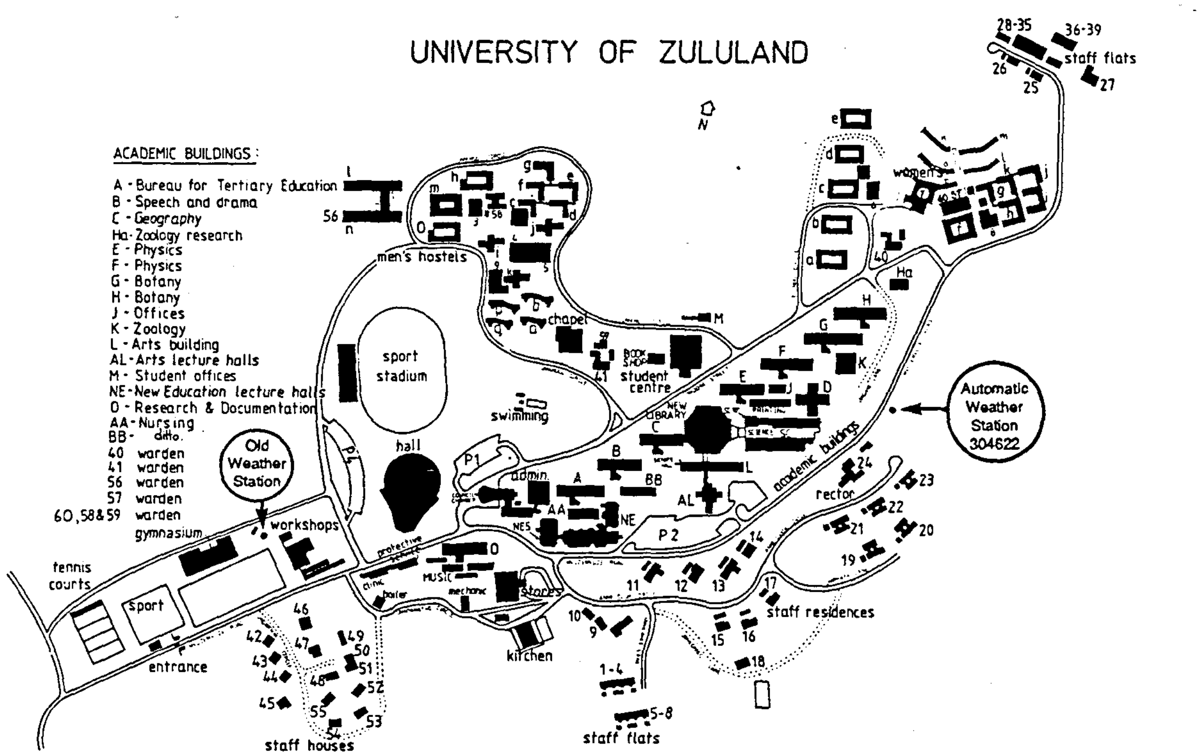

Figure II,1 The locations of Station 304622 on the University of Zululand Campus.

INSTRUMENTATION

A recent workshop on the pros and cons of locally produced dataloggers (Versfeld and Held, 1989) highlighted many problems inherent in data collection and assimilation. It also indicated that many locally produced systems were prototypes and specific to a particular application. Because of the diversity of systems and their different capabilities it is considered necessary to describe each system and associated problems in an effort to alleviate future difficulties with both hardware and software (data format) applications in this projects. Consequently the system used in this study is described in detail. Trade names are used in this report solely for the purpose of providing information. Mention of a trade name does NOT constitute a guarantee of the product and nor is it an endorsement of the products by the author, the Department of Hydrology, University of Zululand, or the Water Research Commission.

DATALOGGER

The central systems utilised in this study for monitoring atmospheric indices (and piezometric surfaces and stream discharge at other locations) consists of the Campbell Scientific CR10 datalogger. The logger is interfaced, through an ECO model TP/10 termination panel (Figure II,2), to different sensors that vary with installation. The termination panel provides easy connections for the incoming sensor wires, input power, lightning protection and it also houses the ECO model CI/RW/10 cassette read/write interface. The termination panel is also equipped with an interface for connecting a telephone modem (ECO model RS/232/10). The equipment at all the stations in the field are housed in standard electrical fibre boxes and mounted on a suitable support. The support at the weather station is a galvanised pipe frame on a tripod which has a cross member at about one and a half meters above the ground (Figure II,3) for supporting several sensors.

The CR10 is battery operated with a real time clock, a serial data interface, a programmable analogue-to-digital converter, and full floating point maths capabilities. The standard data logger has 16K of RAM (an expanded memory of 32K is available) that is

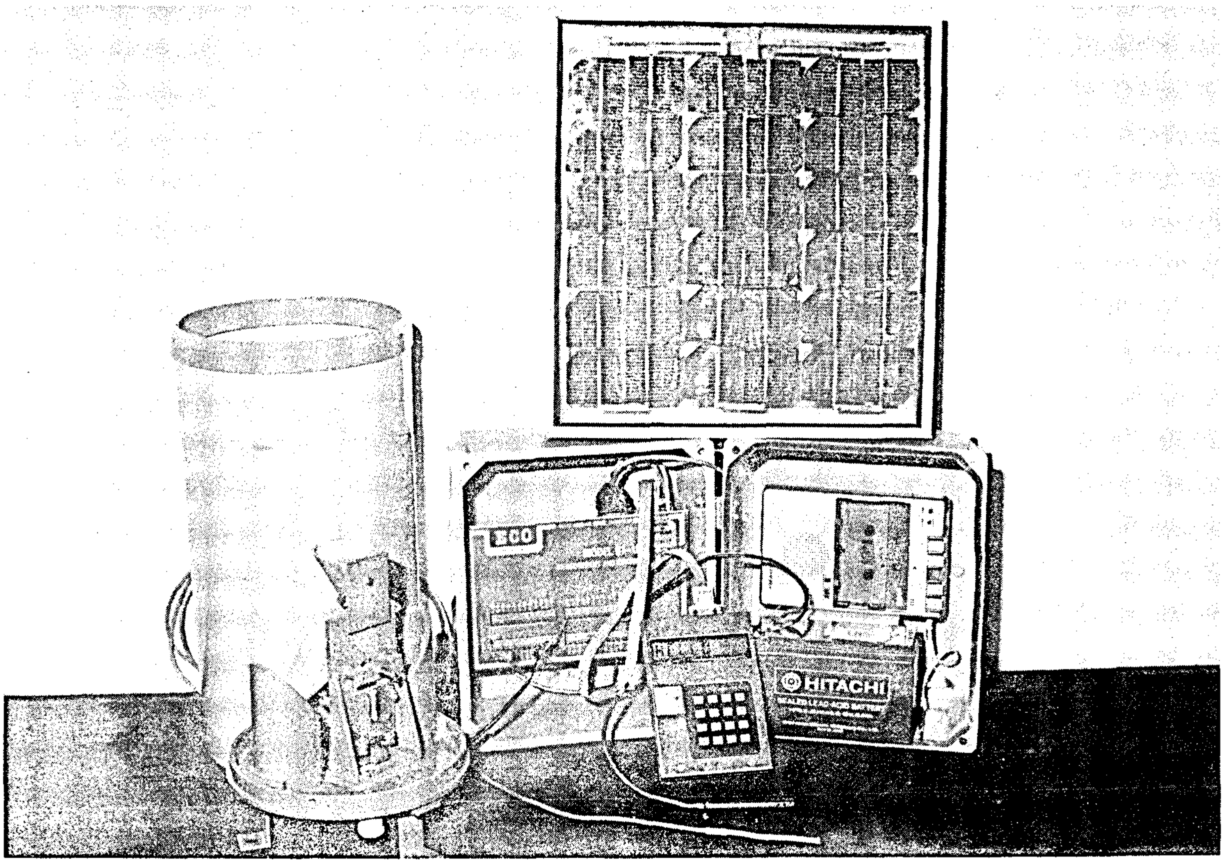

Figure II,2 The basic components of the datalogger system use in this study.

partitioned between program memory and three programmable storage memories (Figure II,4). The Input memory retains the measured values of each sensor which is processed in intermediate storage before being retained in final storage ready for transmission to a cassette tape.

The CR10 is programmed to scan the individual sensors every 10 seconds (execution interval). The analogue-to-digital measurements for each sensor are converted to engineering units according to user-specified commands and are stored in user specified input locations. The input data is processed in intermediate memory before storage in final memory according to user-specified output programmes. Final storage is completed only at the intervals specified in the output table. When the output memory locations are full, the old data is overwritten by the new data. The CR10 is programmed to dumped the output (final) memory automatically to cassette after 512 data values have been stored. The output memory can also be accessed manually by the user with the aid of a keyboard.

The CR10 has six double ended or twelve single ended (common low) analog inputs, two pulse counting input channels and 8 digital input/output ports. Input to the analog channels are through high and low ports. The low is common to all analog channels and is +1V with respect to ground/earth.

The tapes from the CR10's are retrieved manually from the station and the data is then transferred from the cassette tapes to computer storage using the Campbell Scientific PC 201 cassette interface card. This card was faulty and had to be returned to the USA for repairs during 1989.

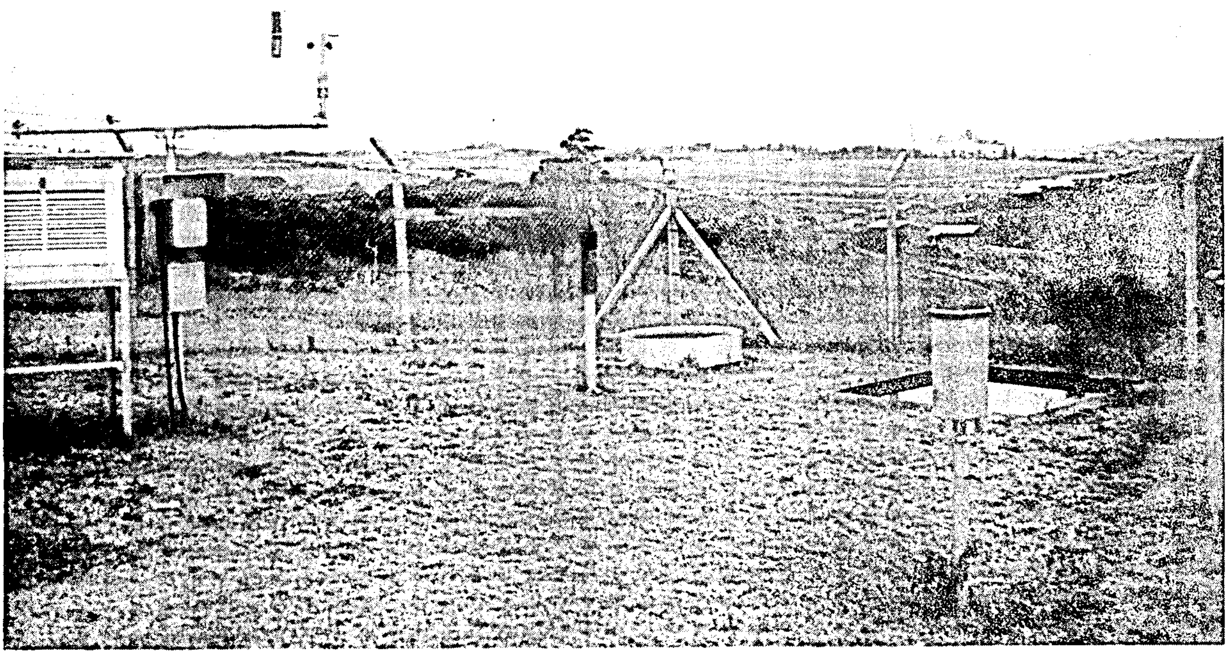

Figure II,3 Photograph of the automatic weather station.

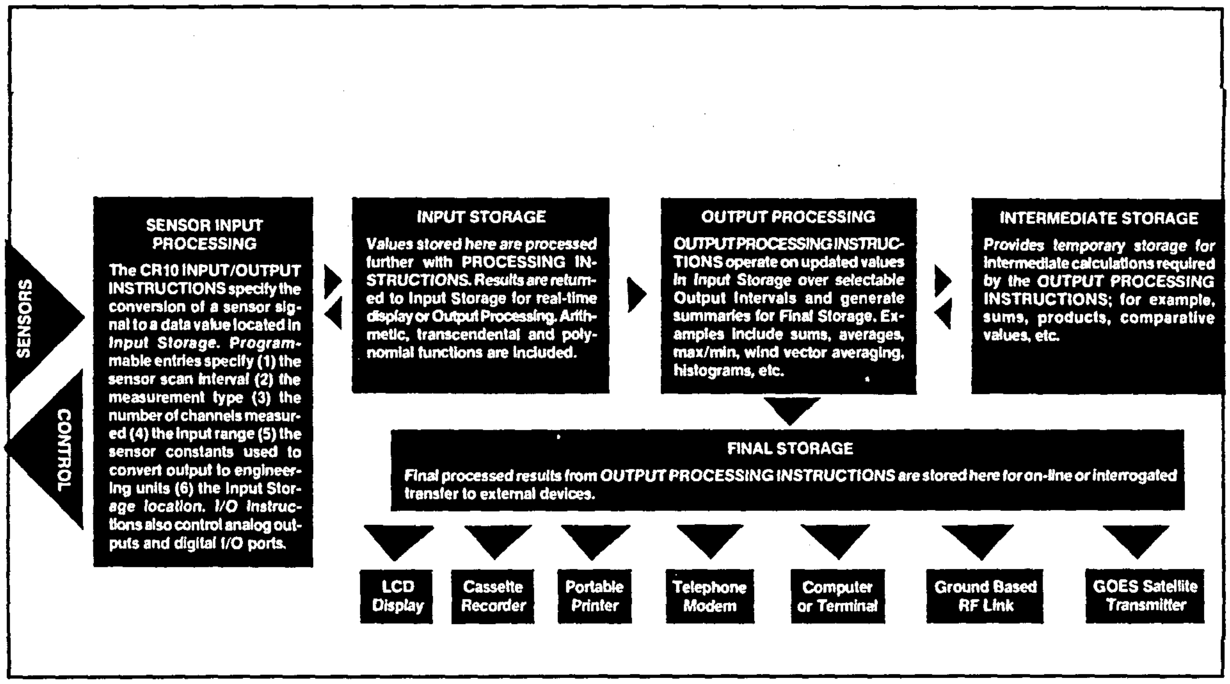

Figure II,4 Diagrammatic representation of the CR10 components

AUTOMATIC WEATHER STATION

The automatic weather station, which is situated on the eastern edge of the University Campus (see Figure II,1) is intended to monitoring atmospheric variables that will provide estimates of potential or reference evapotranspiration for the surrounding area. It is also used to monitor the atmospheric pressure and the rainfall.

SENSORS

The solar radiation is provided by a LICOR pyranometer mounted on the galvanised frame (Figure II,3). The wind speed (and direction) is derived from an ECO anemometer mounted 2 meters above the surface. A thermistor and XNAM hygristor located in the Stevenson screen give measurements of temperature (mean, maximum, and minimum) and vapour pressure (mb).

The data logger is also connected to an ECO tipping bucket raingauge (Figure II,2) and is powered by a 12Volt lead acid battery which is maintained at about 13V by a trickle charge from a local 220VAC mains supply.

DATA FORM AND FORMAT

The memory allocations for this station and the input locations are given in program II-2. The CR10 programme provides records of
hourly and daily mean values of selected variables. Each 80 character record comprise eight fields which are formatted as follows ;

01+XXXX. 02+XXXX. 03+XXXX. 04+XXXX. 05+XXXX. 06+XXXX. 07+XXXX. 08+XXXX.

where the first two digits refer to the field number and 'xxxx.' refers to the value of the selected variable in that field. The different fields for the hourly and daily records are given in Table II,1 and Table II,2.

Table II,1 Fields for hourly records

Field	Data
01	Program location for initiating dump to final memory
02	Time (HHMM)
03	Mean hourly radiation (kW)
04	Mean hourly temperature (°C)
05	Mean hourly water vapour pressure (hPa)
06	Mean hourly atmospheric pressure (hPa)
07	Mean hourly wind speed (m s^{-1})
08	Hourly vector wind direction (deg)
09	Total hourly rainfall (mm)
10	Total hourly evaporimeter reading (mm)

The CR10 is battery operated with a real time clock, a serial data interface, a programmable analogue-to-digital converter, and full floating point maths capabilities. The CR10 has a variable scan rate from 1/64s, which samples the individual sensors according to user-specified commands programmed and stored in user specified input locations. The input data is processed in intermediate memory before storage in final memory according to user-specified output programmes. Final storage is completed only at the output intervals specified in the output Table. When the memory is full, the old data is overwritten by the new data. The memory is dumped automatically to cassette and can be accessed manually by the user.

Table II,2 Fields for daily records

Field	Data
01	Program location for initiating dump to final memory
02	Year
03	Day of the Year (DOY) (Jan 1 = DOY 1)
04	Mean daily radiation (kW)
05	" " temperature (°C)
06	" " barometric pressure (hPa)
07	" " water vapour pressure (hPa)
08	" " wind speed (m s^{-1})
09	Maximum daily Temperature
10	Time of maximum temperature
11	Maximum daily vapour pressure
12	Time of maximum vapour pressure
13	Maximum daily pressure
14	Time of maximum pressure
15	Maximum daily wind speed
16	Time of maximum wind speeds
17	Minimum daily Temperature
18	Time of minimum temperature
19	Minimum daily vapour pressure
20	Time of minimum vapour pressure
21	Maximum daily pressure
22	Time of minimum pressure
23	Total daily rainfall (mm)
24	Battery voltage
25	Frequency of wind direction 0 to 45°
26	" " " " 45 to 90°
27	" " " " 90 to 135°
28	" " " " 135 to 180°
29	" " " " 180 to 225°
30	" " " " 225 to 270°
31	" " " " 270 to 315°
32	" " " " 315 to 360°

The CR10 accepts 6 double ended or 12 single ended analog inputs and two pulse counting input channels. Input to the analog channels are through high and low ports. The low is common to all analog channels and is +1V with respect to ground. The CR10 also has eight control outputs which can be used for controlling external devices such as the ISCO water sampler.

The CR10 displays and stores a maximum value of 6999 in internal memory. The data in memory is programmed to automatically dump to cassette tapes at regular intervals. The tapes are retrieved and the data transferred from the cassette drive to disc storage using the Campbell Scientific PC 201 cassette interface card. The data were stored in files according to the following nomenclature;

1 - Hourly mean data and daily means   File = STNMTHYR.DAY

2 - Monthly summary of daily means   File = STNMTHYR.MON

where MTH = MONTH ; YR = YEAR ; & STN = STATION

station abbreviations are = W16 (weir W1H016)
= W31 (weir W1H031)
= 622 (main campus)
= ST1 (St Lucia weather Stn)
= FLU (St Lucia Flume)

DATA PROCESSING

The data from the meteorological station at 304622 has been processed and is available under separate cover (Kelbe 1988, Kelbe 1989). A computer program was written (program II-1) to correct for any changes in the CR10 program during the year and to present the data in a processed form. Two presentation formats are provided by the program for hourly data and daily data. Examples of these are shown in Table II,3 and in Table II,4. Data for 1988 and 1989 have been processed and published under separate cover (Kelbe 1989, 1990). Included in the processing are hourly and daily estimates of potential evapotranspiration. These will be compared to A-pan readings once the potentiometer has been installed on the A-pan and interfaced to the logger.

EVAPOTRANSPIRATION

During evaporation, a specific amount of energy is required to convert liquid water into water vapour. The dominant source of energy for evaporation to occur in nature is derived from radiation. Consequently evaporation, in the form of latent heat (E), is an important part of the energy transfer in the atmospheric boundary layer. Since air can hold only a limited quantity of water vapour (saturation), the evaporation process is also controlled by the ability of the air to absorb more vapour. If the air surrounding an evaporating surface were motionless it would soon reach saturation and no further evaporation would occur. Consequently evaporation rate, or latent heat transfer, is also a function of the advection of the air (vapour) away from the source of water (transpiring surface). Penman (1948) combined all these processes in the well known equation that still bears his name;

$$\lambda E=\frac{s}{s+\gamma}(R_N-G)+\frac{s}{s+\gamma}\rho C_p(e_{sat}-e)f(u)$$

where

$(R_N - G)$ is the net radiation (W/m^2)
s = slope of the sat vap pres - temp curve (mbar/°C)
gamma = thermodynamic psychometric constant (rho C_p/ lambda)
rho = air density
e = water vapour pressure (mbar)
e_{sat} = saturated water vapour (mbar)
lambda = Latent heat of vaporisation
C_p = specific heat @ constant pressure
f(u) = wind function

If it is assumed that the transport of latent and sensible heat through turbulent motion is the same as momentum transfer, then the wind function can be written in terms of the logarithmic wind law in the form (Campbell, 1986)

$$f(u)=\frac{\lambda}{r_H}$$

where r_H is the aerodynamic resistance and is given for neutral conditions by

$$r_H=r_V=\frac{(\ln[z-d+z_o]/z_o)^2}{k^2u}$$

where

k = von Karmans constant (0.41)
r_H = sensible heat transport resistance
r_V = vapour transport resistance
u = mean wind speed at a height of z meters
z = height (m) of measurements above the ground
z_o = roughness coefficient (m)
d = zero plane displacement (m)

Net radiation (R_N) and soil heat flux (G) are not generally available and require expensive instruments to measure. However, de Jager, van Zyl, Bristow and Van Rooyen (1986) have found that net radiation is related to solar radiation (st) by the following equation ;

$$R_N - G = \frac{S_t - 148}{0.88}$$

Vapour density is related to vapour pressure by the ideal gas law while vapour pressure (e) can be estimated (Campbell, 1986) from measurements of temperature (T)

$$e = e^{52.57633 - \frac{6790.4985}{T} - 5.02808 \ln T} (kPa)$$

These equations provide an estimate of potential evapotranspiration when zo and d are defined and the other variables (T, f, u, S_t) are measured. The automatic weather station was designed to measure these variables to obtain an estimate of potential evapotranspiration. The computer program written to calculate potential evapotranspiration (program II-1) used z_o = 13% of vegetation cover height. A vegetation height of The Penman equation has been validated for a wheat crop using a lysimeter by de Jager, van Zyl, Kelbe and Singels (1987), who also found that corrections for atmospheric stability "minutely improved the accuracy of the estimates".

UNIVERSITY of ZULULAND
DEPARTMENT OF HYDROLOGY

Station 622 - UNIZULU CAMPUS

JANUARY - 1990 file <622JAN90>

Day	Rad^{tn}	Temperatue (C)			Vapour Pressure (mb)			barometric pressure (mb)			wind spd & dir			Rain	Ep
	MJ/m^2	mean	max	min	mean	max	min	mean	max	min	mean	max	deg	mm	mm
1	16.16	22.87	27.03	19.57	25.94	29.45	22.21	1015.3	1018.5	1012.4	1.49	6.40	ESE	0.20	3.40
2	26.87	24.61	30.28	20.52	27.88	33.79	23.43	1015.3	1019.3	1012.6	1.81	6.66	WSW		7.29
3	36.81	25.92	28.75	22.06	28.43	32.01	25.60	1017.8	1019.7	1016.6	1.46	5.11	SSE		7.40
4	30.50	24.37	29.50	19.95	25.49	29.82	22.44	1015.8	1017.6	1013.9	1.34	5.79	ESE		8.49
5	30.50	24.35	30.31	19.19	25.61	30.79	19.03	1010.6	1015.1	1005.9	2.63	8.90	ENE	0.20	8.49
6	28.34	28.82	38.54	20.91	26.99	32.61	19.40	1002.2	1006.8	997.1	2.26	9.50	NNE	9.40	8.27
7	7.34	20.75	24.77	17.22	23.84	30.78	19.15	1015.6	1024.6	1005.9	2.94	0.71	WSW	9.60	0.73
8	15.29	19.41	23.51	16.46	19.59	22.14	18.09	1023.1	1025.5	1020.0	1.56	4.50	WSW	1.80	3.03
9	26.70	23.42	28.57	17.62	21.37	25.73	18.85	1013.7	1020.5	1008.7	3.76	9.67	NNE		7.03
10	8.12	21.50	24.56	18.21	23.27	28.51	19.01	1012.0	1016.1	1008.5	2.16	8.81	WSW	11.6	0.80
11	13.74	21.00	24.69	18.21	21.39	25.38	17.63	1014.8	1016.3	1012.9	1.20	5.02	WSW	2.4	2.64
12	23.67	23.71	28.56	19.00	26.62	31.72	21.50	1012.7	1015.8	1008.5	1.93	7.26	ENE	6.4	6.02
13	28.68	24.73	27.98	22.07	28.84	32.61	25.84	1011.2	1012.6	1009.3	1.69	7.43	SSW		7.81
14	15.12	23.91	28.35	20.52	27.47	31.68	23.48	1012.4	1015.4	1010.5	1.01	4.24	SSE		3.07
15	24.28	24.25	28.17	21.10	26.61	30.95	24.36	1015.4	1017.2	1013.7	1.17	5.36	ESE		6.30
16	22.29	24.59	28.57	20.52	26.60	29.30	23.24	1015.0	1016.7	1012.6	2.16	8.38	ENE		5.62
17	28.77	25.56	30.68	21.48	27.36	30.54	23.41	1013.0	1014.9	1011.0	2.35	8.47	ENE		8.00
18	27.91	26.01	31.27	21.11	27.54	30.62	23.73	1011.8	1013.9	1009.4	2.90	10.36	ENE		7.75
19	28.86	26.95	31.85	22.24	26.56	29.63	23.60	1007.4	1011.8	1002.9	4.54	10.79	ENE		8.19
20	10.28	21.90	24.76	20.32	25.02	26.75	23.02	1012.8	1017.9	1007.4	2.91	9.59	WSW	52.6	1.44
21	18.49	22.67	25.69	19.76	23.47	26.31	20.57	1016.9	1018.4	1015.1	1.28	4.67	SSE		4.30
22	24.19	25.16	29.94	20.51	26.50	29.90	23.22	1012.4	1017.6	1007.6	2.87	9.07	ENE		6.38
23	7.34	24.77	26.68	23.58	29.48	32.07	27.86	1010.6	1015.2	1007.2	2.34	8.64	WSW		0.69
24	24.62	25.26	29.51	22.24	28.21	31.54	24.97	1013.0	1016.5	1009.1	1.92	7.09	SSE	8.0	6.55
25	10.80	23.42	26.27	21.10	27.29	29.74	24.57	1016.8	1019.6	1012.9	1.87	6.14	SSE	22.6	1.80
26	27.30	26.29	34.12	22.82	26.79	30.47	20.07	1011.6	1015.0	1009.6	2.54	7.52	NNE		7.67
27	16.16	24.34	28.15	21.46	27.06	29.65	24.67	1014.2	1016.3	1011.9	1.64	4.85	SSE	1.20	3.74
28	9.76	22.75	25.86	21.10	26.37	30.19	24.50	1016.4	1018.4	1013.5	1.23	5.11	WSW	6.00	1.50
29	21.86	25.05	29.16	21.67	28.69	33.11	25.36	1016.2	1018.0	1013.9	2.63	9.16	ENE	1.80	5.48
30	27.22	26.74	32.22	22.82	29.21	33.35	26.28	1015.5	1017.9	1012.5	3.64	9.24	ENE		7.59
31	27.82	27.13	32.59	23.60	28.91	32.39	24.82	1015.0	1016.9	1012.5	3.63	9.59	ENE		7.86
Ave	**21.48**	**24.26**	**28.74**	**20.61**	**26.27**	**30.11**	**22.71**	**1013.7**	**1016.9**	**1010.5**	**2.22**	**7.55**	**SSE**	**133.8**	**165.4**

Table II,4 Example of processed daily data.

UNIVERSITY of ZULULAND
DEPARTMENT of HYDROLOGY

Station 622 - UNIZULU CAMPUS

Date : 1 / JANUARY / 1990 **DOY : 1**

Time	Radtn W/m^2	Temp °C	Vapour press(mb)	Barometer (mb)	Wind m/s	m	Rainfall mm/hr	Ep mm/hr	Pan mm/hr
1	5.	20.05	22.85	1018.10	0.48	NNW		0.00	
2	5.	19.90	22.69	1017.80	0.55	WNW		0.00	
3	5.	19.82	22.62	1017.30	0.62	WSW		0.00	
4	7.	19.99	22.83	1016.80	0.86	WSW		0.00	
5	5.	19.76	22.51	1016.50	0.47	WNW		0.00	
6	23.	19.81	22.62	1016.80	0.49	ENE		0.00	
7	71.	20.38	23.44	1017.20	0.69	WNW		0.00	
8	173.	21.31	24.66	1017.10	0.78	WSW	0.20	0.03	
9	315.	22.74	26.26	1016.90	0.75	SSE		0.20	
10	703.	24.38	26.51	1016.70	1.10	SSE		0.69	
11	680.	25.77	26.77	1016.50	1.44	ESE		0.67	
12	286.	24.75	27.32	1015.90	1.42	SSE		0.17	
13	287.	24.57	27.66	1015.30	1.29	ESE		0.17	
14	822.	26.19	28.50	1014.70	2.51	ESE		0.85	
15	507.	26.25	28.03	1014.10	2.74	ESE		0.45	
16	265.	25.46	28.73	1013.30	3.22	ESE		0.15	
17	162.	25.01	28.81	1012.80	3.75	ESE		0.02	
18	109.	24.69	28.45	1012.80	3.78	ENE		0.00	
19	35.	24.22	28.16	1013.10	2.54	ENE		0.00	
20	2.	23.47	27.46	1013.30	1.63	ENE		0.00	
21	2.	23.04	26.99	1013.40	1.90	ENE		0.00	
22	3.	22.80	26.67	1013.60	1.15	NNE		0.00	
23	4.	22.49	26.32	1013.80	0.96	NNE		0.00	
24	3.	22.12	25.79	1014.00	0.63	NNE		0.00	
Mean	186.6	22.87	25.94	1015.33	1.49				
Total							0.20	3.40	
							0.20		

Total Radiation 16.12 16.16 MJ/m^2

Extremes	Mean	Maximum	time	Minimum	time
AIR TEMPERATURE	22.87	27.03	13.37	19.57	4.38
VAPOUR PRESSURE	25.94	29.45	13.20	22.21	4.38
BAROMETER PRESSURE	1015.30	1018.50	0.36	1012.40	16.40
WIND SPEED	1.49	6.40	16.22		

WIND-DIRECTION RELATIVE FREQUENCY(%) IN 45 degree SECTORS

Sectors	0 > 45	> 90	> 135	> 180	> 225	> 270	> 315	> 360
Frequency	11.30	18.50	21.30	13.00	4.90	9.10	11.50	9.80

Highest frequency -> ESE

PROGRAM II-1

CR10 PROGRAM FOR AUTOMATIC WEATHER STATION - UNIZULU CAMPUS

Version 285-88 Date 12/10/88

MODE 1

SCAN RATE 10 seconds

```
1:  P01         Licor pyranometer
    1:1           reps
    2:3           range - slow 25 mV
    3:6           Input channel
    4:1           Memory location
    5:0.1642      Multiplier
    6:0           offset

2:  P04         Temperature sensor
    1:1           reps
    2:5           range - slow 2500 mV
    3:4           Input channel
    4:2           Excitation channel
    5:10          Excitation delay (ms)
    6:2000        Excitation voltage
    7:2           Memory location
    8:0.2987      Multiplier
    9:-162.1      offset

3:  P04         Relative humidity
    1:1           reps
    2:5           range - slow 2500 mV
    3:3           Input channel
    4:2           Excitation channel
    5:10          Excitation delay (ms)
    6:2000        Excitation voltage
    7:9           Memory location
    8:0.4612      Multiplier
    9:-371.2      offset
```

```
4:  P56         Saturated vapour pressure
    1:2           Temperature
    2:12          Sat vap pressure

5:  P36         (multiplication)
    1:9           Relative humidity
    2:12          Sat vapour pressure
    3:3           Vapour pressure

6:  P04         Wind direction
    1:1           reps
    2:5           range - slow 2500 mV
    3:12          Input channel
    4:3           Excitation channel
    5:10          Excitation delay (ms)
    6:2000        Excitation voltage
    7:6           Memory location
    8:-0.3564     Multiplier
    9:715         offset

7:  P03         Wind speed
    1:1           reps
    2:1           input location
    3:2           switch closure
    4:5           memory location
    5:.0862       multiplier
    6:.45         Offset

8:  P03         Rainfall
    1:1           reps
    2:2           input location
    3:2           switch closure
    4:7           memory location
    5:.2          multiplier
    6:0           Offset

9:  P89         IF x ? F
    1:7           rainfall
    2:3           >=
    3:.2          0.2
    4:11          SET Flag #1 high
```

```
10: P01         Atmospheric pressure
    1:1            reps
    2:5            range slow 2500 mV
    3:5            input channel
    4:4            memory location
    5:0.1          multiplier
    6:0            offset

11: P05         Symond tank
    1:1            reps
    2:5            range slow 2500 mV
    3:11           input channel
    4:3            excitation channel
    5:2000         excitation voltage
    6:8            memory location
    7:1            multiplier
    8:0            offset

12: P34         Summation
    1:8            Potentiometer voltage - pan
    2:90           factor
    3:11           pan - angle

13: P48         Sin function
    1:11           pan angle
    2:11           sin(pan angle)

14: P37         multiplication
    1:11           sin(angle)
    2:1            factor
    3:8            pan reading - mm

15: P10         Battery voltage
    1:10           location

16: P91         IF (1) Flag
    1:11           #1 is set high
    2:30           DO the next 7 steps ────────────────┐
                                                       |
                                                       |
                                                       |
```

```
17: P92         IF TIME
    1:0            into interval
    2:5            length of interval
    3:10           SET OUTPUT FLAG

18: P80         Set
    1:2            storage area
    2:0            with ID

19: P77         TIME of output
    1:110          YY:DD:HHMM

20: P72         TOTALS
    1:1            reps
    2:7            5 minute rainfall

21: P92         IF TIME
    1:0            into interval
    2:5            length of interval
    3:21           SET Flag #1 LOW

22: P96         Serial output
    1:0            to Tape

23: P80         Set
    1:1            storage area
    2:0            with ID

24: P95         END IF (1)

25: P92         IF TIME
    1:0            into interval
    2:60           length of interval
    3:10           SET OUTPUT FLAG

26: P77         Time
    1:10           HHMM

27: P71         Mean
    1:4            reps
    2:1            rad/temp/vap press/press
```

```
28: P76         Wind vector
    1:1            mean
    2:20           polar
    3:5
    4:6

29: P72         Totals
    1:1            reps
    2:7            Rainfall

30: P71         Means
    1:1            reps
    2:8            Symonds tank

31: P92         IF TIME
    1:0            Into interval
    2:1440         24 hours
    3:10           SET OUTPUT FLAG

32: P77         Time
    1:1200         YY : DD (previous day @ midnight)

33: P71         Means
    1:5            reps
    2:1            R/T/vp/P/WS

34: P73         Maxima
    1:4            reps
    2:10           with time of max
    3:2            T/vp/P/WS

35: P74         Minima
    1:3            reps
    2:10           with time of min
    3:2            T/vp/P/WS

36: P72         Summation
    1:1            reps
    2:7            Rainfall
```

```
37: P71          Mean
    1:1             reps
    2:8             Symonds tank

38: P75          Wind histogram
    1:1             direction
    2:8             # classes
    3:1             closed ends
    4:6             direction
    5:0
    6:0             start value
    7:360           end value

39: P96          Serial output
    1:0             to tape

40:              END OF PROGRAM
------------------------------------------------------------

MODE 2
SCAN RATE 0

MODE 3
    1:          P0

MODE 10         Memory allocation table
    1:28        Input storage
    2:64        Intermediate          storage
    3:600       Final Area 2 storage
    4:4732      Final Area 1 storage
    5:1607

MODE 11
    1:46677
    2:50383
    3:48
    4:0
    5:
```

PROGRAM II-2

GWBASIC PROGRAM FOR PROCESSING THE CR10 DATA

```
10   REM                                                          CAMBELL
20   REM ***************************************************************
30   REM *                    CAMPUS - Station 622
40   REM * PROGRAM ; "CAMBELL" : HYDROLOGICAL RESEARCH UNIT  UNIZULU
50   REM *                   :Prints daily & monthly summaries for CAMPUS
60   REM *
70   REM *  Bruce Kelbe :  version 3/12/89
80   REM *
90   REM ***************************************************************
100   REM
110   REM
120 OPTION BASE 1
130 CLEAR
140  DIM  A$(80),  X(32),  MON(20),  JULIAN(13),  MONTH$(12),  Z(2,32),
SX(5,24),SN(5,24), SQ(5,24)
150       DATA   0,     1,     2,   0.05,  2.43E03 : 'lambda in J/g
160       READ FIN,RECORD,HEIGHT,  CROP,    LAMBDA
170       ZO = .13*CROP
180       DATA "       "," NNE  "," ENE  "," ESE  "," SSE  "," SSW  "
190       DATA " WSW  "," WNW  "," NNW  "
200       FOR I=1 TO 9
210         READ DIR$(I)
220       NEXT I
230       DATA 0,31,59,90,120,151,181,212,243,273,304,334,365
240       INPUT "YEAR";YEAR
250       YR=YEAR
260       FOR I=1 TO 13
270         READ JULIAN(I)
280         IF INT(YR/4)=YR/4 AND I>2 THEN JULIAN(I)=JULIAN(I)+1
290       NEXT I
300       DATA " JANUARY "," FEBRUARY"," MARCH  "," APRIL  ","  MAY
              ","  JUNE  ", "  JULY  "," AUGUST  ","SEPTEMBER"," OCTOBER
              "," NOVEMBER"," DECEMBER"
310       FOR I=1 TO 12
320         READ MONTH$(I)
330       NEXT I
340       INPUT "JULIAN DAY OF FIRST RECORD";DOY
```

```
350       FOR I= 1 TO 13 : IF DOY<=JULIAN(I) GOTO 360 : NEXT I
360       MONTH = I
370       INPUT "Symonds pan reading at start ";PAN
380       INPUT "FILE REQUIRED (eg. ''B:MARCH.DAT )";FILE$
390  OPEN "I",#1,FILE$
400  OPEN "O",#2,"D:DAILY.DAT"
410  GOSUB 2290 ------------------------------------------------------------
420      RECORD=1 : TIME=100
430   IF RECORD=1 AND EOF(1)=0 THEN INPUT #1,A$ ELSE IF EOF(1) GOTO 1860
440  RECORD=1
450      IF MID$(A$,4,4)="0118" THEN GOSUB 2950 : 'rainfall
460      K=0 : IF EOF(1) GOTO 1860
470      P=LEN(A$)
480      FOR I=1 TO P STEP 10
490        K=K+1
500        IF  MID$(A$,I+2,6)="+????." THEN MID$(A$,I+2,6)="-9999."
510        X(K)=VAL(MID$(A$,I+2,7)) : PRINT X(K);
520      NEXT I
530      IF MID$(A$,1,2)= "01" THEN INPUT #1,A$  : GOTO 470
540      NUM=K
550      PRINT A$
560      IF X(1)=131 GOTO 890   : REM DAILY VALUES >>>>>>>>>>>>>>>>>>>>>>>>>
570 REM ................................................      HOURLY VALUES
580       IF X(2)=100 OR TIME=100 THEN GOSUB 1900
590       PRINT #2,
600       IF X(2)=0 THEN X(2)=2400
610       IF X(2)<> TIME THEN GOSUB 2660
620       PRINT #2, TAB(15) USING "###";TIME/100;
630       TIME=TIME+100
640       X(6)=X(6)+800  : 'add 800mb to barometer reading
645       X(3)=(X(3)+.145)*1000 : 'add correction & convert to W/m2
646       X(4)=X(4)+1.6  : 'correction to temp
647       X(5)=X(5)/10   : 'convert to kPa
650      FOR I=3 TO 10
655         IF X(I)<-99 THEN X(I)=-99.99 : GOTO 690
670         Z(1,I)=Z(1,I)+X(I)
680         Z(2,I)=Z(2,I)+1
690      NEXT I
700      PRINT #2, USING "#######.";X(3);     :'radiation (W/m2)
710      PRINT #2, USING "#####.##";X(4);     :'temp
720      PRINT #2, USING "######.##";X(5);    :'vap press
```

```
730       PRINT #2, USING "######.##";X(6);     :'atm press
740       PRINT #2, USING "#####.##";X(7);      :'wind speed
750       IF X(8)<0 THEN ALPHA=1 ELSE ALPHA=INT(X(8)/45)+2
760       PRINT #2, USING "\   \";DIR$(ALPHA); :'wind direction
770       IF X(9)>0 THEN PRINT #2, USING "#####.##";X(9); ELSE PRINT #2,
          "         ";
780        GOSUB 2160
790        PRINT #2, USING "######.##";EP;
800        PRINT #2, "        "; : ' USING "#####.##";X(10);
810        IF X(2)>0 THEN N=INT(X(2)/100) ELSE PRINT "TIME=";X(2)
820        FOR I=1 TO 5
830          IF X(I+2)<-99 GOTO 870
840          SX(I,N)=SX(I,N)+X(I+2)
850          SQ(I,N)=SQ(I,N)+X(I+2)^2
860          SN(I,N)=SN(I,N)+1
870        NEXT I
880        GOTO 430
890    REM ..................................................DAILY VALUES
900 PRINT #2, TAB(15) : FOR I=1 TO 80 : PRINT #2, CHR$(95); : NEXT I
910 PRINT #2,
920 PRINT #2, TAB(14) "Mean";
930 PRINT #2, USING "#####.#";Z(1,3)/Z(2,3); : RADTN=Z(1,3)/Z(2,3)
940 PRINT #2, USING "####.##";Z(1,4)/Z(2,4);
950 PRINT #2, USING "#######.##";Z(1,5)/Z(2,5);Z(1,6)/Z(2,6);Z(1,7)/Z(2,7);
960 PRINT #2,
970 PRINT #2, TAB(15) "Total";: FOR I=1 TO 31 : PRINT #2,CHR$(95);: NEXT I
980 PRINT #2, TAB(65) USING "######.##";Z(1,9);EVAP;
990        FOR I=1 TO 2
1000          FOR J=1 TO 16
1010            Z(I,J)=0
1020          NEXT J
1030        NEXT I
1040   REM ................(MEANS , MAX & MIN + times)....... DAILY VALUES
1050       INPUT #1,A$ : P=LEN(A$) : K=NUM
1060       PRINT A$ : IF MID$(A$,1,2)<>"17" THEN PRINT #2, "WRONG RECORD"
1070       FOR I=1 TO P STEP 10
1080         K=K+1
1090         X(K)=VAL(MID$(A$,I+2,6))
1100         IF X(K)<-99 THEN X(K)=X(K)/100
1110       NEXT I
1120       NUM=K
```

```
1125  PRINT #2, TAB(65) USING "######.##";X(23)
1130  PRINT #2, : PRINT #2, : PRINT #2,CHR$(27)+CHR$(69);
1140  PRINT #2, TAB(15) "Total Radiation "; : X(4)=X(4)+.145
1150  PRINT #2, USING"#####.##"; RADTN*.0864 ; X(4)*86.4;
1160  PRINT #2, "  MJ/m";CHR$(27)+CHR$(83)+CHR$(0);"2"; : PRINT #2,
1170  PRINT #2, CHR$(27)+CHR$(84); CHR$(27)+CHR$(69);
1180  PRINT #2, TAB(15) "Extremes                 Mean      Maximum     time
       Minimum     time"
1190  PRINT #2, TAB(15);
1200  FOR I=1 TO 75 : PRINT #2, CHR$(95); : NEXT I : PRINT #2,
1210  PRINT #2, TAB(15) "AIR TEMPERATURE  ";CHR$(27)+"F";
1215   X(5)=X(5)+1.6 : X(9)=X(9)+1.6 : X(17)=X(17)+1.6
1220  PRINT #2, USING "########.##";X(5);X(9);X(10)/100;X(17);X(18)/100
1230  PRINT #2, CHR$(27)+CHR$(69); TAB(15) "VAPOUR PRESSURE   ";
        CHR$(27)+"F";
1240  PRINT #2, USING "########.##";X(6)/10;X(11)/10;X(12)/100;X(19)/10;
        X(20)/100
1250  PRINT #2, CHR$(27)+CHR$(69); TAB(15) "BAROMETER PRESSURE";
        CHR$(27)+"F";
1260   X(7)=X(7)+800 : X(13)=X(13)+800 : X(21)=X(21)+800
1270  PRINT #2, USING "########.##";X(7);X(13);X(14)/100;X(21);X(22)/100
1280  PRINT #2, CHR$(27)+CHR$(69); TAB(15) "WIND SPEED        ";
        CHR$(27)+"F";
1290  PRINT #2, USING "########.##";X(8);X(15);X(16)/100 : PRINT #2,
        TAB(15);
1300  FOR I=1 TO 75 : PRINT #2, CHR$(95); : NEXT I : PRINT #2,
1310  REM ............................................ WIND HISTOGRAM
1320      INPUT #1,A$   : P=LEN(A$)
1330      IF MID$(A$,1,2)<>"25" THEN PRINT A$ : STOP
1340      FOR I=1 TO P STEP 10
1350        K=K+1
1360           REM   K=VAL(MID$(A$,I,2))
1370        X(K)=VAL(MID$(A$,I+2,6))
1380      NEXT I
1390      NUM=K
1400       PRINT #2,
1410       PRINT #2, : PRINT #2, CHR$(27)+CHR$(69);
1420       PRINT #2, TAB(15) "WIND-DIRECTION ";
1430       PRINT #2, CHR$(15) "   RELATIVE FREQUENCY(%) IN 45 degree
           SECTORS"
1440       PRINT #2,
```

```
1450        PRINT#2, TAB(25); : FOR I=1 TO 75 : PRINT #2, CHR$(95); : NEXT I
1460        PRINT #2,
1470        PRINT #2, TAB(25) "Sectors    0   >   45   >   90   >   135   >
            180   >   225   >   270   >   315   >   360";
1480        PRINT #2, : PRINT #2, TAB(25) "Frequency";
1490        S=0 : N=1
1500        FOR I=25 TO 32
1510          IF X(I)<0 THEN X(I)=-.9999
1520          IF X(I)<S THEN GOTO 1550
1530          N=I-23
1540          S=X(I)
1550          PRINT #2, USING "#######.##";X(I)*100;
1560        NEXT I
1570        ALPHA=N
1580        TIME=100 : DOY = X(3)+1
1590        PRINT #2, CHR$(18)
1600        PRINT #2, : PRINT #2, TAB(25);
1610        IF ALPHA<0 THEN PRINT #2, "Highest frequency ->  -99.99 " ELSE
              PRINT #2, "Highest frequency -> ";DIR$(ALPHA)
1620 PRINT #3,CHR$(15);
1630 PRINT #3, TAB(1) USING "####";DATE;          : MON(1)=MON(1)+1
1640 PRINT #3, USING "#####.##";X(4)*86.4;       : MON(2)=MON(2)+X(4)*86.4
1650 PRINT #3, USING "#####.##";X(5);            : MON(3)=MON(3)+X(5)
1660 PRINT #3, USING "#####.##";X(9);            : MON(4)=MON(4)+X(9)
1670 PRINT #3, USING "#####.##";X(17);           : MON(5)=MON(5)+X(17)
1680 PRINT #3, USING "#####.##";X(6)/10;         : MON(6)=MON(6)+X(6)/10
1690 PRINT #3, USING "#####.##";X(11)/10;        : MON(7)=MON(7)+X(11)/10
1700 PRINT #3, USING "#####.##";X(19)/10;        : MON(8)=MON(8)+X(19)/10
1710 PRINT #3, USING "#######.##";X(7);          : MON(9)=MON(9)+X(7)
1720 PRINT #3, USING "#######.##";X(13);         : MON(10)=MON(10)+X(13)
1730 PRINT #3, USING "#######.##";X(21);         : MON(11)=MON(11)+X(21)
1740 PRINT #3, USING "#####.##";X(8);            : MON(12)=MON(12)+X(8)
1750 PRINT #3, USING "#####.##";X(15);           : MON(13)=MON(13)+X(15)
1760 PRINT #3, USING "   \    \";DIR$(ALPHA);    : MON(14)=MON(14)+ALPHA
1770 IF X(23)=0 THEN PRINT #3,"          "; ELSE
                    PRINT #3, USING "#####.##";X(23);
1780                                               MON(15)=MON(15)+X(23)
1790 IF EVAP =0 THEN PRINT #3, "          "; ELSE
                    PRINT #3, USING "#####.##";EVAP;
1800 MON(16)=MON(16)+EVAP : EVAP = 0
1810 'IF X(24)=0 THEN PRINT #3, "          "; ELSE
```

```
                    PRINT #3,USInG "#####.##";X(24);
1820                                              MON(17)=MON(17)+X(24)
1830 PRINT #3, CHR$(18)
1840   IF MID$(A$,1,2) = "01" THEN RECORD = 0
1850   IF FIN=0 GOTO 430
1860   GOSUB 2520
1870   GOSUB 2720
1880   CLOSE
1890   STOP   : END
```

```
1900   REM ....................................SUBROUTINE TO PRINT HEADINGS
1910   PRINT #2, CHR$(12); : PRINT #2, CHR$(27)+CHR$(69)
1930   PRINT #2, "                              UNIVERSITY  of  ZULULAND"
1940   PRINT #2, "                             DEPARTMENT   of   HYDROLOGY"
1950   PRINT #2,
1960   PRINT #2, CHR$(14);"       Station 622 - UNIZULU CAMPUS"
1970   PRINT #2, CHR$(20) : PRINT #2, CHR$(27)+CHR$(70)
1980   YR=YEAR-1900
1990   FOR I=1 TO 13
2000     IF DOY<= JULIAN(I) GOTO 2020
2010   NEXT I
2020   IF DOY=JULIAN(I) THEN FIN=1
2030   I=I-1
2040   MONTH=I
2050   DATE= DOY-JULIAN(I)
2060   IF DATE=1 THEN FIN=0
2070  PRINT #2, TAB(15) "Date :";DATE;"/";MONTH$(I);"/";YEAR,TAB(68);"DOY
       :"; DOY 2080  PRINT #2,
2090  PRINT #2, CHR$(27)+"x"+CHR$(0);
2100  PRINT #2, CHR$(27)+CHR$(77);
2110  PRINT #2, TAB(15) " Time   Radtn   Temp   Vapour  Barometer   Wind
         Rainfall    Ep     Pan"
2120   PRINT #2, TAB(15) "         ";CHR$(27); CHR$(83); CHR$(0); "2";
         SPC(4); "o";
2130   PRINT #2,  CHR$(27)+CHR$(84);"C    press(mb)   (mb)    m/s    ";
         CHR$(237); "     mm/hr   mm/hr   mm/hr"
2140    PRINT #2, CHR$(27)+CHR$(70);
2150  RETURN
2160 REM ....................................POTENTIAL EVAPOTRANSPIRATION
2170   TEMP=X(4)+273.15 : RAD=X(3) : VA=X(5)/10 : 'vap pres=va (kPa)
2180   IF X(3)<0 OR X(4)<-99  THEN ER=0 : GOTO 2205
2190   CONST=.4019914 + .017251 * X(4) - .0001485 * X(4) * X(4)
                                                         :'s/(s+gamma)
2200   IF RAD<148 THEN ER=0 ELSE ER=CONST * ((RAD-148)/.88)/LAMBDA*3.6
                                                         :'W/m^2
2205   IF X(4)<-99 OR X(5)<9 OR X(7)<9 THEN EV=0 : GOTO 2260
2210   RH=(LOG((HEIGHT-.64 * CROP)/ZO))^2/(.41 *.41 * X(7))
2220   EVS=EXP(52.57633-6790.4985#/TEMP-5.02808*LOG(TEMP))
                                                   :' sat vap pres (kPa)
2230   DIF=EVS-VA : IF DIF<0 THEN DIF=0 : 'vap pres deficit kPa
2240   DIF=DIF/.000462/TEMP : ' vap den deficit  g/m^3
```

```
2250   EV=(1-CONST)*DIF/RH *3.6 :'(g/m^2/s)*3600s/hr*e-06m^3/g
2260   EP=ER+EV : 'PRINT USING "####.##";RH;EVS;VA;DIF;EV;CONST;ER
2270   EVAP=EVAP+EP
2280   RETURN
2290 REM ..............................................MONTHLY SUMMARY
2310   OPEN "O",#3,"D:MONTHLY.DAT"  : ' MONTHLY SUMMARY IN FILE #3
2320   PRINT #3, CHR$(27)+CHR$(72); :'SET DRAFT MODE
2330   PRINT #3, CHR$(24);          :'CLEAR PRINT BUFFER
2340   PRINT #3, CHR$(18);          :'CLEAR CONDENSED MODE
2350   PRINT #3, CHR$(20);          :'CLEAR ENLARGED MODE
2360   FOR I=1 TO 13
2370     IF DOY<= JULIAN(I) GOTO 2390
2380   NEXT I
2390   MONTH=I-1 : DATE=DOY-JULIAN(I-1)
2400   PRINT #3, CHR$(12)
2410   PRINT #3, CHR$(27);CHR$(69)
2420   PRINT #3, "                         UNIVERSITY  of  ZULULAND"
2430   PRINT #3, "                          DEPARTMENT OF HYDROLOGY"
2440   PRINT #3,
2450   PRINT #3, CHR$(14);"    Station 622 - UNIZULU CAMPUS" : PRINT #3,
2460   PRINT #3, TAB(20);MONTH$(MONTH);"-";YEAR;
2470   PRINT #3, TAB(50);"file <";FILE$;">" : PRINT #3,
2480   PRINT #3, CHR$(27)+CHR$(70) : PRINT #3, CHR$(15);
2490   PRINT #3, TAB(1) " Day   Radtn     Temperature (C)       Vapour
                 Pressure (mb)     barometric pressure (mb)   wind speed
                 and dir     Rain     Ep"
2500   PRINT #3, TAB(1) "        MJ/m2   mean    max     min     mean    max
                 min         mean        max      min      mean      max  (deg)
                 (mm)     (mm)"
2510  RETURN
2520 ' MONTHLY SUMMARY
2530   FIN=0
2540   PRINT #3, CHR$(15)
2550   PRINT #3, TAB(1) "Mean";
2560   FOR J=2 TO 13
2570     IF J=9 THEN PRINT #3,"  "; ELSE
             IF J=10 THEN PRINT #3,"  "; ELSE
                IF J=11 THEN PRINT #3,"  ";
2580     PRINT #3, USING "#####.##";MON(J)/MON(1);
2590   NEXT J
2600   PRINT #3, USING "   \   \";DIR$(INT(MON(14)/45)+2);
```

```
2610 IF MON(15)=0 THEN PRINT #3,"          "; ELSE PRINT #3,USING "######.#";
       MON(15);
2620 IF MON(16)=0 THEN PRINT #3,"          "; ELSE PRINT #3,USING "######.#";
       MON(16);
2630'IF MON(17)=0 THEN PRINT #3,"          "; ELSE PRINT #3,USING "######.#";
      MON(17);
2640  PRINT #3,
2650  RETURN
2660 REM ..........................................Missing times
2670      FOR I=TIME+100 TO X(2)-100 STEP 100
2680         PRINT #2, USING "###";I/100
2690      NEXT I
2700      TIME=X(2)
2710      RETURN
2720 REM ...........................................Hourly means
2730      PRINT #3, CHR$(12);
2740      PRINT #3,
2750      PRINT #3,
2760      PRINT #3, TAB(10);FILE$ : PRINT #3, TAB(10);"MEAN HOURLY VAL"
2770      PRINT #3, "      Time   Radiation  Temperature  Vap Pres
               Barometer  Wind speed "
2780      FOR I=1 TO 24
2790        PRINT #3, USING "#########.##";I;SX(1,I)/SN(1,I);
2800        PRINT #3, USING "#########.##";SX(2,I)/SN(2,I);
2810        PRINT #3, USING "#########.##";SX(3,I)/SN(3,I);
2820        PRINT #3, USING "#########.##";SX(4,I)/SN(4,I);
2830        PRINT #3, USING "#########.##";SX(5,I)/SN(5,I)
2840      NEXT I
2850      PRINT #3, : PRINT #3, : PRINT #3, TAB(10);"STANDARD DEVIATION"
                    : PRINT #2,
2860      'STANDARD DEVIATION
2870      FOR I=1 TO 24
2880        FOR J=1 TO 5
2890          SQ(J,I)=SQR((SQ(J,I)-(SX(J,I)^2/SN(J,I)))/(SN(J,I)-1))
2900          IF SN(J,I)<2 THEN SQ(J,I)=-999.99
2910        NEXT J
2920  PRINT #3, USING "#########.##";I;SQ(1,I);SQ(2,I);SQ(3,I); SQ(4,I);
                                  SQ(5,I)
2930      NEXT I
2940      RETURN
```

```
2950 REM 15 min rainfall data
2960      IF EOF(1) = 0 THEN INPUT #1,A$  ELSE GOTO 1860
2970      RECORD=1 : PRINT A$
2980      IF MID$(A$,4,4)="0118" GOTO 2960 : 'rainfall
2990   RETURN
3000  PRINT #3, TAB(50);"file <";FILE$;">" : PRINT #3,
3010  EP=ER+EV : 'PRINT USING "####.##";RH;EVS;VA;DIF;EV;CONST;ER
```

APPENDIX III

DESIGN, CONSTRUCTION AND RATING OF WEIR W1H031

An abandoned dam wall situated several hundred meters outside the Ngoye Nature Reserve boundary provided the opportunity to design and construct a weir which would monitor the discharge from an undisturbed catchment. The control structure was designated W1H031 and was designed as a compound sharp crested weir (Figure III,1, see Figure III,2) to accommodate direct comparisons with W1H016 (Figure III,3). A parapet in the centre of the weir was included to protect the instrument housing which was built directly over the existing stilling well. The lowest notch is fitted with a sharp crested 90° v-notch for accurate low flow monitoring.

The weir was surveyed and rated by the Department of Water Affairs on June 20, 1989. The station identification is given in Table III,1. The discharge table, approach velocity, cross-sectional area, and other relevant information are given in Table III,2, to Table III,4. The rating curve for W1H031 is shown in Figure III,4 together with the corresponding curve for W1H016. Both weirs have identical discharge rating for the V-notch above which they deviate slightly.

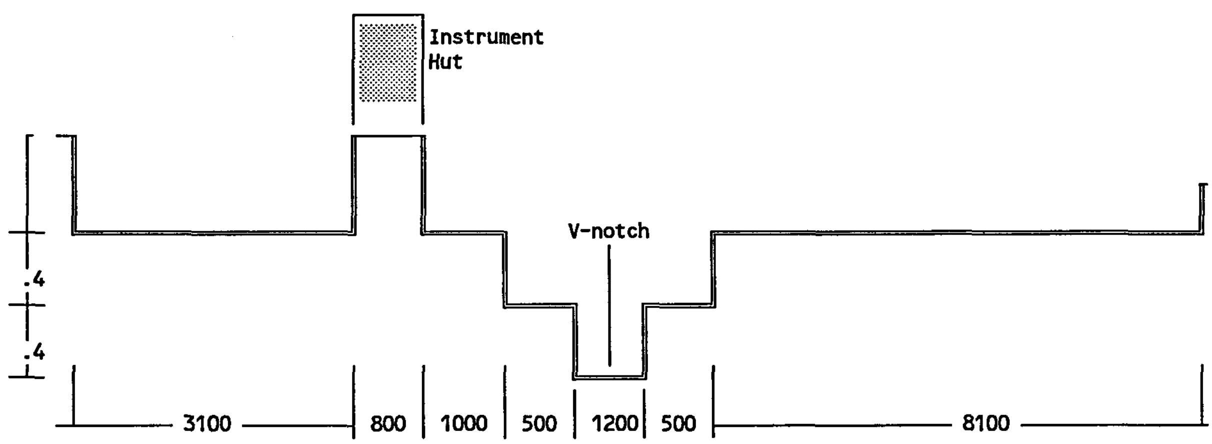

Figure III,1 The cross-sectional profile of weir W1H03, with dimensions in metres.

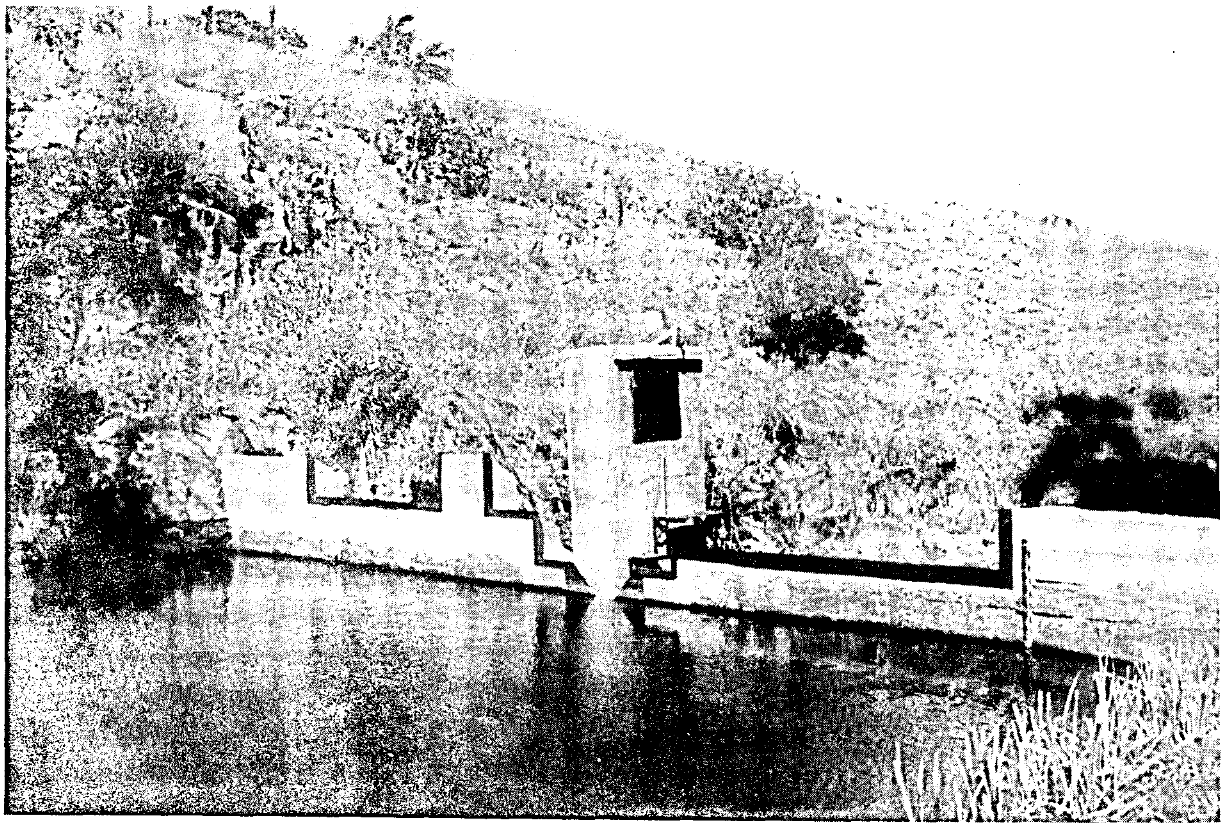

Figure III,2 View of the cross-sectional profile of W1H031.

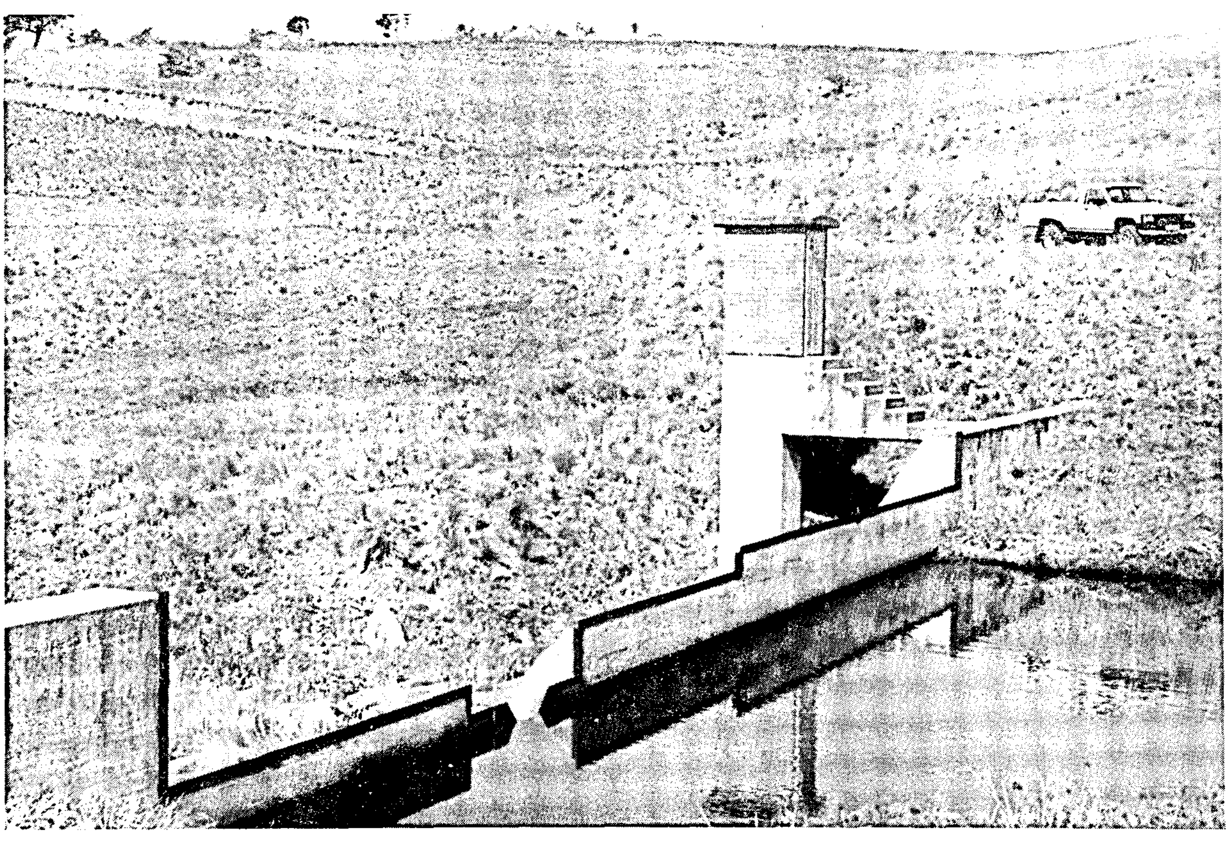

Figure III,3 View of cross-sectional profile of W1H016.

Table III,1 Weir W1H031 Information

Gauging station number	Amanzi
Name of river	Amanzimnyama
Name of Place	Mission School
Date of rating	June 20, 1989
Table type	Weir with 6 notches
Table limit	1.19 m

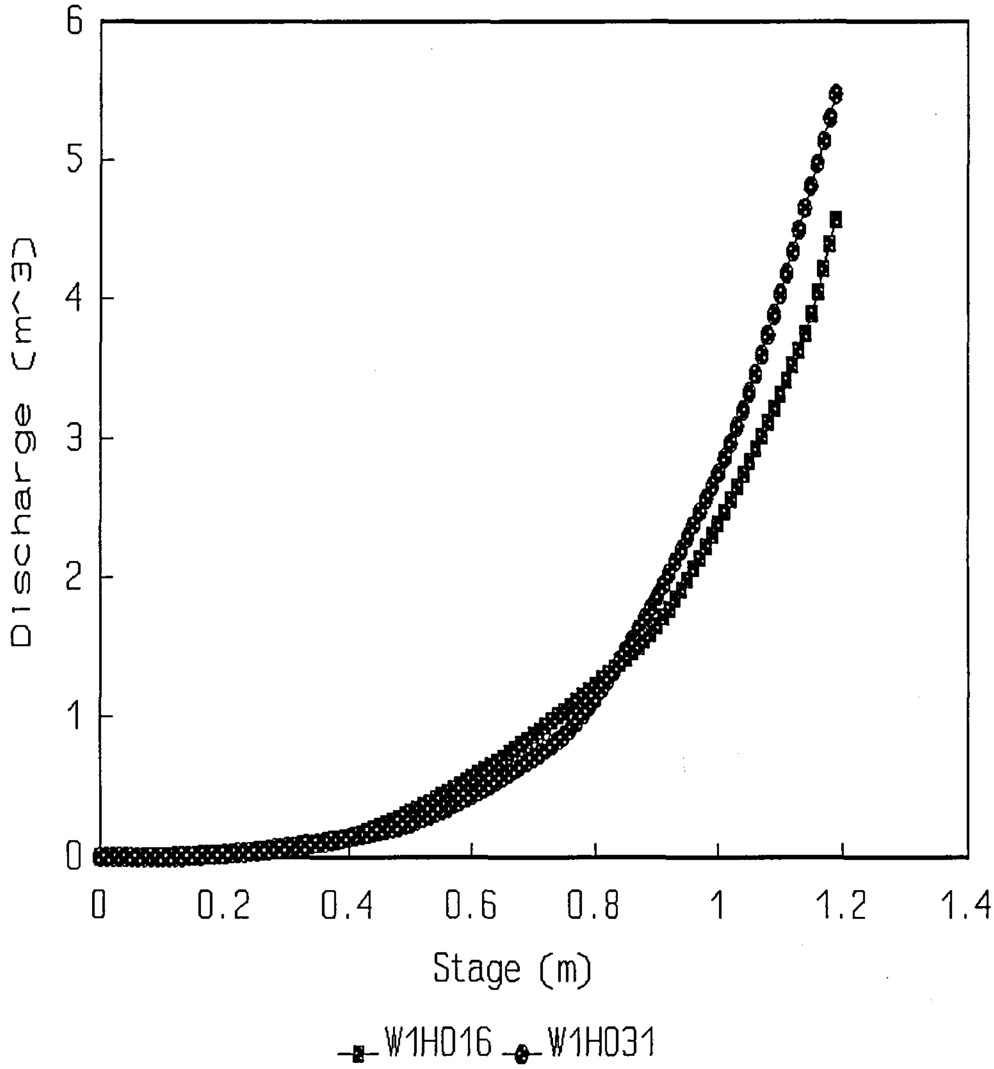

Figure III,4 The rating curves for W1H016 and W1H031.

Table III,2 Rating Table for W1H031; Discharge in m^3/s (CUMEC) for 0.01m rise in water level (H)

H	0.00	+0.01	+0.02	+0.03	+0.04	+0.05	+0.06	+0.07	+0.08	+0.09
1	0.0000	0.0000	0.0001	0.0002	0.0005	0.0008	0.0013	0.0019	0.0026	0.0035
2	0.0045	0.0058	0.0071	0.0087	0.0104	0.0124	0.0145	0.0169	0.0194	0.0222
3	0.0252	0.0284	0.0319	0.0356	0.0395	0.0437	0.0482	0.0529	0.0579	0.0631
4	0.0685	0.0744	0.0805	0.0868	0.0935	0.1004	0.1076	0.1152	0.1230	0.1314
5	0.1425	0.1564	0.1714	0.1874	0.2041	0.2218	0.2404	0.2596	0.2796	0.3005
6	0.244	0.259	0.277	0.295	0.314	0.335	0.355	0.377	0.400	0.423
7	0.446	0.471	0.495	0.521	0.547	0.573	0.601	0.628	0.656	0.685
8	0.715	0.745	0.775	0.806	0.838	0.872	0.916	0.966	1.019	1.076
9	1.136	1.198	1.264	1.331	1.401	1.473	1.546	1.622	1.699	1.778
10	1.859	1.941	2.025	2.111	2.198	2.287	2.377	2.469	2.562	2.656
11	2.754	2.856	2.968	3.087	3.210	3.337	3.469	3.606	3.746	3.889
12	4.035	4.184	4.336	4.491	4.648	4.808	4.970	5.135	5.302	5.472

Table III,3 W1H031 Velocity tables for 0.01m rise in water level (H)

H	0.00	+0.01	+0.02	+0.03	+0.04	+0.05	+0.06	+0.07	+0.08	+0.09
1				21E-6	43E-6	74E-6	11E-5	16E-5	23E-5	30E-5
2	38E-5	47E-5	58E-5	70E-5	83E-5	97E-5	11E-4	13E-4	15E-4	16E-4
3	18E-4	21E-4	23E-4	25E-4	27E-4	30E-4	33E-4	35E-4	38E-4	41E-4
4	44E-4	48E-4	51E-4	54E-4	58E-4	61E-4	65E-4	69E-4	73E-4	77E-4
5	81E-4	85E-4	89E-4	93E-4	98E-4	0.010	0.011	0.011	0.012	0.020
6	0.013	0.013	0.014	0.015	0.016	0.016	0.017	0.018	0.019	0.020
7	0.021	0.022	0.023	0.024	0.025	0.026	0.027	0.028	0.029	0.029
8	0.030	0.031	0.032	0.033	0.034	0.036	0.037	0.039	0.040	0.042
9	0.044	0.046	0.048	0.051	0.053	0.055	0.057	0.060	0.062	0.064
10	0.067	0.069	0.071	0.074	0.076	0.079	0.081	0.084	0.086	0.089
11	0.091	0.094	0.097	0.100	0.103	0.106	0.110	0.113	0.117	0.120
12	0.124	0.128	0.131	0.135	0.139	0.142	0.146	0.150	0.154	0.157

APPENDIX IV

INSTRUMENTATION AT WEIRS W1H016 AND W1H031

The newly commissioned weir at W1H031 was fitted with an OTT water level recorder similar to those fitted at all the other weirs in the research catchments. The charts from these recorders are changed weekly and digitised by the HRU_Z. The digitised data is checked for gross errors (backward time steps, etc) and then distributed to the CCWR. Unfortunately this form of error checking is not sufficient and further checks are needed. During the data processing, other errors are observed and corrected. Some of these errors are noted in this report. The digitised data for 1988-1989 for W1H016 & W1H031 have been processed and the daily summary of discharge has been presented under separate cover by Kelbe (1990).

An ISCO automatic water sampler was installed at both W1H016 & W1H031 to obtain flow related samples. The pen release arm within the OTT water level recorders, which are installed at all weirs, was used as a trigger mechanism (microswitch) to activate the ISCO water samplers. This mechanism operated from August 1988 to January 1989 but was not satisfactory.

A Cambell Scientific Datalogger (CR10), interfaced to a GEOKON vibrating wire piezometer and a tipping bucket raingauge, were subsequently installed at W1H016 and W1H031 and used to activate the water sampler (Figure IV,1). The CR10 was chosen because it allowed several additional features that simplified data processing and it provided several channels that could be used for other sensors such as temperature, conductivity, pH, and possibly turbidity. The HRU_Z has had difficulty in obtaining the services of competent people or students to complete the digitisation of autographic charts. The utilisation of the CR10 dataloggers is being considered as a means of overcoming this problem as the loggers store the data in computer compatible form that is easily transferred directly to computers. Unfortunately, these systems are sophisticated electronic devices which require highly skilled technicians to maintain them. Regular maintenance is required because of the corrosive coastal environment which causes frequent contact failure.

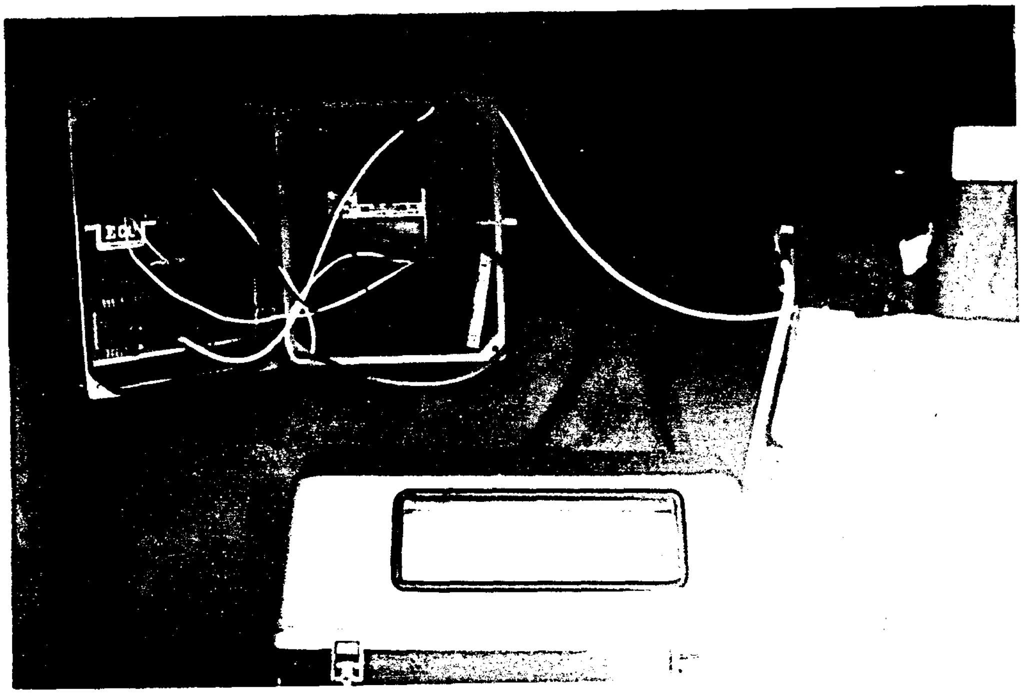

Figure IV,1 CR10 installation at weir W1H031

IV-1 CR10 DATALOGGER

The data logger for the automatic discharge/sampler stations consisted of the basic CR10 unit described in appendix II. The CR10 is housed in a standard electrical fibre box mounted on the wall of the instrument hut at each weir. The box is sealed to reduce the corrosive effect of the coastal environment. The rainfall is monitored by a tipping bucket raingauge which is mounted on the roof of the instrument hut. The piezometer rests on the floor of the stilling well and monitors the pressure and temperature of the water which is than converted to depth relative to the bottom of the V-notch on each weir through appropriate calibrations.

The memory allocations for the two weir stations are given in Table IV,1 while the input locations are shown in Table IV,2. The piezometer at W1H016 was replaced by a one-turn potentiometer half bridge while it was sent for repairs. Input locations 7, 8, and 9 were used to monitor the voltage of the potentiometer and the number of revolutions that it had accumulated in one direction in order to calculate the actual stage. A flow diagram of the CR10 program for both weirs is shown in Figure IV,2 while the program listing is given in program IV-1. The AC half bridge program is included at the end of the program listing as an insert for the main program listed.

TABLE IV-1 Memory allocations.

MEMORY ALLOCATIONS	W1H016	W1H031
Input storage	28	28
Intermediate storage	64	64
Final storage : Area 2	1500	1500
: Area 1	3832	3832
Remaining program memory	1632	1632

The CR10 is programmed to provide mean hourly values of selected variables which are derived from 360 measurements at 10 second intervals as well as mean daily values derived from 8640 measurements. Each 80 character record comprises eight fields which are formatted as follows;

01+xxxx. 02+xxxx. 03+xxxx. 04+xxxx..... 07+xxxx. 08+xxxx.

The first two digits refer to the field number and the **xxxx.** fields refer to the values of the selected variable. The different fields for the hourly and daily records are given in Table IV,3 to Table IV,5.

Table IV,2 Input location fields for both stations.

Location	Field or parameter	Units
1	Geokon Temperature	C
2	pressure	psi
3	Pressure	psi
4	Temp - Temp(0)*constant	C
5	Stage	ft
6	STAGE	m
7	STAGE (Potentiometer)	m
8	Previous STAGE (+ No revolutions)	m
9	No Revolutions of POT for Stage	
10		
11		
12		
13	RAINFALL	mm
14		
15		
16	CUMULATIVE DISCHARGE	m^3
17	ACTUAL DISCHARGE	m^3
18	Battery Voltage	V
19	RAINFALL	mm

IV-2 Calibration of the piezometers

The GEOKON vibrating wire piezometers utilise the change in frequency of a vibrating wire attached to a pressure diaphragm. Measurements are made using the signal conditioning provided in the Cambell Scientific Inc AVW1 interface. Subsequent information from the agents indicate that the piezometers can be linked to the CR10 data logger directly as shown in Figure IV,3, with only minor changes to the CR10 program.

Three of the GEOKON vibrating wire piezometers were calibrated

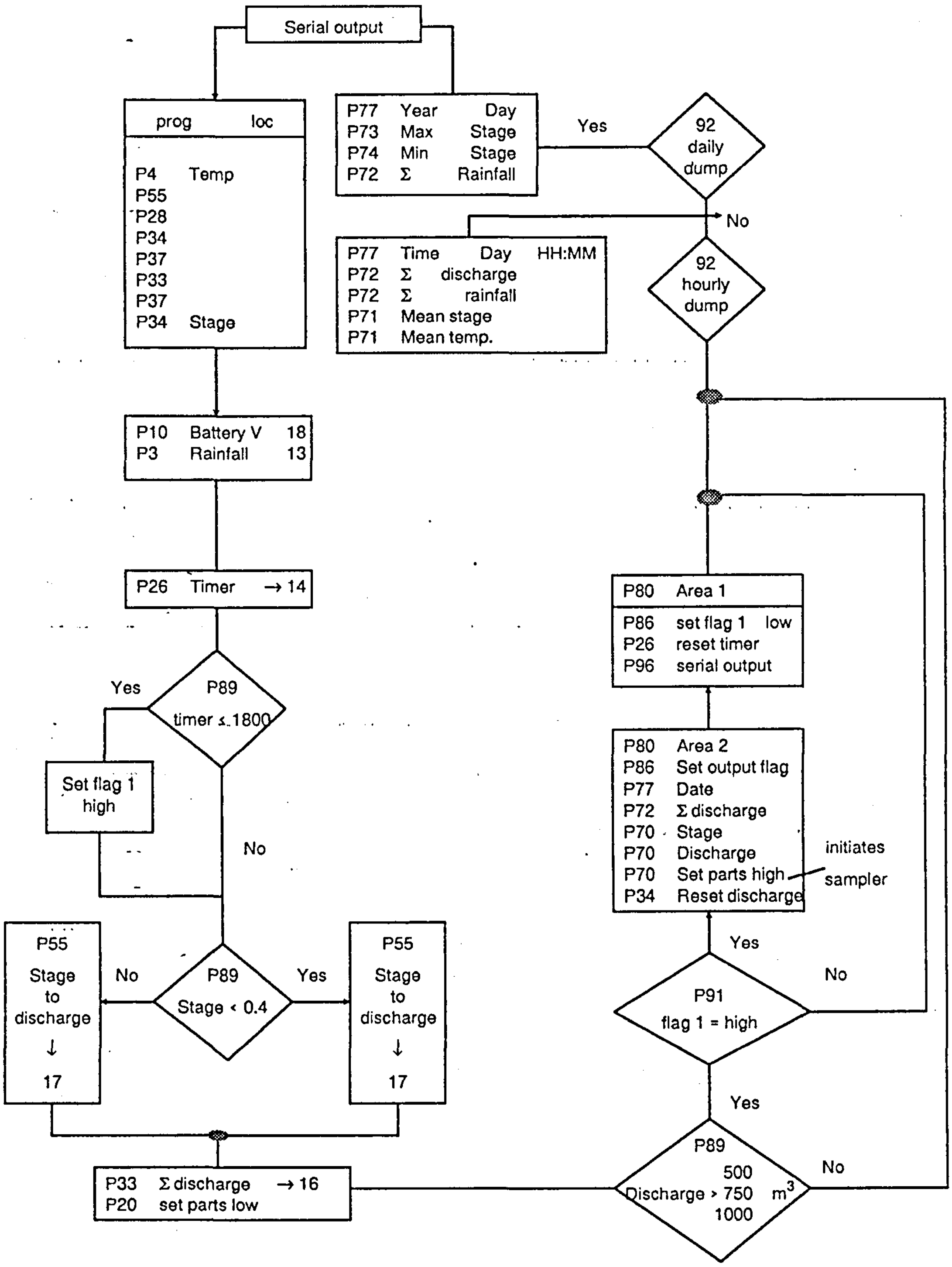

Figure IV,2 Flow diagram of the CR10 program for both weirs.

Table IV,3 Fields for HOURLY records

Field	Data
01	Program location for initiating dump to final memory.
02	Day of the year
03	Hours:Minutes
04	Cumulative Discharge for the hour
05	Cumulative rainfall for the hour
06	Mean stage
07	Mean Temperature of stilling well

Table IV,4 Fields for DAILY records

FIELD	DATA
01	Program location for initiating dump to final memory.
02	Year
03	Day of the Year
04	Mean stage for the day
05	Maximum stage and time of maximum stage
06	Minimum stage and time of minimum stage
07	Cumulative rainfall for the day

in the laboratory water tank before installation in the field. The calibration curve for all three are shown in Figure IV,4. Analysis of variance gave a r^2 of better than 99.97% in all three cases.

IV-3 Stage - discharge equations for the CR10

The stage (and temperature) in the stilling well at both weirs, as well as the rainfall from a gauge on the instrument housing roof, are recorded by the CR10 at specified intervals. The CR10 uses the stage to calculate the discharge (m^3/10s) from a 5-term polynomial equation. The data logger integrates the discharge

Table IV,5 Fields for SAMPLING records

Field	Data
01	Program location for initiating dump to final memory.
02	Day of the year (Julian Day)
03	Time (HHMM)
04	Cumulative discharge
05	Stage
06	Discharge

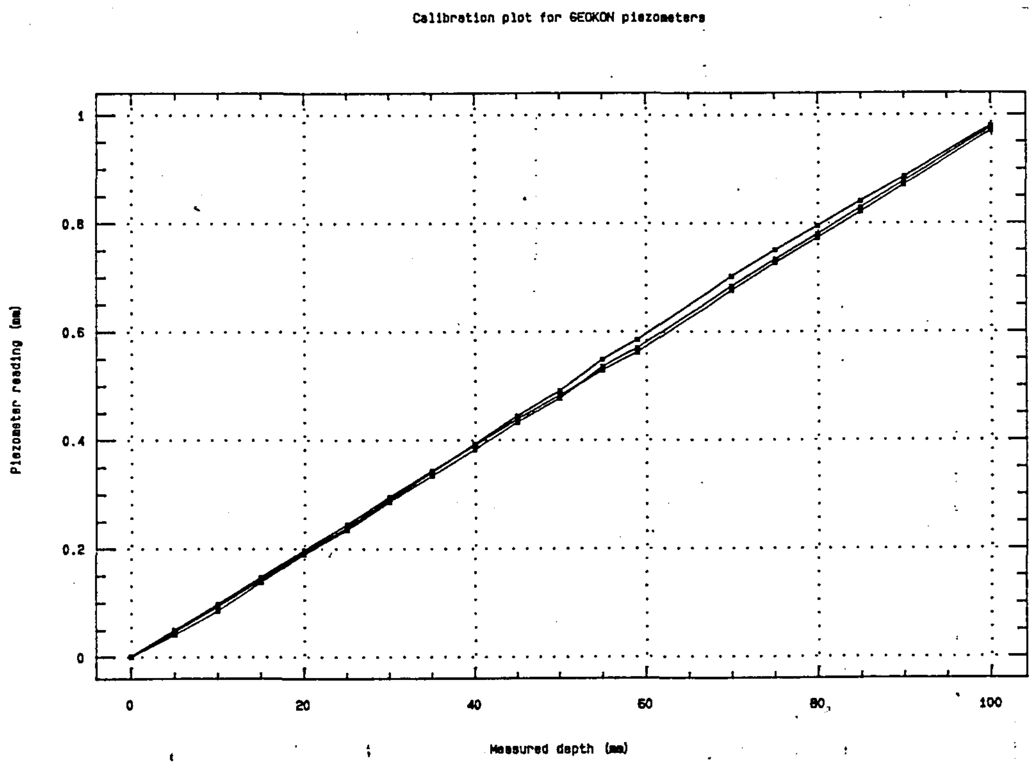

Figure IV,4 Calibration of piezometers

with time and is programmed to activate the ISCO sampler (control port) after a specified volume of water has been recorded. The CR10 program was changed on several occasions to accommodate different size flood events. Unfortunately, no simple flow volume was suitable for the full range of flood hydrographs. Consequently, the CR10 was programmed to activate the ISCO sampler after every 500m^3 of discharge provided the sample

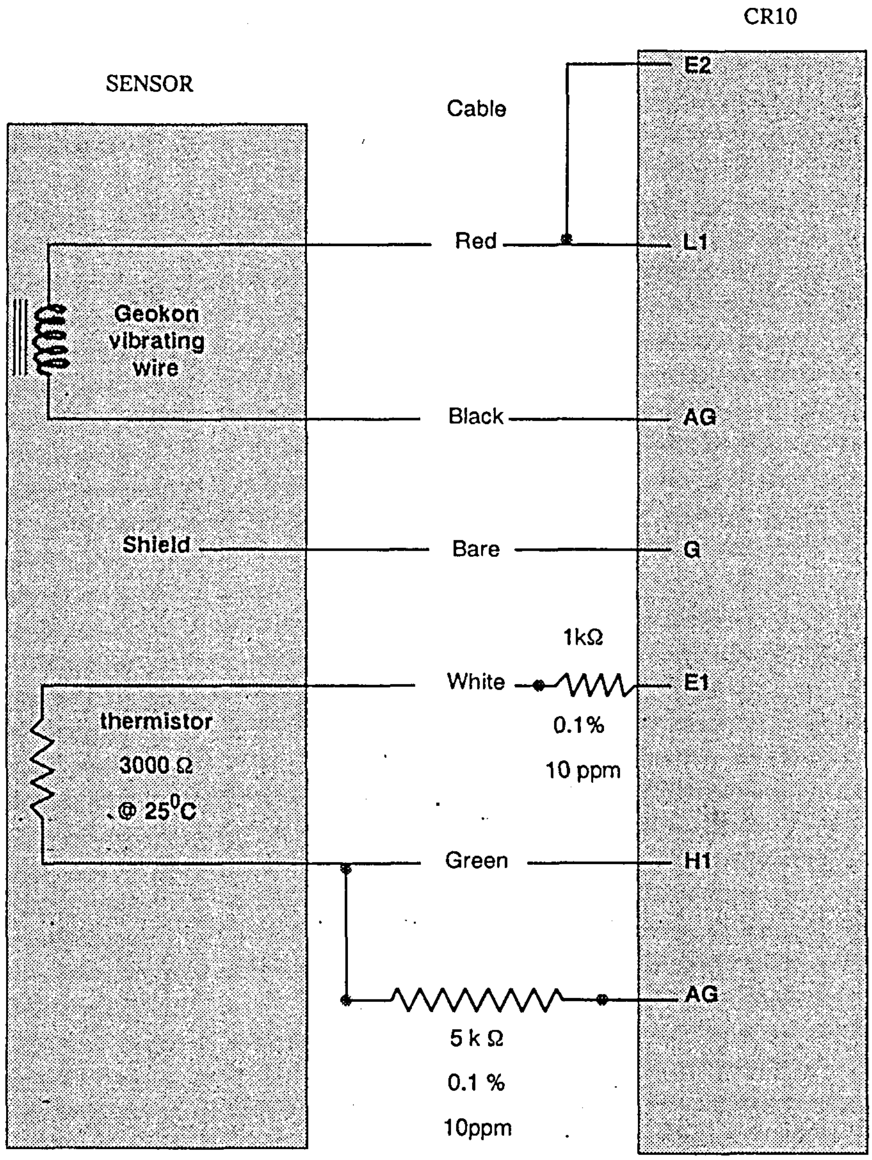

Figure IV,3 Schematic diagram of the piezometer/CR10 connection.

interval did not exceed 30 minutes. This limited the collection of samples to half hourly intervals during large storm events. It also provided sufficient samples to analyze small flood events. The changes to the program are shown in Table IV,6.

The CR10 recorded the time, date, stage and discharge volume of every time the water sampler was activated (even if the sampler did not respond or was full). The sample bottles were collected after each storm event and either analyzed by the HRU_Z or they were sent to the Division of Water Technology, CSIR, Durban.

The stage-discharge relationship (appendix III) was divided into two section because the 5-term polynomial regression equation for the full range of stages did not give sufficient accuracy at the lower range of discharge. Both sections were fitted to 5-term polynomial equations and used in the CR10 datalogger to derive discharge. The polynomial coefficients are given in Table IV,7 for W1H016 & W1H031. A plot of the predicted discharge against the rated values is shown in Figure IV,4.

Table IV,6 Calendar of events and program changes for CR10 stations.

DATE	LOCATION	EVENT	
	W1H031	Set piezometer offset to	-1.115 m
	W1H016	Set piezometer offset to	-1.290 m
	both	Set sampling volume to	500 m^3
	both	Change sampling volume to	1000 m^3
5/ 1/90	both	Change sampling volume to	750 m^3
22/ 1/90	W1H031	Change piezometer offset to	-1.143 m
18/ 4/90	W1H031	"	-1.410 m
23/ 4/90	W1H016	"	-1.319 m
	W1H031	"	-1.415 m
8/ 5/90	both	Change to variable sample volume >500 m^3	
/90	W1H016	Change piezometer offset to	-3.390 m
/ 8/90	W1H016	"	-2.650 m
24/ 8/90	"	"	-2.850 m
3/10/90	"	"	-3.380 m
15/10/90	W1H016	Change piezometer offset to	-3.500 m
/90	w1h016	Remove piezometer for repairs	
/90	W1H016	Incorporate 1-turn potentiometer	

Table IV,7 Polynomial regression coefficients for stage-discharge

--------------- WEIR W1H016 ------------------		
Interval	0 < Stage < 0.4m	0.4 < Stage
Constant	-0.000156	+4.9400
Stage^1	+0.01552	-37.3845
Stage^2	-0.1253	+106.0893
Stage^3	+5.4997	-137.3884
Stage^4	-13.1353	+85.0548
Stage^5	+13.6428	-18.9519

--------------- WEIR W1H031 ------------------		
Interval	0 < Stage < 0.4m	0.4 < Stage
Constant	-0.000156	+3.1812
Stage^1	+0.01552	+20.9874
Stage^3	-0.1253	-51.4205
Stage^3	+5.4997	+60.1298
Stage^4	-13.1353	-31.0795
Stage^5	+13.6428	+7.3356

IV-4 ISCO WATER SAMPLER

The collection of water samples commenced in August 1988 and was operational until January 1989. Unfortunately this method was not entirely reliable and it was difficult to link the time of sample to the stage on several occasions. Consequently, Cambell Scientific CR10 dataloggers coupled to Geokon piezometers were obtained to monitor discharge continuously and to activate the ISCO water samplers after a specified volume of discharge had occurred in order to provide flow related samples.

The dataloggers, with some accessories were acquired during 1988. Unfortunately severe problems with the initial equipment (faulty piezometers and interface cards) and services by the agent delayed the development of this system until June 1989.

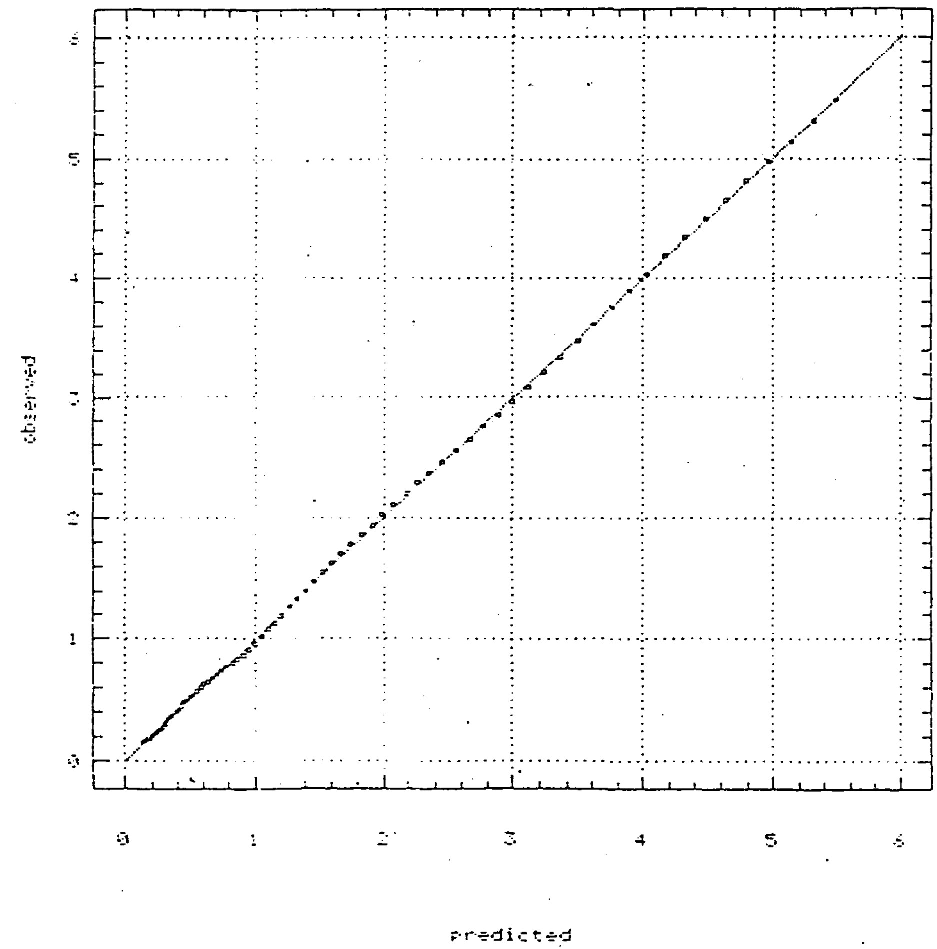

Figure IV,5 Predicted and actual stage-discharge relationship

The dataloggers, connected to a vibrating wire piezometer and tipping bucket raingauge, have now been developed to initiate sampling after a certain discharge has been reached. The system is programmed to record the time and the stage for each sample.

The ISCO programmes were devised to overcome the length of piping to the sample point (weir outlet) and the varying heads during the changing hydrograph. The programme for both stations is shown in Table IV,8.

IV-5 DATA PROCESSING

The CR10 is programmed to dump the data for both memory allocation table to cassette tape at regular intervals. This data is collected when the sample bottles are changed, or at other appropriate times, and transferred to the HRU_Z data bank. All the

Table IV,8 ISCO sampler programs

Program step		Program mode/value	
	Station	**W1H016**	**W1H031**
1.	Mode	flow	flow
2.	Interval between samples	1 min	1 min
3.	Blank in flow mode		
4.	Nominal sample volume	15	
5.	Type of suction line	3/8" by 25'	1/4" by 25'
6.	Suction Head	3'	3'
7.	Multiplex mode	samples	
8.		2	2

data relating to the water samples are transferred to files with the nomenclature W??SAMYY.DOY, where ?? refers to the weir (either 16 or 31), YY is the year and doy is the day of the year (julian day) when the data was dumped (samples collected). The other data comprises the hourly and daily values which are stored in files with the name W??mmmYY where mmm refers to the month.

The hourly and daily data from both weirs is processed using the BASIC program given in Program IV-2. This processed data has been published under separate cover (Kelbe, 1989). An example of the form for the daily and hourly processed data is shown in Table IV,9 and Table IV,10 respectively. The program also provides mean hourly values of discharge, stage and stilling well temperature together with the total hourly rainfall for each hour of the day (Table IV,11).

Table IV.9 Monthly summaries of daily data for W1H016 and W1H031.

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DEPARTMENT OF HYDROLOGY

WIER # W1H 16

JANUARY - 1990 file <d:w16jan90>

Day	Discharge (m^3/day)	Rain (mm)	Stage (m) with extremes & times Mean	Max @	(hhmm)	Min @	(hhmm)	Temp C
1	4536		0.267	0.325	0	0.236	2354	22.25
2	2955		0.225	0.242	1201	0.210	2118	23.46
3	2370	0.2	0.206	0.218	1733	0.196	2356	24.12
4	2004		0.192	0.214	1457	0.182	2327	24.34
5	1630		0.180	0.190	1023	0.173	2357	24.38
6	1498	1.2	0.171	0.178	1656	0.159	2056	25.05
7	1861	15.4	0.185	0.244	2359	0.162	113	23.61
8	3295	1.0	0.235	0.257	226	0.206	2358	20.13
9	1986		0.192	0.206	1	0.175	2355	21.33
10	1941	14.0	0.188	0.264	2358	0.173	1324	22.12
11	3820	1.8	0.249	0.289	114	0.212	2352	20.65
12	3281	7.0	0.234	0.268	354	0.206	0	21.76
13	2058		0.195	0.207	1	0.181	2354	23.92
14	1697		0.180	0.183	1232	0.178	1900	23.89
15	1644		0.178	0.182	1209	0.172	2349	23.69
16	1434		0.168	0.173	916	0.161	2112	23.99
17	1254		0.159	0.165	203	0.151	2115	24.79
18	1069		0.149	0.157	1257	0.141	2029	25.18
19	903		0.140	0.148	907	0.130	2325	25.50
20	3096	27.6	0.224	0.294	512	0.130	13	23.63
21	1860		0.186	0.208	1	0.173	2359	22.66
22	1353		0.164	0.173	26	0.153	2100	23.69
23	1153		0.154	0.156	2359	0.152	1720	24.51
24	1338	26.2	0.161	0.361	0	0.149	1920	24.37
25	13087	23.4	0.393	0.466	1005	0.320	152	23.16
26	4307		0.260	0.321	0	0.214	2352	23.93
27	2296	4.2	0.203	0.215	2	0.194	2004	24.57
28	2678	3.6	0.217	0.227	1514	0.204	9	23.04
29	2495	0.2	0.210	0.219	230	0.195	2359	23.51
30	1800		0.184	0.196	1	0.171	2242	24.64
31	1338		0.164	0.173	14	0.153	2333	25.68
Mean			0.200	0.230		0.181		23.60
Total	78037	125.8						

where (hhmm) refers to the TIME of maximum

Table IV,10 Hourly values for selected month for W1H016 and W1H031.

UNIVERSITY of ZULULAND
DEPARTMENT of HYDROLOGY

WIER # W1H 16

Date : 1 / JANUARY / 1990 **DOY : 1**

Time (hr)	Discharge (m^3/hr)	Rain (mm/hr)	Stage (m)	Temp (°C)	pH	Turb	Cond	SS	NO_3
1	290.0		0.320	21.95		.	.	.	.
2	270.6		0.311	21.82		.	.	.	.
3	254.1		0.303	21.70		.	.	.	.
4	239.8		0.296	21.63		.	.	.	.
5	227.8		0.290	21.52		.	.	.	.
6	217.2		0.285	21.39		.	.	.	.
7	209.6		0.280	21.33		.	.	.	.
8	203.8		0.277	21.42		.	.	.	.
9	198.8		0.274	21.58		.	.	.	.
10	193.8		0.272	21.72		.	.	.	.
11	188.7		0.269	21.92		.	.	.	.
12	183.4		0.266	22.10		.	.	.	.
13	178.1		0.262	22.23		.	.	.	.
14	173.4		0.259	22.36		.	.	.	.
15	168.1		0.256	22.52		.	.	.	.
16	163.4		0.253	22.67		.	.	.	.
17	159.0		0.250	22.79		.	.	.	.
18	154.5		0.247	22.88		.	.	.	.
19	150.3		0.245	22.97		.	.	.	.
20	147.1		0.243	23.05		.	.	.	.
21	144.3		0.241	23.11		.	.	.	.
22	141.9		0.239	23.17		.	.	.	.
23	140.1		0.238	23.19		.	.	.	.
24	138.5		0.237	23.09		.	.	.	.
MEAN	189.0		0.27	22.25					
TOTAL		0.0							

Extremes

MAX STAGE & TIME	0.325	0
MIN STAGE & TIME	0.236	2354
RAINFALL	0.00 (mm)	
RUNOFF	4536 (m^3/day)	

Table IV,11 Example of the means and total for each HOUR of the DAY during a month.

d:wl6jan90

MEAN HOURLY VALUES

Time hh.mm	Discharge m^3	Rainfall mm	Stage m	Temperature C
1.00	106.93	2.00	0.20	23.64
2.00	103.62	0.80	0.20	23.49
3.00	103.24	12.80	0.20	23.32
4.00	105.12	12.00	0.20	23.11
5.00	105.91	11.20	0.20	22.92
6.00	106.94	2.60	0.21	22.75
7.00	106.74	11.80	0.20	22.66
8.00	116.69	2.00	0.21	22.72
9.00	116.83	3.20	0.21	22.83
10.00	120.29	1.60	0.21	22.96
11.00	119.61	0.00	0.21	23.15
12.00	118.19	0.20	0.21	23.37
13.00	115.31	1.00	0.20	23.60
14.00	112.19	6.80	0.20	23.82
15.00	110.02	0.80	0.20	23.99
16.00	106.61	0.80	0.20	24.14
17.00	102.09	6.80	0.20	24.23
18.00	98.63	0.20	0.20	24.27
19.00	93.63	1.40	0.19	24.32
20.00	90.21	3.20	0.19	24.35
21.00	88.26	11.00	0.19	24.34
22.00	88.67	7.20	0.19	24.28
23.00	88.89	13.00	0.19	24.14
24.00	92.74	13.40	0.19	23.95
STANDARD DEVIATION				
1.00	80.90	0.26	0.05	1.65
2.00	70.27	0.09	0.05	1.63
3.00	70.32	1.55	0.05	1.58
4.00	73.23	1.90	0.05	1.53
5.00	67.37	1.83	0.05	1.47
6.00	67.08	0.33	0.05	1.43
7.00	70.06	2.08	0.05	1.41
8.00	117.74	0.29	0.06	1.39
9.00	133.52	0.50	0.06	1.36
10.00	141.20	0.22	0.06	1.31
11.00	147.88	0.00	0.06	1.30
12.00	147.68	0.04	0.06	1.32
13.00	139.80	0.12	0.06	1.35
14.00	130.58	0.97	0.06	1.37
15.00	125.89	0.10	0.06	1.40
16.00	115.54	0.11	0.05	1.41
17.00	104.87	0.91	0.05	1.40
18.00	94.23	0.04	0.05	1.44
19.00	79.20	0.18	0.05	1.49
20.00	69.56	0.36	0.04	1.56
21.00	62.53	1.28	0.04	1.65
22.00	58.02	0.53	0.04	1.73
23.00	55.12	1.98	0.04	1.73

PROGRAM IV-1

```
01   P04  GEOKON VIBRATING WIRE (mV with excitation)
     01   1          reps
     02   15         2500 mV fast range
     03   1          sensor channel #
     04   1          exc channel # (channel 1 if no interface)
     05   1          delay for excitation
     06   2500-      excitation voltage
     07   1          input location for storage (TEMP)
     08   -0.001     multiplier
     09   0.000      offset

02   P55  GEOKON VIBRATING WIRE (polynomial)
     01   1          reps
     02   1          X location TEMP
     03   1          F(X) loc (:TEMP  C)
     04   -104.78    CO
     05   378.11     C1
     06   -611.59    C2
     07   544.27     C3
     08   -240.91    C4
     09   43.089     C5

03   P28  GEOKON VIBRATING WIRE (Sensor # 8228)
     01   1          Reps
     02   2          sensor channel #
     03   2          excitation channel #
     04   34         starting frequency
     05   40         end frequency
     06   500        # cycles
     07   00         Rep delay
     08   2          input location for storage (PRESS psi)
     09   -2.848     multiplier (Gage factor 0.002848)
     10   44.517     offset (Zero reading 15631)

04   P34  GEOKON VIBRATING WIRE (Z = X + F)
     01   1          X location (TEMP)
     02   -19        F calibration "TEMP" in C
     03   4          input location Z = (T-To)*C

05   P37  GEOKON VIBRATING WIRE (Z = X * F)
     01   3          location of X [(T-To)*C]
     02   -0.00256   F (temp coefficient)
     03   4          input location of Z = (T-To)*C
```

```
06     P33   GEOKON VIBRATING WIRE (Z = X + Y )
       01    2          location of X (press)
       02    4          location of Y = (T-To)*C
       03    3          input location of Z [Pt psi]

07     P37   GEOKON VIBRATING WIRE (Z=X*F convert psi -> ft)
       01    3          location of X [ Pt psi]
       02    0.70308    F CORRECTION ft to m H2O
       03    5          input location of Z (-Pt mm H2O)

08     P34   GEOKON VIBRATING WIRE (Z=X+F add depth of well)
       01    5          location of X (-Pt mm H2O)
       02    -1.280     Offset (NB - set for each installation)
       03    6          location of Z [DISTANCE IN mm]

09     P10   Battery Voltage
       01    18         location

10     P03   RAINFALL (pulse counts)
       01    1          reps
       02    2          sensor channel # (pulse)
       03    2          switch closure
       04    13         input location for storage
       05    0.20       multiplier
       06    0.00       offset

11     P03   RAINFALL (pulse counts)
       01    1          reps
       02    2          sensor channel # (pulse)
       03    2          switch closure
       04    19         input location for storage
       05    0.20       multiplier
       06    0.00       offset

12     P72   Total rainfall
       01    1          rep
       02    19         rainfall

13     P89   If
       01    6          stage
       02    4          <
       03    0.4        THEN
       04    30         DO ------------------------------------------+
                                                                     |
14     55    Polynomial (stage -> discharge)                         |
       01    1          reps                                         |
       02    6          stage location (m)                           |
```

```
      03   17         discharge location (m^3)
      04   0.00002    constant coefficient
      05   0.1552
      06   -1.2529
      07   54.4997
      08   -131.35
      08   136.43

15    P94  ELSE

16    P55  Polynomial (stage -> discharge)
      01   1          reps
      02   6          stage location (m)
      03   17         discharge location (m^3)
      04              constant coefficient
      05   -373.84
      06   1060.89
      07   -1373.88
      08   850.50
      09   -189.50

17    95   End IF

18    P33  X+Y : Cumulative discharge
      01   16         input location cumulative discharge Q
      02   17         input location actual discharge Qa
      03   16         input location cumulative discharge (Q+Qa)

19    P20  Set Port 4
      01   0000
      02   0000       LOW

20    P89  IF
      01   16         Cumulative discharge
      02   3          >=
      03   500.0      FIXED VALUE OF DISCHARGE
      04   30         DO LOOP - SAMPLES

21    P80  Set active storage
      01   02         Area 2
      02   0

22    P86  Set output flag
      01   10

23    P77  Time
      01   1110       Year:DOY:HH:MM
```

```
24   P72  Total rainfall
     01   1          rep
     02   19         rainfall

25   P70  Sample stage
     01   1          reps
     02   6          stage location

26   P70  Sample discharge
     01   1          reps
     02   17         discharge location

27   P20  SET PORT 4 ( OUTPUT 5 volts)
     01   0          PORTs 8-7-6-5 LOW
     02   1000       PORT 4 set HIGH & 3-2-1 LOW

28   P34  Reset cumulative discharge
     01              input location cumulative discharge
     02   -500.0     NEGATIVE value of F
     03              (Qt-Q)

29   P96  Dump to tape
     01   00         when 512 final storage location full

30   P95  END OF DO LOOP - SAMPLES

31   P92  IF Time
     01   0          mins
     02   60         into hour
     03   10         SET OUTPUT FLAG

32   P77  If TIME
     01   10         DOY:HH:MM

33   P72  TOTALIZE
     01   1          reps
     02   17         Discharge

34   P72  TOTALIZE
     13   Rainfall

35   P71  AVERAGE
     01   1          reps
     02   6          Stage
```

```
36   P92   IF TIME
     01    00          mins
     02    1440        into the day
     03    10          SET OUTPUT FLAG

37   P77   TIME
     01    1100        YEAR:DOY

38   P72   TOTALIZE
     01    13          Rainfall

39   P73   MAXIMUM
     01    1           reps
     02    10          with time
     03    6           Stage

40   P74   MINIMUM
     01    1           reps
     02    10          with time
     03    6           Stage

41   P96   ACTIVATE SERIAL DATA OUTPUT
     01                Tape dump : 512 final storage location
```

With the installation of the ONE-TURN potentiometer in the OTT cabling system, measurements of the stage were obtained through the following additional programming instructions inserted between program steps 10 and 11.

```
11   P5    AC half bridge - potentiometer
     01    5           reps
     02    12          slow 2500mV range
     03    3           excitation channel
     04    2000        excitation voltage
     05    7           storage location
     06    1           multiplier (voltage = 0.0 -> 1.0)
     07    0           offset

12   P35   Subtract
     01    8           Previous reading (# revs + previous V)
     02    7           Subtract present voltage (between 0 & 1.0)
     03    9           store in location

13   P34   Add constant to
     01    9           location
     02    0.5         constant &
     03    9           store in location
```

14	P45	INT(x)	
	01	9	location of x
	02	9	number of revolutions
15	P33	Add	
	01	7	present voltage and
	02	9	number of revolutions to
	03	8	location of (# revs + voltage)
16	P37	Multiply	
	01	8	Voltage + revolutions
	02	0.075	conversion factor
	03	7	Depth or stage (m)
17	P31	Move	
	01	7	Depth or stage (m) to
	02	6	location

PROGRAM IV-2

```
10   REM                                            WEIR.BAS
20   REM *********************************************************
30   REM *                       NTUZE WEIRS W1H016 & 31          *
40   REM * PROGRAM; "WEIRS" : HYDROLOGICAL RESEARCH UNIT UNIZULU *
50   REM *                   :Prints daily & monthly summaries    *
60   REM *                                                        *
70   REM *  BRUCE KELBE :  VERSION  BK/2/90                       *
80   REM *                                                        *
90   REM *********************************************************
100  REM
110  REM
120      OPTION BASE 1
130      CLEAR
140      DIM A$(80),X(32),MON(20),JULIAN(13),MONTH$(12),Z(2,32),SX(5,24),
         SN(5,24),SQ(5,24)
150      DATA  0,    1,     2,   0.05,  2.43E03 : 'lambda in J/g
160      READ FIN,RECORD,HEIGHT,  CROP,    LAMBDA
170      ZO = .13*CROP
180      DATA "       "," NNE  "," ENE  "," ESE  "," SSE  "," SSW  "
190      DATA "  WSW  "," WNW  "," NNW  "
200      FOR I=1 TO 9
210        READ DIR$(I)
220      NEXT I
230      DATA 0,31,59,90,120,151,181,212,243,273,304,334,365
240      INPUT "YEAR";YEAR
250      INPUT "WEIR NUMBER";WEIR
260      YR=YEAR
270      FOR I=1 TO 13
280        READ JULIAN(I)
290        IF INT(YR/4)=YR/4 AND I>2 THEN JULIAN(I)=JULIAN(I)+1
300      NEXT I
310      DATA " JANUARY "," FEBRUARY","  MARCH  ","  APRIL  ","   MAY
         ","   JUNE  ", "   JULY  "," AUGUST  ","SEPTEMBER"," OCTOBER ","
         NOVEMBER"," DECEMBER"
320      FOR I=1 TO 12
330        READ MONTH$(I)
340      NEXT I
350      INPUT "JULIAN DAY OF FIRST RECORD";DOY
360      FOR I= 1 TO 13 : IF DOY<=JULIAN(I) GOTO 370 : NEXT I
370      MONTH = I
380      INPUT "FILE REQUIRED (eg. ''B:MARCH.DAT )";FILE$
390  OPEN "I",#1,FILE$
400  OPEN "O",#2,"D:DAILY.DAT"
410  GOSUB 1610
420     RECORD=1 : TIME=100
430   IF RECORD=1 AND EOF(1)=0 THEN INPUT #1,A$ ELSE IF EOF(1) GOTO 1330
440     RECORD=1
450     IF MID$(A$,1,2)="01" THEN GOTO 460 ELSE GOSUB 2310 : 'not data
460     K=0
470     P=LEN(A$)
480     FOR I=1 TO P STEP 10
490       K=K+1
500       IF  MID$(A$,I+2,6)="+????." THEN MID$(A$,I+2,6)="-9999."
510       X(K)=VAL(MID$(A$,I+2,7)) : PRINT X(K);
520     NEXT I
530     NUM=K
540     PRINT A$
550  IF X(1)>135 GOTO 820  : REM DAILY VALUES >>>>>>>>>>>>
560 REM ................................. HOURLY VALUES
570    S=X(6) : Q=X(4) : GOSUB 3000  : X(6)=S : X(4)=Q
```

```
580       IF X(3)=100 OR TIME=100 THEN GOSUB 1370
590       PRINT #2,
600       IF X(3)=0 THEN X(3)=2400
610       IF X(3)<> TIME THEN GOSUB 2000
620       PRINT #2, TAB(15) USING "###";TIME/100;
630       TIME=TIME+100
640      FOR I=4 TO 8
650        IF X(I)<-99 THEN X(I)=-99.99 : GOTO 680
660        Z(1,I)=Z(1,I)+X(I)
670        Z(2,I)=Z(2,I)+1
680      NEXT I
690      PRINT #2, USING "########.#";X(4);     :'DISCHARGE m^3/hr
700      IF X(5)=0 THEN PRINT #2,"        "; ELSE PRINT #2, USING
         "######.#";X(5);
710      PRINT #2, USING "######.###";X(6);     :'STAGE  m
720      PRINT #2, USING "#######.##";X(7);     :'TEMPERATURE C
730      PRINT #2, "      .     .     .     .";
740       IF X(3)>0 THEN N=INT(X(3)/100) ELSE PRINT "TIME = ";X(3)
750       FOR I=1 TO 5
760         IF X(I+3)<-99 GOTO 800
770         SX(I,N)=SX(I,N)+X(I+3)
780         SQ(I,N)=SQ(I,N)+X(I+3)^2
790         SN(I,N)=SN(I,N)+1
800       NEXT I
810   GOTO 430
820  REM.............................................DAILY VALUES
830 PRINT #2, TAB(15) : FOR I=1 TO 50 : PRINT #2,CHR$(95); :NEXT I
840 PRINT #2, TAB(15) "MEAN";
850 PRINT #2, USING "########.#";Z(1,4)/Z(2,4);
860 PRINT #2, TAB(35) USING "########.##";Z(1,6)/Z(2,6);Z(1,7)/Z(2,7)
870 PRINT #2, TAB(15) "TOTAL";
880 PRINT #2, TAB(27) USING "########.#";Z(1,5);
890 PRINT #2, : PRINT #2,
900 PRINT #2, CHR$(27)+CHR$(84); CHR$(27)+CHR$(69);
910  PRINT #2, TAB(15) "  Extremes---------------------------------"
911  S=X(4) : GOSUB 3000 : X(4)=S
920  PRINT #2, TAB(15) "MAX STAGE & TIME";
930  PRINT #2, USING "####.###";X(4);
940  PRINT #2, USING "  #####";X(5);
945  PRINT #2, USING "#########";Q
950  PRINT #2, TAB(15) "MIN STAGE & TIME";
951  S=X(6) : GOSUB 3000 : X(6)=S
960  PRINT #2, USING "####.###";X(6);
970  PRINT #2, USING "  #####";X(7);
975  PRINT #2, USING "#########";Q
980  PRINT #2, TAB(15) "RAINFALL        ";
990  PRINT #2, USING "####.##";X(8);
1000  PRINT #2, " (mm)"
1010  PRINT #2, TAB(15) "RUNOFF          ";
1020  PRINT #2, USING "##########";Z(1,4);
1030  PRINT #2, " (m^3/day)"
1040  PRINT #2, TAB(15) : FOR I=1 TO 50 : PRINT #2, CHR$(95); : NEXT I
1050  PRINT #2,
1060  IF X(2)<>YEAR THEN PRINT "WRONG YEAR ??????????????????????????????"
1070  IF X(3)=DOY+1 THEN GOTO 1150
1080    D=DATE
1090    FOR I=DOY+1 TO X(3)-1
1100      PRINT #3, TAB(5) USING "####";D
1110      D=D+1
1120    NEXT I
1130    DATE=D
1140    GOSUB 1370
1150    DOY=X(3)
```

```
1160 PRINT #3, TAB(5) USING "####";DATE;       : MON(1)=MON(1)+1
1170 PRINT #3, USING "##########";Z(1,4);      : MON(2)=MON(2)+Z(1,4)
1180 IF X(8)=0 THEN PRINT #3,"         "; ELSE PRINT #3, USING
    "#######.#";X(8);
1190 PRINT #3, USING "######.###";Z(1,6)/Z(2,6); :
    MON(4)=MON(4)+Z(1,6)/Z(2,6)
1200 PRINT #3, USING "####.###";X(4);          : MON(5)=MON(5)+X(4)
1210 PRINT #3, USING "######";X(5);
1220 PRINT #3, USING "#####.###";X(6);         : MON(6)=MON(6)+X(6)
1230 PRINT #3, USING "######";X(7);
1240 PRINT #3, USING "######.##";Z(1,7)/Z(2,7);  :
    MON(7)=MON(7)+Z(1,7)/Z(2,7)
1250                                              MON(3)=MON(3)+X(8)
1260 PRINT #3, CHR$(18)
1270     FOR I=1 TO 2
1280        FOR J=1 TO 16
1290          Z(I,J)=0
1300        NEXT J
1310     NEXT I
1320   IF FIN=0 GOTO 430
1330   GOSUB 1850
1340   GOSUB 2080
1350   CLOSE
1360   STOP   : END
1370   REM ..................................SUBROUTINE TO PRINT HEADINGS
1380   PRINT #2, CHR$(12); : PRINT #2, CHR$(27)+CHR$(69)
1390   PRINT #2, "                              UNIVERSITY  of  ZULULAND"
1400   PRINT #2, "                             DEPARTMENT   of   HYDROLOGY"
1410   PRINT #2,
1420   PRINT #2, TAB(26);CHR$(14);"WEIR #    W1H"; WEIR
1430   PRINT #2, CHR$(20) : PRINT #2, CHR$(27)+CHR$(70)
1440   YR=YEAR-1900
1450   FOR I=1 TO 13
1460     IF DOY<= JULIAN(I) GOTO 1480
1470   NEXT I
1480   IF DOY=JULIAN(I) THEN FIN=1
1490   I=I-1
1500   MONTH=I
1510   DATE= DOY-JULIAN(I)
1520   IF DATE=1 THEN FIN=0
1530  PRINT #2, TAB(15) "Date :";DATE;"/";MONTH$(I);"/";YEAR,TAB(68);"DOY
      :";DOY
1540  PRINT #2,
1550  PRINT #2, CHR$(27)+"x"+CHR$(0);
1560  PRINT #2, CHR$(27)+CHR$(77);
1570  PRINT #2, TAB(15) " Time  Discharge  Rainfall  Stage   Temp    pH
      Turb  Cond    SQ   NO3"
1580  PRINT #2, TAB(15) "(hr)  (m^3/hr)   (mm/hr)    (m)     (C) "
1590  PRINT #2, CHR$(27)+CHR$(70);
1600  RETURN
1610 REM ............................................ MONTHLY SUMMARY
1620 ' MONTHLY SUMMARY IN FILE #3
1630   OPEN "O",#3,"D:MONTHLY.DAT"
1640   PRINT #3, CHR$(27)+CHR$(72); :'SET DRAFT MODE
1650   PRINT #3, CHR$(24);          :'CLEAR PRINT BUFFER
1660   PRINT #3, CHR$(18);          :'CLEAR CONDENSED MODE
1670   PRINT #3, CHR$(20);          :'CLEAR ENLARGED MODEL
1680   FOR I=1 TO 13
1690     IF DOY<= JULIAN(I) GOTO 1710
1700   NEXT I
1710   MONTH=I-1 : DATE=DOY-JULIAN(I-1)
1720   PRINT #3, CHR$(12)
```

```
1730  PRINT #3, CHR$(27);CHR$(69)
1740  PRINT #3, "          UNIVERSITY  of  ZULULAND"
1750  PRINT #3, "          DEPARTMENT OF HYDROLOGY"
1760  PRINT #3,
1770  PRINT #3, TAB(26);CHR$(14);"WEIR # W1H";WEIR : PRINT #3,
1780  PRINT #3, TAB(20);MONTH$(MONTH);"-";YEAR;
1790  PRINT #3, TAB(50);"file <";FILE$;">" : PRINT #3,
1800 ' PRINT #3, CHR$(27)+CHR$(70) : PRINT #3, CHR$(15);
1810  PRINT #3, TAB(5) " Day   Discharge   Rain     Stage (m) with
      extremes & times        Temp"
1820  PRINT #3, TAB(5) "       (m^3/day)   (mm)     Mean    Max @ (hhmm)
      Min @ (hhmm)      C"
1830  PRINT #3, TAB(5) "-----------------------------------------"
1840 RETURN
1850 ' MONTHLY SUMMARY
1860  FIN=0
1870  PRINT #3,
1880  PRINT #3, TAB(5) "Mean                    ";
1890 PRINT #3, USING "######.###";MON(4)/MON(1);
1900 PRINT #3, USING "####.###";MON(5)/MON(1);
1910 PRINT #3, "       ";
1920 PRINT #3, USING "####.###";MON(6)/MON(1);
1930 PRINT #3, "       ";
1940 PRINT #3, USING "#####.##";MON(7)/MON(1)
1950  PRINT #3, TAB(5) "Total";
1960 PRINT #3, USING "#########";MON(2);
1970 PRINT #3, USING "#######.#";MON(3)
1980  PRINT #3,
1990  RETURN
2000 REM .....................................................Missing times
2010       FOR I=TIME+100 TO X(3)-100 STEP 100
2020        PRINT #2, TAB(15) USING "###";I/100;
2030        PRINT #2, TAB(34) ".      .      .     .   .   .    ."
2040       NEXT I
2050       TIME=X(3)
2060       IF DOY<>X(2) THEN DOY=X(2) : GOSUB 1370
2070       RETURN
2080 REM .....................................................Hourly means
2090       PRINT #3, CHR$(12);
2100       PRINT #3,
2110       PRINT #3,
2120       PRINT #3, TAB(10);FILE$ : PRINT #3, TAB(10);"MEAN HOURLY
           VALUES"
2130 PRINT #3, "        Time     Discharge    Rainfall     Stage
     Temperature"
2140 PRINT #3, "        hh.mm     m^3          mm             m        C"
2150       FOR I=1 TO 24
2160         PRINT #3, USING "#########.##";I;SX(1,I)/SN(1,I);
2170         PRINT #3, USING "#########.##";SX(2,I);
2180         PRINT #3, USING "#########.##";SX(3,I)/SN(3,I);
2190         PRINT #3, USING "#########.##";SX(4,I)/SN(4,I)
2200       NEXT I
2210       PRINT #3, : PRINT #3, : PRINT #3, TAB(10);"STANDARD DEVIATION"
           : PRINT #2,
2220       'STANDARD DEVIATION
2230       FOR I=1 TO 24
2240         FOR J=1 TO 4
2250           SQ(J,I)=SQR((SQ(J,I)-(SX(J,I)^2/SN(J,I)))/(SN(J,I)-1))
2260           IF SN(J,I)<2 THEN SQ(J,I)=-999.99
2270         NEXT J
2280       PRINT #3, USING
           "#########.##";I;SQ(1,I);SQ(2,I);SQ(3,I);SQ(4,I)
2290       NEXT I
```

```
2300        RETURN
2310 REM ISCO SAMPLES OR UNKNOWN STATEMENT
2320     IF EOF(1) = 0 THEN INPUT #1,A$  ELSE GOTO 1330
2330     RECORD=1 : PRINT A$
2340     IF MID$(A$,1,2)="01" THEN RETURN ELSE GOTO 2320
2350   RETURN
2360   PRINT #2, USING "##########";Z(1,4);
3000     'correction to stage etc for W1H031 DURING MARCH\APRIL
3010      IF WEIR=16 OR DOY<86 OR DOY>108 THEN RETURN
3020      IF DOY=86 AND TIME<1300  THEN RETURN
3030      IF DOY=108 AND TIME>1200  THEN RETURN
3040      IF WEIR <>31 THEN STOP
3045      S=S-.162
3050      IF S>.4 GOTO 3080
3060      Q=.1552*S-1.2529*S^2+54.997*S^3-131.35*S^4+136.43*S^5
3070      GOTO 3090
3080      Q=-31.81+209.87*S-514.2*S^2+601.3*S^3-310.79*S^4+73.36*S^5
3090      Q=Q*6*60 : ' m^3/s
3100   RETURN
```

APPENDIX V

ANALYTICAL TECHNIQUES FOR WATER SAMPLE ANALYSES

During the course of this project, the HRU_z acquired, through the University, several pieces of equipment to conduct chemical and physical measurements of water samples. The developed of a water analyses laboratory was considered necessary in order to supplement the water analyses under taken by the Division of Water Technology (DWT), CSIR for this project. Since only selected samples from suitable storm hydrographs were analyzed by DWT, the remaining samples would have been discarded. Consequently the HRU_z developed the water analyses laboratory to extend the analyses to those samples not sent to DWT. However, direct comparison of the results between the two laboratories would be complicated if the analytical techniques were not compatible. This appendix outlines the procedure use by HRU_z and provides some comparisons.

Several samples were kindly analyzed by ALUSAF, Richards Bay, for particle size distribution. The frequency distribution from some of these measurements are shown in this appendix.

1. INSTRUMENTATION

Only the instrumentation and procedures at the HRU_z laboratory used in the analyses presented in this report are described here.

pH - field model Hanna H18014 with the Hanna liquid combination pH electrode HI1211 was used when calibrated against standard buffers of pH 7 and pH 8.

Conductivity meter - Schott Gerate CG857 field model.

Turbidity - Hach Ratio Turbidimeter Model 18900. The 90° scatte red light beam passing through the water sample is factored against the transmitted light signal. The output of the detector system is a ratio of the 90° scattered detector signal to an electronically weighted sum of the transmitted and forward signals.

2. ANALYTICAL PROCEDURES

In an effort to determine any significant difference in analytical results between the measurements from DWT and HRU_z compatible sets of readings were compared for the turbidity.

While the instrument at both laboratories may give identical reading, the sample preparation procedures at both establishment were different. Consequently it was necessary to compare the measurements for the two procedures. The DWT method of sample analysis involved shaking the sample followed by a stand over period of 1 minute. At the HRU_z the shaken sample was allowed to stand for 24 hours. Since no measurements were conducted on the same set of samples by both laboratories both procedures were employed on a regular basis by HRU_z from August 1990. A comparison of the two set of results done by the HRU_z using both methods of sample preparation are shown in Figure V,1 for sets of samples from two different storms. The comparative plot for the one storm indicates a good relationship between the two methods for the samples from catchment W1H016. The other storm however shows a very poor relationship. The scatterplot (Figure V,2) for W1H031 indicates a very poor correlation between the two methods. The cause and effect of these results need further investigation as they will have a considerable effect on comparisons when the measurements are from different procedures. They may also indicate the relative concentrations of particles size (terminal velocities).

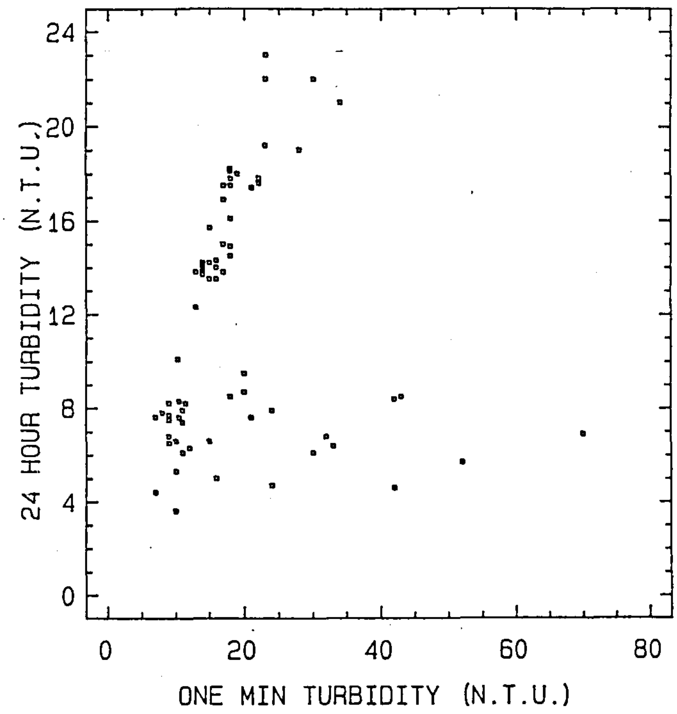

Figure V,1 **A scatterplot of turbidity measurements by HRU_z for two sample preparation methods (for W1H016).**

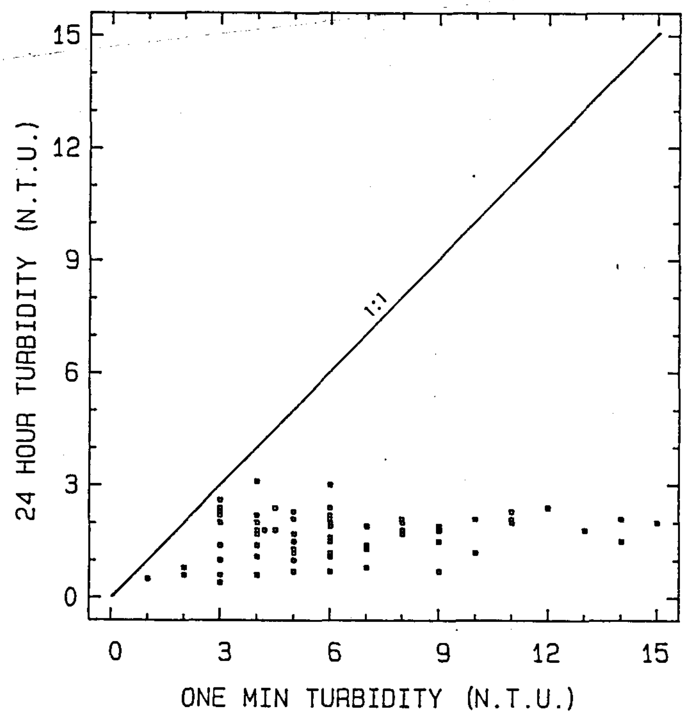

Figure V,2 **A scatterplot of turbidity measurements by HRU_z for two sample preparation methods (for W1H031)**