FINAL REPORT

QUANTIFICATION OF THE EFFECTS OF LAND-USE ON RUNOFF WATER QUALITY IN SELECTED CATCHMENTS IN NATAL

by

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LIST OF ABBREVIATIONS

Cl	chloride
COD	chemical oxygen demand
COND	conductivity
DOC	dissolved organic carbon
HU	Hazen units (measure of colour intensity)
kg/ha/a	kilograms/hectare/annum
mg/l	milligrams/litre
mS/m	milliSiemens/metre (measure of conductivity)
N	nitrogen
NH3	ammonia
NO3	nitrate
P	phosphorus
PN	particulate nitrogen
PP	particulate phosphorus
SP	soluble phosphorus
SKN	soluble Kjeldahl nitrogen
SS	suspended solids
TDS	total dissolved salts
TKN	total Kjeldahl nitrogen
TURB	turbidity
μg/l	micrograms/litre

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EXECUTIVE SUMMARY

1 BACKGROUND AND MOTIVATION FOR PROJECT

Various forums and bodies in Natal (Natal Town and Regional Planning Commission, Umgeni Water) identified the need for water quality planning and catchment management in the province, particularly with respect to the Mgeni River which is such a vital water resource, providing the needs of 45% of the population of the region. Since effective catchment management includes the control of both point and non-point sources of pollution, the modelling of runoff quality for different land-use scenarios in the catchment would be a useful tool. A project was then proposed by the University of Natal for the development of a distributed water quantity/quality model for the Mgeni Catchment as a management tool. But a recognised problem was that there was little information available on the effects of different land-uses such as forestry, agriculture and peri-urban settlements on runoff water quality which is essential for the calibration or verification of a water quality model. Existing water quality data consisted of grab samples from various routine river water sampling programmes. The samples, taken at set time intervals and generally at sites encompassing general land-uses could not really satisfy all the needs of the model such as runoff quality from specific land-uses and the type of flow-quality relationships to use in the model. Consequently there was a need for reliable and realistic water quality information.

The opportunity to obtain highly cost effective runoff water quality data from a number of small catchments, presented itself as an ongoing hydrological monitoring programme of catchments at the Department of Agricultural Development's Cedara research farm by the Department of Agricultural Engineering, University of Natal. Flow monitoring at the weirs was already taking place and all that was needed was an automatic sampling system to sample runoff throughout hydrographs. The present day cost of erecting such flow structures for this purpose would be prohibitive, and here was the opportunity to make use of these facilities. The land-uses of the catchments at Cedara are representative of some land-uses in the Mgeni Catchment and one under forestry and the other with smallholdings and some agriculture were chosen for study. A collaborative project with the University of Natal providing services during their routine monitoring operations was accordingly set up.

At the same time staff of the Department of Hydrology, University of Zululand were entering into a contract to investigate runoff from two catchments of the Ntuzi group which also had weir structures in place. The land-use in one is settlements with subsistence farming and a limited amount agriculture and in the other just natural veldt and bush as it forms part of a nature reserve and is therefore mostly undisturbed. All the physical attributes for these two catchments are similar, the only real difference being in land-use, so here was an opportunity for another collaborative project. The University of Zululand staff would supply samples taken throughout hydrographs for analysis and evaluation as part of this project. Since the Mgeni Catchment contains many areas with this type of land-use, the results would not only be of use to the model but also yield new information.

2 OBJECTIVES

The aims of the project as given in the original research proposal are as follows:

(a) To characterise and compare runoff water quality and annual loads from different types of land-use, with particular reference to important land-uses in the Mgeni Catchment. Measurement to be made during low and high flow periods for water quality variables of concern.

(b) To synthesise the data collected into a suitable form for inclusion into the proposed Mgeni Catchment water quantity/quality model being developed by the University of Natal.

(c) To investigate the need to set up a long term monitoring programme (5 years or more) on one or more selected catchments with specific land-uses in order to assess spatial, temporal and development effects on water quality.

3 MAJOR RESULTS AND CONCLUSIONS

Six catchments were monitored for runoff quality during the three year period of the contract, two catchments at Cedara for two wet seasons and two at the Ntabamhlope complex in the following wet season using automatic monitoring equipment specifically developed for the project. The two Ntuzi catchments were sampled by University of Zululand staff using their own equipment. Although it was planned to analyse samples from these catchments for the full period, problems arose that resulted in effectively obtaining only one year of runoff water quality data. Results for the catchments are discussed and compared as pairs, which is most logical as similar monitoring techniques were applied for each set.

Since the Cedara catchments were studied for two years, temporal variation in runoff quality and export coefficients could be assessed. Flow weighted mean runoff quality (calculated according to flow volumes that samples represented) varied appreciably between years, particularly for suspended solids and related parameters but the variation for soluble constituents such as dissolved salts and soluble phosphorus was much lower. The differences are considered to be normal variation and are attributed to different rainfall/runoff cycles, which shows the necessity for longer term monitoring of catchments in order to establish reliable mean qualities and export coefficients.

The forested catchment, U2H018, had higher mean suspended solids, particulate phosphorus and nitrogen concentrations than catchment U2H016 with smallholdings and farming as the major difference in land-use. The reason for the higher concentrations is considered due to the much higher average slope of the forested catchment, 29% compared to only 16% for U2H016, and consequently the greater erosion potential. On the other hand, higher dissolved salts and soluble phosphorus concentrations were obtained for the farming catchment, which appears to be a land-use effect. Calculated export coefficients for the forested catchment were 2 to 3 times higher, mainly because of the much higher runoff for the catchment which was almost double that for U2H016 over the two year study period. The different physical aspects of these two catchments is a confounding factor and does not make them directly comparable when comparing them for land-use/water quality effects. Rather, the results can be considered typical for catchments with similar land-uses and factors such as slopes, soils, rainfall etc.

Comparison of mean runoff quality from the Ntuzi catchments showed that the disturbed one with subsistence farming had significantly higher suspended solids, turbidity, soluble phosphorus and nitrate levels than the natural, undisturbed catchment. A very definite land-use effect was shown here since all other attributes for the catchments are similar, ie: soils, slopes, areas.

Results for the Ntabamhlope catchments showed major differences in water quality. The small catchment which had been used as a wintering feedlot for cattle had concentrations of phosphorus, Kjeldahl nitrogen, nitrate and Chemical Oxygen Demand an order of magnitude or more higher than that for the grassland catchment which acted as a control. At times, the concentrations reached levels commonly found in raw sewage for the nutrients, nitrogen and phosphorus and chemical oxygen demand. Runoff from this type of land-use, feedlots, or just areas with heavy concentrations of cattle as was the case here could cause eutrophication and other problems in receiving waters.

Examination of pollutant concentrations during hydrographs showed that some were strongly influenced by changes in flow. For all catchments, concentrations of suspended solids, particulate phosphorus and nitrate, and turbidity increased and decreased with corresponding changes in flow. Conversely, conductivity had an inverse relationship with flow, except for the feedlot catchment which was positive. The relationship with flow, however, was not consistent, in that concentration peaks were not always in the same proportion to corresponding flow peaks. This was borne out by regression analysis of the constituents on flow which generally produced poor to mediocre results, as judged by the regression coefficients. Plots of constituent concentrations against flow for individulal hydrographs graphically showed the disparity, ie: sometimes concentrations were higher on the rising than the falling limbs of the hydrographs or vice versa. Clearly there is no simple relationship between concentration and flow levels.

It was also noted that concentrations were high at the beginning of the wet seasons and generally showed a falloff through the season. This behaviour indicates a "first flush" effect (high initial concentrations) caused by washoff of pollutants that have accumulated on surfaces during the dry season. An exception was soluble phosphorus concentrations in runoff from the disused feedlot catchment which remained high throughout the wet season. The process here is most likely one of phosphorus being leached from decomposing materials, which could carry on for some time.

4 MEETING OF OBJECTIVES

The objectives have been achieved. Firstly, typical runoff water quality and annual loads have been determined for catchments with widespread land-use in the Mgeni catchment. They comprise a steep forested catchment, a general farming (smallholding and forestry) catchment, one with subsistence farming, a natural grassland, and finally a disused feedlot catchment. Secondly, the data have been extensively examined for flow/water quality and inter-variable relationships and presented in forms that can be used, ie: raw data converted to information. Based on this, recommendations are made for inclusion of the information into water quality models, ie: the Mgeni catchment model. Thirdly, one pair of catchments studied is suitable for long term monitoring to assess the effects of development on water quality, ie: the Ntuze catchments where settlement and agriculture is steadily increasing.

The data obtained can be used for a number of purposes. Annual export coefficients may be used at a coarse level of modelling or as decision support for planning and management considerations. If it is desired to estimate loads of pollutants or water quality from a large mixed land-use catchment, or for a change in land-use, then knowing typical values for subcatchments with particular land-uses will facilitate this calculation. Alternatively, the data may be included in models as mean runoff qualities or the quality may be generated using the statistical relationships developed. For other types of models the data can be used for calibration or verification purposes. Finally the analytical data will be stored in the Computer Centre for Water Research's data base for use by other researchers.

5 RECOMMENDATIONS

The results for the small disused feedlot catchment at Ntabamhlope showed that this land-use has a very high potential to contaminate receiving waters. Runoff for only one wet season was obtained and therefore the results are limited. Further monitoring could answer questions such as:

(a) Is mean runoff quality and load variable between years with different hydrological cycles or what is the natural variability?

(b) Can flow/concentration relationships be improved or better understood with more data and a different sampling technique?

(c) In the long term will the leaching/washing off of nutrients and organic pollutants continue unabated (an indication of this was found), or is there a limit?

(d) Can the washoff processes be simulated by a model, and if so what is the best technique to adopt?

It is recommended that monitoring of this catchment be continued, dependent on the data forthcoming, probably for a period of three years. It will be cost effective because of the infrastructure that is already in place.

Runoff from the Ntuze catchments has shown a land-use effect on water quality. Since the one catchment has an increasing subsistence farming community (the 1988 figure of 302 huts is predicted to double by 2002), it is ideal for long term monitoring to gauge the effects on runoff quality. Again the infrastructure is in place for a collaborative project with the University of Zululand.

A final comment is that maximum use should be made of existing flow gauging structures to set up automatic equipment for sampling continuously to include periods of changing flow in order to to obtain realistic water quality data. The technology to do this has been developed or could be adapted where necessary.

1 INTRODUCTION

1.1 Background

At a workshop held in 1985 in Durban entitled "Water Quality Management in the Mgeni Catchment" it was stated that the Mgeni River is a vital water resource in Natal which provides water for 45% of the population of the region where approximately 20% of the Gross National Product is produced (Breen et al, 1985). Continued development of the region would result in increased return flows of sewage and industrial effluents and more pollution from diffuse sources. It was recognised that water quality would deteriorate as a consequence, and therefore a dynamic systems model linking rural, urban and industrial sources to predict future water quality was essential for scenario planning and the protection of water resources. Another recommendation to come out of the workshop was that the relationship between land-use and nutrient/pollutant export from catchments should be established. Furness and Richards (1987), as representatives of Umgeni Water also recognised the need for water quality planning with the proviso that models should provide answers to practical problems. They concluded that since the concept of catchment management includes control of point and non-point sources of pollution, modelling is a potentially important tool in formulating catchment management strategies. This is quite true, but for models to be successfully calibrated and verified, reliable water quality information is essential.

A literature survey revealed that a large amount of work had been conducted overseas on the effects of specific land-uses on runoff quality. The results had largely taken the form of annual export coefficients for particular pollutants, expressed on an area basis. There was, however, little uniformity of results reported even for similar land-uses. For example, phosphorus export coefficients summarised by Reckhow and Simpson (1980) ranged from 2 to 45 kg/km^2/a for forested and from 10 to 300 kg/km^2/a for agricultural catchments. Factors such as climate, morphology and investigative technique used could well be reasons for the wide variations. Consequently, although published data does give an idea of the magnitude of pollutant export coefficients for different land-uses, the values cannot really be used or adopted for use in models for South African catchments. There was no alternative but to conduct local research in order to obtain the information.

Some water quality information on local rivers was available, mostly as a result of routine sampling programmes. The usefulness of the information for characterising land-use water quality relationships was and still is limited for two basic reasons. Firstly, sampling stations are usually sited at points on rivers where the contributing catchments are quite large and represent mixed rather than specific land-uses, thus giving only generalised water quality results. Secondly, the sampling strategy commonly employed is weekly or monthly grab samples which do not take account of changing quality during hydrographs, ie: washoff of accumulated materials from surfaces in the initial stages of runoff. Many researchers support the view that automatic sampling based on samples taken at specific flow intervals is necessary to obtain realistic water quality results (Feher, 1983, Miertschin, 1986).

This project arose as a result of a general need for reliable information on the effects of different types of land-use such as forestry, agriculture and peri-urban developments on runoff water quality. It formed part of a collaborative catchment research programme linked to two other projects also funded by the Water Research Commission titled "Development of a distributed systems model for the Mgeni catchment" carried out by the Department of Agricultural Engineering, University of Natal and "An investigation of the hydrological responses to third world settlements in peri-urban areas of Natal/KwaZulu" by the Department of Hydrology, University of Zululand. Samples of runoff from catchments being monitored for hydrological responses by the Universities of Natal and Zululand were to be analysed and evaluated as part of this project. Resulting data such as mean runoff quality, pollutant export coefficients and flow-water quality relationships could then be used as input to the proposed Mgeni catchment model and for various other purposes. Consequently there was close co-operation with University staff in obtaining the samples and in running the project. Similar Steering Committees guided all three projects.

Since land use in the Mgeni catchment ranges from natural scrub and grassland through silviculture and various types of agriculture to different types of urban land uses and industrial complexes, it followed that there would be a number of distinctive hydrological sub-models which would require associated water quality sub-models. In other words each category of land use would generate both different types and amounts of pollutants which would need to be taken into account when developing the quality section of the model.

1.2 Objectives

The objectives as given in the research proposal are listed below:

1.2.1 To characterise and compare runoff water quality and annual loads from different types of land-use, with particular reference to important land-uses in the Mgeni Catchment. Measures to be made during low and high flow periods for water quality variables of concern.

1.2.2 To synthesise the data collected into a suitable form for inclusion into the proposed Mgeni catchment water quantity/ water quality model being developed by the University of Natal.

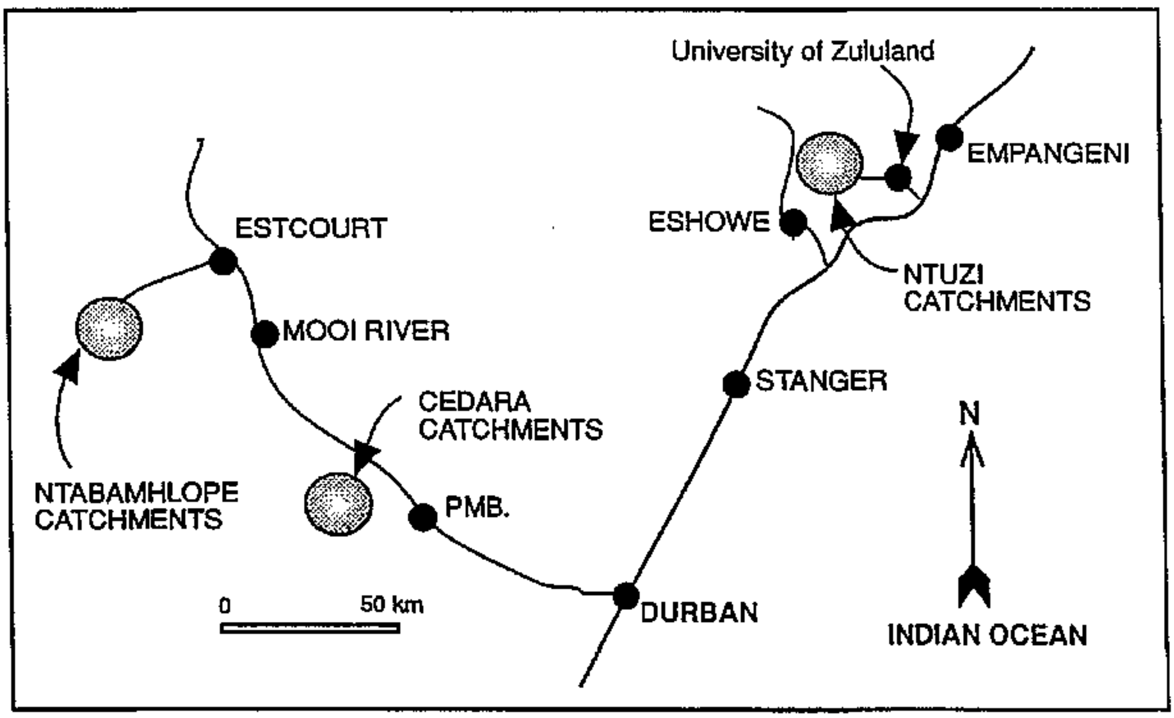
1.2.3 To investigate the need to set up a long term monitoring programme (5 years or more) on one or more selected catchments with specific land-uses in order to assess spatial, temporal and development effects on water quality.

As the research progressed it became evident that the flow rates strongly influenced runoff quality and consequently examination of flow-quality relationships and relationships between water quality variables became further objectives to assist the modelling exercise.

2 CATCHMENTS

To realise the objectives it was proposed that suitable equipment be developed to automatically sample runoff in selected catchments in Natal. A proviso here was that the work would have to be carried out in catchments where there were suitable flow measurement weirs, since the costs of construction of weirs in new catchments would be prohibitively high. The research would therefore be limited to the Cedara, Ntuze and Ntabamhlope sets of catchments. A preliminary grab sampling programme sponsored by FRD in 1986/87 identified two catchments at Cedara and two in the Ntuze complex as having distinctly different runoff water qualities and land-uses respectively (Simpson 1988). Consequently, these catchments were chosen as being suitable for investigation. Their general location can be seen in Figure 1.

Figure 1: Location of research catchments



2.1 Cedara catchments

The catchments are situated 15 km northwest of Pietermaritzburg in the Natal Midlands (see location map, Figure 1). They comprise a set of five small agricultural catchments ranging in size from 0,095 to 5,25 km^2 which were instrumented for flow measurement in 1976. Their land-use, soils and physiography are considered as being representative of large parts of the Natal Midlands. Runoff is to the Rietspruit and its tributaries which is a subcatchment of the Mgeni River. The land is partly privately owned, partly State forests and partly of the Cedara Agricultural College belonging to the Department of Agricultural Development (information from Schulze, 1979).

As stated earlier, two catchments were selected on the basis of previous work and on their land-use for more intensive runoff studies. The pertinent details for the catchments are given in Table 1 below.

Table 1: Physical characteristics of the Cedara catchments

Catchment	U2H016	U2H018
Area, km^2	5,25	1,31
Average slope, %	16,4	29,2
Mean erosion potential, t/ha/a	3,3	4,6
Land-use, %:		
Timber plantation,	56,8	77,2
Scrub & veld,	31,8	22,8
Smallholdings	11,4	0

Note: Mean soil erosion potential calculated from grid map of catchments giving erosion potentials calculated using the Universal Soil Loss Equation (Schulze, 1979).

The catchments clearly have different land-uses with the development of farms in U2H016 being the essential difference but also different physiography. Their proximity and similarity in geology and soils is advantageous in reducing the number of variables for comparative purposes, but unfortunately catchment U2H018 has almost double the average slope of U2H016 and a 39% higher average soil loss potential. While 43% of the area of catchment

U2H016 had a potential soil loss of less than 1 t/ha/a, the corresponding figure for U2H018 is only 23%; 21% of the area of U2H016 and 37% of U2H018 respectively had erosion potential values greater than 9 t/ha/a (Schulze, 1979). Although these differences mitigate against direct comparisons for runoff quality, both catchments represent important land-uses in the Mgeni River Catchment. According to a land-use classification carried out by the Institute of Natural Resources, University of Natal, 20% of the Mgeni Catchment is under forests of various types and 37% under grassland and general farming (Bromley, 1989).

2.2 Ntuze catchments

Information about the Ntuze catchments has been taken from Kelbe and Mulder, (1989) and Kelbe, Mulder and Bodenstein (1990). These catchments form part of a group generally known as the Ntuze catchments just south of Empangeni on the Natal North Coast (see Figure 1). The complex comprises six nested catchments ranging in size from 0,7 to 82 km^2 that have been equipped with weirs and have been monitored for rainfall and runoff since 1974. The two catchments of interest, chosen as a result of earlier work, share a number of similarities as regards size, slopes, soils and geological formations, the only real difference being in land-use. Some pertinent details for the two catchments of interest are given in Table 2.

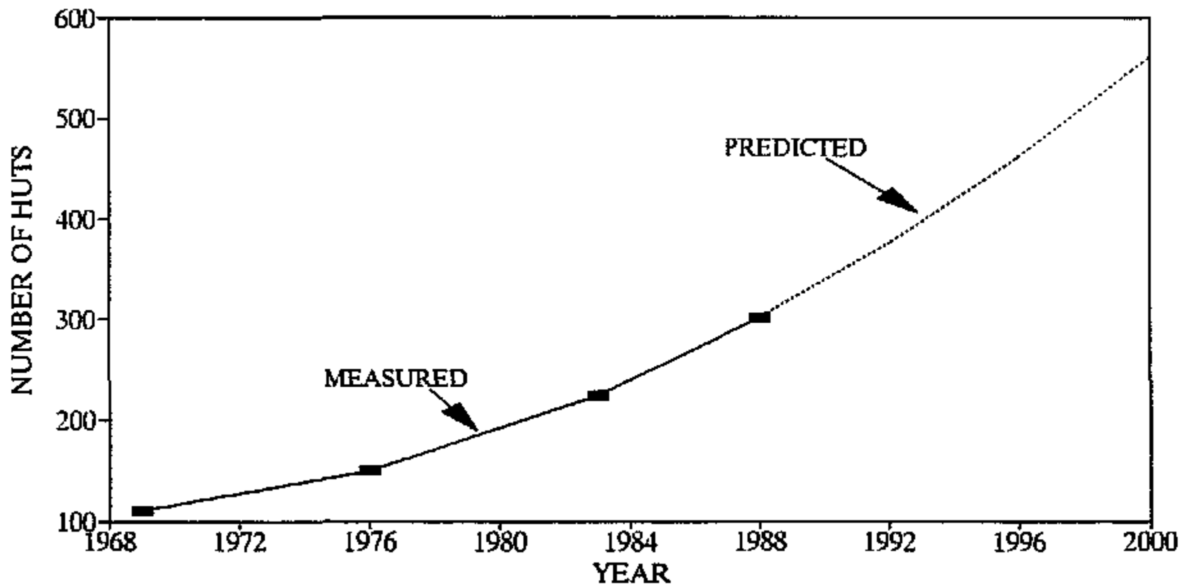
Table 2: Physical characteristics for the Ntuze catchments

Catchment		W1H016	W1H031
Area, km^2		3,23	3,19
Average slope, %		22,0	20,0
Land-use, %:			
	Forest	4,5	28,0
	Plantation	6,5	0
	Sugarcane	2,0	0
	Grassland	71,0	66,0
	Rock outcrops	13,0	6,0
	Subsistence farming	3,0	0

Note: The average slope and land-use data have been calculated from figures given in Kelbe et al, 1990.

The essential difference between the catchments is that W1H016 has subsistence farming by the local population and a limited amount of commercial forestry. The number of dwellings (huts) in this catchment is growing and the progressive increase has been measured by Kelbe using aerial photographs taken in 1969, 1976, 1983 and 1988. This increase is shown in Figure 2 and statistical analysis shows that the pattern is well represented by a quadratic equation with an R^2 statistic value of 0,9999. If the trend continues, the equation predicts that by about 1996/97 the number of dwellings will have risen by 50% from the 1989 figure and have doubled by the year 2002. Apart from subsistence farming, sugarcane has been established in one area of the catchment and is expected to increase, which is likely to promote further settlement in the catchment. This changing land-use pattern, particularly subsistence farming which is a common land-use practice in many parts of Natal, makes this catchment especially valuable for monitoring the effects of development on runoff quality. According to the Institute of Natural Resources land-use classification for the Mgeni Catchment, 10% of the area is covered by the Valley of a Thousand Hills which is a similar land-use, ie: subsistence farming (Bromley, 1989). Therefore, although these catchments are remote from the Mgeni system, the land-use is important and the results should be applicable in some manner.

Figure 2: Increase in hut count for catchment W1H016



The other catchment, W1H031, is adjacent to W1H016 with a similar catchment area. It forms part of the Ngoye Nature Reserve which was scheduled for refencing and stocking with indigenous fauna during 1988. Unfortunately this has not as yet taken place and a small part of the area is used by local inhabitants for the grazing of cattle. Nevertheless, since the catchment does not have any significant human settlements or other activities such as crop raising taking place within its borders, runoff from the catchment can be considered as a good control to evaluate the effect of land-use in catchment W1H016. As mentioned above the physical characteristics of the catchments are similar.

2.3 Ntabamhlope catchments

Between 1962 and 1967 more than 20 weirs were constructed in the Ntabamhlope/De Hoek area by the Department of Water Affairs (see Figure 1 for location). The purpose of the flow measurement was to assess the importance of wetlands with respect to water supply, flood control and intensified agriculture. Further, the effects of changes in land-use upon flow regimes was to be measured. The soils of the region are highly leached, non-structured and have a low erosion potential (Schmidt and Schulze, 1989).

These catchments are also remote from the Mgeni System as they eventually drain to the Tugela River, but the interest here is that one of them, a small one, has been used for a number of years as a wintering feedlot for cattle from the Ntabamhlope research farm. Runoff from feedlots is known to have a high potential for water pollution and here was an opportunity to obtain both qualitative and quantitative data. As a control to measure the difference in runoff quality, which could not be ascribed to confounding factors such as different soils and climate but only to land-use, another catchment , a grassland was chosen for simultaneous monitoring. Details of the two catchments are given in Table 3.

Table 3: Physical characteristics for the Ntabamhlope catchments

Catchment	V7H010	V1H028
Area, km^2	0,08	0,41
Average slope, %	10,0	13,0
Land-use: %		
Grassland and natural forest	0	100
Feedlot	100	0

3 DATA COLLECTION

3.1 Field equipment

The existing monitoring equipment at the outfall of catchments U2H016 and U2H018 at Cedara consists of clockwork driven Ott Recorder and float combinations to measure depths of flow over rated V-notches. The equipment is housed in small brick huts which have connecting pipes from the stilling wells to the weir ponds. In order to control an automatic sampler it was necessary to obtain a measure of the flow. This could have been done either by installing a separate flow measurement system or by using the existing one. It was decided to translate the movement of the float-driven shaft of the Ott recorder into an electrical signal. To do this a 10 turn potentiometer was attached by means of a bracket to the end of the shaft, so that as flow changed and the float rose the potentiometer shaft would turn. Then, by applying a fixed voltage to the potentiometer, a variable voltage related to flow would be given out and received by a data logger.

The data logger chosen was a Sharp PC1500A, a hand held calculator/computer with 8K of RAM which had been used by the Division of Production Technology (DPT) of CSIR as the central unit for various data logging/control applications. The DPT was contracted to design and build an interface for the Sharp to perform certain specific functions, namely to output a fixed voltage to the potentiometer on demand, to convert the return voltage from an analog signal into a digital signal and to enable a contact closure to operate the sampler. A programme for the computer to use these functions and record flow, time and sample number when the sampler operated was written. Details of the logger programme and interface are given in Appendix A.1 and A.2 respectively.

The equipment huts in the catchments are located on the stream banks approximately 30 metres from the V-notches of the weirs. As it was desirable to sample in fast-flowing water to obtain representative samples and the water quality actually leaving the catchments, sample lines were led right up to the V-notches. This was accomplished by housing the 6 mm diameter plastic sample tubing used within 20 mm diameter plastic electrical conduit, which was fixed to the weir walls by means of brackets and glue.

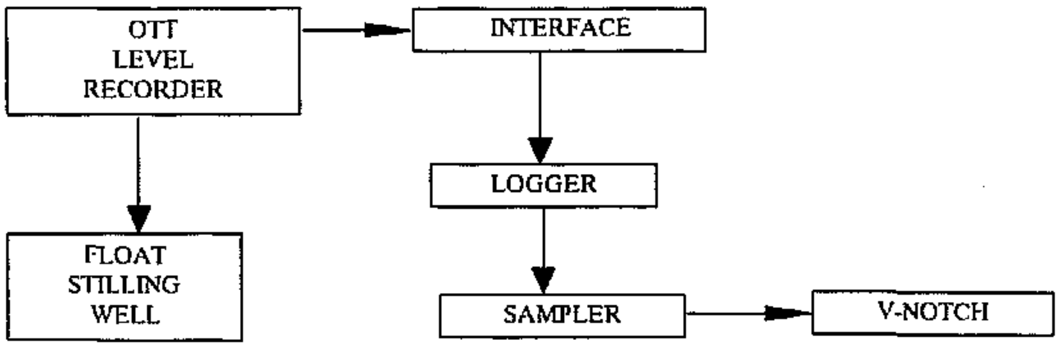
Care was taken to ensure that the sample lines had continuous falls from sampler to intake so that the tubing could drain properly, thereby minimising sample cross-contamination and the collection of stagnant water in the line. A purpose-made plastic strainer was attached to the intake to prevent the possibility of a complete blockage of the intake by suspended material.

Isco samplers, obtained from the University of Natal who had used them for a previous WRC contract were installed. They contain 28 sample bottles and draw up water by means of a peristaltic pump. The velocity of water drawn up in the sample line was measured at about 0,5 m/s, which will not allow settlement of fine suspended materials. The samplers were powered by 12V car batteries. An electronic modification had to be carried out to the samplers to extend the pumping times as the standard settings were insufficient to obtain samples from the V-notches. These details are given in Appendix A.3.

The data loggers and interfaces were fitted into weather-proof plastic enclosures which were fixed onto the walls of the huts. Since the internal batteries of the loggers (4 penlight batteries) were insufficient to supply power to the loggers with the programme running continuously, drycell, rechargeable 9,5 A hr batteries were used. These batteries also supplied the regulated voltage to the potentiometers when required. A diagram of the connectivity of the field equipment is shown in Figure 3.

A number of problems were encountered during these investigations which resulted in a loss of data. Firstly there was the odd equipment failure that occurred. These happenings cannot be predicted and as a precaution, backup equipment should ideally be available to substitute with and thus avoid long downtimes when equipment is repaired. Of course, this does involve a higher capital outlay. Secondly there is the "human error" which in equipment handling can also be problematic. On a number of occasions incorrect settings or placement of data loggers occurred with resultant loss of data. This problem is bound to arise in any long term monitoring study and can only be contained with diligent attention to detail by personnel involved. A final problem which arose was vandalism or theft of field equipment. Luckily this only occurred at one station, U2H018, where the equipment hut was broken into on a number of occasions.

Figure 3: Schematic of flow measurement and sampling equipment



3.2 Sample handling and data transfer

As a routine the installations were serviced on a weekly basis by field staff of the University of Natal when the data loggers and the rechargeable batteries were replaced and sent to the Durban laboratory together with the samples that had been taken. But if a large rainfall event occurred in the interim period, a special visit was made from the CSIR to collect the samples. In other words, two data loggers were provided per catchment.

The selection of the sampling interval volume to use in each catchment had to be an arbitrary choice, although due cognizance was taken of past flow records. The problem was that if the interval was set too low then the capacity of the sampler (28 bottles) could easily be exceeded if a large hydrograph occurred, resulting in obtaining only partial results. On the other hand the setting of a large volume between samples could result in little definition of changing quality during smaller hydrographs. In practice, the sampling intervals were often changed between weeks, the judgment being based on flow conditions pertaining at the time. On occasions the sampler capacity was exceeded and at other times little information was obtained concerning small hydrographs. For catchment U2H016 the sample volumes varied between 500 and 3 000 m^3 and for catchment U2H018 between 200 and 1 500 m^3.

At the laboratory, the data logger containing the recorded information was connected via a Sharp RS232 adapter (CE-1580) to a computer and the stored records written to file using an inter computer communication software package called Crosstalk. Further purpose written programmes converted the data into full date and time records as well as producing graphical displays of flow rates. Based on this decoded information a decision was then made on which samples should be analysed as individual samples, and which should be made up into composite ones for analysis. This was in the interests of saving on unnecessary analytical costs. As sequential samples were sometimes taken at very similar flow rates, for example during base flow, composite samples were often prepared.

The same equipment and sampling technique was used for the Ntabamhlope catchments after completion of the work at Cedara.

Sampling equipment for the Ntuze catchments was independently developed and installed by staff of the University of Zululand. At first, a simple switching device attached to the float wire of the Ott Flow Recorder was used to initiate a time interval sampling sequence (hourly samples) for an Isco Sampler. This was set to occur at the start of the rising limbs of hydrographs. The system was not, however, entirely satisfactory as there was at times some uncertainty about the time that sampling was initiated and therefore doubt about where samples were taken on the hydrographs. A further drawback was that time interval sampling could miss peak flows and concentrations during hydrographs.

Consequently a new system, similar in principle to the one used for the Cedara catchments was developed by the University, that is flow interval sampling controlled by a Cambell Data Logger. This system is fully described in Kelbe, Mulder and Bodenstein (1990). The samples taken during hydrographs were packed in cooler boxes and sent by road transport to the CSIR laboratory in Durban for analysis. For the same reasons as stated earlier, not all samples were analysed on an individual basis and initially ones with similar flow rates were made up into composite samples.

3.3 Sample analysis

Because of the costs it was not practical to analyse for all of the usual constituents such as the different forms of nitrogen and phosphorus in every sample taken. It was decided to analyse for certain constituents in individual samples and other constituents in composite samples. In line with project objectives the following analyses were generally conducted:

For the Cedara catchments suspended solids, turbidity, conductivity, soluble and total phosphorus, nitrate and chloride on individual samples and soluble and total Kjeldahl nitrogen on composite ones. For the Ntuze catchments the same pattern, but excluding chloride on individual samples. Soluble and total Kjeldahl nitrogen, dissolved organic carbon and volatiles of suspended solids analyses were carried out on composite samples. For the Ntabamhlope catchments analyses were similar except that ammonia, chemical oxygen demand (COD) and colour analyses were conducted on some samples.

The analyses were conducted by established methods and auto-analytical techniques (Environmental Monitoring and Support Laboratory, Cincinnati, 1979; Standard Methods for the Examination of Water and Wastes, 1980). Total dissolved salts (TDS) concentration was calculated from conductivity according to the relationship given by Kemp (1977).

3.4 Rainfall collection

Rainfall samples were collected at the Cedara meteorological station during the second year of the study. The equipment used consisted of a 0,25 m diameter plastic funnel supported above a plastic bottle, just above ground level. When no rain occurred the funnel was rinsed daily with deionised water to remove dust deposits as the object was to analyse rainfall only. After rainfall occurred samples were sent to the Durban laboratory for analysis. The technician looking after the station serviced the equipment.

Some rainfall samples were also collected at the University of Zululand but the results are too few to justify inclusion in this report.

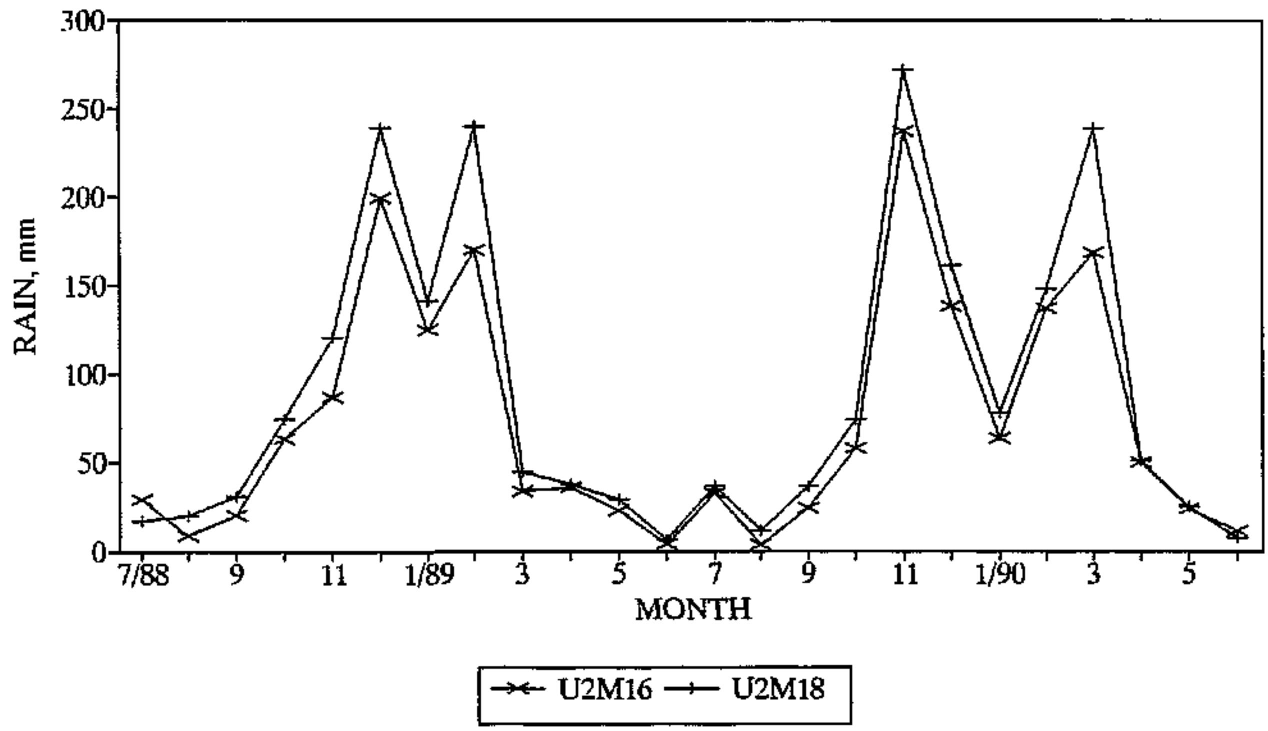
4 RESULTS FOR THE CEDARA CATCHMENTS

Design and installation of the field equipment was complete by the middle of October 1988. Sampling was then commenced at weir U2H016, but the weir at U2H018 did not overflow until the end of November.

4.1 Rainfall

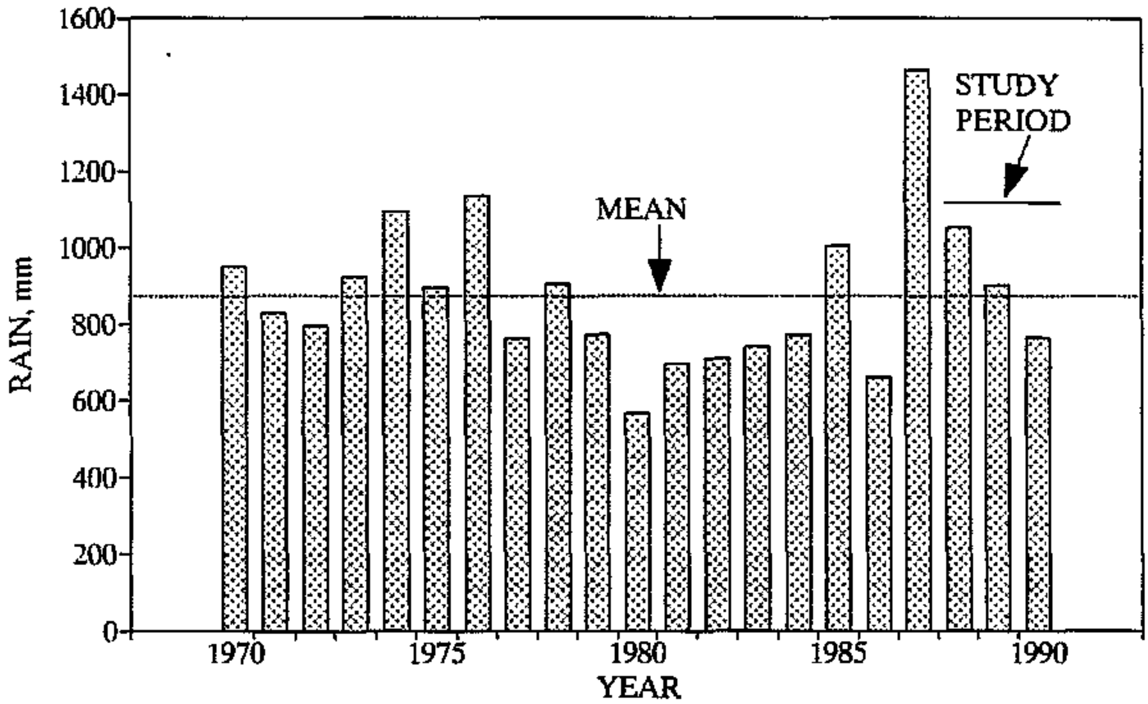
The mean monthly rainfalls for raingauges sited in catchments U2H016 and U2H018 (three for U2H016, variations from mean of 3%, 4% and 7%, and one for U2H018) during the study period are given in Figure 4. Comparison shows that rainfall in catchment U2H018 was generally higher than in U2H016, that is 25% higher for the 7/1988 to 6/1989 season and 20% higher for the 7/1989 to 6/1990 period. This does not make quality or other comparisons between the catchments invalid, but simply means that this difference should be borne in mind when considering the magnitude of runoff loads.

Figure 4: Monthly rainfall for catchments U2H016 and U2H018 during study period



In order to see if rainfall during the study period was abnormal, since extremes would affect mean quality and other results, the annual rainfalls for station 580, the meteorological at Cedara, for the past 20 years are shown in Figure 5. Although the station is not actually within the boundaries of either catchment, the records do give an idea of the normality of rainfall for the area during the sampling period. As may be seen there are small deviations from the overall mean but it may be concluded that rainfall was quite typical for the area during the study years, ie: neither very dry nor wet years. It follows therefore that runoff quality and loads may also be considered as being typical.

Figure 5: Annual rainfall variation for Cedara catchment area



Rainfall collection and analysis of samples was conducted in order to give some idea of the concentrations in relation to those in runoff from the catchments. In this manner estimates of loads derived from rainfall and from catchment surfaces alone could then be made. Further, a typical water quality could be given to rainfall for use in a water quality model at a future date. A total of 66 samples were analysed between October 1989 and April 1990.

Table 4: Analytical and statistical data for rainfall samples collected at Cedara Meteorological Station 580

Parameter	Units	Mean	No. Samp.	Std. Dev.	Min.	Max.	Wt. Mean (mm Rain)
Rain,	mm	10,5	66	10,3	1,1	57,4	-
pH		5,1	66	0,6	4,3	7,3	4,9
[H+] (calc)	µg/l	7,9	-	-	0,05	50,1	13,2
Conductivity,	mS/m	1,7	66	1,0	0,4	4,1	1,3
TDS (calc),	mg/l	11,3	-	-	2,7	27,3	8,7
Soluble P,	µg/l	13	47	13	1	69	9
Nitrate-N,	µg/l	311	58	215	1	960	260
Ammonia-N,	µg/l	82	34	129	1	540	65
Sol. Kjel-N,	µg/l	357	61	278	70	1697	288
Chloride,	mg/l	1,5	32	1,5	0,1	8,7	1,0
Sulphate,	mg/l	2,2	29	1,3	0,3	5,9	1,9
Sodium,	mg/l	0,39	14	0,29	0,04	0,98	0,26
Potassium,	mg/l	0,19	14	0,12	0,03	0,46	0,13
Calcium,	mg/l	0,34	14	0,25	0,07	0,90	0,30
Magnesium,	mg/l	0,12	14	0,09	0,03	0,30	0,08

Rainfall events analysed ranged from 1 to 57 mm, thus giving a wide spread of both large and small events. As shown by the number of samples analysed for each constituent, the main emphasis was on pH, conductivity and the nutrients with limited analysis of the cations and anions, ie: 14 samples. The wide range of values for the constituents is amply shown by the minimum and maximum data and the high standard deviations relative to the arithmetic means, eg: soluble phosphorus values varied from 1 to 69 µg/l with a standard deviation the same value as the mean. Total dissolved salts was calculated from conductivity values while pH values were converted to hydrogen ion concentrations before calculating means. Rainfall amounts were used to weight results for calculation of the weighted means given in the right hand column of Table 4. The mean pH of 4,9 which equates to a hydrogen ion concentration of 13,2 µg/l reflects some acidity in the rain since pure water saturated with carbon dioxide has a higher pH of 5,6 which is equivalent to only 2,5 µg/l hydrogen ions. From past data, however, the pH of runoff from the catchments was seldom below pH 7 and never below pH 6, showing that any acidity in the rainfall is neutralised during runoff. The mean results for the other constituents will be discussed in relation to mean runoff quality from the catchments in a later section.

A relationship between rainfall amount and constituent concentrations for an event could be expected if progressive washout of salts and gases from the atmosphere occurs during precipitation. This supposition was tested using correlation analysis between rainfall amount and concentrations but the results showed low coefficients for all constituents. The highest coefficient was for conductivity at -0,40, which is considered a weak relationship. All coefficients had negative values indicating falling concentrations with increasing rainfall amounts. Scatterplots of pH, conductivity and nutrient concentrations against rainfall amount are shown in Figure 6. The absence of any firm relationships can clearly be seen.

4.2 Flows

Flow data obtained from the University of Natal was divided up into two periods, that is from July 1988 to June 1990 and from July 1990 to June 1991. The purpose was to gauge variability in analytical and washoff load data between these years. Runoff patterns, as denoted by monthly volumes, are shown for the two study years in Figures 7 and 8 for catchments U2H016 and U2H018 respectively. The patterns for both catchments are quite different between years, particularly for the months of January and February which show much higher volumes in the first year, ie: 1988/89 wet season. Overall, runoff for catchment U2H016 was 25% higher for the first year (133 against 107 mm) and 13% higher for catchment U2H018 (248 against 220 mm) for the first year. The higher rainfall, as mentioned earlier and higher runoff for catchment U2H018 compared to U2H016 has an important bearing on the calculation of export coefficients as will be discussed later.

Figure 6: Cedara rainfall-concentration scatterplots

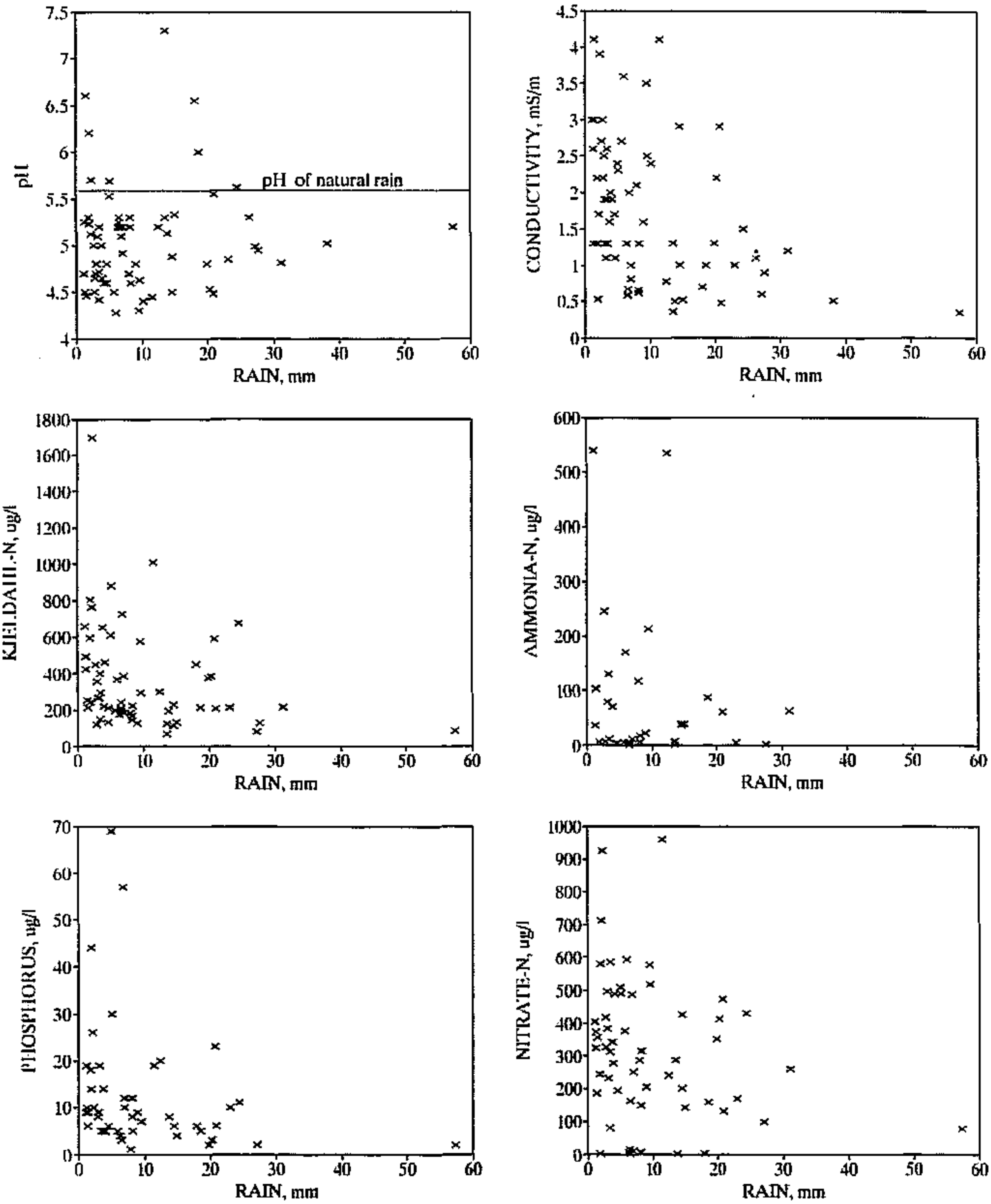


Figure 7: U2H016: Monthly runoff during 2 year study period

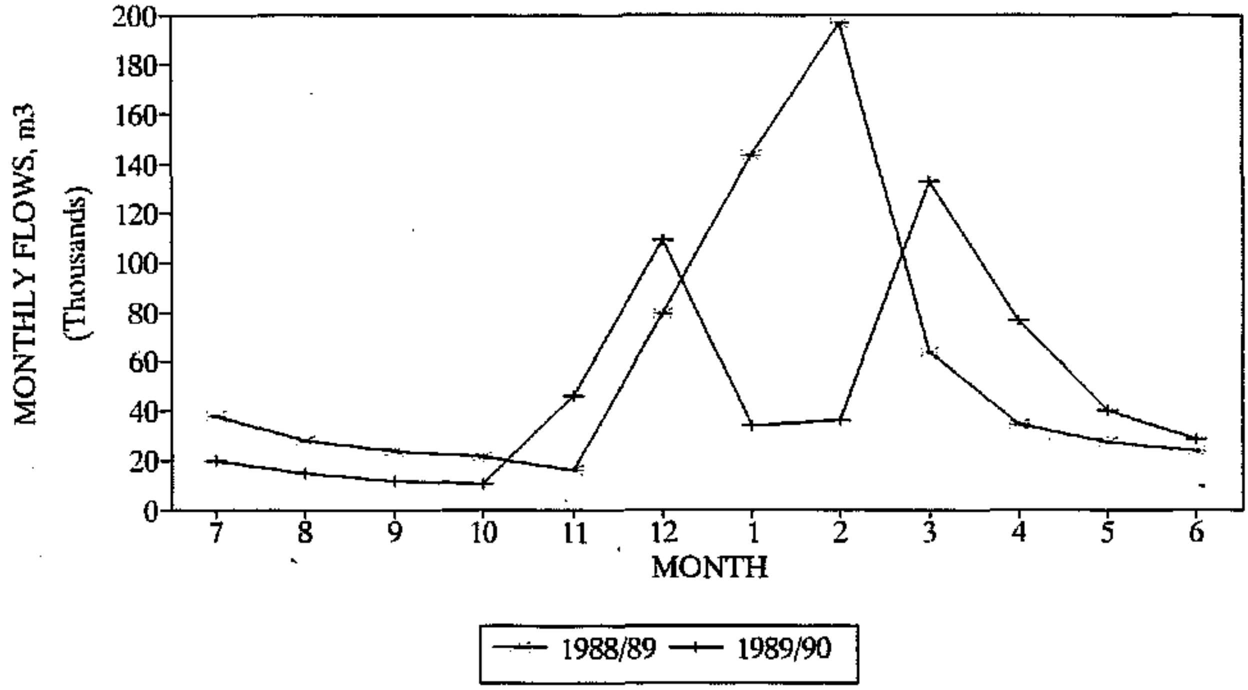
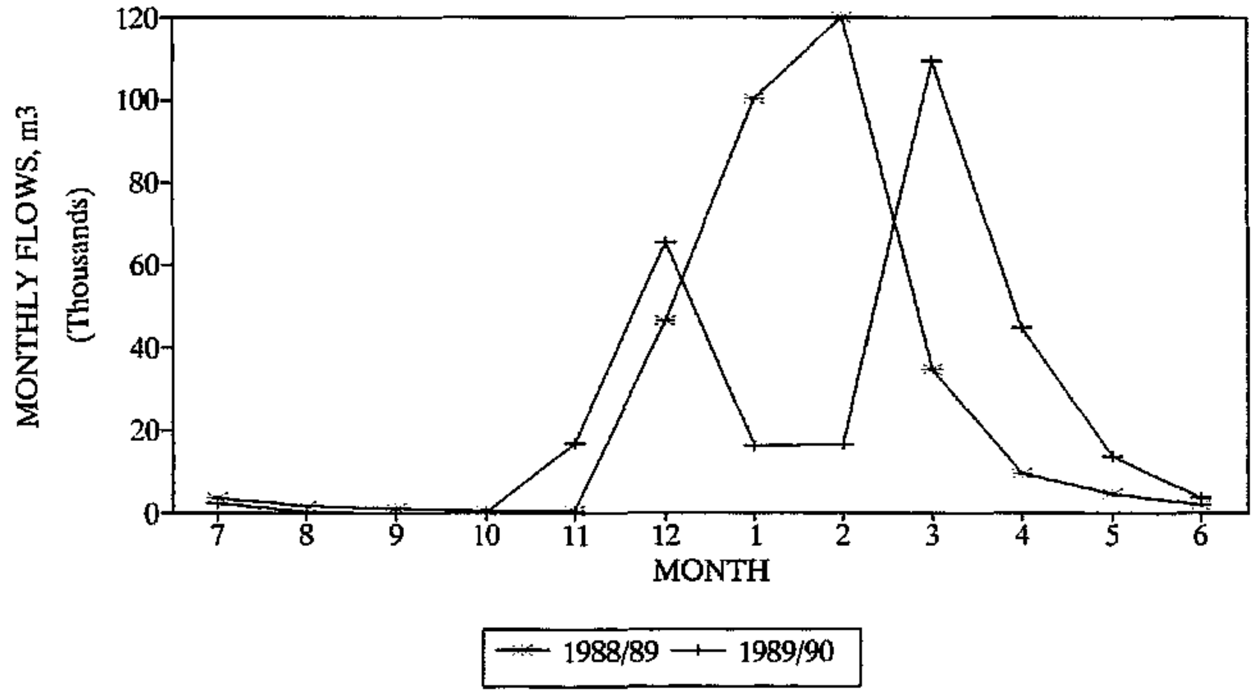


Figure 8: U2H018: Monthly runoff during 2 year study period



4.3 Mean runoff quality

The mean runoff quality for each of the study years, as given above was calculated by weighting each analysis in the data sets by the flow volume it represented. For example a sample taken at a 100 m^3 sampling interval would carry twice the weight of one representing a 50 m^3 interval. In this way very high or low results do not have any undue influence on means as would be the case if arithmetic means were calculated. The relative differences in mean qualities between years is shown in Figures 9 and 10 for catchments U2H016 and U2H018 respectively. For easy comparison 1988/89 results are expressed as unity and 1989/90 results as fractions thereof.

For catchment U2H016 the comparison between mean runoff water quality for the 1988/89 and 1989/90 periods shows major differences only for suspended solids and turbidity levels. Suspended solids for the second year was double that of the previous one while turbidity was up by about 40%. One reason for this large rise is due to the very high rainfall which occurred in November, 1989 for catchment U2H016 (see Figure 4) which no doubt resulted in high erosion and effective washoff of materials accumulated on surfaces. The data set clearly reflects higher concentrations for this period. Turbidity as well as particulate phosphorus concentrations show smaller increases since larger particles which are mainly the result of erosion give less turbidity and adsorb less phosphorus than equivalent amounts of finer particles. Concentrations for the other constituents show a closer agreement between years.

The same analysis for catchment U2H018 (Figure 10) shows less deviation of suspended solids concentrations, ie: between 30 and 40% higher in the second year. Particulate phosphorus and particulate nitrogen concentrations show similar increases in percentage. Other constituents are not very different between years.

Such variation in concentrations between years is to be expected due to different rainfall cycles and should be taken into account when using mean values for either calculation of export coefficients or for use in water quality models. In order to ascertain a mean runoff quality for a particular catchment a minimum period of two years is necessary, but longer is preferable.

Figure 9: U2H016: Comparison of mean runoff quality between years

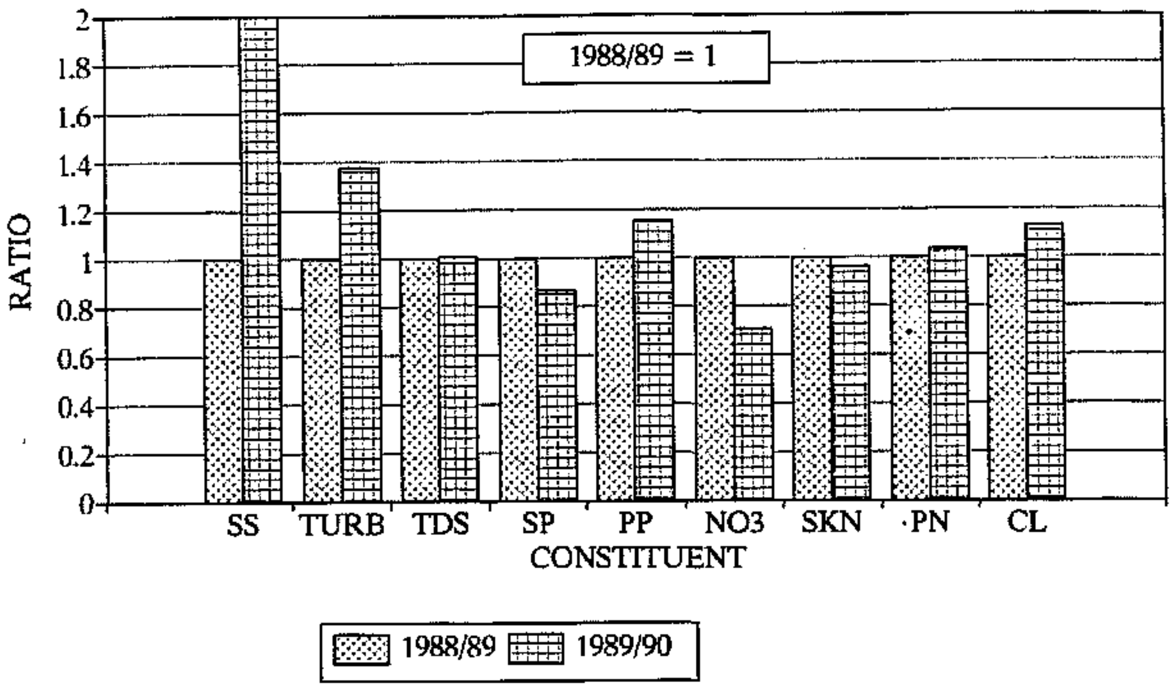
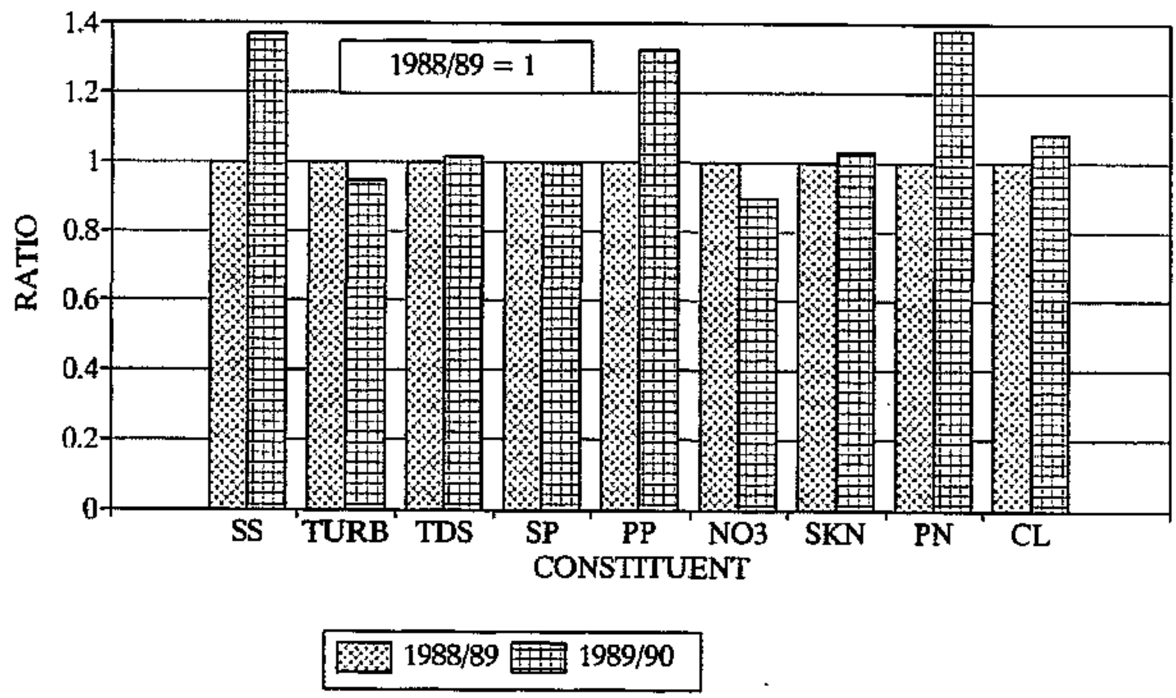


Fig. 10 :U2H018: Comparison of mean runoff quality between years



The overall mean water qualities, weighted according to flow for each year, together with statistical data are given in Tables 5 and 6 for catchments U2H016 and U2H018 respectively. Also a limited number of analyses for cations and anions was conducted on composite runoff samples in order to identify the major ions and to compare the results with concentrations in rainfall.

Tables 5 and 6 show wide ranges in constituent concentrations and high standard deviations in relation to the arithmetic means. In general the standard deviations for the solids associated pollutants (suspended solids, total phosphorus and nitrogen) are relatively higher than those for the soluble ones (conductivity, phosphorus, chloride and sulphate). A point to note here is the differences between arithmetic and volume weighted means. This is particularly true for suspended solids, total phosphorus and total Kjeldahl nitrogen concentrations where the arithmetic means are two to three times higher, which clearly shows the need for flow interval sampling in order to obtain accurate mean runoff quality data. More samples were analysed for catchment U2H016 than for U2H018 because the latter weir dried up in the winter months and generally did not overflow until November in the wet season whereas runoff from U2H016 was continuous.

Comparison of weighted mean rainfall quality with runoff quality from the catchments (data in Tables 4, 5 and 6) shows that total dissolved salts concentration in rainfall was low compared to that for the catchments, ie: 9 for rainfall against 85 and 46 for U2H016 and U2H018 respectively. The same is true for the cations and anions analysed which contribute towards conductivity. Sulphate in rainfall is the only one which had a relatively high concentration in relation to that for catchment U2H018 (1,9 against 2,7 mg/l respectively) but the concentration is still very low compared to that for U2H016. Unfortunately it is not possible to compare loads of salts in rainfall with loads washed off the catchments, that is give a mass balance, as a much longer and more comprehensive data base would be required. But notwithstanding catchment salt concentration processes such as salt exclusion by plants and evaporation, comparison of mean concentrations indicates that most of the salts in runoff are derived from the soils and activities in the catchments rather than from rainfall.

Table 5: Analytical and statistical data for runoff samples from weir U2H016 between October 1988 and May 1990

Parameter		Mean	No. Samp.	Std. Dev.	Min.	Max.	Wt. Mean (by Vol.)
Susp. Sol.	mg/l	56	287	107	1	812	29
Turbidity,	NTU	30	287	41	2	220	19
Conductivity,	mS/m	13,4	287	2,9	4,9	21,8	12,7
TDS (calc),	mg/l	89	-	19	33	145	85
Soluble P,	µg/l	26	272	16	4	112	21
Total P,	µg/l	79	272	82	11	557	49
Nitrate-N,	µg/l	362	179	325	51	2846	333
Sol. Kjel-N,	µg/l	295	133	148	85	1001	266
Total Kjel-N,	µg/l	498	117	469	146	2730	434
Chloride,	mg/l	7,3	140	1,3	0,4	11,7	8,1
Sulphate,	mg/l	11,6	37	2,9	7,1	21,3	11,5
Sodium,	mg/l	7,5	8	1,2	5,6	8,8	7,6
Potassium,	mg/l	0,78	8	0,4	0,46	1,5	0,79
Calcium,	mg/l	10,0	8	2,3	6,8	12,4	8,5
Magnesium,	mg/l	7,3	8	1,3	5,4	9,1	6,3

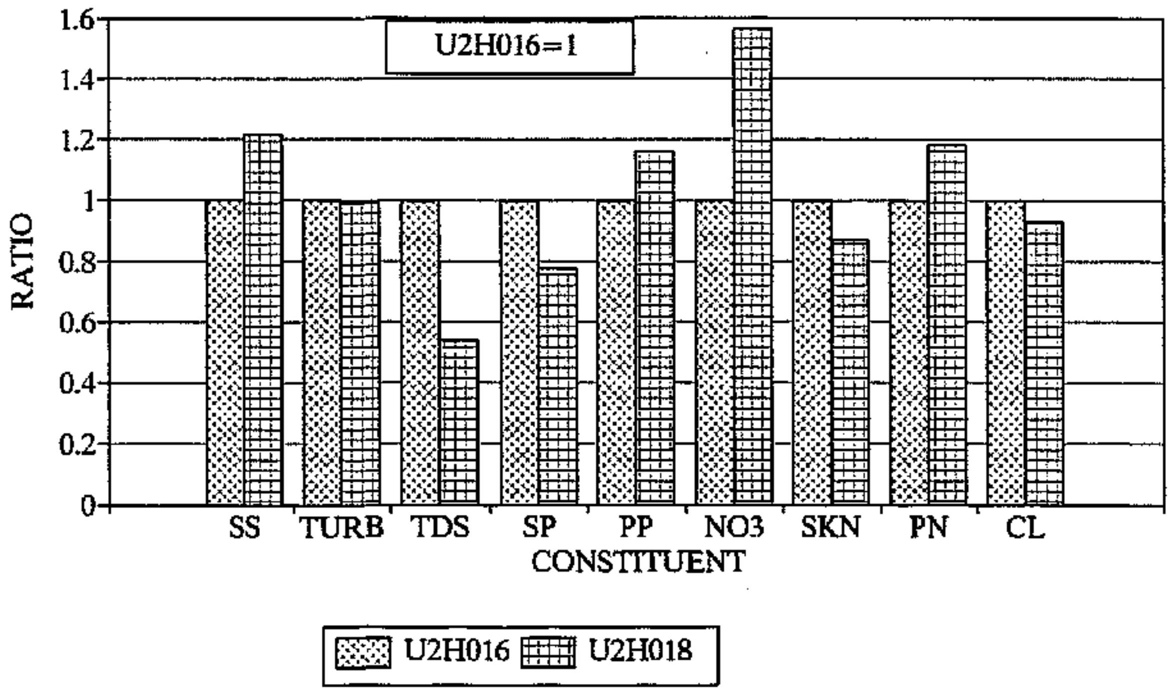
Table 6: Analytical and statistical data for runoff samples from weir U2H018 between October 1988 and May 1990

Parameter		Mean	No. Samp.	Std. Dev.	Min.	Max.	Wt. Mean (by Vol.)
Susp. Sol.	mg/l	118	193	296	2	2780	35
Turbidity,	NTU	47	193	72	3	360	19
Conductivity,	mS/m	7,0	193	1,4	2,6	15,1	6,9
TDS (calc),	mg/l	47	-	9	17	101	46
Soluble P,	µg/l	17	184	6,6	3	49	16
Total P,	µg/l	104	184	188	17	1767	48
Nitrate-N,	µg/l	610	137	419	59	2632	521
Sol. Kjel-N,	µg/l	275	89	94	124	520	231
Total Kjel-N,	µg/l	956	90	1166	168	7010	430
Chloride,	mg/l	6,9	99	1,2	2,4	10,1	7,6
Sulphate,	mg/l	2,4	18	0,6	1,5	4,2	2,7
Sodium,	mg/l	6,8	4	1,0	5,3	8,0	6,4
Potassium,	mg/l	1,0	4	0,3	0,73	1,5	1,0
Calcium,	mg/l	3,9	4	1,0	2,7	5,3	3,4
Magnesium,	mg/l	3,3	4	0,6	2,3	3,9	3,1

It may be noted that the nutrient concentrations in rainfall are relatively high in relation to those in runoff from the catchments. Soluble phosphorus is almost half, nitrate more than half and soluble Kjeldahl nitrogen is shown as being higher. This is not altogether a surprising result since similar observations (high rainfall relative to runoff concentrations) have been recorded in previous projects for nitrogen species. The fact that the nutrients are not conservative, in that they may be taken up or released by catchment processes means that concentrations in rainfall relative to those in runoff are only an indication of the net effect at the time, ie: at times nutrients may be taken up in growth and at other times released due to decay and therefore the balance for a catchment is dependent upon current processes taking place. These analyses show that rainfall can be an important source for some constituents such as the nutrients. The mean rainfall quality could be used in a model which had this capability, to simulate initial concentrations in runoff.

Comparison of flow weighted mean runoff qualities between the catchments can most easily be seen in Figure 11 where the values for U2H016 are expressed as unity and those for U2H018 as fractions thereof.

Figure 11: Comparison of flow weighted mean runoff quality between catchments U2H016 and U2H018



Suspended solids concentration for catchment U2H018 is about 20% higher than that for U2H016 but turbidity levels are almost identical which indicates coarser material in washoff from U2H018 for reasons mentioned earlier. Particulate phosphorus and particulate nitrogen levels also show higher levels for U2H018. The higher average slope of the land for catchment U2H018 and the greater erosion potential is the most likely reason for the higher concentrations (see Table 1). On the other hand total dissolved salts concentration for catchment U2H016 is more or less double that for U2H018. The cation and anion concentrations also show some interesting facts. While chloride, sodium and potassium levels are not very different between the catchments, sulphate, calcium and magnesium concentrations are much lower for U2H018 (Tables 5 and 6). Another difference between the catchments is that the major cation for U2H016 is sulphate but for U2H018 the major one is chloride.

Comparison of soluble nutrient levels between the catchments shows higher phosphorus and Kjeldahl nitrogen for U2H016 but a distinctly lower nitrate nitrogen level. While the higher soluble phosphorus concentration (as well as sulphate, calcium and magnesium) for catchment U2H016 may well be attributed to a land-use effect (small holdings, fertiliser for crop production etc.), the higher nitrate concentration for U2H018 is a surprising result as the reverse order may have been expected. No logical reason for this anomaly can be given.

4.4 Export coefficients

Pollutant export coefficients for the catchments were calculated by multiplying weighted mean concentration by annual runoff volumes and expressing the results as kg/ha/a. Variation in values between the two study years (7/88-6/89 and 7/89-6/90) for each catchment is given together with a comparison of overall means between catchments. The actual figures are given in Table 7 but easier comparisons may be seen in Figures 12, 13 and 14 where one set of results is expressed as unity and the other as a fraction thereof.

Figure 12: U2H016: Comparison of export coefficients between years

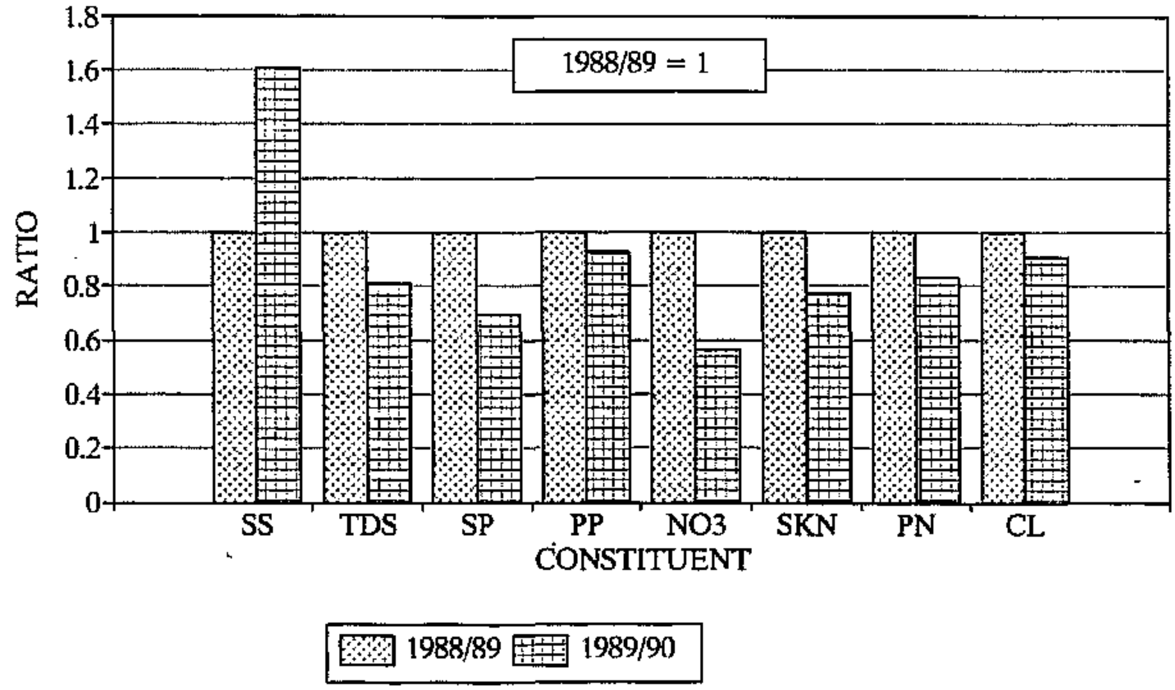


Figure 13: U2H018 Comparison of export coefficients between years

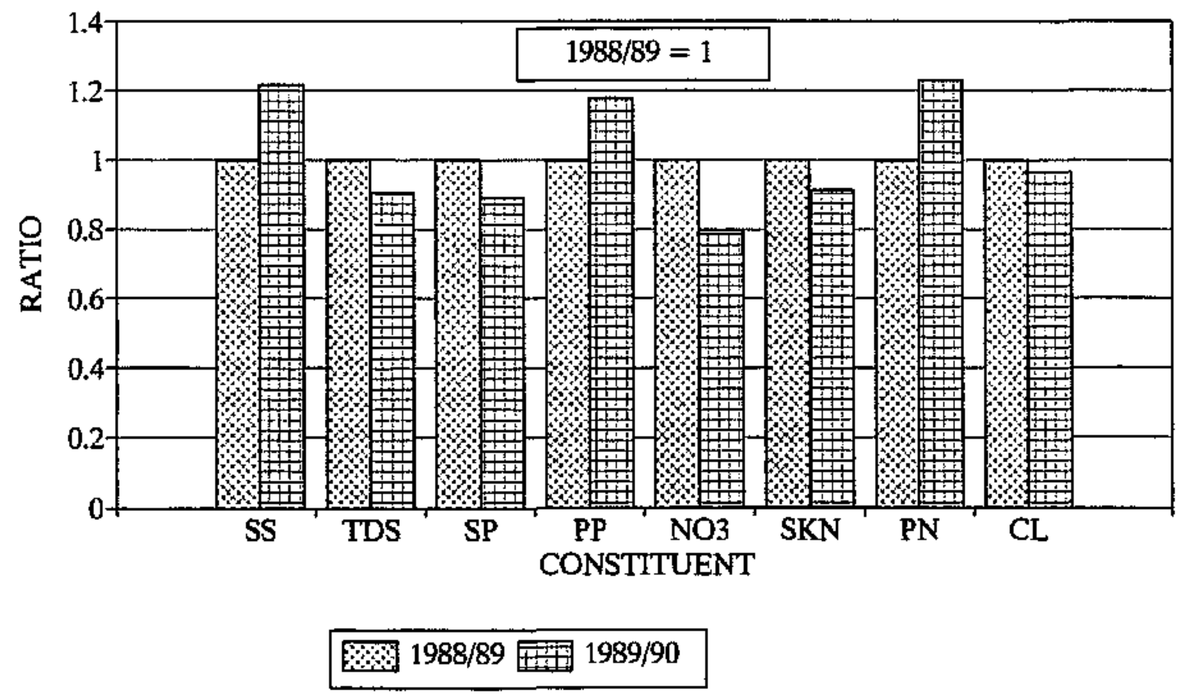


Table 7: Export coefficients for catchments U2H016 and U2H018, kg/ha/a

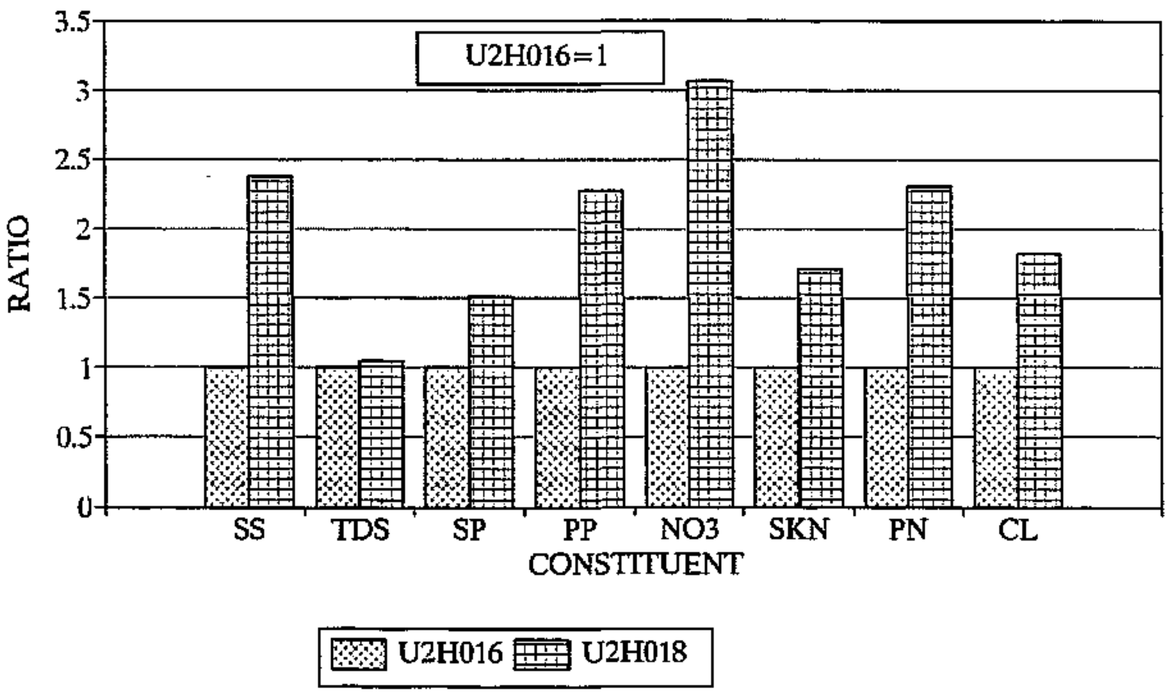
	U2H016 1988/89	1989/90	Mean	U2H018 1988/89	1989/90	Mean
Susp. solids	26,5	42,7	34,6	74,3	90,4	82,3
TDS	112	91	102	112	101	107
Soluble P	0,029	0,020	0,025	0,040	0,035	0,037
Total P	0,063	0,052	0,058	0,109	0,117	0,112
Nitrate-N	0,51	0,29	0,40	1,36	1,08	1,22
Sol. Kjel-N	0,36	0,28	0,32	0,57	0,52	0,54
Tot. Kjel-N	0,58	0,46	0,52	0,98	1,03	1,01
Chloride	10,2	9,3	9,7	18,1	17,4	17,7

It is of interest to note that the magnitudes of the erosion potentials (Table 1) and export coefficients of suspended solids given above for the catchments are quite different. The mean erosion potentials are 95 and 56 times higher than the measured export coefficients for suspended solids for catchments U2H016 and U2H018 respectively. A close agreement between these two parameters could not be expected since the measurement of suspended solids in water samples does not include soil particles greater than about 0,2 mm in diameter due to sampling and analytical techniques, whereas the erosion potential estimate includes particles of all sizes. Nevertheless, the order is correct (U2H018 > U2H016 for both) and perhaps the tenuous relationship given here may be used for estimates of suspended solids washoff from other catchments.

In Figures 12 and 13, results for both catchments for the first years are expressed as unity and for the second as fractions thereof. Runoff for the second year was lower and therefore the coefficients for suspended solids are closer together than was the case for mean qualities. However, there are still appreciable differences with the second year being approximately 60% and 20% higher for catchments U2H016 and U2H018 respectively. For associated parameters, particulate phosphorus and nitrogen, similar results may be seen for catchment U2H018 but there is a slight reversal for U2H016. Lower variation is evident for some of the soluble constituents, particularly for chloride. Generally, the variation between years for catchment U2H018 is less than that for U2H016 which has much lower levels for soluble phosphorus and nitrate in the second year.

Comparison between the catchments is shown in Figure 14 with the results for U2H016 expressed as unity. Here the differences are large. U2H018 is 2,5 times higher for suspended solids and 3 times higher for nitrate. The only close result is for total dissolved salts. As shown earlier, although catchment U2H018 had higher mean concentrations for some constituents the main reason for the much higher export coefficients is the higher runoff for U2H018, ie: 468 mm compared to 240 mm for the two year period. However, it is possible that there could have been major water abstractions from U2H016 during this period, ie: dams, irrigation. If this was the case it is considered a normal activity in the catchment.

Figure 14: Comparison of export coefficients between catchments U2H016 and U2H018



4.5 Quality variation with flow during study period

In order to obtain a general idea of changes in runoff quality with flow and during the entire study period, the results for both individual and composite samples, where applicable, have been plotted with flow in Figures 15 to 26. Base flow results have been omitted in favour of showing hydrographs which are separated by line breaks in the plots. The time scale on the x-axis is not linear but the dates indicate the start of the hydrographs.

Suspended solids

As shown in Figures 15 and 16, suspended solids are very clearly responsive to flow changes but the degree of response is variable as is the shape of the concentration plots. The hydrographs for both catchments starting on 11/88 show large increases in suspended solids concentrations which more or less follow the shapes of the hydrographs. Subsequent hydrographs (12/88, 2/89), although of the same magnitude, have much lower increases in suspended solids concentrations. Further, the shape of the suspended solids graphs is different in that although there are initial rises in concentrations with flow there is rapid falloff in spite of increasing flows. This is particularly evident for the hydrograph of 2/89 in Figure 16. The reason for this behaviour would seem to be initial washoff of accumulated materials from surfaces by the first rains of the wet season, ie: a first flush effect. The fact that suspended solids concentrations are not sustained during hydrographs would appear to be a combination of depletion of a "surface store" and increased dilution of surface runoff from interflow. The second wet season starting on 11/89 shows an almost identical behaviour, particularly for U2H016 for the first and subsequent hydrographs, ie: high suspended solids concentrations followed by lower ones as the season progressed.

Turbidity

Turbidity is related to suspended solids and therefore a similar response to flow may be expected and can be seen in the Figures 17 and 18. There are unequal responses of turbidity to peaks during hydrographs as seen above, ie: lower levels for subsequent peaks. However, there are some quite noticeable differences to the suspended solids concentration patterns. The falloff in turbidity levels from the beginning of the wet seasons is not as pronounced as is the case for suspended solids. This indicates a non-linear relationship between suspended solids and turbidity. Whereas turbidity is a measure of only fine particles, suspended solids encompasses both fine and coarser particles.

Conductivity

The response of conductivity to changing flows may be seen in Figures 19 and 20 for catchments U2H016 and U2H018 respectively. Both graphs clearly display the inverse relationship of conductivity to flow. As with the previous graphs there is an inconsistent response of the conductivity levels to peak flows. Hydrographs with similar sized peaks do not show the same decreases in conductivity levels. The largest decreases in conductivity for catchment U2H018 are associated with the first hydrographs for each season (see Figure 20, dates 11/88 and 11/89). This may be due to the fact that runoff from this catchment virtually ceases during the dry season. In the case of catchment U2H016 the largest decreases are associated with the largest peak flows. The mechanism in both cases is one of dilution of salts derived from the catchments by rainfall since, as shown earlier, rainfall contains low salt concentrations.

Soluble phosphorus

Changing soluble phosphorus concentrations are shown in Figures 21 and 22. Although at times there appears to be a tenuous relationship of concentration to flow, it is contradictory since there are both increases and decreases in concentration with flow. The overall conclusion is that soluble phosphorus concentrations fluctuate randomly within a low level band and that mean levels should be used for modelling or other purposes.

Particulate phosphorus

Particulate phosphorus concentrations in relation to flow shown in Figures 23 and 24 are virtually mirror images of the earlier suspended solids graphs. This is to be expected as high correlation coefficients were found between these variables, as will be shown in a later section.

Figure 15: U2H016: Variation in suspended solids concs. with flow

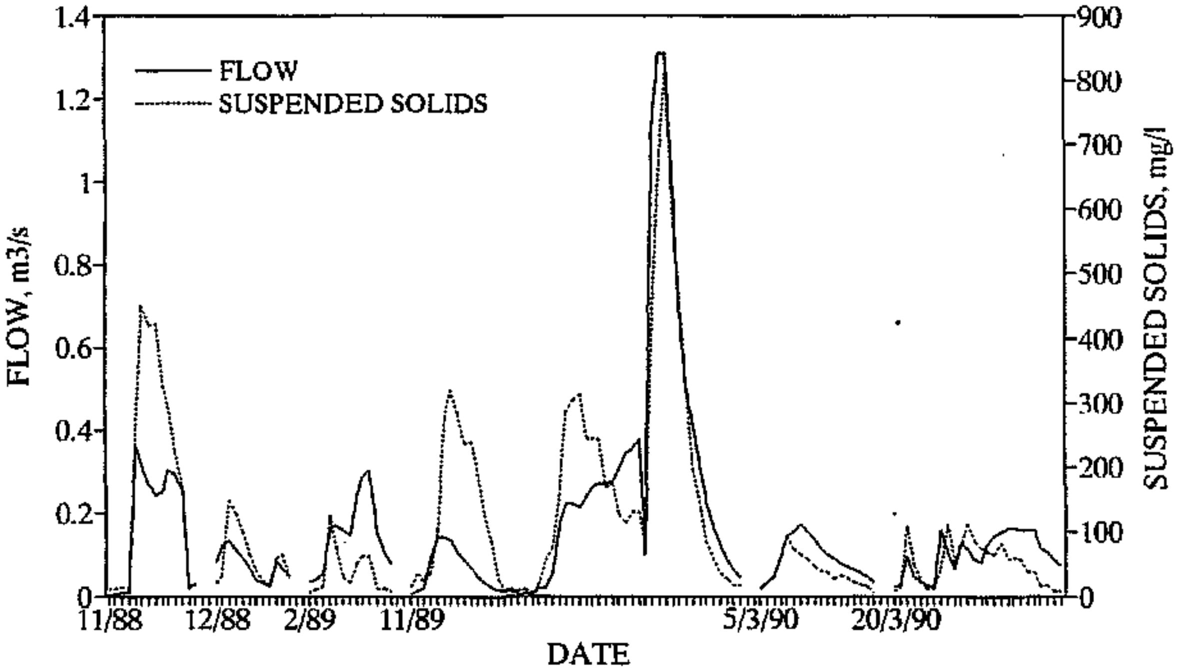


Figure 16: U2H018: Variation in suspended solids concs. with flow

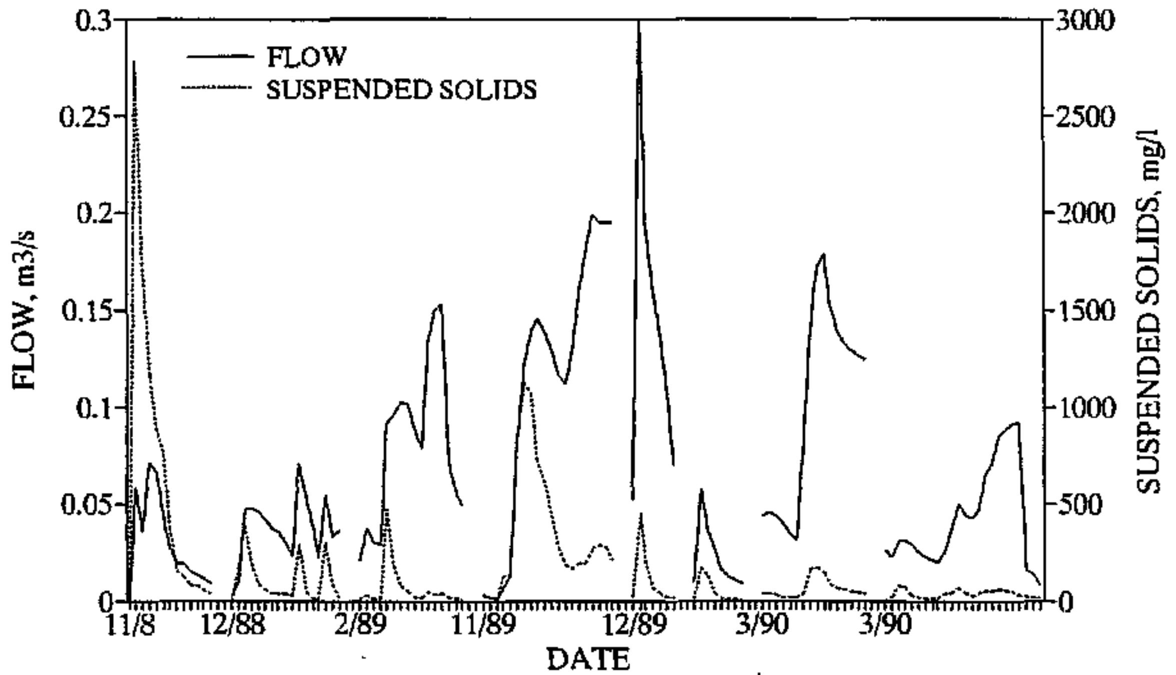


Figure 17: U2H016: Variation in turbidity levels with flow

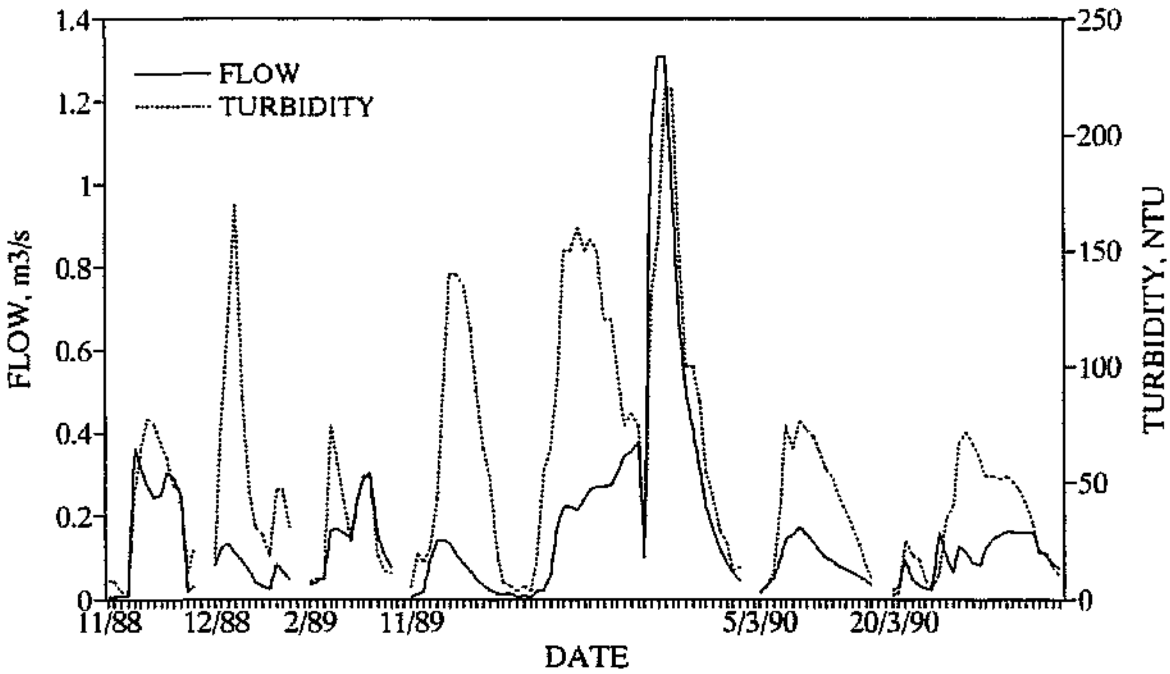


Figure 18: U2H018: Variation in turbidity levels with flow

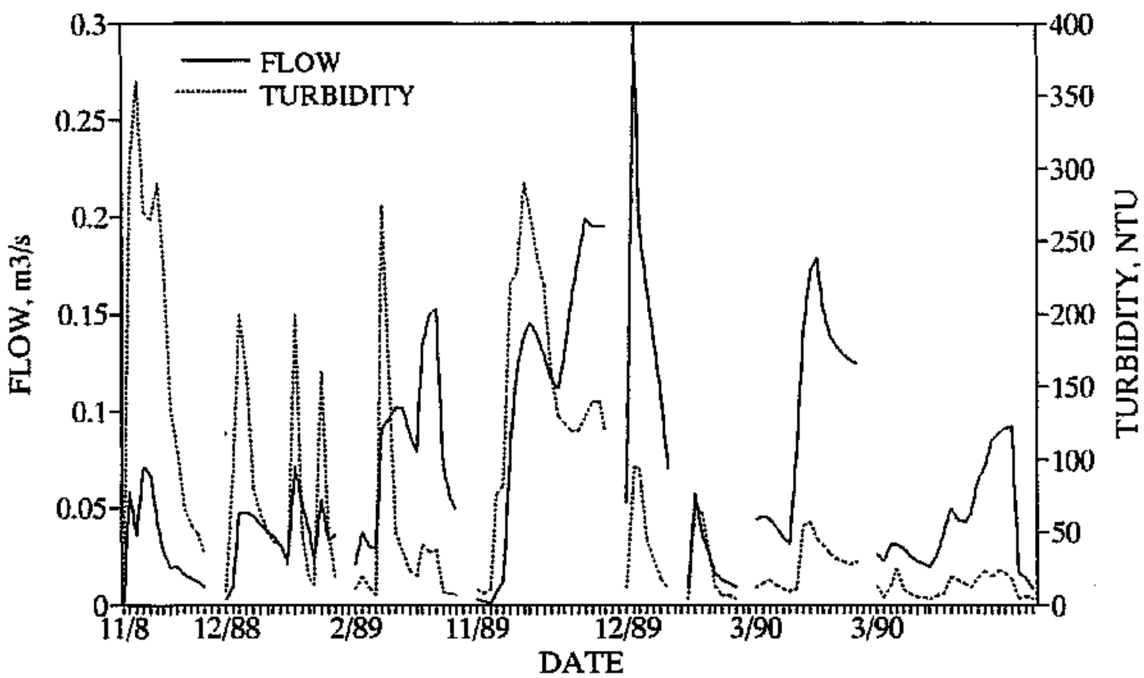


Figure 19: U2H016: Variation in conductivity levels with flow

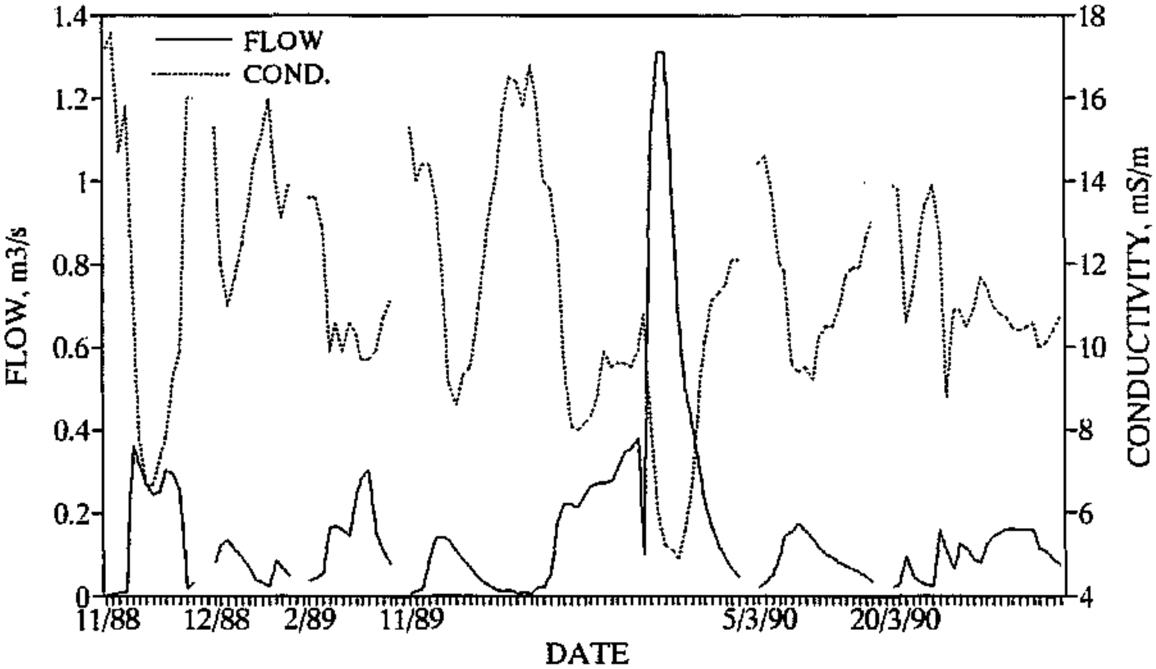


Figure 20: U2H018: Variation in conductivity levels with flow

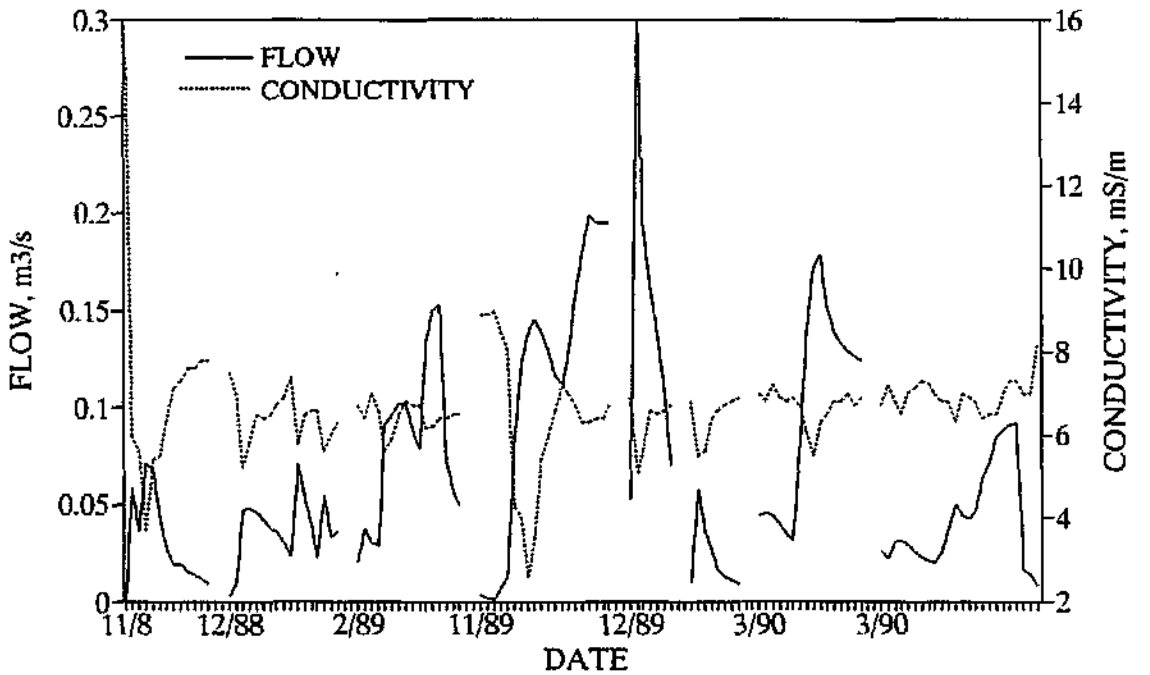


Figure 21: U2H016: Variation in soluble P concentrations with flow

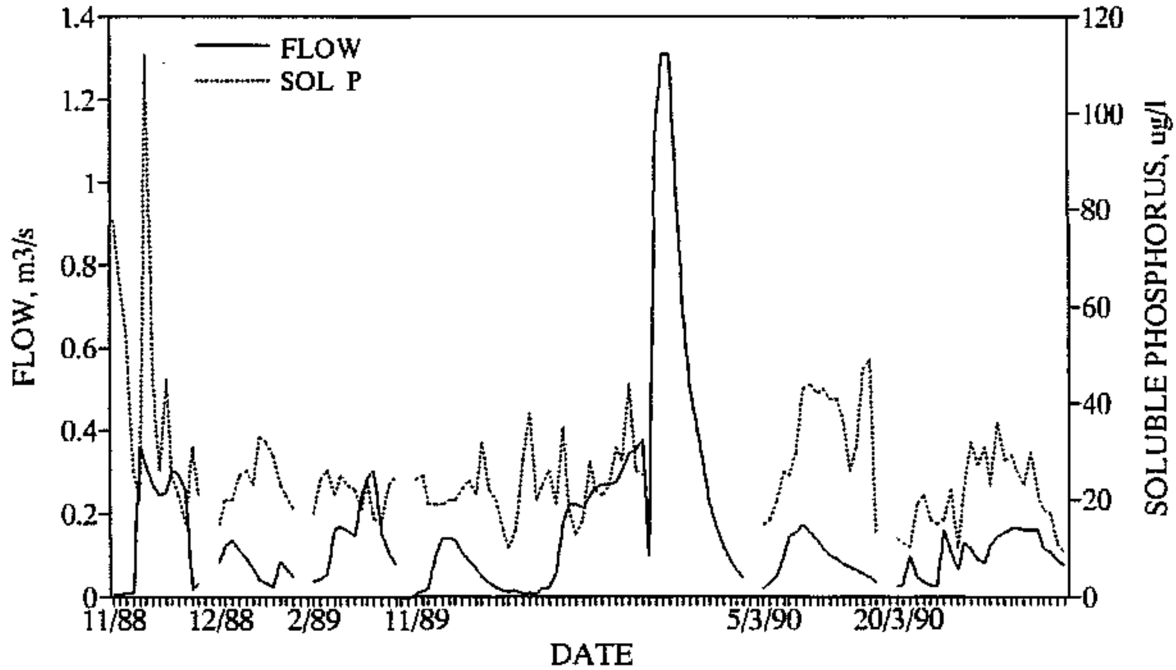


Figure 22: U2H018: Variation in soluble P concentrations with flow

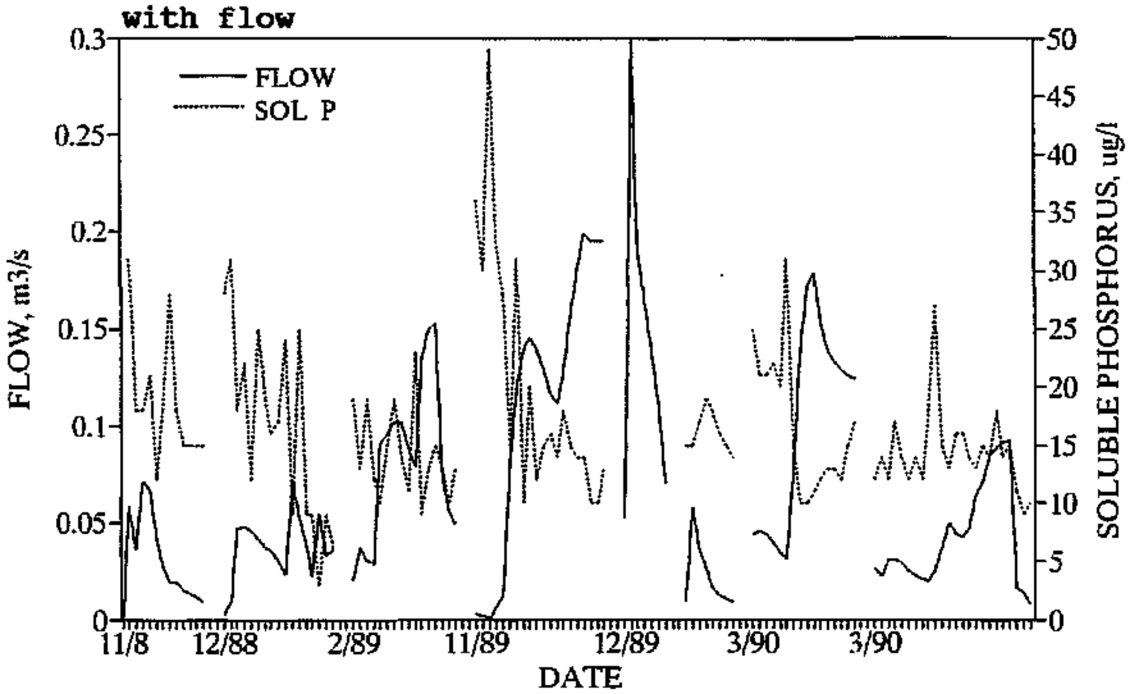


Figure 23: U2H016: Variation in particulate P concs. with flow

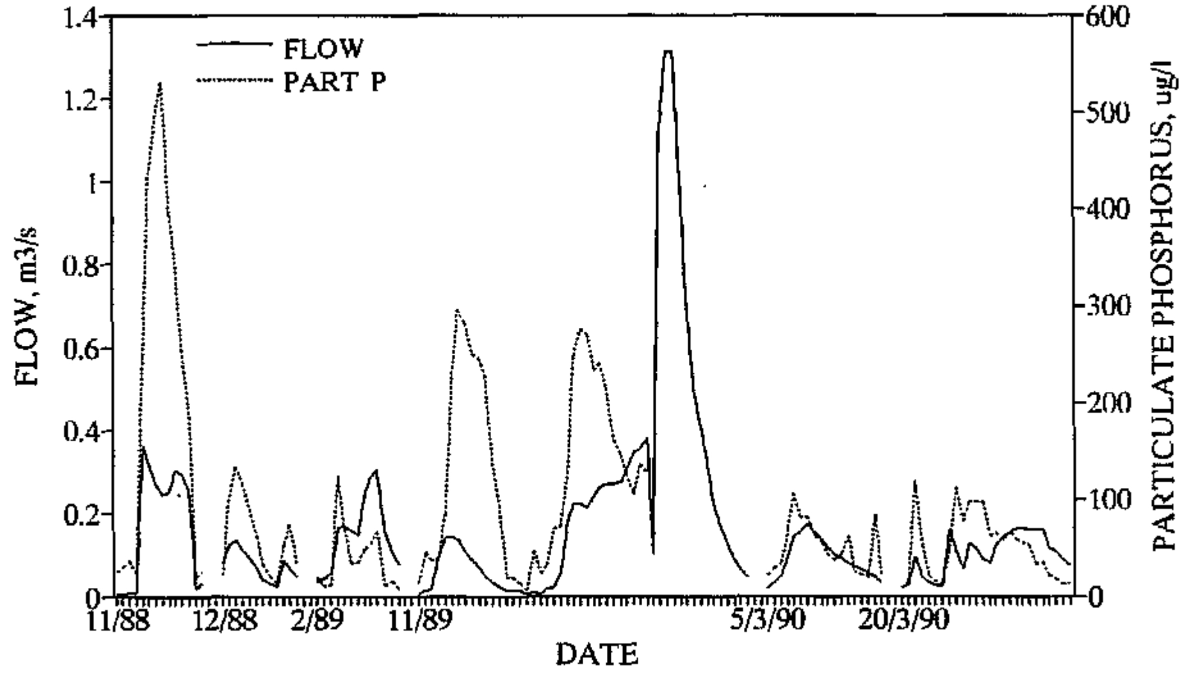


Figure 24: U2H018: Variation in particulate P concs. with flow

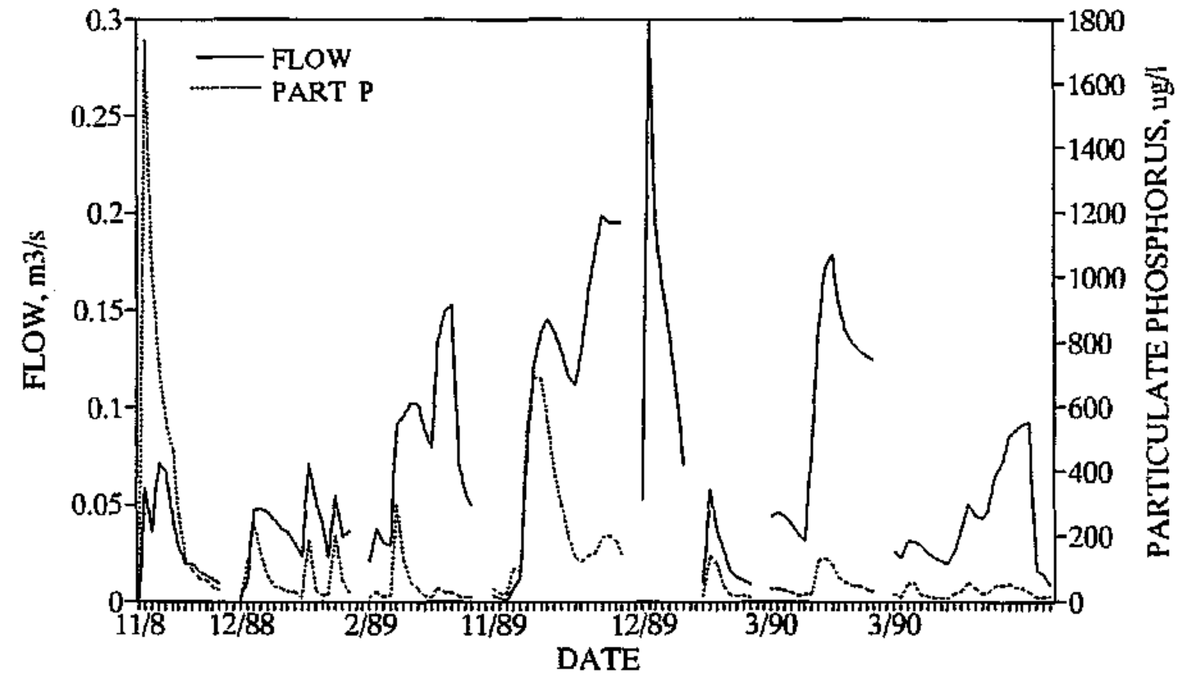


Figure 25: U2H016: Variation in nitrate concentrations with flow

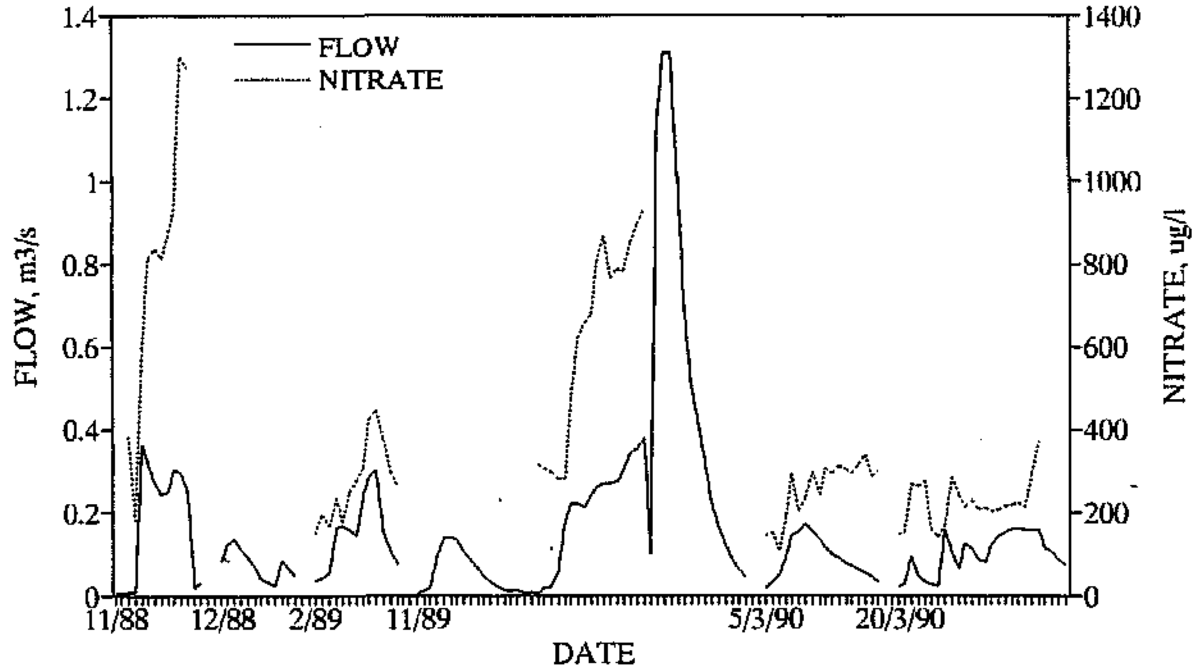
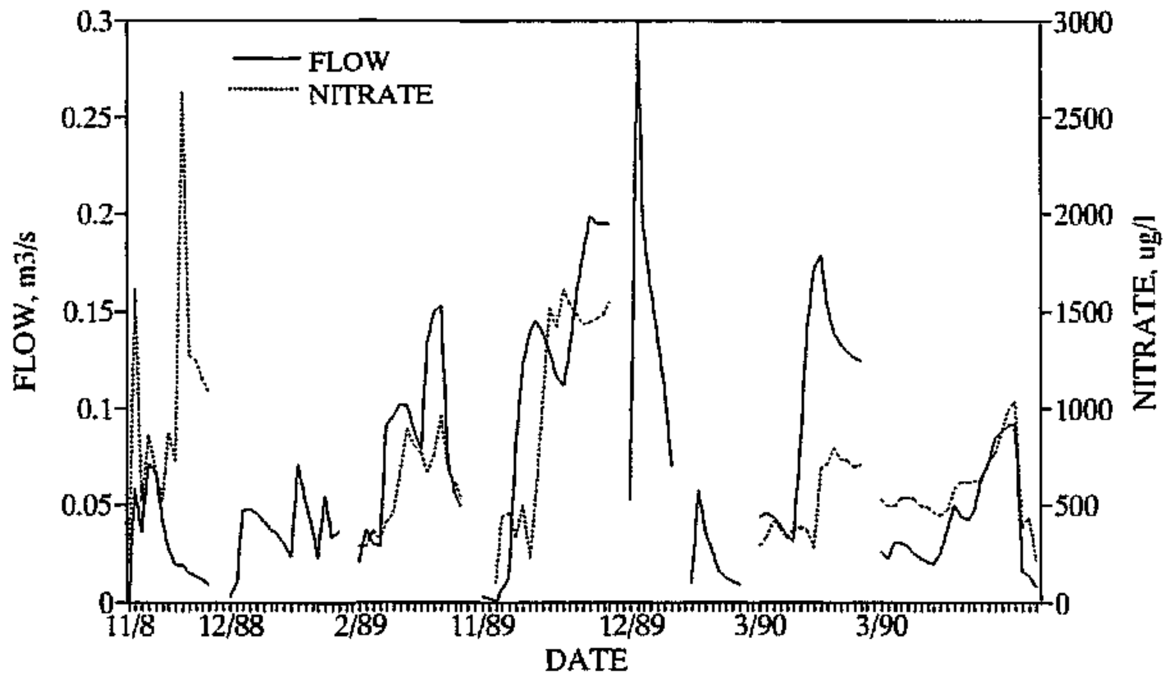


Figure 26: U2H018: Variation in nitrate concentrations with flow



Nitrate

The final constituent measured for a limited number of samples is nitrate and these graphs are given in Figures 25 and 26. The records are incomplete for various reasons, one being financial constraints. For the data shown for catchment U2H016, nitrate concentrations do rise with increasing flow, particularly during the largest hydrograph and the one at the beginning of the first wet season. The positive response of nitrate concentrations to flow changes is also clearly shown in Figure 26 for catchment U2H018. Here there is little doubt about the tendency for higher concentrations at higher flows and a delayed effect in concentration rise and fall with flow appears to be present (Figure 26, dates 2/89 11/89 and 3/90). The high concentrations cannot be ascribed to rainfall since, although rainfall was earlier shown to be a significant source of nitrate, the rainfall data actually showed a tendency for lower concentrations with large events. The fact that higher concentrations are present at the beginning of both wet seasons indicates a "first flush" effect as was discussed for suspended solids.

4.6 Quality changes during hydrographs

In order to gain a better insight into the manner in which quality parameters change during individual hydrographs, constituent concentrations have been plotted against flow and the plotted points joined so that the path of the changing concentrations could be followed. Concentration is on the x-axis and flow on the y-axis and the purpose here is to identify patterns and see if they are repetitive.

Suspended solids

Six plots of suspended solids against flow are shown for catchment U2H016 in Figure 27 and the hydrograph is identified by the date of the first sample. The first three hydrographs dated 881203, 881216 and 891108 show similar behaviour patterns, that is a delayed rise in concentration with flow, then increasing concentrations at more or less stable high flows followed by falling concentrations with flow. The higher concentrations on the falling limb of the hydrograph or "looped effect" would be consistent with initial dilution caused by the weir pond since samples were taken from the V-notch and not from the incoming flow which would have contained the high concentrations. A different pattern may be seen for the hydrograph dated 891128 which had a higher peak of almost 0,4 m^3/s. After a brief lull in flow the next hydrograph dated 891201 began and in fact really forms part of the same storm but was not plotted in the same figure so as to avoid a confusion of lines. Here a very large peak came through and concentrations were slightly lower on the rising than on the falling limb. The dominant process in this case was probably erosion. The final hydrograph in Figure 27 dated 900320 was small in terms of both flow and concentrations and initially showed linear concentration increases and decreases with flow. Subsequently, after sample no. 6 when higher flows occurred the same clockwise path for suspended solids levels against flow is shown ie: higher concentrations on the rising than on the falling limb of the hydrograph.

Similarly, six plots are shown for catchment U2H018 in Figure 28. The pattern is different here as in all six graphs a tendency for higher concentrations on the rising than on the falling limbs of the hydrographs can be seen. Two hydrographs (890210 and 891126) clearly show more or less stable lower concentrations after initial high concentrations even with increasing or high flows. This would indicate exhaustion of the supply of material.

What this all means is that there are identifiable patterns to washoff of suspended solids during hydrographs, albeit different for the two catchments. A model or process that takes into account the build-up of materials on catchment surfaces during dry periods, their removal from the store by runoff, and replenishment by rainfall-runoff mechanisms should be effective in simulating concentrations.

The other solids associated parameters, turbidity and particulate phosphorus were investigated in the same manner but are not presented here as they showed similar trends to those seen for suspended solids. Their generation in a model could be linked to suspended solids concentrations through an appropriate relationship such as a regression equation.

Figure 27: U2H016: Changes in suspended solids concentrations during hydrographs

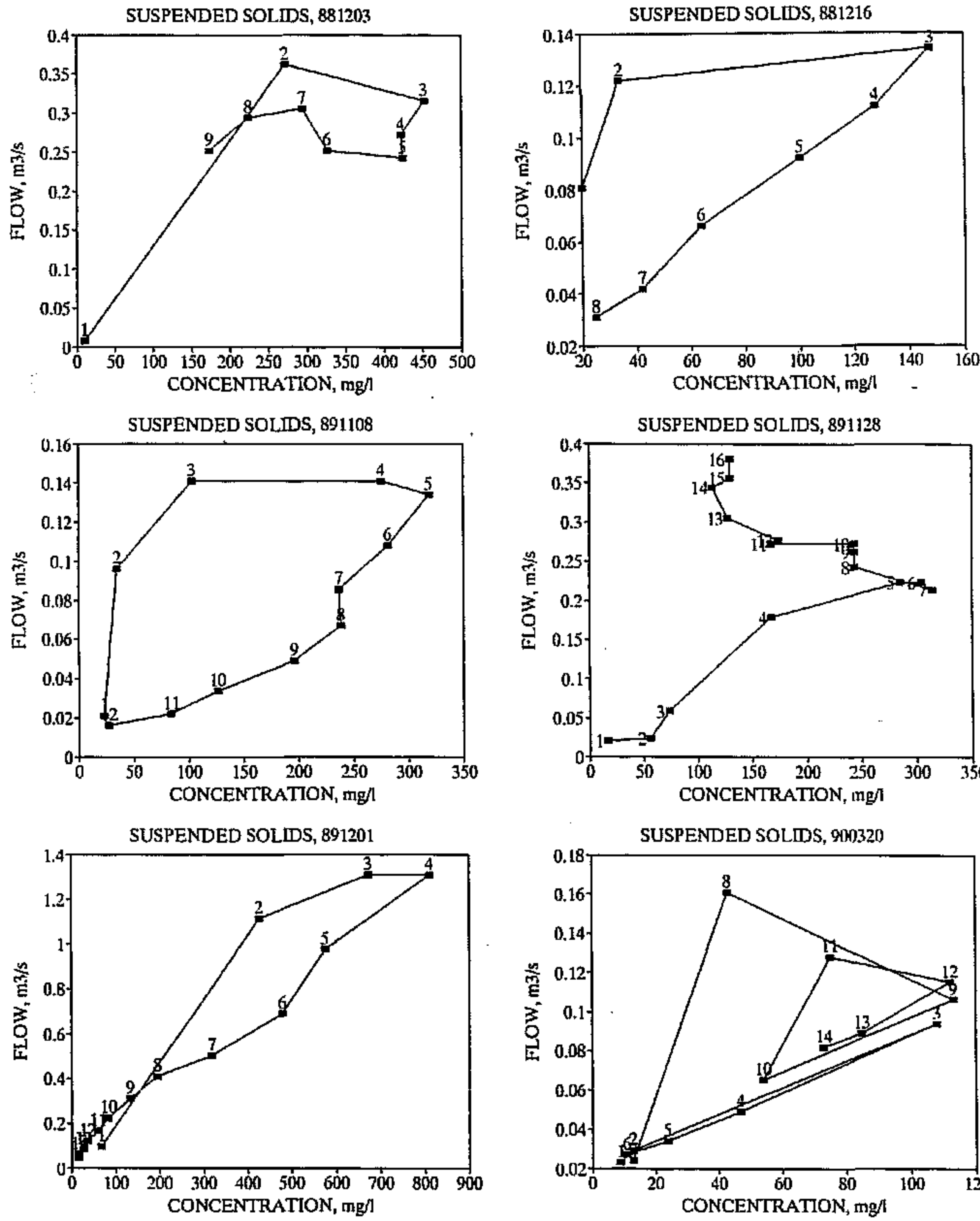
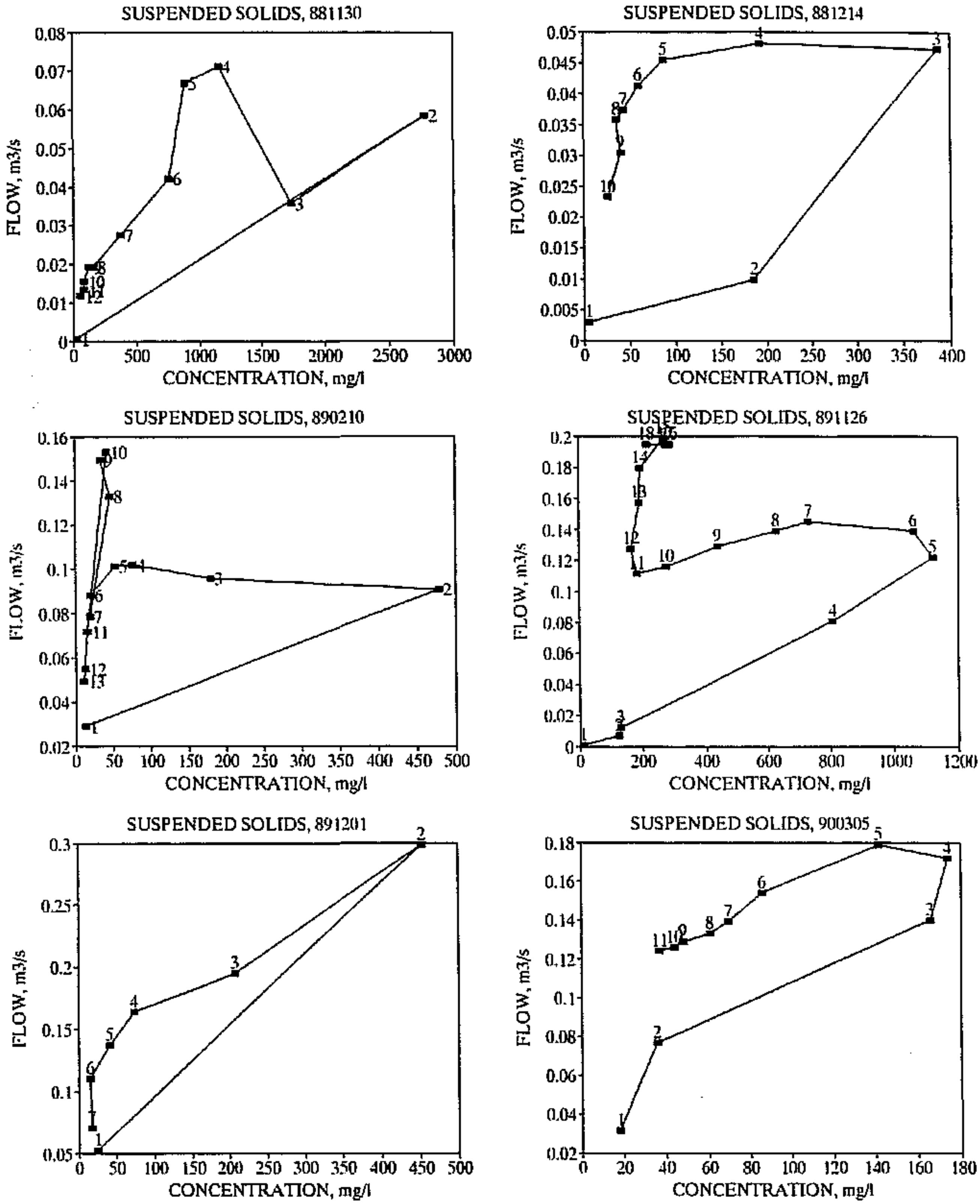


Figure 28: U2H018: Changes in suspended solids concentrations during hydrographs



Conductivity

As discussed earlier, conductivity has an inverse relationship with flow and this can clearly be seen in Figures 29 and 30 for catchments U2H016 and U2H018 respectively. The general trend of the graphs for catchment U2H016 is one of higher conductivity levels on the rising than on the falling limbs of the hydrographs. This "looped effect" in an anti-clockwise direction would indicate a delayed dilution effect from rainfall. Again the buffer effect in the weir pond may be the reason for this phenomenon, ie: different incoming and outgoing concentrations. The hydrograph dated 900320 shows a multiple "loop effect".

The patterns shown for catchment U2H018 in Figure 30 are not as well defined and tend to be confusing, but if anything show the reverse clockwise "looped effect", ie: higher levels on the falling than on the rising hydrograph limbs. There is no ready explanation for this observed effect.

The variable patterns seen for conductivity and the differences between catchments show that the processes occurring are complicated and largely unknown. What is known is that there is a dilution effect from rainfall.

Soluble phosphorus

As discussed earlier, soluble phosphorus did not indicate any clear relationship with flow. For interest, as a considerable number of analyses have been conducted, variation in phosphorus concentrations are shown for two hydrographs in Figure 31 for catchment U2H016 and for two in Figure 32 for U2H018. For catchment U2H016 the first hydrograph shows rather random changes in phosphorus concentrations with flow while in the second hydrograph dated 891128 the concentrations show a tendency to both rise and fall with flow. For catchment U2H018 falling concentrations are indicated for the hydrograph dated 881214 but concentrations for the other one seem to be completely random.

All in all there are no convincing or repeatable patterns shown for soluble phosphorus and therefore a mean concentration would be most appropriate for use in a model.

Figure 29: U2H016: Changes in conductivity levels during hydrographs

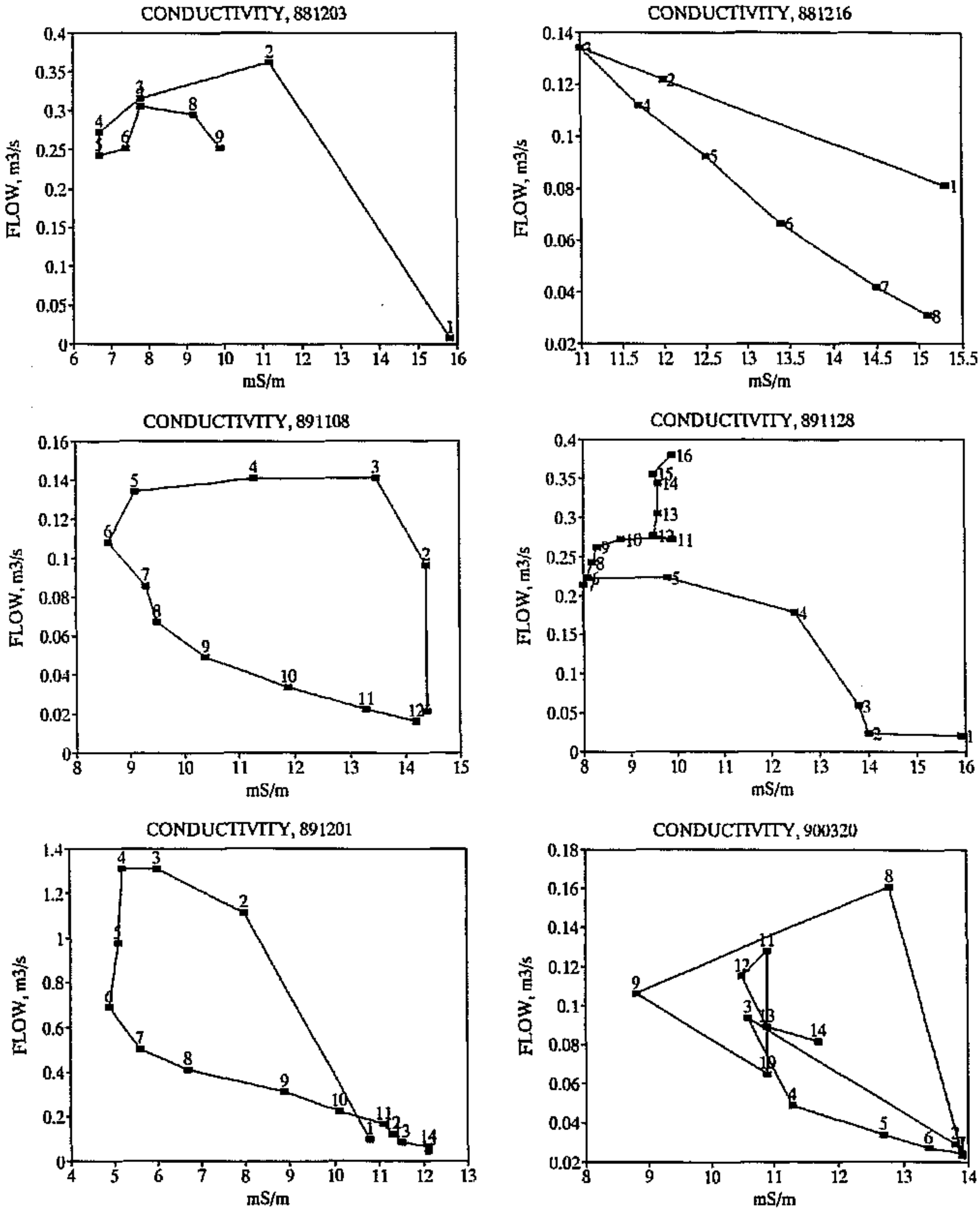


Figure 30: U2H018: Changes in conductivity levels during hydrographs

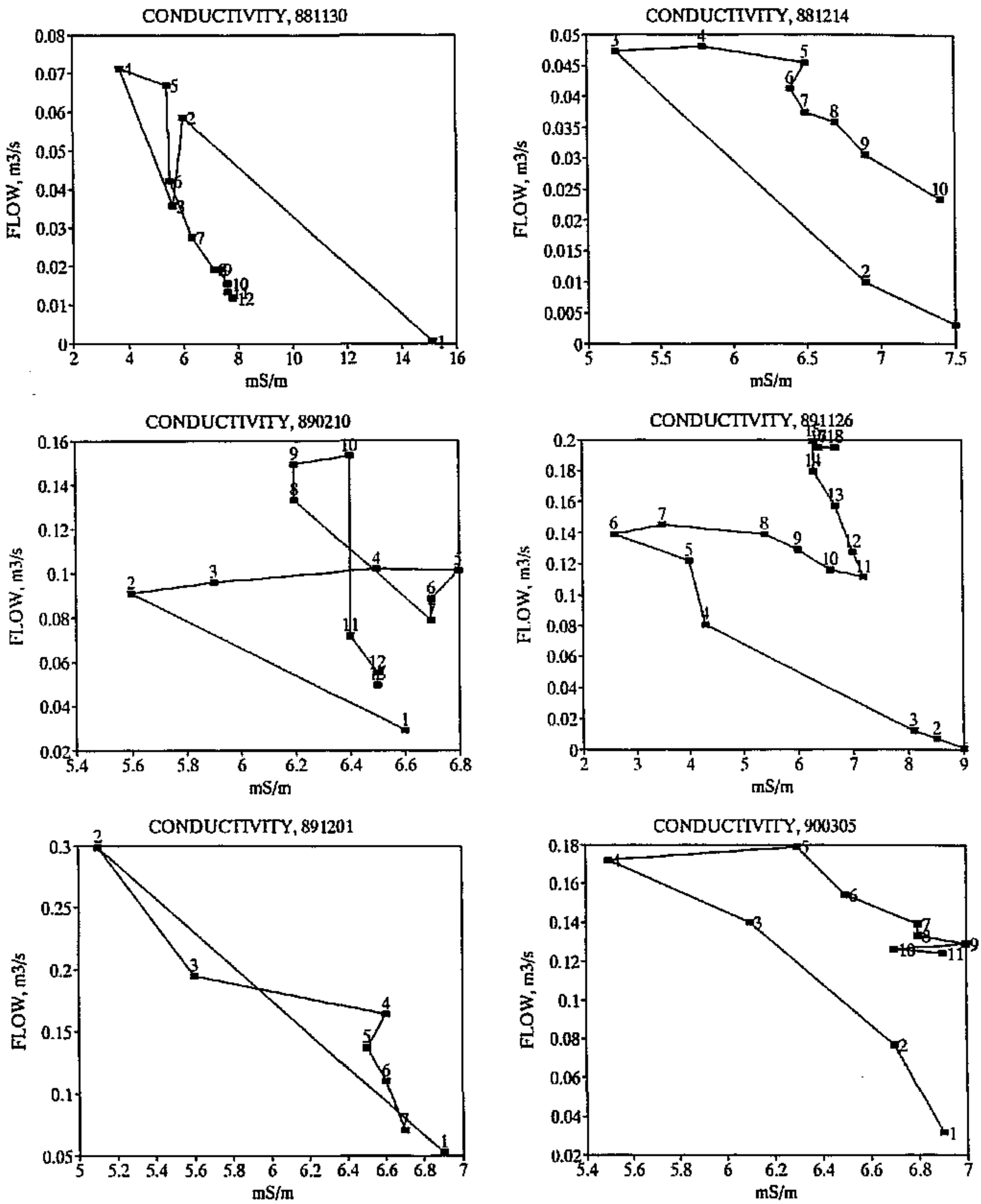


Figure 31: U2H016: Changes in soluble P concs. during hydrographs

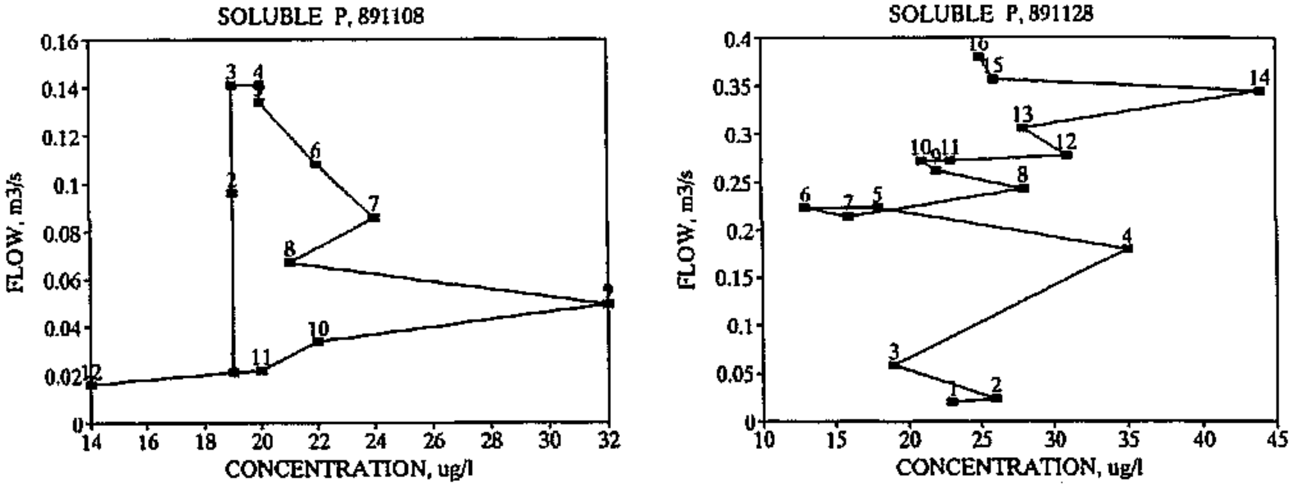
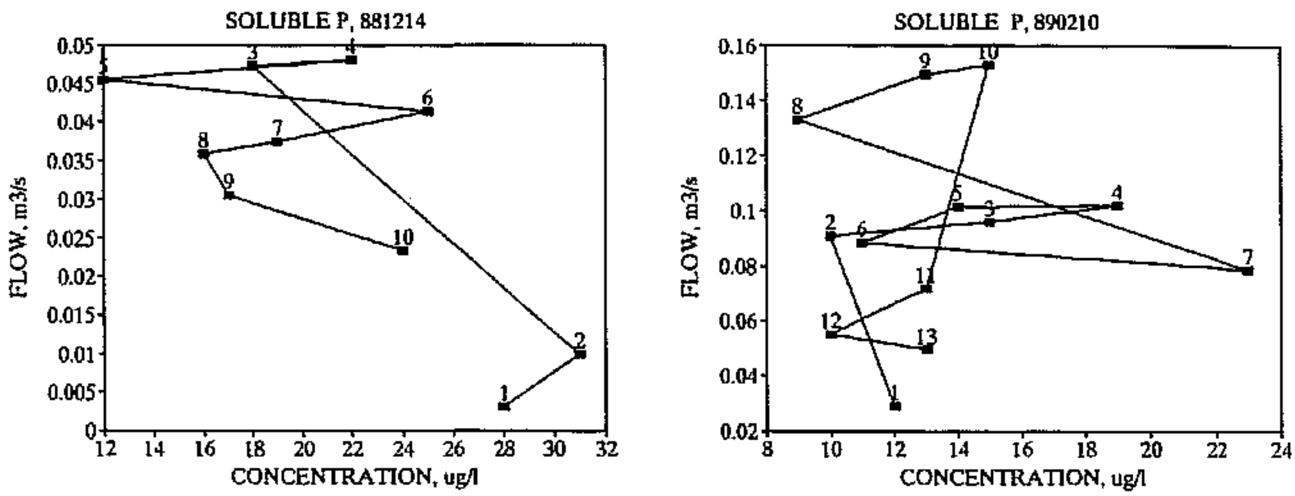


Figure 32: U2H018: Changes in soluble P concs. during hydrographs



4.7 Regression of water quality variables on flow

A regression analysis to test the degree of dependency of constituent concentrations on flow was carried out using four different model types, ie: linear, multiplicative, exponential and reciprocal. The squared values of the regression coefficients, that is the amount of variance explained by the model, has been used as the criterion to judge the goodness of fit of the models. These values are given in Table 8 and are expressed as percentages. Since each model indicates a different type of relationship, an insight is given into which is potentially suitable and which is not.

Table 8: Regression analysis of water quality variables on flow for different models for catchments U2H016 and U2H018

Constituent	Model Type	R^2 value as a percentage U2H016	U2H018
Susp. sol.	Linear	**74**	7
	Multiplicative	65	32
	Exponential	45	**33**
	Reciprocal	13	18
Turbidity	Linear	54	16
	Multiplicative	**66**	32
	Exponential	37	32
	Reciprocal	18	29
Conductivity	Linear	50	22
	Multiplicative	**81**	**45**
	Exponential	62	23
	Reciprocal	72	20
Soluble P	Linear	0	10
	Multiplicative	3	17
	Exponential	0	9
	Reciprocal	1	5
Particulate P	Linear	49	8
	Multiplicative	46	27
	Exponential	**52**	**30**
	Reciprocal	18	23
Nitrate-N	Linear	**44**	22
	Multiplicative	19	**33**
	Exponential	39	26
	Reciprocal	21	21
Chloride	Linear	17	**10**
	Multiplicative	1	4
	Exponential	22	9
	Reciprocal	**27**	7

Note: Coefficients for the best fit models are highlighted in bold print.

The results show that no one model fits best for all constituents, eg: for catchment U2H016 the linear model is best for suspended solids, the multiplicative one for turbidity and conductivity, the exponential one for particulate phosphorus and the reciprocal one for chloride. The nature of the best fit model in each case is informative about the relationship. The straight line linear model for suspended solids predicts even increases in concentrations with flow, the multiplicative one for turbidity predicts increasing levels with flow but at a decreasing rate and the exponential one for particulate phosphorus predicts increasing concentrations at an increasing rate. For catchment U2H018 the best fit models are the same ones for conductivity and particulate phosphorus but different for the other constituents. The highest R^2 values are shown for suspended solids at 74% and for conductivity at 81% for catchment U2H016, but many are less than 50%, as is the case for all values for catchment U2H018. The lowest values were found for soluble phosphorus which, as discussed earlier showed little or no relationship with flow.

For each of the constituents, excluding soluble phosphorus the best fit model curves for the data points are plotted in Figures 33 and 34 for catchments U2H016 and U2H018 respectively. The inner pair of dotted lines represent the 95% confidence interval for the regression curves and the outer pair of dotted lines the 95% prediction limits for new observations. The graphs amply show the wide scatter of the data. There is a preponderance of points at low flows and a considerable range of concentrations in these regions. The higher concentrations/levels generally show the influence of flow.

To summarise, the type of relationship of the various constituents to flow is different and their strength is variable, ranging from R^2 values of 10% to 81%. If an R^2 value of greater than 50% is considered significant then only 4 out of a possible 12 results meet this criterion. Clearly, there are other factors besides flow which determine runoff quality. However, in the absence of physically based algorithms in a model, these statistical relationships can be used as a first attempt to predict runoff quality. A problem though with this type of relationship is that there is no limit to pollutant production, which is not logical. The regression coefficients for the best fit models and equations are given in Table 9.

Figure 33: U2H016: Best fit regression curves for variables on flow

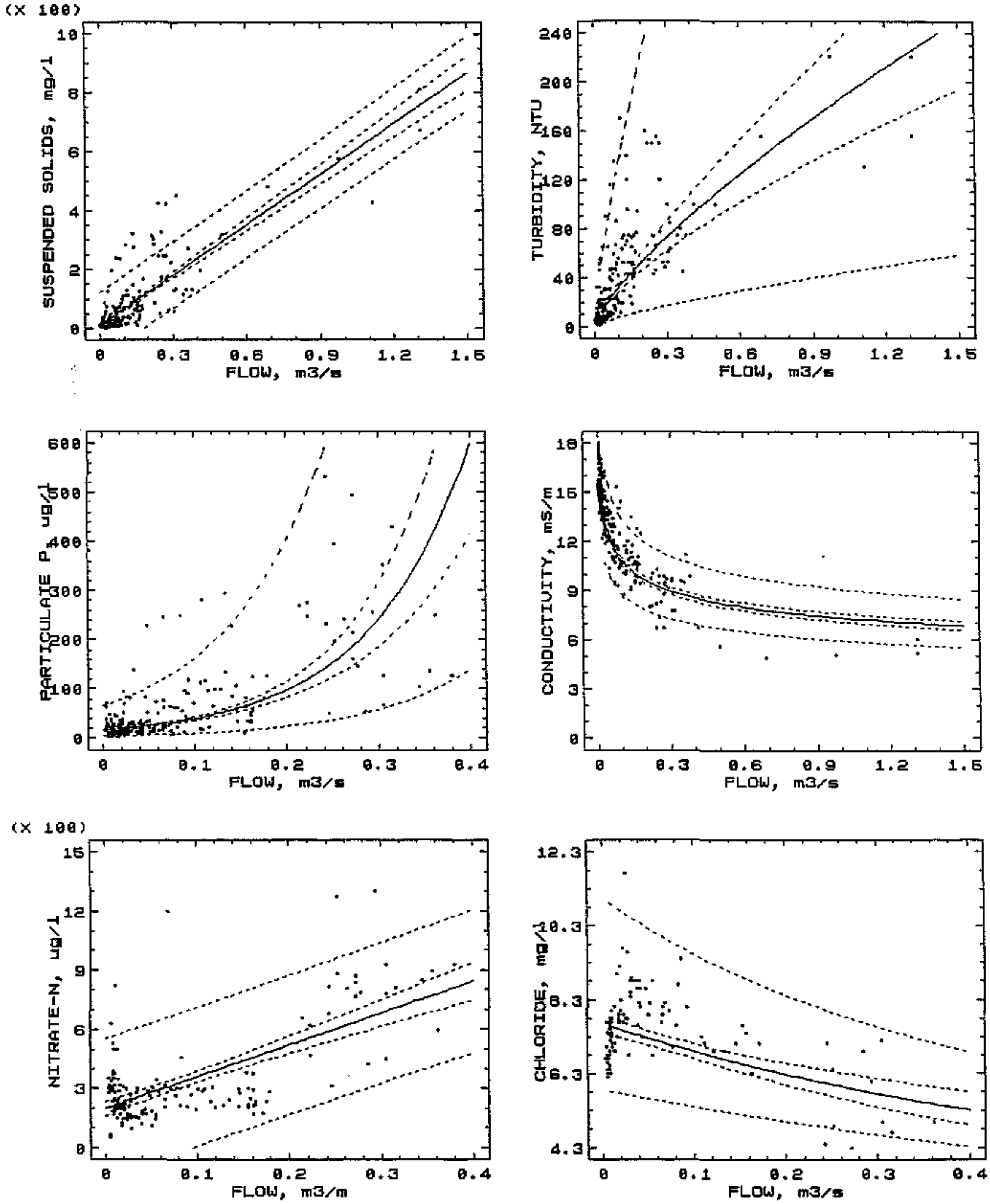


Figure 34: U2H018: Best fit regression curves for variables on flow

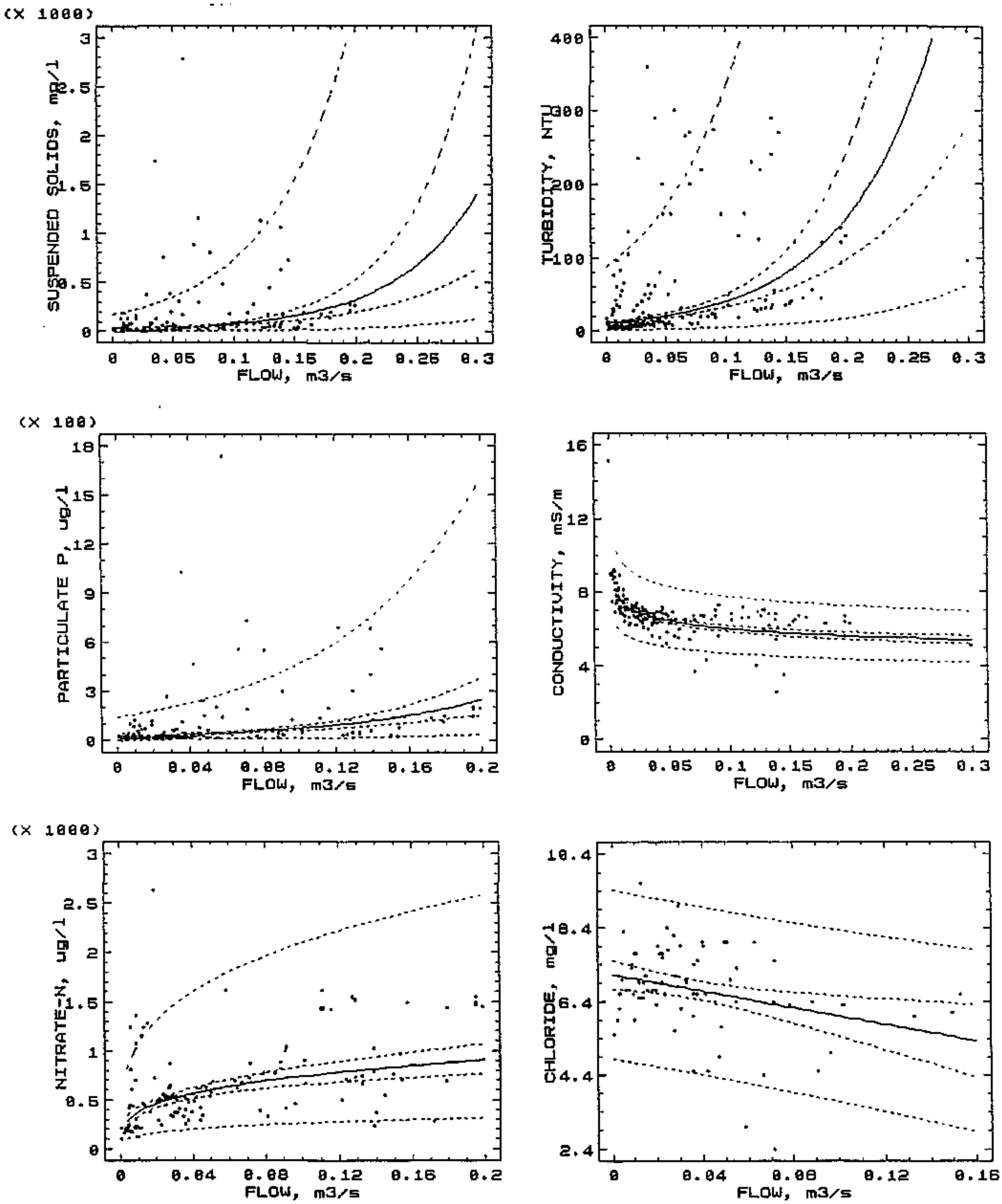


Table 9: Regression coefficients for best fit models for catchments U2H016 and U2H018

Constituent	Catchment	Model	Coefficient a	Coefficient b
Susp. sol.	U2H016	Linear	8,12	572
	U2H018	Exponential	2,87	14,6
Turbidity	U2H016	Multiplicative	5,21	0,765
	U2H018	Exponential	2,35	13,4
Conductivity	U2H016	Multiplicative	1,99	-0,169
	U2H018	Multiplicative	1,57	-0,097
Particulate P	U2H016	Exponential	2,77	9,06
	U2H018	Exponential	3,13	11,9
Nitrate-N	U2H016	Linear	197	1616
	U2H018	Multiplicative	7,28	0,294
Chloride	U2H016	Reciprocal	0,131	0,144
	U2H018	Linear	7,13	-11,2

Note: 1. Model equations:

Linear	y=a+bx
Multiplicative	y=ax^b
Exponential	y=e^(a+bx)
Reciprocal	1/y=a+bx

2. For Multiplicative a=log(base e)

4.8 Correlation between water quality variables

The advantages of establishing the strength of relationships between water quality variables is that if one can be confidently predicted from another, then sample analysis for a long term monitoring project could be reduced and further, the relationships could also be used in models for the same purpose. Accordingly, a correlation analysis was carried out for both catchments and the coefficients are given in Table 10.

As may be expected the correlations between suspended solids, turbidity and particulate phosphorus are reasonable. The highest are shown between suspended solids and particulate phosphorus at 0,98 and 0,99. Those between turbidity and suspended solids are lower at 0,85 and 0,82 which is not surprising as discussed earlier, ie: unequal response of constituents at higher flows.

There is a moderate inverse relationship between suspended solids and conductivity for catchment U2H016 which could be used to predict suspended solids during hydrographs if conductivity was measured continuously, but a much poorer relationship for U2H018. A good correlation between conductivity and chloride was expected but this was not the case as shown by low coefficients of 0,20 for both catchments. Although chloride does contribute towards conductivity it does not constitute a large fraction of the dissolved salts, ie: 0,10 and 0,16 for catchments U2H016 and U2H018 respectively (see Tables 5 and 6).

Soluble phosphorus does not show any meaningful correlation with any other constituent. Nitrate on the other hand shows moderate relationships with suspended solids, turbidity and particulate phosphorus for catchment U2H016 but far poorer coefficients for U2H018.

Table 10: Correlation coefficients between water quality variables for catchments U2H016 and U2H018

U2H016	Turb	Cond	Sol P	Part P	Chloride	Nitrate
Susp. sol.	0,85	-0,71	0,08	0,98	-0,56	0,66
Turbidity		-0,74	0,01	0,74	-0,26	0,51
Conductivity			0,21	-0,66	0,20	-0,45
Soluble P				0,11	-0,36	0,15
Particulate P					-0,58	0,66
Chloride						-0,46

U2H018	Turb	Cond	Sol P	Part P	Chloride	Nitrate
Susp. sol.	0,82	-0,44	0,09	0,99	-0,69	0,22
Turbidity		-0,52	-0,04	0,83	-0,77	0,36
Conductivity			0,35	-0,45	0,20	-0,13
Soluble P				0,01	-0,14	-0,15
Particulate P					-0,69	0,23
Chloride						-0,17

4.9 Summary and discussion

The investigation was carried out over two wet seasons and the mean runoff quality and calculated export coefficients are compared on this basis for each catchment. Fortunately the rainfall for these periods, and implied runoff from the catchments was fairly typical as judged by the long term means for the Cedara area. Consequently, results obtained can be considered as being representative for the catchments and their respective land-uses.

Flow weighted mean runoff quality did vary between years, mostly for suspended solids and related constituents. This may be attributed to different rainfall cycles producing different runoff patterns, variable entrainment of particulates and soluble constituents. Another cause for the variation could be the method used to obtain the results. To get a true mean quality it would be necessary to sample on a regular runoff volume basis continuously throughout the year. Although this was attempted with the automatic equipment installed, there were periods when no sampling took place for various reasons such as when the capacity of the sampler was exhausted during large hydrographs. Longer term monitoring is desirable but was not possible here. Nevertheless, the results obtained are the most accurate to date for the catchments. There was a similar variation in constituent export coefficients between years.

Comparison of runoff quality between the catchments showed higher concentrations of suspended solids, particulate phosphorus and nitrogen and a very much higher nitrate concentration for U2H018, the forested catchment. The greater washoff of particulate materials from U2H018 could be attributed to the much higher average slope of the catchment and consequent higher erosion potential. Conversely, catchment U2H016, with small holdings and a little crop production had double the dissolved salts concentration and higher soluble phosphorus and Kjeldahl nitrogen levels, which may be due to a land-use effect. When converted to export coefficients for the pollutants, those for the forested catchment, U2H018, were much higher, two to three times for some constituents, because of the higher rainfall and runoff for the catchment. This shows that apart from land-use, climatic and physical aspects such as slope play an important part in determining export of pollutants.

Analysis of rainfall in relation to runoff samples indicated that the catchment surfaces/soils were mostly responsible for the production of dissolved salts. Soluble nutrients, phosphorus, nitrate and Kjeldahl nitrogen concentrations were closer to those found in runoff showing that rainfall is an important source. The rainfall collection and analysis was not carried out throughout the project and therefore these conclusions are tentative.

Runoff quality was shown to vary considerably during hydrographs. All constituents, suspended solids, turbidity, particulate phosphorus, conductivity and nitrate with the exception of soluble phosphorus were shown to be highly responsive to changes in flow. All had positive relationships with flow except for conductivity which had an inverse one. An unequal response of suspended solids concentration rises to flow peaks for different hydrographs was evident. Higher concentrations for equivalent flows were noted at the beginning of the wet seasons which is consistent with the theory of a buildup on surfaces during the dry season.

Quality changes during hydrographs were investigated and some patterns became evident. A "looped pattern" with lower concentrations of suspended solids on the rising than on the falling limbs of the hydrographs was shown for catchment U2H016. The reverse pattern was seen for conductivity, ie: higher but falling levels on the rising limbs than on the falling limbs of the hydrographs. This behaviour could be a dilution effect as a result of sampling at the V-notch of the weir instead of at the incoming flow to the weir pond. Almost the reverse "looped pattern" was evident for catchment U2H018 for the same constituents. This is a more logical sequence for suspended solids, higher concentrations at the beginning of hydrographs due to washoff of accumulated materials, ie: a first flush. The much smaller weir pond in catchment U2H018 may be the reason for this different behaviour.

Regression analysis of the water quality variables on flow showed some reasonable relationships for suspended solids and conductivity as judged by the R^2 values (explained variance). Of the four different models tried, no single one was the best for any particular constituent. The linear model was best for suspended solids for catchment U2H016 whereas the exponential one had the highest coefficient for catchment U2H018. For conductivity the multiplicative model was best for both catchments. Soluble phosphorus showed no relationship to flow at all. These statistically derived equations could be used in a model to predict quality, but with an accuracy dependent on the strength of the particular relationship. A weakness, however, would be that there is no limit to the generation of pollutants by high flows which is not logical. In other words this method does not take account of the first flush of stored materials from catchment surfaces (high concentrations), as was amply shown earlier.

Correlation analysis between the water quality variables showed some strong relationships for suspended solids and particulate phosphorus and moderate ones between turbidity, suspended solids and conductivity showing that prediction of one from another is possible where limited measurements are taken. An expected strong correlation between conductivity and chloride did not materialise, showing these variables to be largely independent of one another. As expected soluble phosphorus had poor or negligible relationships with the other constituents.

5 RESULTS FOR THE NTUZE CATCHMENTS

As stated earlier, the collection of runoff samples from these two catchments, W1H016 and W1H031, was carried out by staff of the University of Zululand. Samples were sent to the Durban laboratory of CSIR for analysis and data evaluation. The automatic sampler control systems originally installed at the weirs were not too successful as doubt arose as to exactly where upon the hydrographs samples were taken. As a consequence, results for these samples were suspect and therefore not of much value. Before the second wet season, 1989/90 an electronic data logger and sampler control system was installed, which proved to be far more successful. However, troubles were experienced later on in the year with loss of potential samples. The net result is that reliable sample data was only obtained for the periods July 1989 to May 1990 for catchment W1H016 and August 1989 to October 1990 for catchment W1H031. This essentially means that only one year's data is available for synthesis and therefore variation between years cannot be assessed.

5.1 Rainfall

As with the Cedara catchment research, it is essential to know if rainfall in the study year was typical or abnormal. Since long term records are not available for the catchments themselves, records for a station at the University of Zululand are used to make this assessment. The annual rainfalls since 1968, October to September, given in Figure 35 show that the rainfall for the study year was just a little above the mean. It may be noted that the mean rainfall of 1400 mm is well above that for the Cedara catchments (< 900 mm).

Since the catchments are adjacent, it may be expected that rainfall on them would be similar. As all other attributes for the catchments are similar except for land-use (Table 2), rainfall during the study period is important. The monthly rainfalls for the catchments are given in Figure 36. Rainfall for some months was similar but for others it was appreciably higher for catchment W1H031. In fact, the totals for the period July 1989 to June 1990 were 1280 and 1526 mm for catchments W1H016 and W1H031 respectively.

Figure 35: Annual rainfall variation for Ntuze Catchment Area

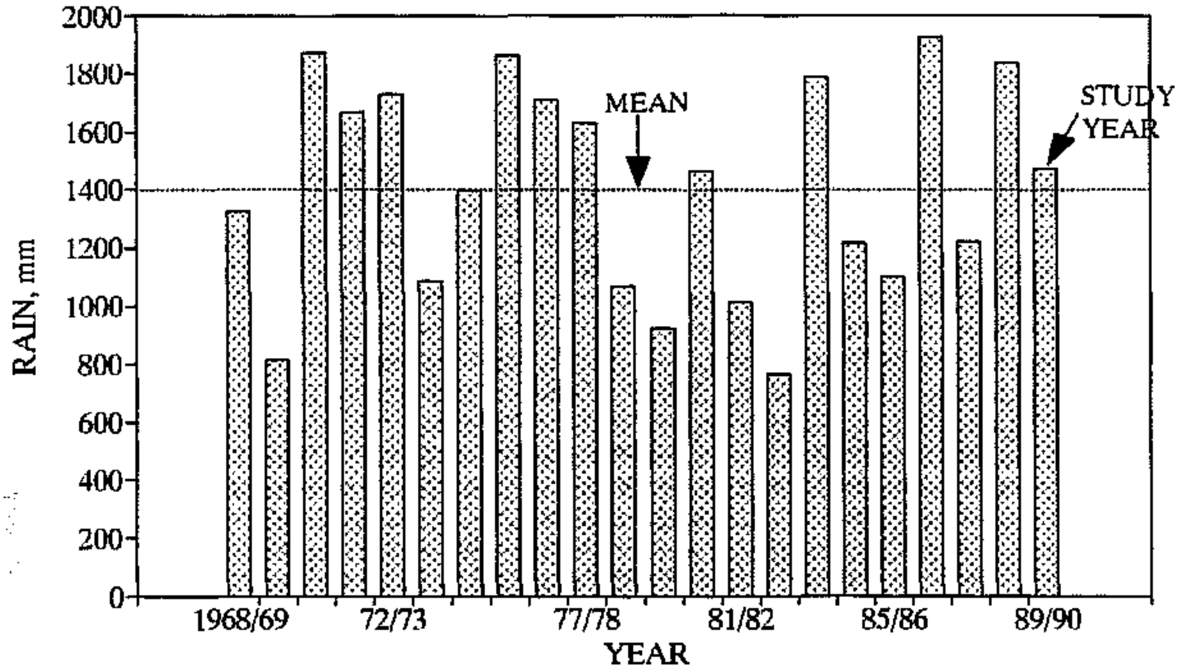


Figure 36: Monthly rainfall for catchments W1H016 and W1H031 during study year

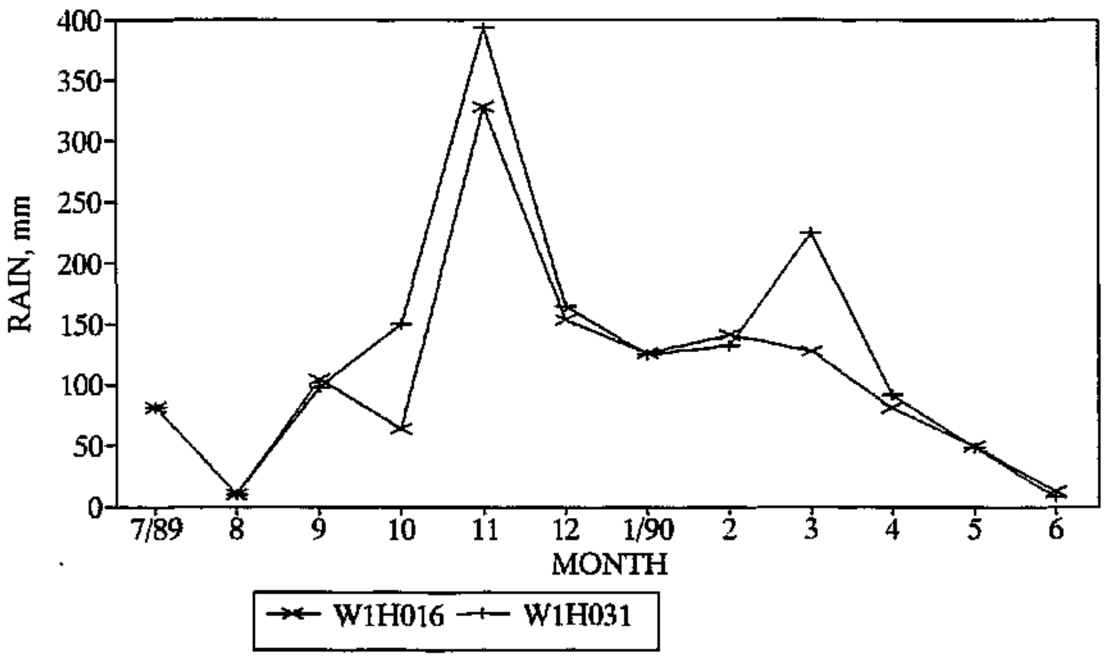
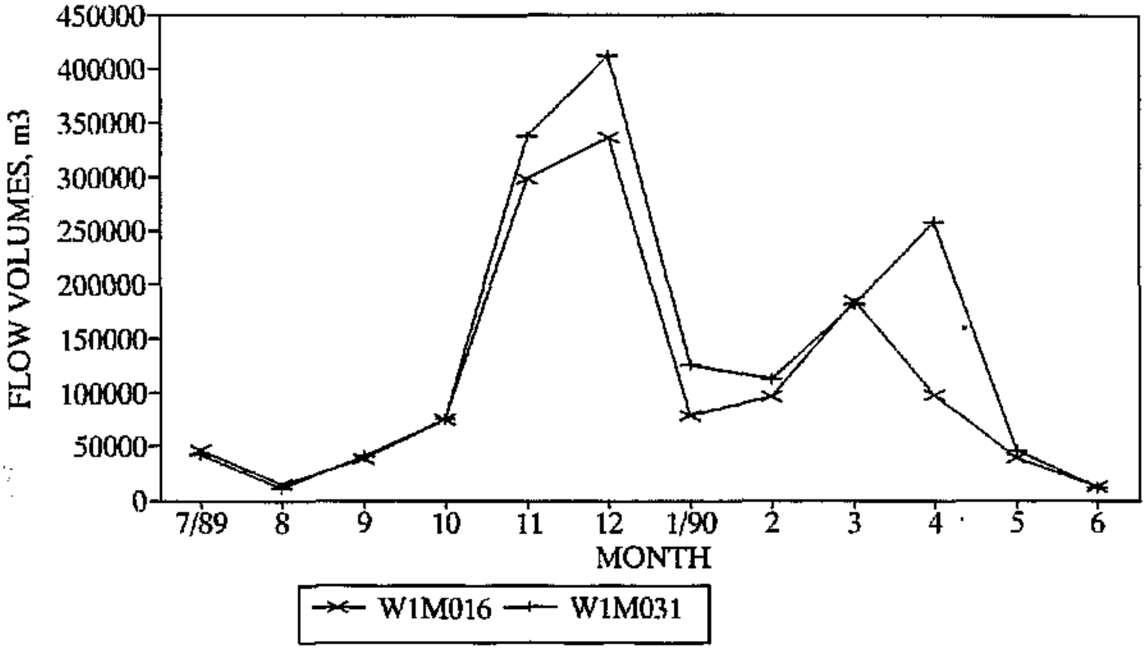


Figure 37: Monthly runoff volumes for catchments W1H016 and W1H031 during study year



5.2 Flows

Comparison of monthly runoff volumes for the catchments are given in Figure 37. For the first part of the period they are similar but from November onwards the volumes for catchment W1H031 are quite a lot higher, particularly for April where it is more than double. Direct comparison of runoff volumes is possible since the catchments are identical in size. Summation of the flows gave 1,32 million m^3 for catchment W1H016 and 1,66 million m^3 for W1H031 which is 26% higher. However, the rainfall for catchment W1H031 was only 19% higher which leads one to suspect a possible problem with the results for W1H016. As before, the higher runoff for W1H031 does impact on pollutant export loads. It is important to note that the raingauges were on the catchment boundaries and therefore the total catchment rainfall may have been different from the measurements.

5.3 Mean runoff quality

Analysis of samples for these catchments was conducted on a slightly different basis to that for the Cedara study. Essentially samples were analysed on a hydrograph basis in order to develop flow-quality relationships and also determine runoff loads. Consequently very few base flow samples were analysed. To obtain the mean runoff quality, the mean for each hydrograph was first calculated by weighting each sample analysis by the flow that it represented followed by calculation of overall means by weighting these results by corresponding hydrograph runoff amounts.

The results and statistical data for the catchments are given in Tables 11 and 12 for catchments W1H016 and W1H031 respectively. More samples were analysed for catchment W1H031, 221 against 163 because trouble was experienced with the equipment for W1H016. The usual wide variation in concentrations as denoted by the high standard deviations in relation to the means may be seen. Differences between arithmetic and volume weighted means are not as pronounced as was the case for the Cedara catchments, because samples from hydrographs were mainly analysed. It may be noted that dissolved organic carbon and the volatiles content of suspended solids was analysed on composite samples. This was an attempt to characterise dissolved and particulate organic loads derived from the catchments.

Table 11: Analytical and statistical data for runoff samples from weir W1H016 between July 1989 and May 1990

Parameter		Mean	No. Samp.	Std. Dev.	Min.	Max.	Wt. Mean (by Vol.)
Susp. Sol.	mg/l	126	163	126	7	772	120
Turbidity,	NTU	24	163	19	6	150	23
Conductivity,	mS/m	16,2	163	8,3	7,1	55,6	15,3
TDS (calc),	mg/l	108	-	55	47	371	102
Soluble P,	µg/l	17	163	11	4	72	17
Total P,	µg/l	112	163	76	29	540	107
Nitrate-N,	µg/l	256	157	354	1	1676	256
Sol. Kjel-N,	µg/l	382	15	71	280	573	392
Total Kjel-N,	µg/l	1212	15	372	737	1961	1253
DOC	mg/l	8,7	10	3,5	4,3	14,8	8,5
Volatiles	%	23,8	8	4,0	19	33	22,2

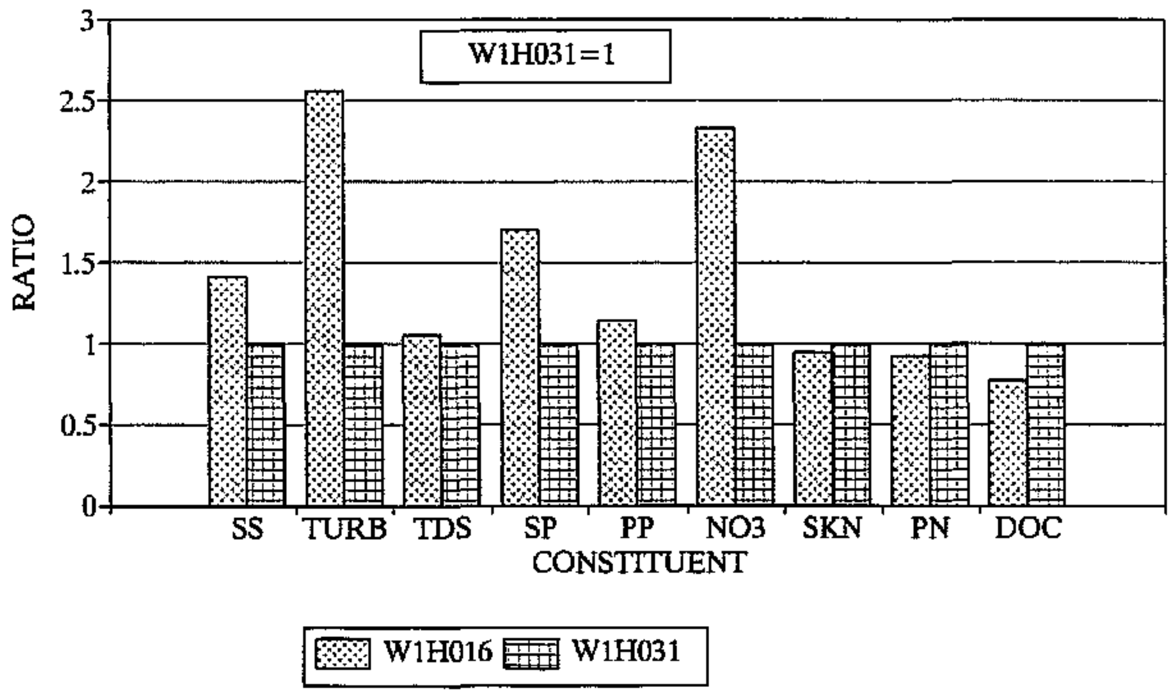
Note: Volatiles are for suspended solids ashed at 600°C

Table 12: Analytical and statistical data for runoff samples from weir W1H031 between August 1989 and October 1990

Parameter		Mean	No. Samp.	Std. Dev.	Min.	Max.	Wt. Mean (by Vol.)
Susp. Sol.	mg/l	75	221	107	4	852	85
Turbidity,	NTU	9	221	13	1	85	9
Conductivity,	mS/m	15,3	221	8,3	6,6	64,9	14,5
TDS (calc),	mg/l	102	-	55	44	433	97
Soluble P,	µg/l	10	200	4,9	4	34	10
Total P,	µg/l	82	200	90	9	613	89
Nitrate-N,	µg/l	107	200	147	1	1763	110
Sol. Kjel-N,	µg/l	404	16	53	307	507	416
Total Kjel-N,	µg/l	1259	16	572	641	2759	1355
DOC	mg/l	8,7	10	5,1	1,5	20,2	11,1
Volatiles	%	35,9	8	5,3	29	44	33,0

Comparison of mean runoff quality between the catchments can most easily be seen in Figure 38.

Figure 38: Comparison of mean runoff quality between catchments W1H016 and W1H031



The generally poorer water quality for the disturbed catchment, W1H016 is clearly evident. Mean suspended solids, turbidity, soluble phosphorus and nitrate concentrations for W1H016 range from almost 50% to more than 250% higher. Other constituents have similar levels such as dissolved salts and Kjeldahl nitrogen. Conversely, dissolved organic carbon and volatiles for suspended materials (see Tables 12 and 13) are distinctly greater for the natural catchment. This is perhaps due to natural processes occurring in the well vegetated stream beds of catchment W1H031 where no artificial clearance of the vegetation has occurred, as opposed to catchment W1H016 where there is less natural cover due to human incursions. Since topography, soils, area, slopes and other factors are similar the land-use in catchment W1H016, that is subsistence farming with huts, cattle and some limited agriculture, must be the main reason for the poorer runoff water quality.

5.4 Export coefficients

Export coefficients of pollutants were calculated in the usual manner and are given and compared in Table 13.

Table 13: Export coefficients for catchments W1H016 and W1H031 from July 1989 to June 1990, kg/ha/a

	W1H016		W1H031
Suspended solids	481	(507)	428
TDS	409	(431)	487
Soluble phosphorus	0,07	(0,07)	0,05
Total phosphorus	0,43	(0,46)	0,45
Nitrate-N	1,03	(1,08)	0,55
Soluble Kjeldahl-N	1,57	(1,66)	2,09
Total Kjeldahl-N	5,03	(5,29)	6,82
DOC	34	(36)	56

Note: Figures in parenthesis are flow adjusted

Because of the higher runoff for catchment W1H031, export coefficients are relatively higher and therefore closer to those for catchment W1H016 compared to the mean runoff quality results. In fact, slightly higher export of dissolved salts is shown for catchment W1H031 when the reverse was true for the quality results. Total phosphorus export coefficients are similar but export of nitrate-N is still very much higher for catchment W1H016, in fact more or less double. Since, as discussed earlier, the total flow for W1H016 appeared to be low, the coefficients were adjusted upwards by 5%, the difference in rainfall/ runoff ratios for the catchments. These values are given in parenthesis in Table 13 and are considered to be more realistic under the circumstances.

5.5 Quality variation with flow during study period

As was done with the Cedara data, the response of water quality variables to changes in flow was investigated and is shown as a series of line graphs in Figures 39 to 48. The gaps between the graphs represent different hydrographs which are numbered 1 to 9 for catchment W1H016 and 1 to 8 for W1H031. The dates for the start of these hydrographs which has some bearing on the results are listed below:

		Catchment	
		W1H016	W1H031
Hydrograph number	1	890714	891030
	2	891030	891113
	3	891113	891129
	4	891127	900123
	5	900122	900212
	6	900205	900322
	7	900212	900423
	8	900323	901006
	9	900423	

Suspended solids

The variation of suspended solids with flow is shown in Figures 39 and 40 for catchments W1H016 and W1H031 respectively. Suspended solids concentrations show very clear and definite responses to changes in flow during the hydrographs. However, as seen for the Cedara data, the response is not equal in terms of matching flow and suspended solids peaks. Some of the reason for this may be due to the timing of the hydrographs during the year. For catchment W1H016 the first hydrograph is in July and for a fairly large peak flow the corresponding response of suspended solids is low but with the second hydrograph at the end of October the flow peak is smaller and the suspended solids peak is almost 10 times higher than previously. Since the October hydrograph was the first large one at the beginning of the wet season the high concentrations could be due to washoff of materials that had accumulated on catchment surfaces during the dry season. The same pattern may be seen for catchment W1H031 in Figure 40 where the highest suspended solids concentration also occurred for the hydrograph in October. Support for this theory is given by the third very large hydrograph for catchment W1H031 and fourth one for W1H016, both in November which only produced relatively low suspended solids concentrations. By this stage the catchment store of easily removable materials had been depleted. A point to note in these graphs is that the rise in suspended solids concentrations precedes the rise in flow for many of the hydrographs shown. More positive evidence of this will be shown later.

Turbidity

The graphs for turbidity variation with flow are given in Figures 41 and 42. They display much the same behaviour as seen for suspended solids, that is also a "first flush" effect for the October hydrographs. Although turbidity rises with flow are similar to suspended solids rises, comparison between the graphs shows that their magnitudes are different between hydrographs, or in other words the relationship between turbidity and suspended solids is not consistent. Again, turbidity rises precede flow for some hydrographs.

Conductivity

Conductivity level changes during hydrographs are given in Figures 43 and 44. For catchment W1H016 conductivity levels show some strange behaviour during the first and second hydrographs. In the first one conductivity shows hardly any response at all while in the second conductivity falls very sharply on the rising limb of the hydrograph and thereafter increases rapidly on the falling limb. Otherwise, for the other hydrographs conductivity levels show the expected inverse trends with flow and appear to be more or less proportional to the size of the hydrographs.

Figure 39: W1H016 Variation in suspended solids concs. with flow

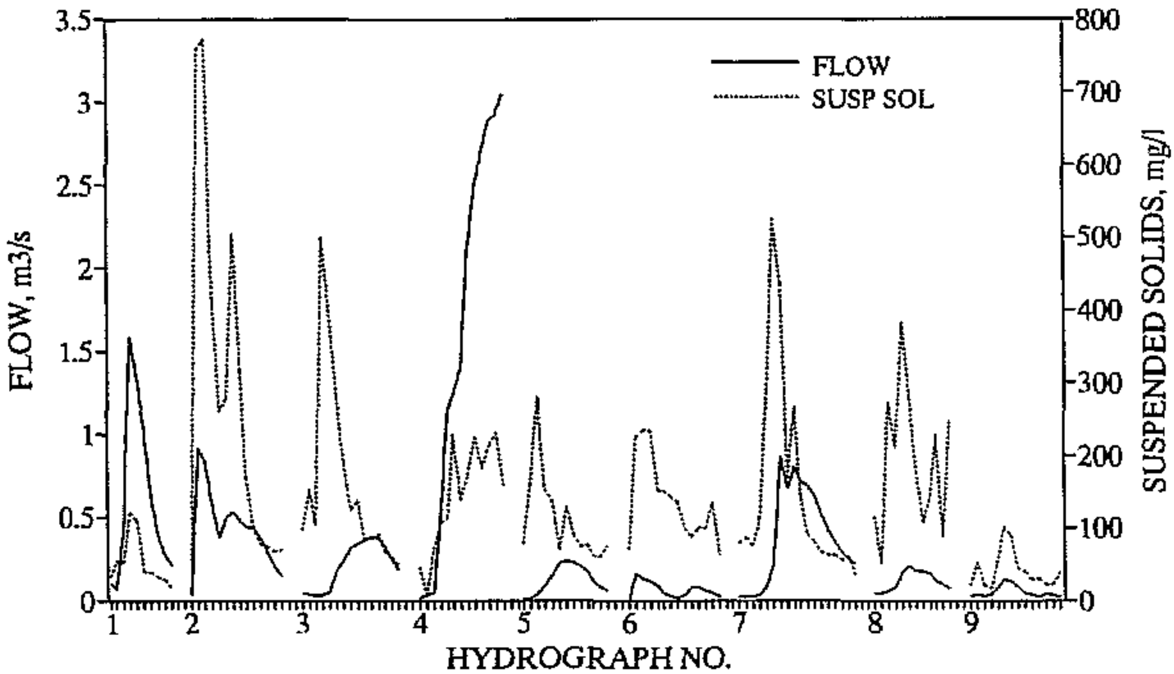


Figure 40: W1H031 Variation in suspended solids concs. with flow

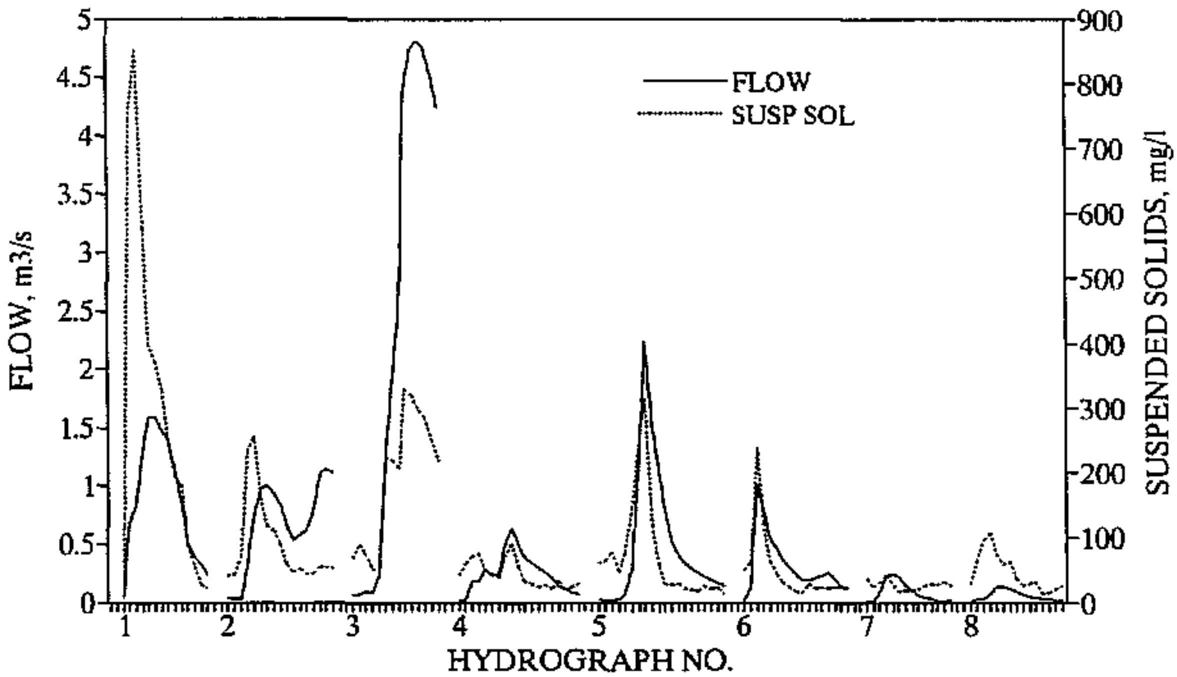


Figure 41: W1H016: Variation in turbidity levels with flow

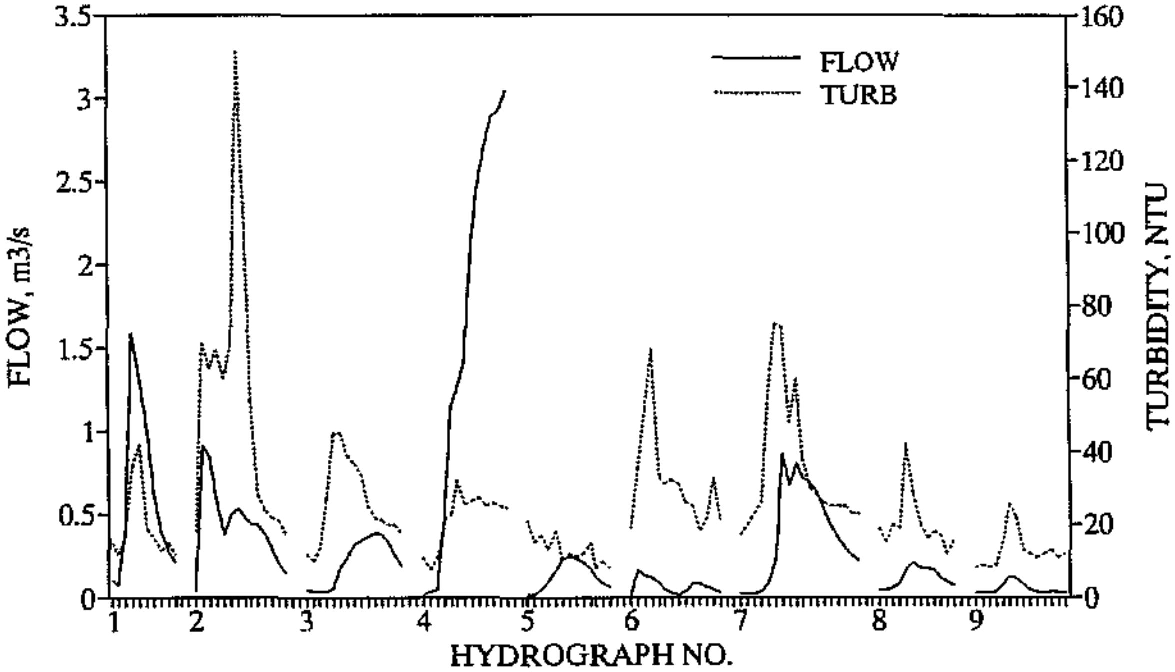


Figure 42: W1H031: Variation in turbidity levels with flow

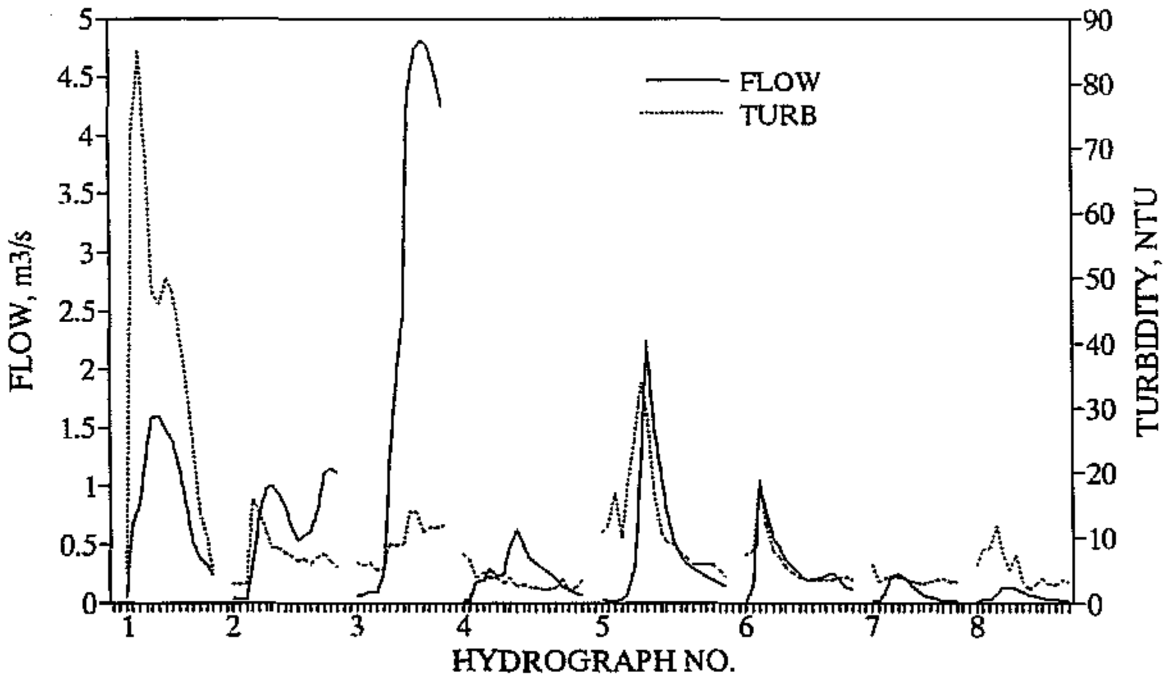


Figure 43: W1H016: Variation in conductivity levels with flow

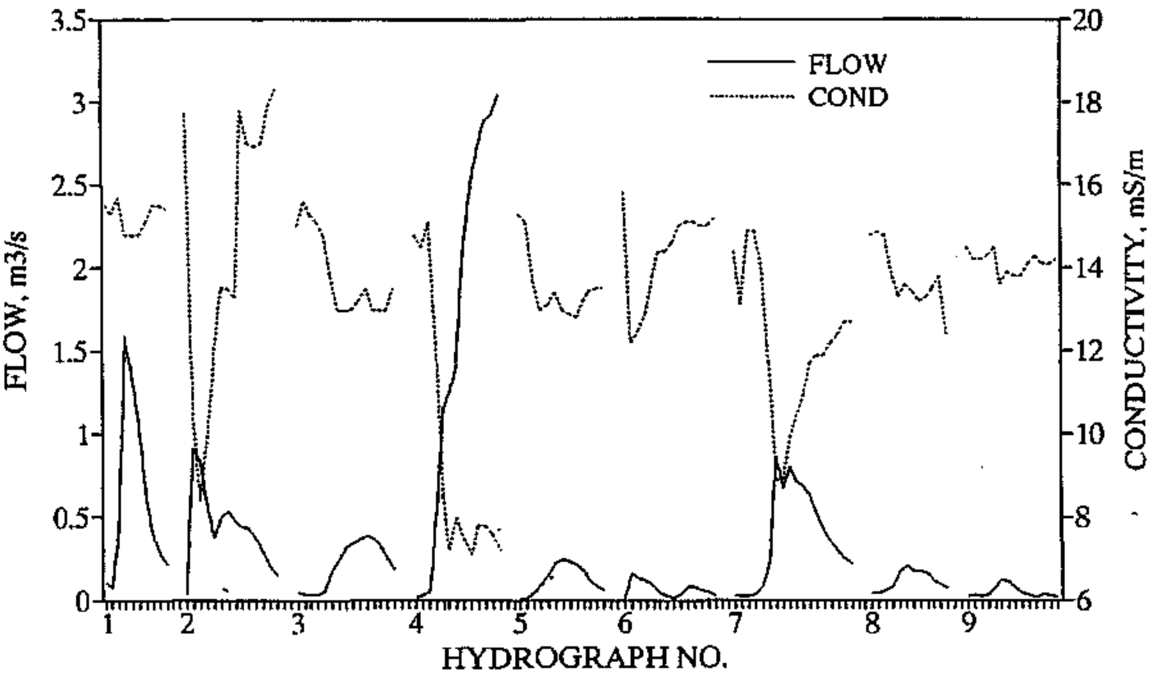
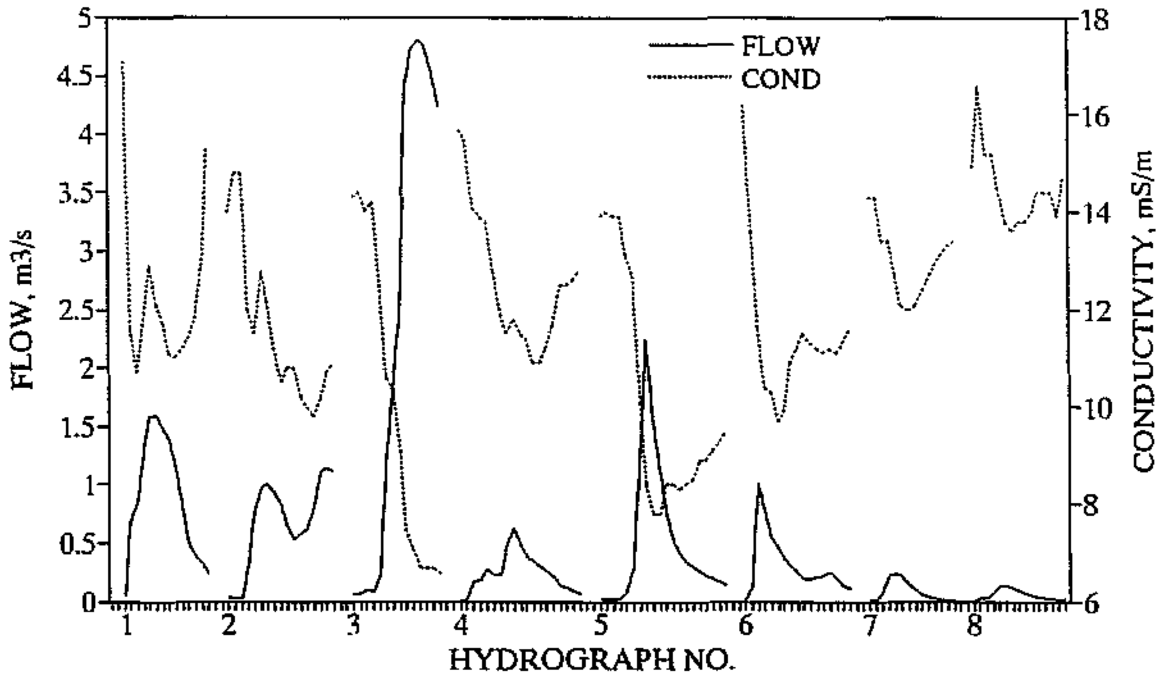


Figure 44: W1H031: Variation in conductivity levels with flow



The graphs for catchment W1H031 show similar odd changes in conductivity levels during some hydrographs. In both the first and second hydrographs, conductivity falls with rise in flow but then shows sharp inflections coincident with the flow peaks. This is unlikely to be due to sample contamination as the inflections represent more than single samples. Otherwise, the pattern shown is much the same as that for catchment W1H016. Notably, the lowest conductivity levels are shown for the largest peak flows for both catchments. Undoubtedly, a major mechanism in determining conductivity levels is dilution by rainfall.

Soluble phosphorus

These plots are given in Figures 45 and 46. For catchment W1H016 there is an indication of falling phosphorus concentrations with rising flows but the relationship is not strong. Both rising and falling concentrations are shown in the graph for catchment W1H031 and there are no real trends visible. Generally, phosphorus concentrations are low and their ranges are not large. Their levels seem to fluctuate in a band with no clear relationship to flow. This pattern was also evident for the Cedara catchments.

Nitrate

The final constituent analysed in all samples during hydrographs was nitrate and these plots with flow are given in Figures 47 and 48. The graph for catchment W1H016 shows large rises in nitrate concentrations with flow for all hydrographs. As was the case for suspended solids, an unequal response in concentration changes between hydrographs is evident. Very high levels of nitrate occurred during the second hydrograph but the later much larger fourth hydrograph, with a peak flow of 3 m^3/s had lower nitrate concentrations. The reason for this inconsistency may be twofold. Firstly, as suggested for suspended solids it might be a "first flush" effect as the second hydrograph was at the beginning of the wet season. Secondly, it might be a dilution effect from rainfall during the fourth very large hydrograph. Nitrate concentrations do not reach the same high levels for the rest of the wet season indicating more complexity than just a simple relationship with flow. The data for catchment W1H031 shows far lower concentration rises with flow compared to W1H016 (scales for nitrate different). This is clearly due to a land-use effect.

Figure 45: W1H016: Variation in soluble P concs. with flow

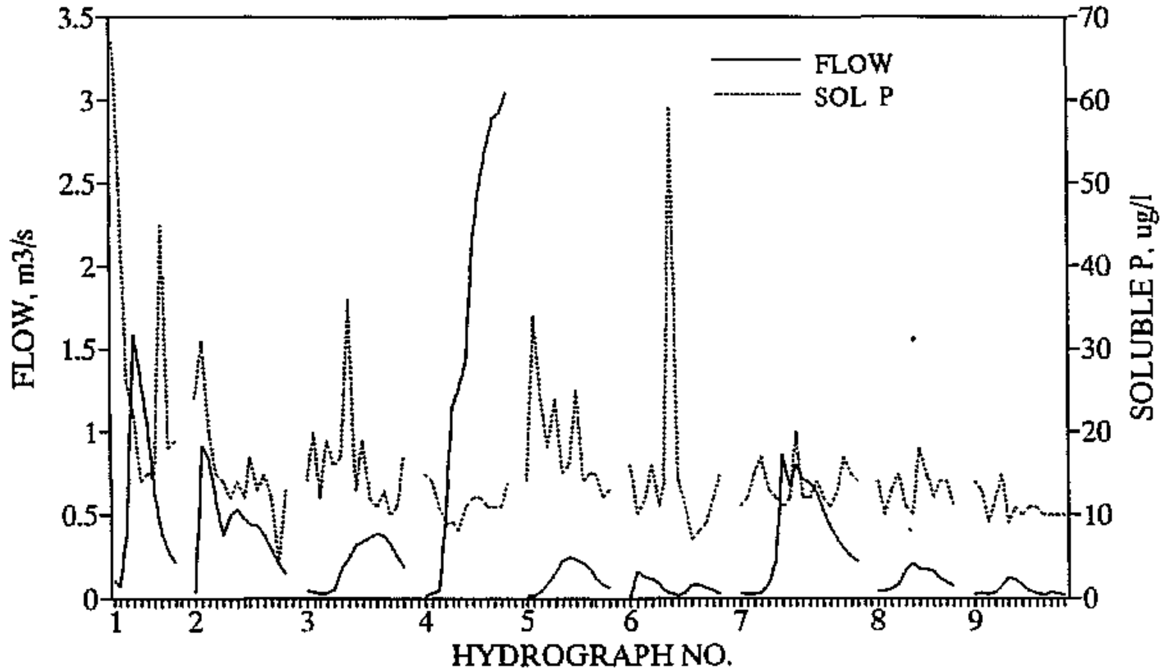


Figure 46: W1H031: Variation in soluble P concs. with flow

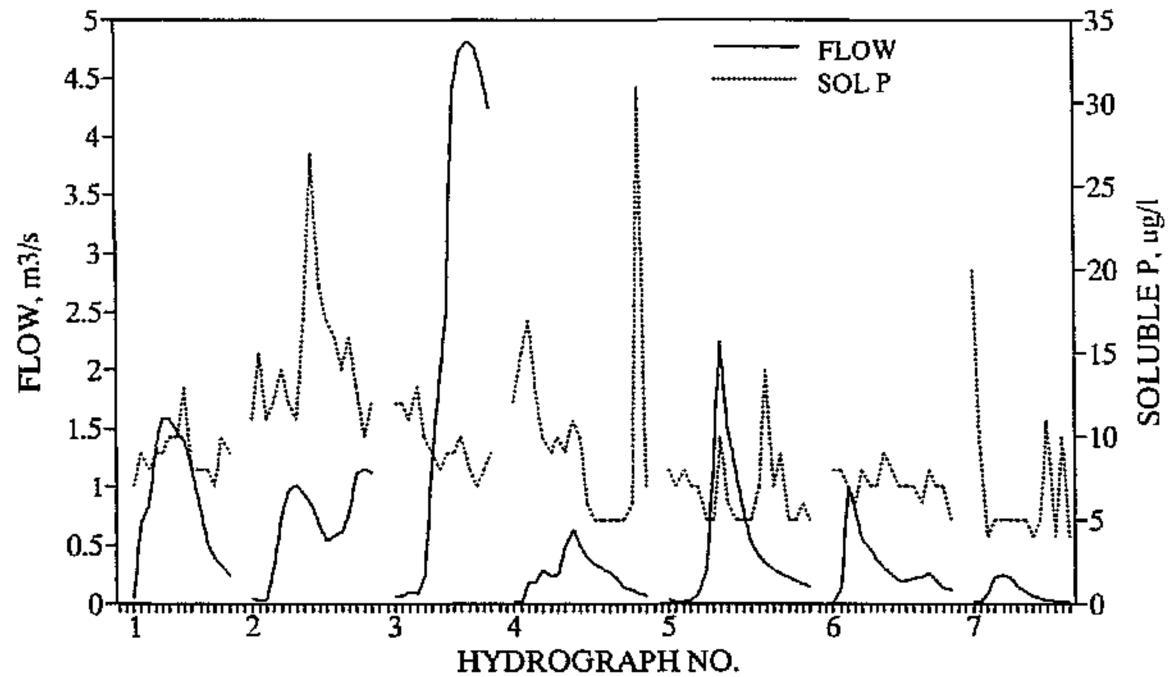


Figure 47: W1H016: Variation in nitrate concs. with flow

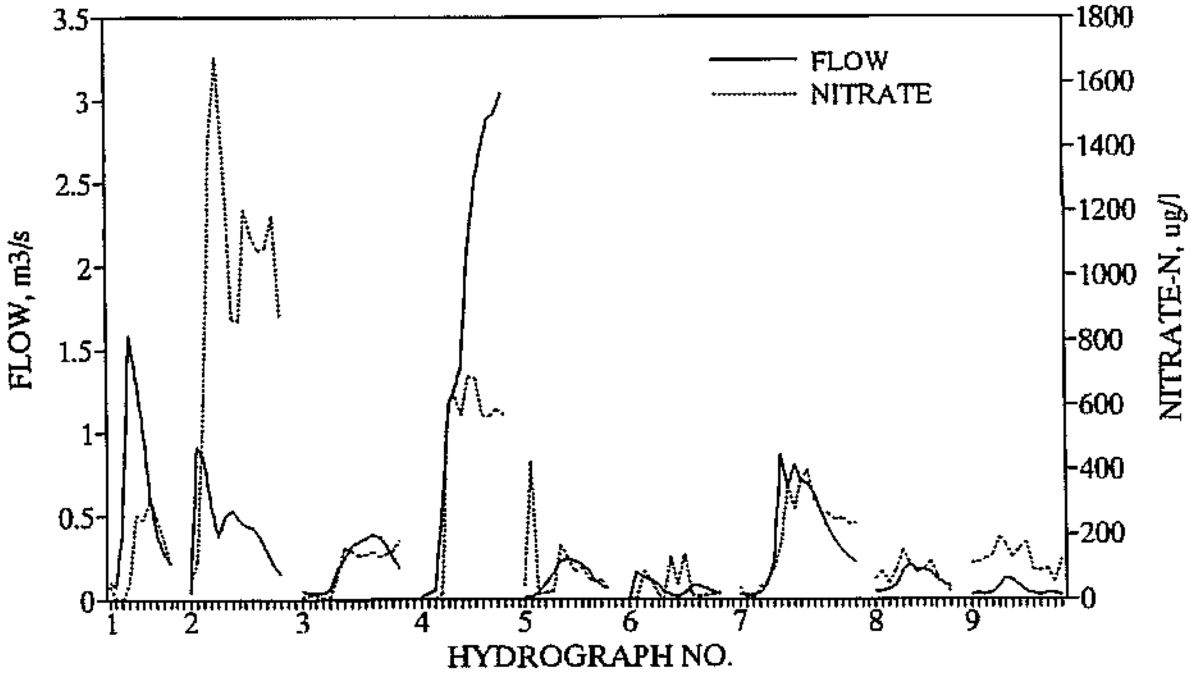
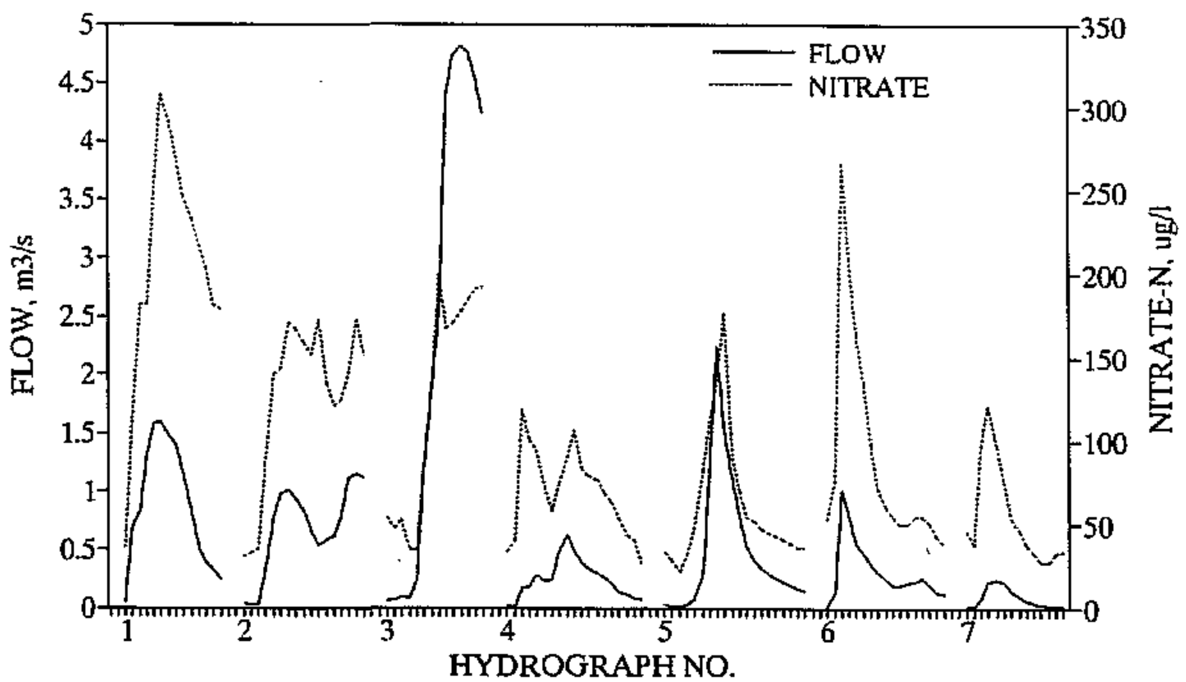


Figure 48: W1H031: Variation in nitrate concs. with flow



5.6 Quality changes during hydrographs

As before, in order to gain a better insight into the manner in which quality variables change during hydrographs, constituent concentrations have been plotted against flow and the plot points joined so that the path of the changing concentrations could be followed. Hydrographs were separated from the data set and concentration is given on the x-axes and flow on the y-axes.

Suspended solids

Six plots of suspended solids concentration against flow are shown for catchment W1H016 in Figure 49. The numbers next to the data points denote the order of samples taken during the hydrographs. Although there are many different shapes shown in the figures a pattern is discernible for some events, ie: a rapid rise in concentration to a peak value in the initial stage of the hydrograph followed by a fall in concentration before the peak flow. Thereafter, in some cases concentration returned to initial levels or sampling of the hydrograph was not complete. This anti-clockwise pattern is shown for all events to varying degrees. The behaviour indicates a build-up of materials on surfaces during dry periods which are washed off by initial runoff from a storm.

Similar patterns of suspended solids washoff are shown for catchment W1H031 in the graphs given in Figure 50, ie: higher concentrations in initial runoff.

Conductivity

The change in conductivity values during hydrographs are shown in Figures 51 and 52. The general pattern here is one of falling levels on the rising limbs of the hydrographs and rising values on the falling limbs. The anti-clockwise loop as seen for the Cedara catchments is discernible, although not as clearly for some events as for others, ie: higher concentrations on the rising than on the falling limbs of the hydrographs. The mechanism seems to be mainly one of dilution by rainfall of water held in the soils.

Figure 49: W1H016: Changes in suspended solids concentrations during hydrographs

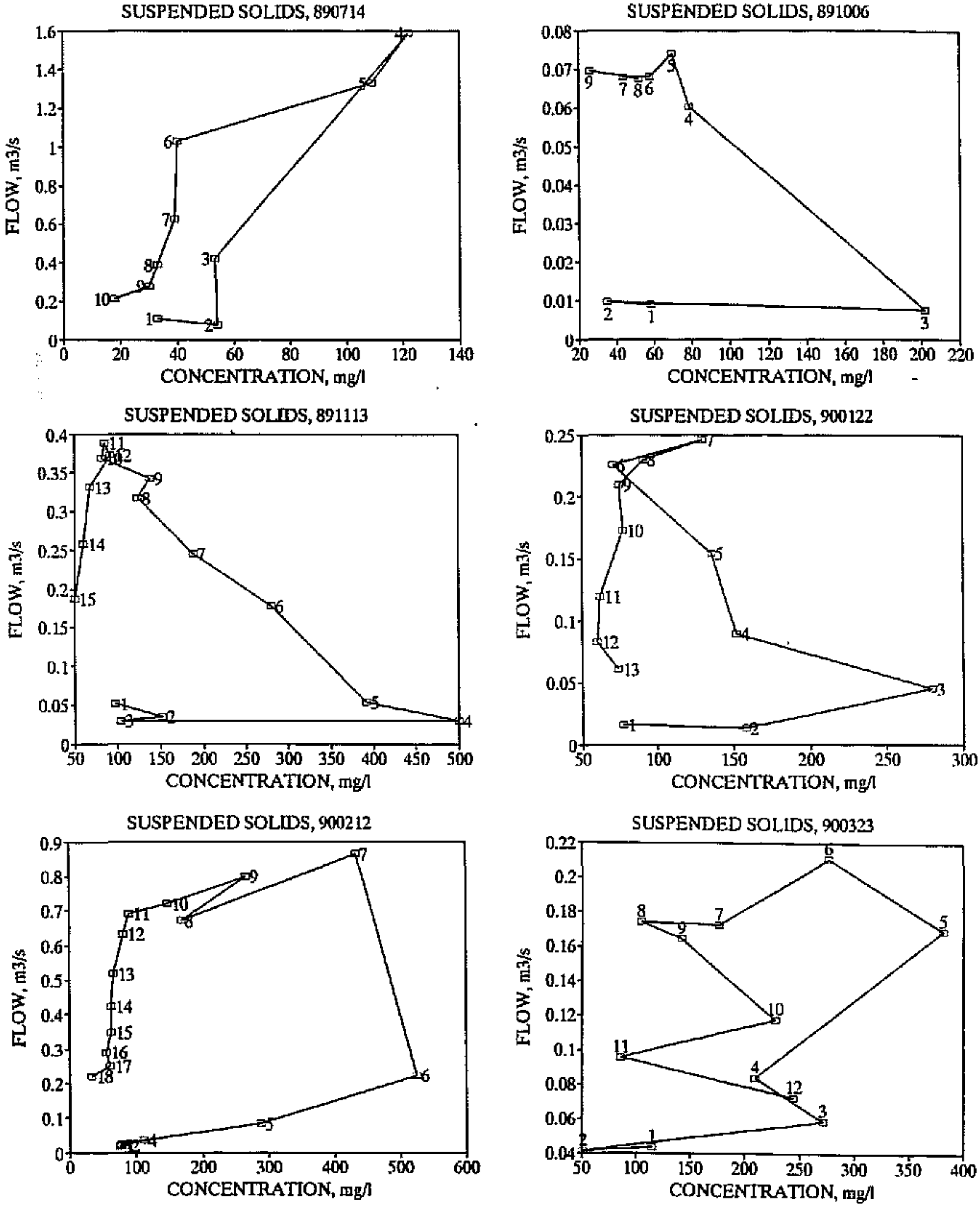


Figure 50: W1H031: Changes in suspended solids concentrations during hydrographs

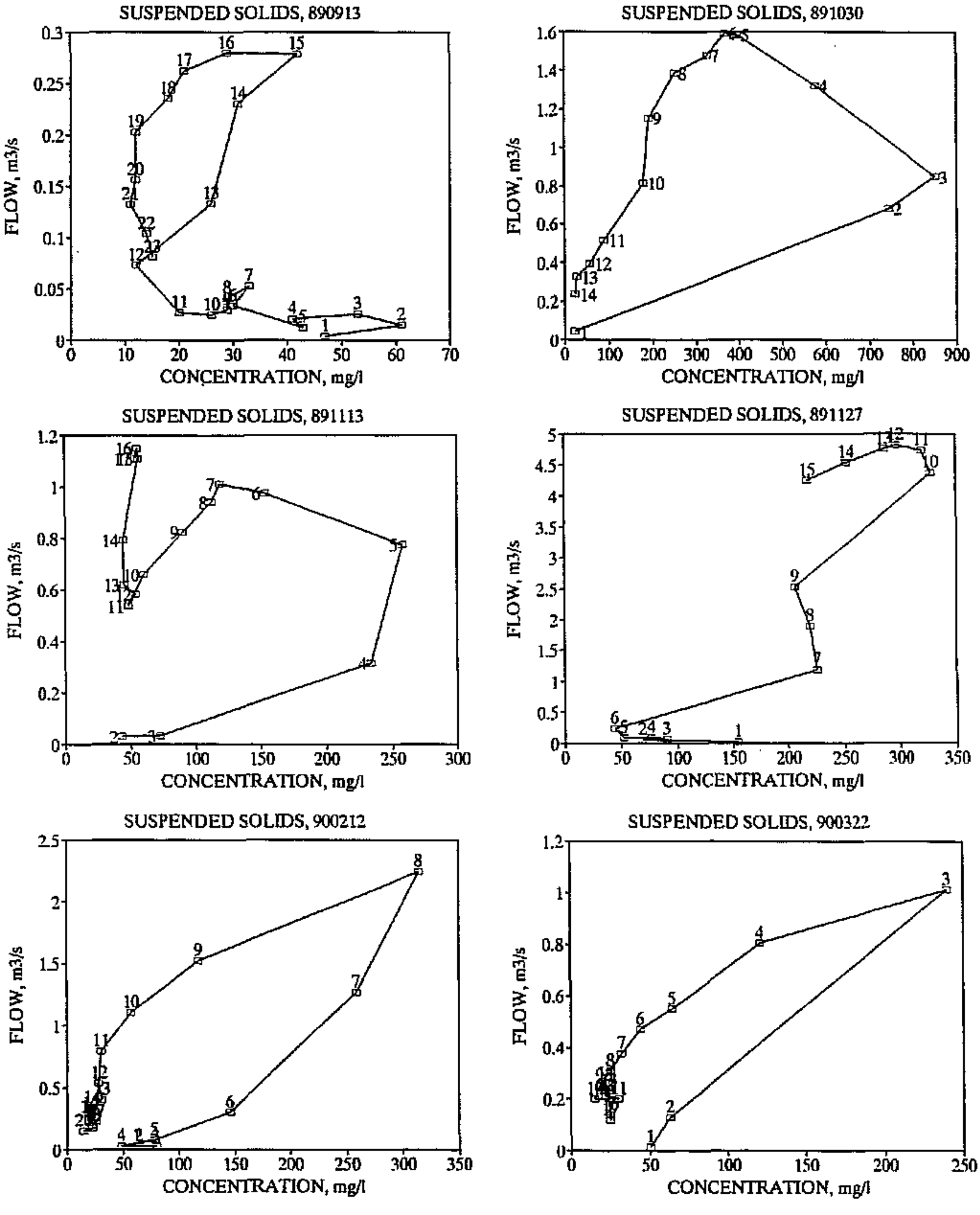


Figure 51: W1H016: Changes in conductivity levels during hydrographs

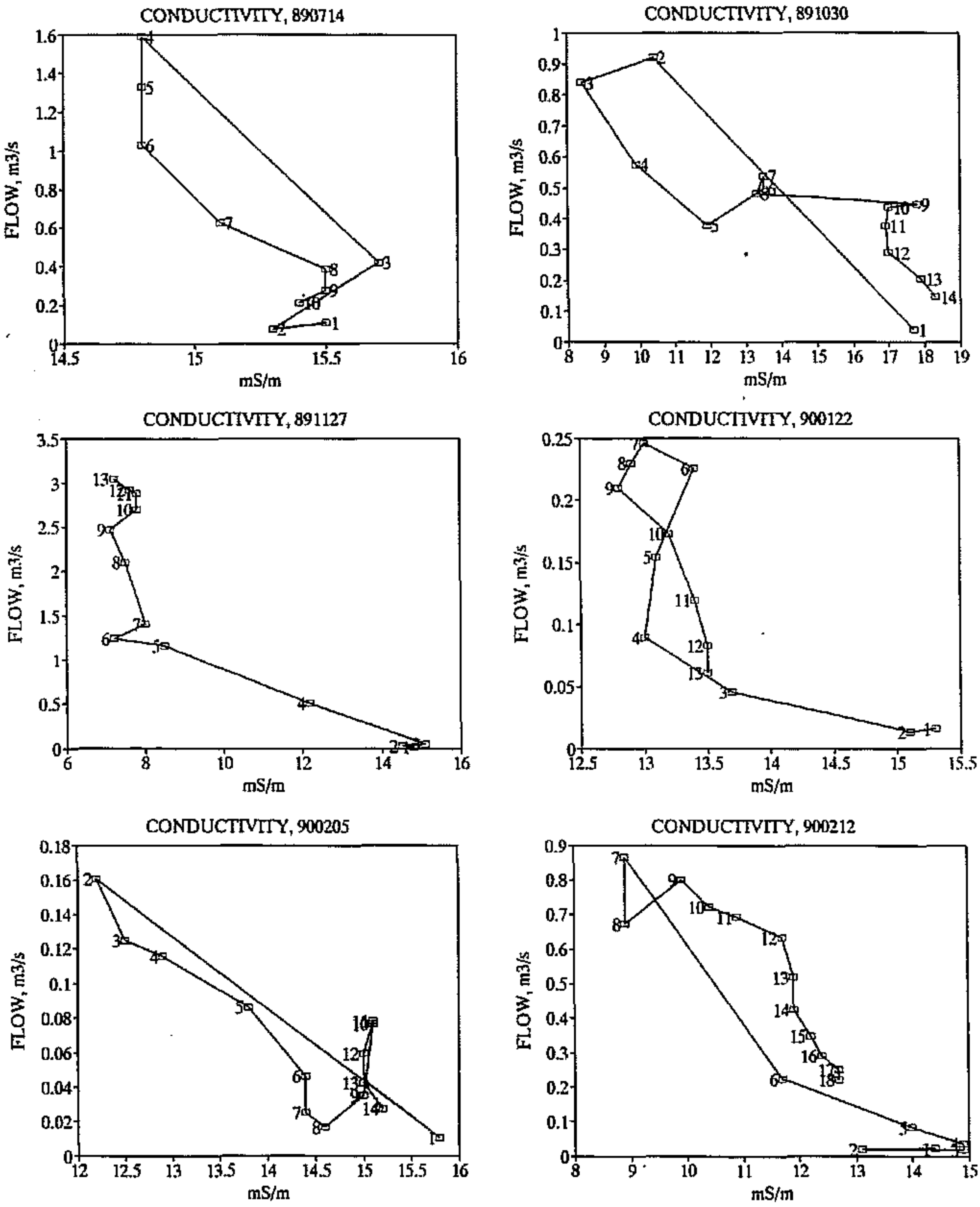
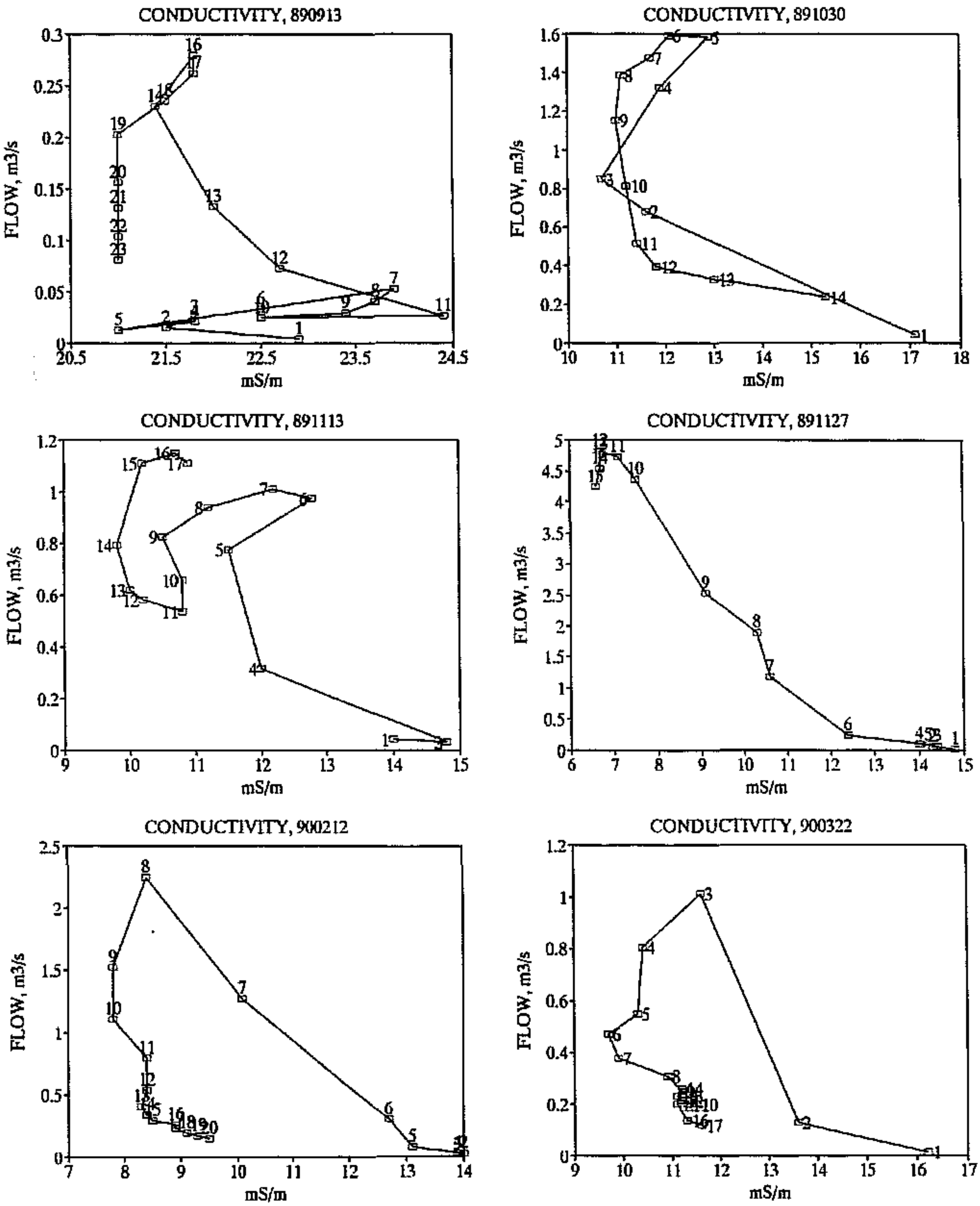


Figure 52: W1H031: Changes in conductivity levels during hydrographs



Nitrate

These results are shown in Figures 53 and 54. The most common behaviour in these graphs is a rise in nitrate concentrations with flow. The manner in which the rises take place is not however consistent at all. Both the "clockwise loop", lower concentrations on the rising than on the falling limbs of the hydrographs and the "anti-clockwise loop", the reverse of the above is indicated. In some cases the rise in concentration is rapid, but in other cases slow and only after the peak flow has passed. This erratic behaviour mitigates against obtaining good relationships with flow. As already noted, nitrate concentrations rise to far higher levels for catchment W1H016 than for W1H031, although initial concentrations (base flow) tend to be similar. There is clearly a much greater store of nitrate in W1H016, the disturbed catchment with settlements, subsistence farming and a little agriculture (sugarcane).

Soluble phosphorus

No plots are shown for soluble phosphorus concentration changes with flow as examination of the data did not reveal any meaningful relationships. In some cases there was an indication of a rise in concentration with flow and in others a fall. Mostly the concentrations fluctuated about low levels. As stated for the Cedara catchments, if soluble phosphorus was to be simulated by a model then a mean concentration would be most appropriate. All that can really be said, is that runoff from catchment W1H016 has a higher mean soluble phosphorus concentration than that from W1H031.

Figure 53: W1H016: Changes in nitrate concentrations during hydrographs

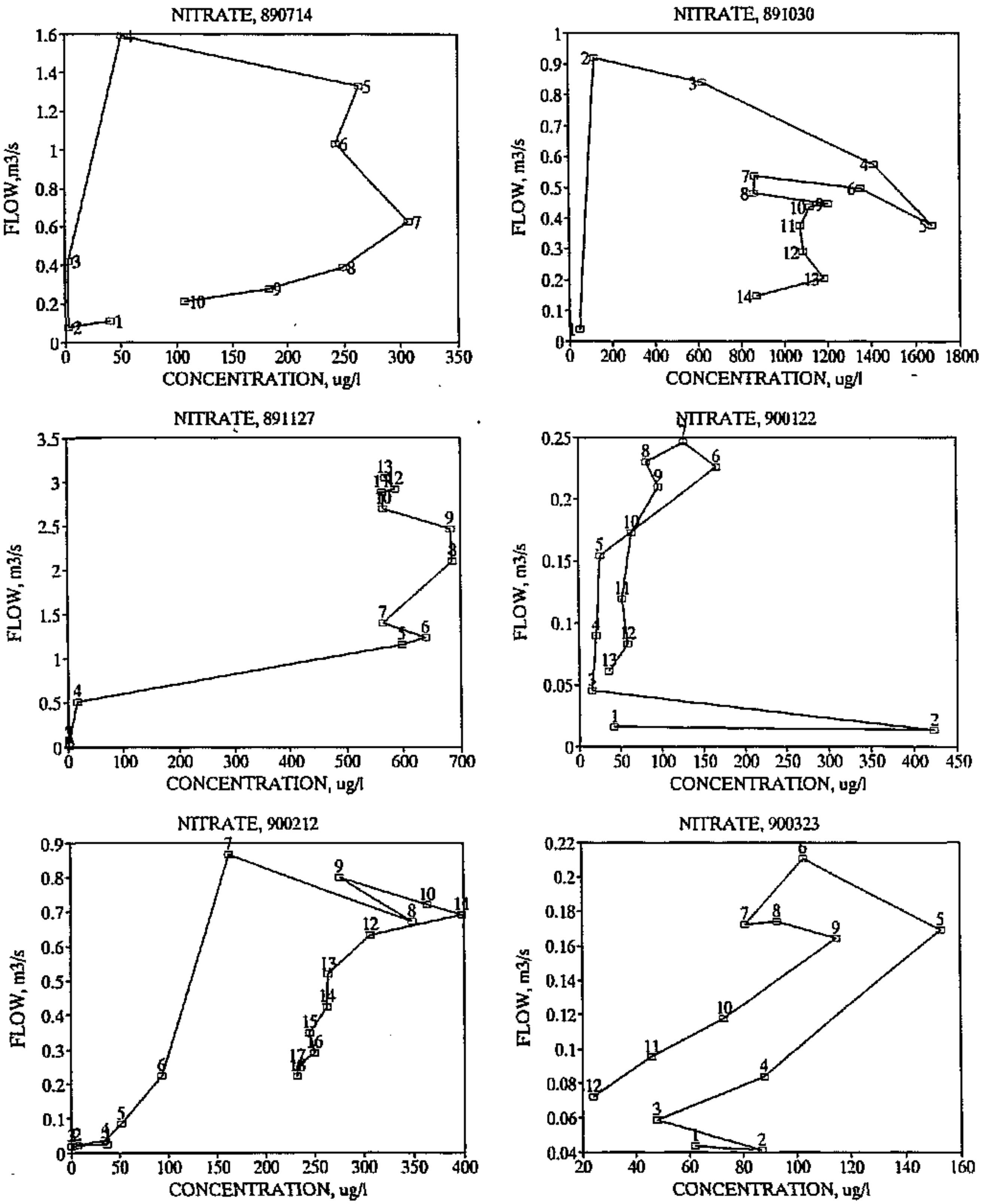
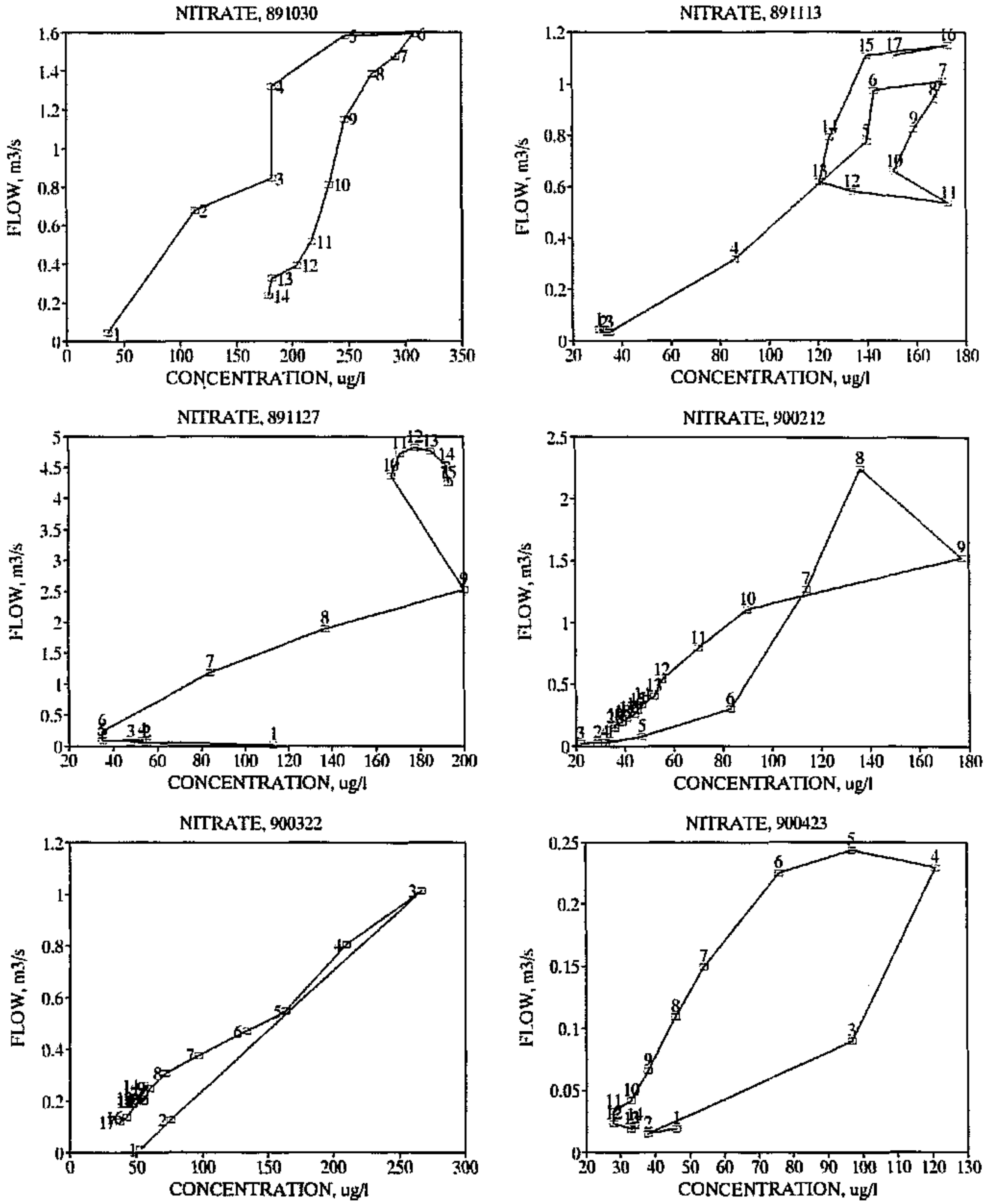


Figure 54: W1H031: Changes in nitrate concentrations during hydrographs



5.7 Regression of water quality variables on flow

As with the Cedara catchments, a regression analysis was carried out for the dependence of water quality variables on flow. The same four models were tested for each constituent and a summary of the results is given in Table 14, that is R^2 values (explained variance for the models).

Table 14: Regression analysis of water quality variables on flow for different models for catchments W1H016 and W1H031

Constituent	Model Type	R^2 value as a percentage W1H016	W1H031
Susp. sol	Linear	6	32
	Multiplicative	**16**	24
	Exponential	10	**34**
	Reciprocal	6	8
Turbidity	Linear	5	7
	Multiplicative	**22**	12
	Exponential	9	**14**
	Reciprocal	9	10
Conductivity	Linear	32	26
	Multiplicative	37	47
	Exponential	47	37
	Reciprocal	**61**	**50**
Soluble P	Linear	2	1
	Multiplicative	**11**	**3**
	Exponential	2	0
	Reciprocal	1	0
Total P	Linear	3	32
	Multiplicative	3	17
	Exponential	4	**34**
	Reciprocal	**5**	15
Nitrate-N	Linear	10	23
	Multiplicative	**36**	**34**
	Exponential	16	22
	Reciprocal	2	13

Note: The best fit model is highlighted in bold

The results for both catchments show generally poor relationships with flow. The multiplicative model, which predicts increasing concentrations with flow but at a decreasing rate gave the best fit for suspended solids, turbidity, soluble phosphorus and nitrate for catchment W1H016. However, R^2 values are not high ranging from 11% to 36%. The best prediction was given for conductivity where the reciprocal model which predicts decreasing concentrations at a decreasing rate with flow had an R^2 value of 61%. For total phosphorus there was hardly any relationship at all.

For catchment W1H031 the exponential model gave the highest R^2 values for suspended solids and turbidity, but only at 34% and 14% respectively. This model predicts increasing concentrations with flow at increasing rates, which seems logical. Again, the reciprocal model had the best fit for conductivity with an R^2 of 50%. Prediction of total phosphorus was better than was the case for catchment W1H016 with an R^2 value of 34%. The accuracy of prediction of nitrate was similar to that found for catchment W1H016.

The best fit regression curves for each constituent for the catchments are shown in Figures 55 and 56. The data points show a wide scatter, particularly at the lower flows where both high and low concentrations may be seen. Some of the scatter may well be due to factors such as "first flush" effects both in the seasonal and hydrograph context, as indicated earlier. For modelling purposes the same remarks as given for the Cedara catchments apply. Clearly, a high level of accuracy would not be achieved by using these regression equations to predict pollutant concentrations in runoff from the catchments. Constituent concentrations are definitely responsive to flow but there are also a number of other confounding and largely unknown factors.

Figure 55: W1H016: Best fit regression curves for variables on flow

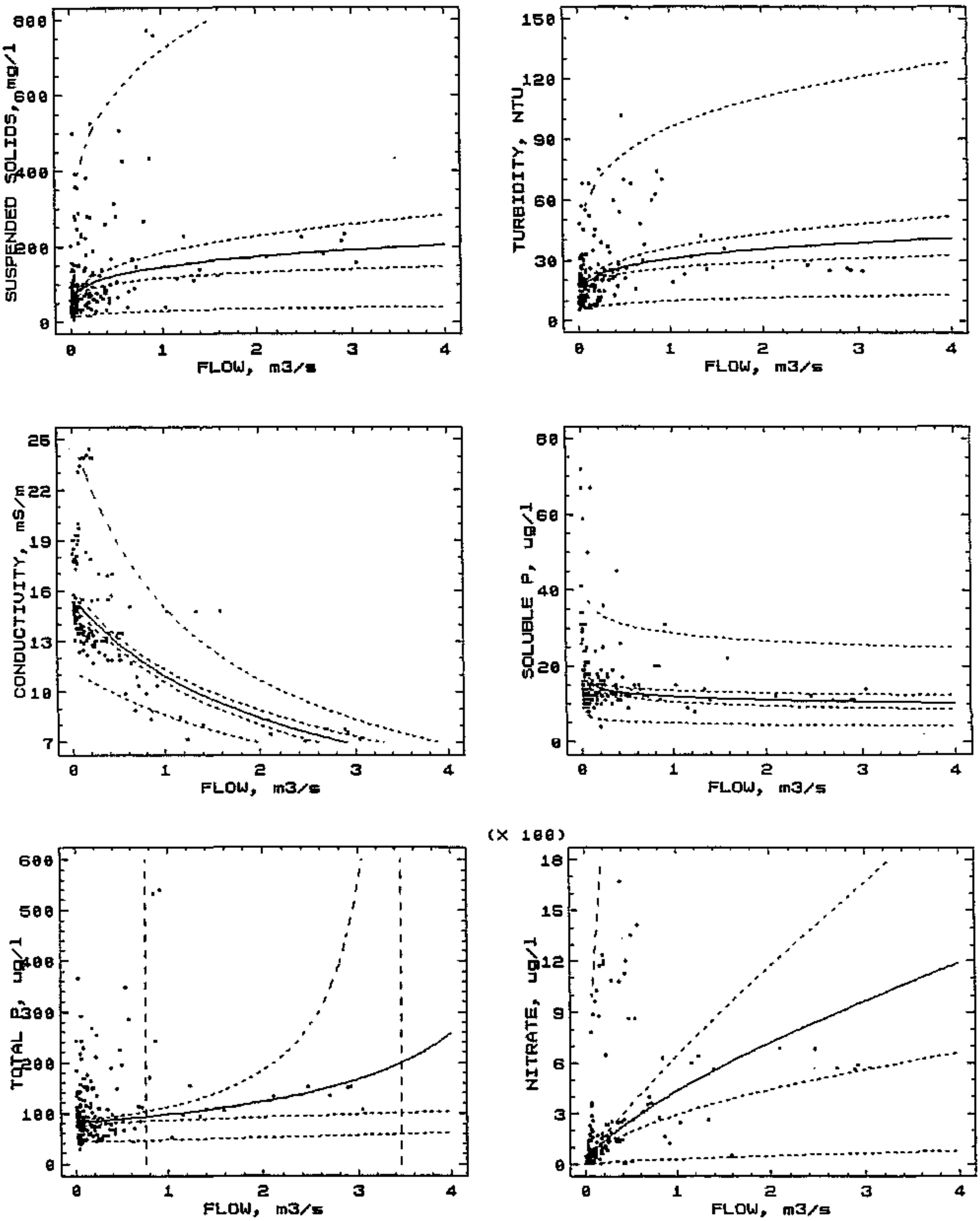
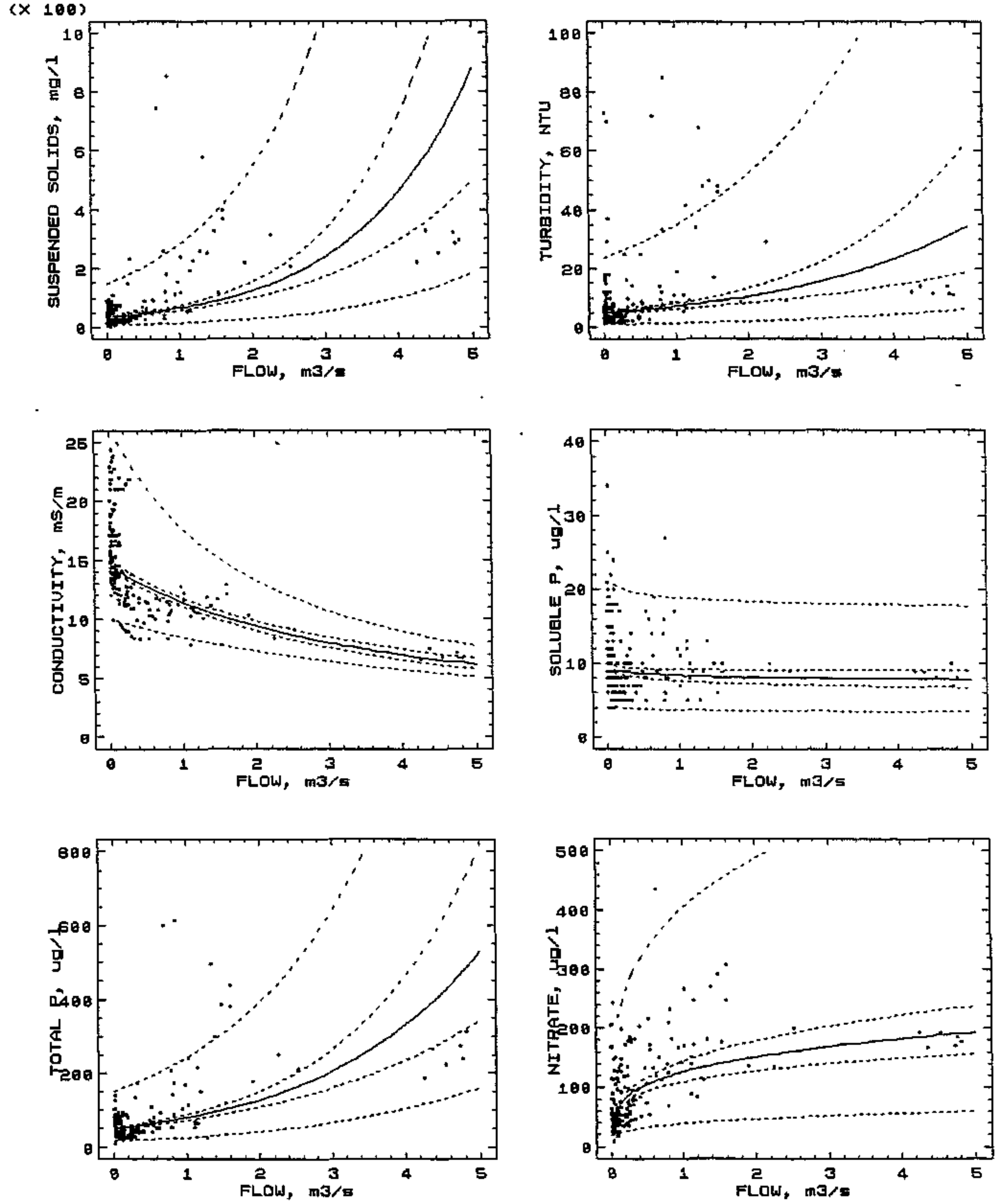


Figure 56: W1H031: Best fit regression curves for variables on flow



5.8 Correlation between water quality variables

A correlation analysis was carried out between constituent concentrations to identify any meaningful relationships. Once a good correlation has been established between constituents, measurements may be limited and one estimated from another. The correlation coefficients found are given in Table 15.

Table 15: Correlation coefficients between water quality variables for catchments W1H016 and W1H031

W1H016	Turb	Cond	Sol P	Tot P	Nitrate
Suspended solids	0,67	-0,43	-0,04	0,95	0,15
Turbidity		- 0,34	-0,11	0,60	0,24
Conductivity			0,13	-0,31	0,14
Soluble P				0,15	-0,19
Total P					0,13

W1H031	Turb	Cond	Sol P	Tot P	Nitrate
Suspended solids	0,73	-0,33	-0,04	0,96	0,44
Turbidity		-0,20	0,12	0,76	0,29
Conductivity			0,22	-0,30	-0,12
Soluble P				0,02	-0,01
Total P					0,49

The only correlations of any real significance are those between suspended solids, turbidity and total phosphorus. For both catchments suspended solids is very strongly correlated with total phosphorus (0,95 and 0,96 coefficients) but not as strongly related to turbidity. As stated earlier, the tests measure different properties in a water sample and generally diverge at the higher suspended solids concentrations. Conductivity shows inverse relationships to suspended solids but they are not strong and could not really be used with any confidence for predictive purposes. There are no really good correlations for nitrate and, as was the case for the Cedara catchments, soluble phosphorus has no meaningful relationships with any of the other constituents.

5.9 Summary and discussion

Comparison of mean runoff qualities between the catchments showed that catchment W1H016, with a land-use under subsistence farming, had higher suspended solids, turbidity, conductivity, phosphorus and nitrate levels than the natural catchment, W1H031, acting as a control. On the other hand catchment W1H031 had the higher dissolved organic carbon and soluble Kjeldahl nitrogen concentrations. A theory put forward for this is entrapment and degradation of organic flotsam in the undisturbed waterways of the natural catchment (W1H031) as against the clearer waterways of the partially developed catchment (W1H016).

Catchment W1H031 had a higher runoff coefficient than W1H016 (runoff total/rainfall total), but it is suspected that the difference could be due to either losses from the weir or measurement errors rather than due to a land-use effect. As a consequence, calculated export coefficients for the catchments were closer than the mean water qualities.

Suspended solids, turbidity and nitrate concentrations showed large increases during hydrographs for both catchments. The increases, however, are not consistent in magnitude relative to flow, indicating that other processes or factors besides flow are involved in determining concentrations. There is an indication that a "first flush" effect occurs at the beginning of the wet season as these higher concentrations are not reached during subsequent hydrographs. Nitrate concentration rises for catchment W1H016 are far higher than for W1H031, showing a clear land-use effect. Flow changes do not seem to really influence soluble phosphorus concentrations for either catchment. The changeable concentrations during hydrographs again shows the need to sample continuously throughout in order to obtain reliable and meaningful data.

Examination of changing concentrations during hydrographs showed that suspended solids concentrations were relatively higher on the rising limbs of the hydrographs compared to the falling limbs. This pattern indicates washoff of materials that have accumulated during drier periods. Conductivity levels generally showed simple dilution of salt concentrations with rising flow. Nitrate concentrations usually increased on the rising limbs of the hydrographs and sometimes showed similar patterns to those found for suspended solids. Models that take account of buildup and washoff of stored pollutants would best describe these phenomena.

A regression analysis of pollutant concentrations on flow showed generally poor relationships for both catchments. The best relationships (reciprocal) were found for conductivity with R^2 values of 50% and 60% for catchments W1H016 and W1H031 respectively. Use of these equations to predict pollutant concentrations from flow will not be very accurate.

The only inter-variable relationships of any consequence were between suspended solids, turbidity and total phosphorus. Phosphorus could be well predicted from measurement of suspended solids while prediction of suspended solids from turbidity would be at a lower level of accuracy.

6 RESULTS FOR THE NTABAMHLOPE CATCHMENTS

As shown in the location map (Figure 1) these catchments are situated just south of Estcourt. They were only investigated for one wet season and to do this an extension of the contract was necessary. The purpose of the research was to characterise runoff quality from one small catchment, V7H010, that had been used for a number of years as a wintering feedlot for cattle from the Ntabamhlope research farm. Unfortunately, records of numbers of cattle placed on the catchment are not available. When investigating the effect of a specific land-use on runoff quality, it is advisable to simultaneously monitor a control catchment so that effects such as rainfall, soils and slopes can be nullified, ie: the net effect of the land-use on runoff quality can be found. Catchment V1H028, a grassland with limited use for grazing was chosen for this purpose. The average slopes of the catchments are 10% and 13% for V7H010 and V1H028 respectively, which is not very different and therefore the erosion potentials should be similar.

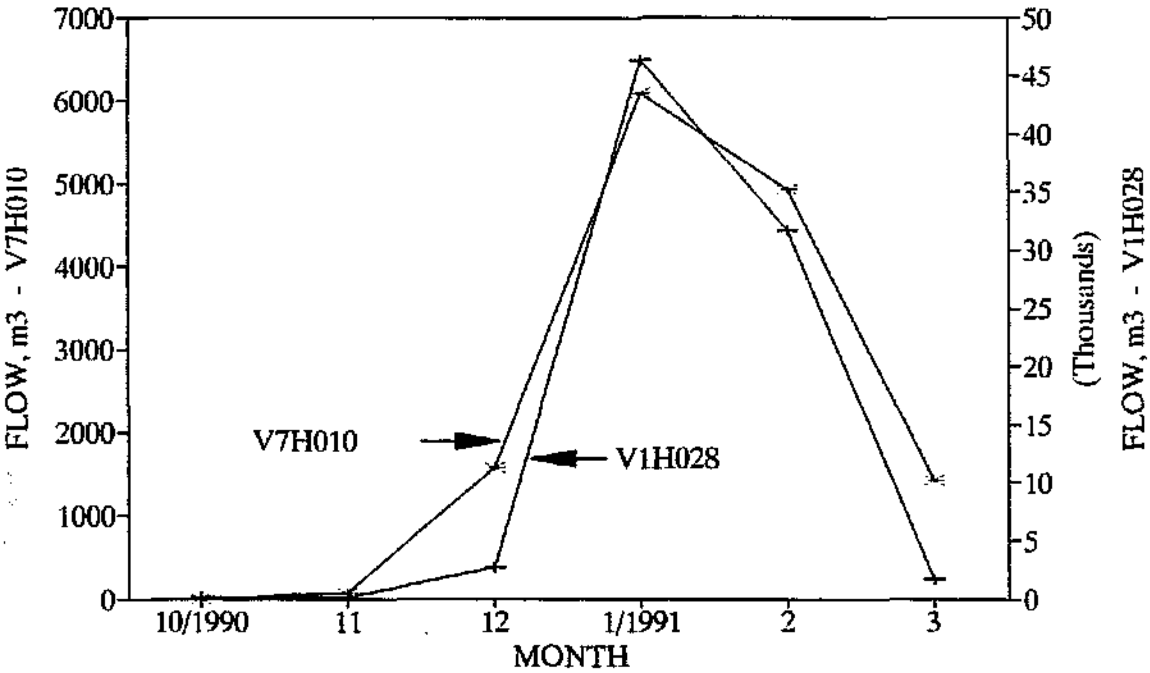
6.1 Rainfall

Unfortunately, at the time of writing rainfall records for the entire study period were not available. However, annual rainfall for the period 1988 to 1990 gave averages of 924 mm for catchment V7H010 and 918 mm for V1H028. Since these are close it may be assumed that rainfall during the study period was also similar. Examination of these records showed that there was little rain in the winter months with most occurring between October and March.

6.2 Flows

The monthly flows recorded for the period when samples were taken are shown in Figure 57. Substantial amounts of runoff only started after November and by March the flows were well down and almost over. This shows the very short season for these catchments. Summation of these flows and division by area gave 176 mm runoff for catchment V7H010 and 202 mm for V1H028 which is 15% higher.

Figure 57: Monthly runoff volumes for catchments V7H010 and V1H028 for study period



6.3 Mean runoff quality

A total of 89 samples were analysed for catchment V7H010 and 51 for V1H028. Additional analyses, namely ammonia, chemical oxygen demand and colour were done for these catchments, as these proved to be pertinent in characterising runoff from catchment V7H010. The means, standard deviations, ranges and flow weighted means are given in Tables 16 and 17.

The data for catchment V7H010 shows some extremely high values for the different forms of nitrogen and phosphorus. Soluble phosphorus at 4700 µg/l, nitrate at 6000 µg/l, total Kjeldahl nitrogen at more than 10000 µg/l and chemical oxygen demand at 408 mg/l are levels commonly found in raw sewage. The range of concentrations for the samples is very wide with total phosphorus and nitrate concentrations up to more than 14000 µg/l and 28000 µg/l respectively. These high concentrations were not detected in any of the base flow samples taken prior to the investigation. The results for the control catchment, V1H028 are more normal and in line with levels found for the Cedara and Ntuze catchments. The discrepancy between arithmetic flow weighted means is again apparent, particularly for suspended solids, turbidity and total phosphorus.

Table 16: Analytical and statistical data for runoff samples from weir V7H010 between October 1990 and February 1991

Parameter		Mean	No. Samp.	Std. Dev.	Min.	Max.	Wt. Mean (by Vol.)
Susp. Sol.	mg/l	332	89	466	9	1755	280
Turbidity,	NTU	44	89	52	2	170	37
Conductivity,	mS/m	48,2	89	26,6	19,3	139,6	39,5
TDS (calc),	mg/l	321	-	177	129	931	263
Soluble P,	μg/l	4474	89	3430	44	10890	4690
Total P,	μg/l	6058	89	4428	93	14683	5967
Nitrate-N,	μg/l	6166	75	7300	5	28742	4162
Ammonia-N	μg/l	680	45	886	29	2400	359
Sol. Kjel-N,	μg/l	6668	63	3870	667	15373	7145
Total Kjel-N,	μg/l	10947	63	7278	1009	26471	10298
COD,	mg/l	408	9	144	114	549	-
Colour,	HU	763	48	431	25	1250	-

Table 17: Analytical and statistical data for runoff samples from weir V1H028 between October 1990 and February 1991

Parameter		Mean	No. Samp.	Std. Dev.	Min.	Max.	Wt. Mean (by Vol.)
Susp. Sol.	mg/l	437	51	391	4	1723	150
Turbidity,	NTU	208	51	127	17	415	77
Conductivity,	mS/m	2,9	51	0,64	1,5	4,6	3,5
TDS (calc),	mg/l	19	-	4,3	10	31	23
Soluble P,	μg/l	35	51	20	9	105	39
Total P,	μg/l	163	50	96	29	434	68
Nitrate-N,	μg/l	33	34	42	1	177	77
Ammonia-N,	μg/l	92	5	15	74	118	99
Sol. Kjel-N,	μg/l	492	7	91	365	642	469
Total Kjel-N,	μg/l	613	7	337	563	1315	720
COD,	mg/l	42	1	-	-	-	-
Colour,	HU	21	18	8	10	45	-

6.4 Export of pollutants

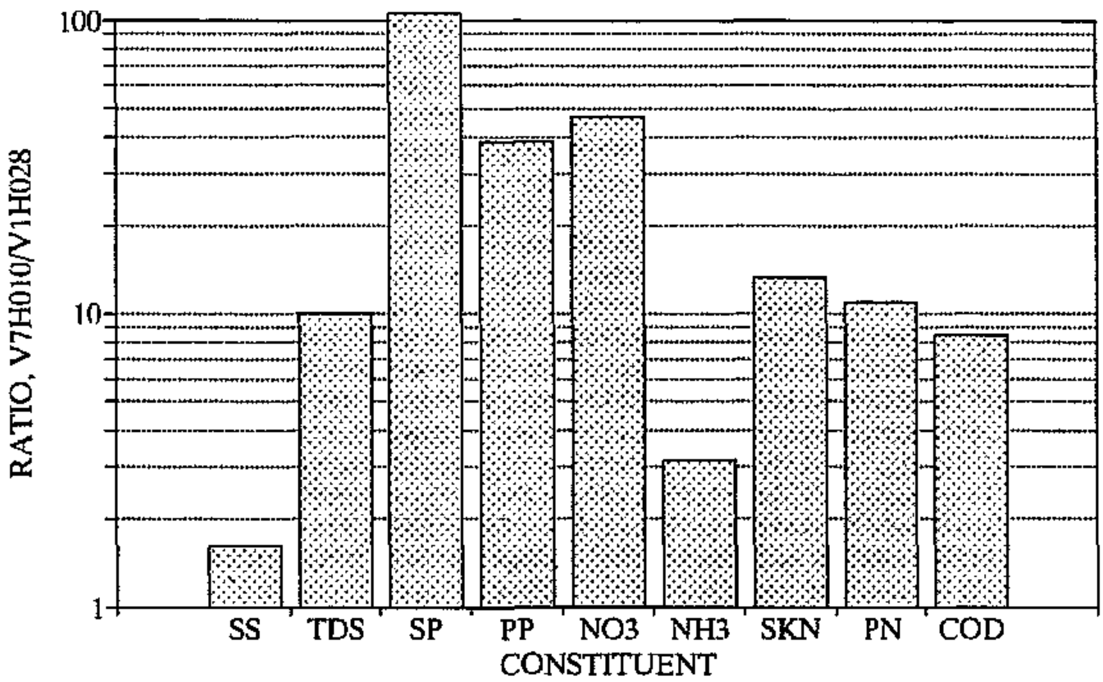
As the study was only conducted for a limited time, annual export coefficients cannot really be given with any accuracy. However, an estimate of pollutant export can be made for the period under review. These are given in Table 18.

Table 18: Washoff loads from catchments V7H010 and V1H028 for study period, kg/ha/a

Variable	V7H010	V1H028
Suspended solids	494	303
Total dissolved salts	464	46
Soluble phosphorus	8,3	0,08
Particulate phosphorus	2,3	0,06
Nitrate nitrogen	7,3	0,16
Ammonia nitrogen	0,63	0,20
Soluble Kjeldahl nitrogen	12,6	0,95
Particulate nitrogen	5,6	0,51
Chemical Oxygen Demand	719	85

Loads from catchment V7H010 are clearly very much higher. The net effect of the feedlot catchment on quality can best be seen in Figure 58 where the mean results are expressed as ratios on a log scale, ie: V7H010/V1H028. The difference in suspended solids loads is not that great at only 1,6 times higher, but the nutrients range from 3 times higher for ammonia to more than 100 times higher for soluble phosphorus. Even dissolved salts concentrations are 10 times higher. Chemical oxygen demand is close to 9 times greater which shows the very high organic load in runoff from the feedlot catchment. These high loads could have a detrimental impact on receiving waters under certain circumstances, ie: if dilution by cleaner river water was insufficient.

Figure 58: Comparison of washoff loads between catchments V7H010 and V1H028 for study period



6.5 Quality variation with flow during study period

Hydrographs were separated from the data set and as was done previously, the changing concentrations of the various constituents are plotted as line graphs with flow in Figures 59 to 67. The results for catchment V7H010 are dealt with first.

Figure 59 shows six distinct hydrographs with changing suspended solids concentrations. The first hydrograph on 901027 was a small one but produced high suspended solids concentrations of up to 1800 mg/l. Subsequent ones with similar (910116) or much larger (910124) peak flows, had much lower peak suspended solids concentrations, ie: 600 mg/l. As seen before this appears to be a "first flush" effect.

The results for conductivity in Figure 60 show a positive instead of the more usual negative relationship with flow. The rises in conductivity are quite appreciable, such as from 40 to 80 mS/m for the first hydrograph (901027) and from 30 to 140 mS/m for the second one (901205). The response to flow after that is not as pronounced, almost as if the store of salts in the catchment/soil matrix had been depleted.

Figure 61 for soluble phosphorus shows that concentrations follow the flow peaks very closely, although there appears to be a lag in falloff of concentrations on the falling limbs of the hydrographs, ie: a tail or residual effect. A point to note is that high concentrations of soluble phosphorus are present in all hydrographs throughout the wet season, as if there was no limit to the store of this nutrient in the catchment. It is quite logical that cow dung would have built up on the surfaces and in the soils of the catchment to be slowly leached out over a period of time. During the study it was noticed that the samples taken during hydrographs had a brown colour. A common cause of colour in water is from humic substances, tannins and lignins produced by decaying vegetation. Measurements of colour intensity were made on a few hydrographs and the results of one are plotted with soluble phosphorus concentrations in Figure 63 below. Note the close resemblance between the shapes of the chemigraphs. Clearly the source material for both phosphorus and colour is the same, ie: leaching from the cow dung/soil matrix.

Figure 63: Variation in soluble P concentration with colour

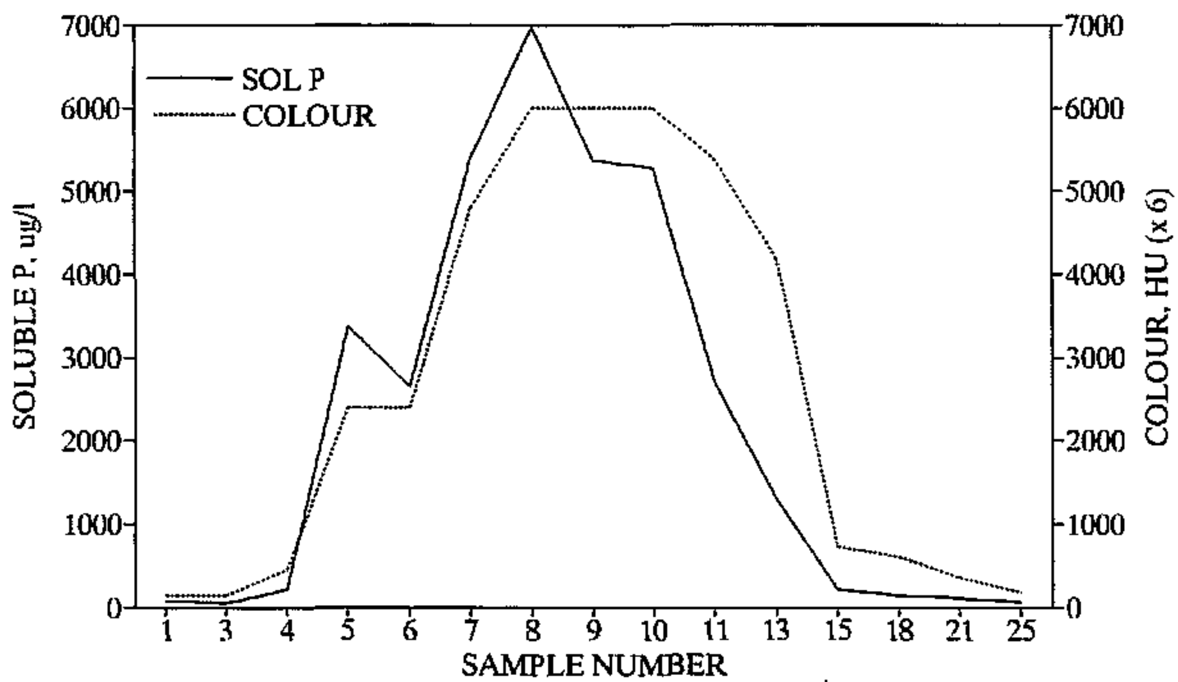


Figure 59: V7H010: Variation in susp. sol. concs. with flow

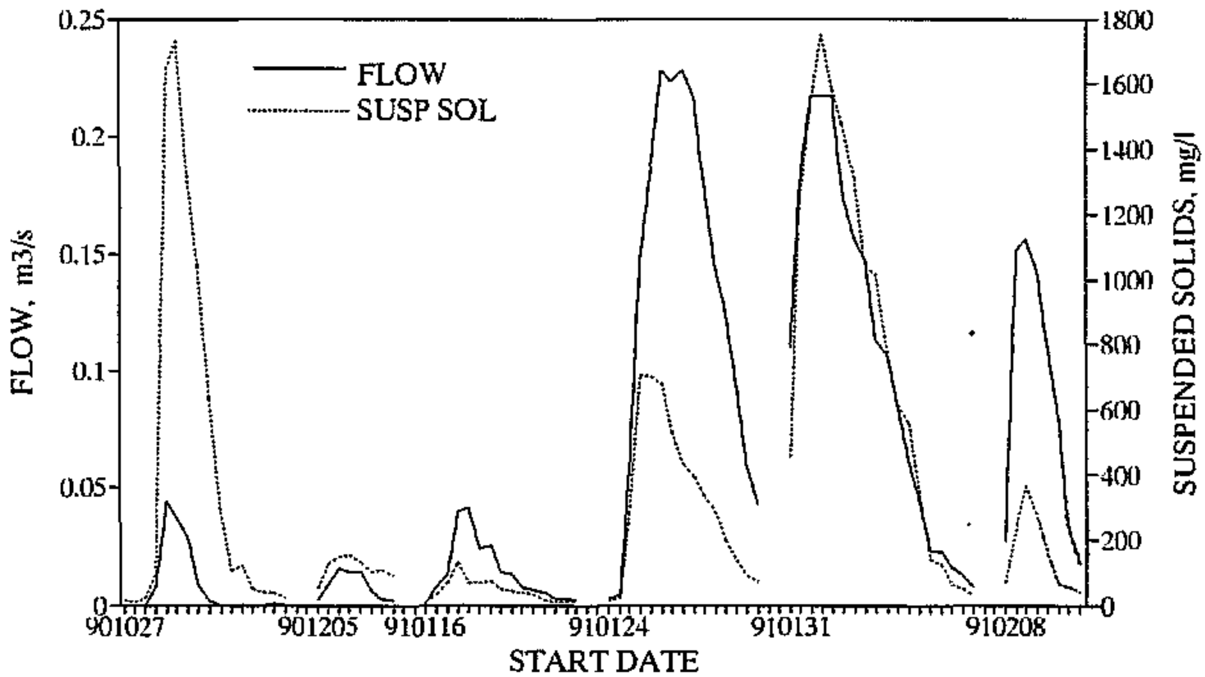


Figure 60: V7H010: Variation in conductivity levels with flow

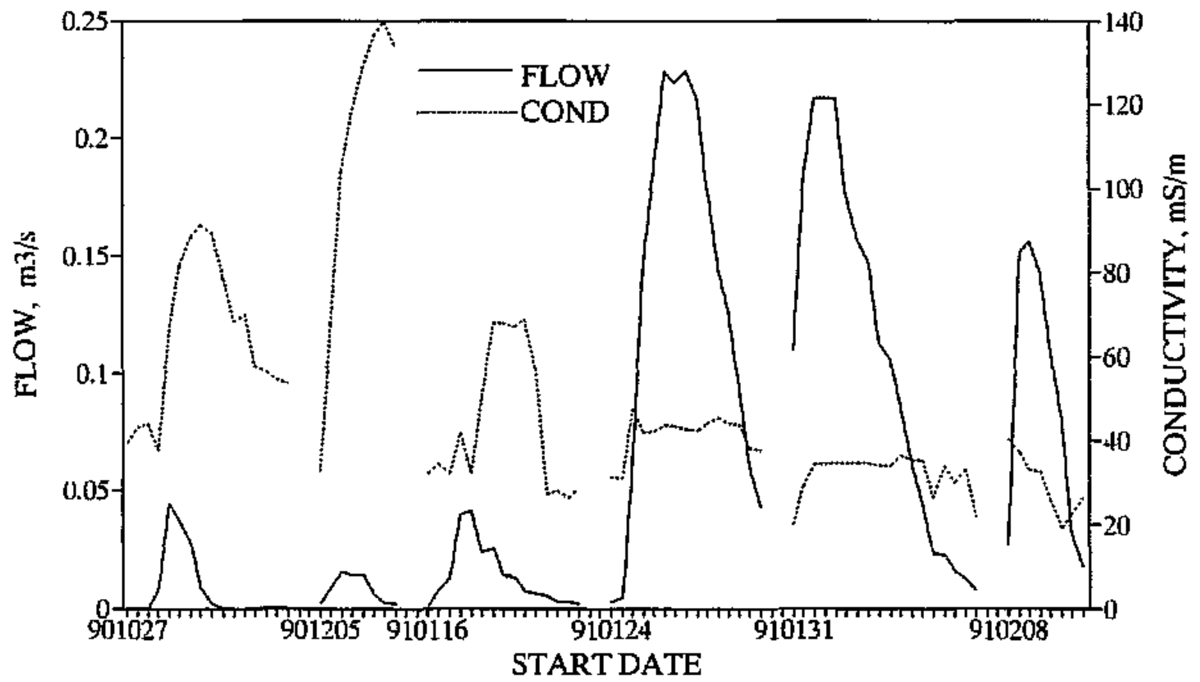


Figure 61: V7H010: Variation in soluble P concs. with flow

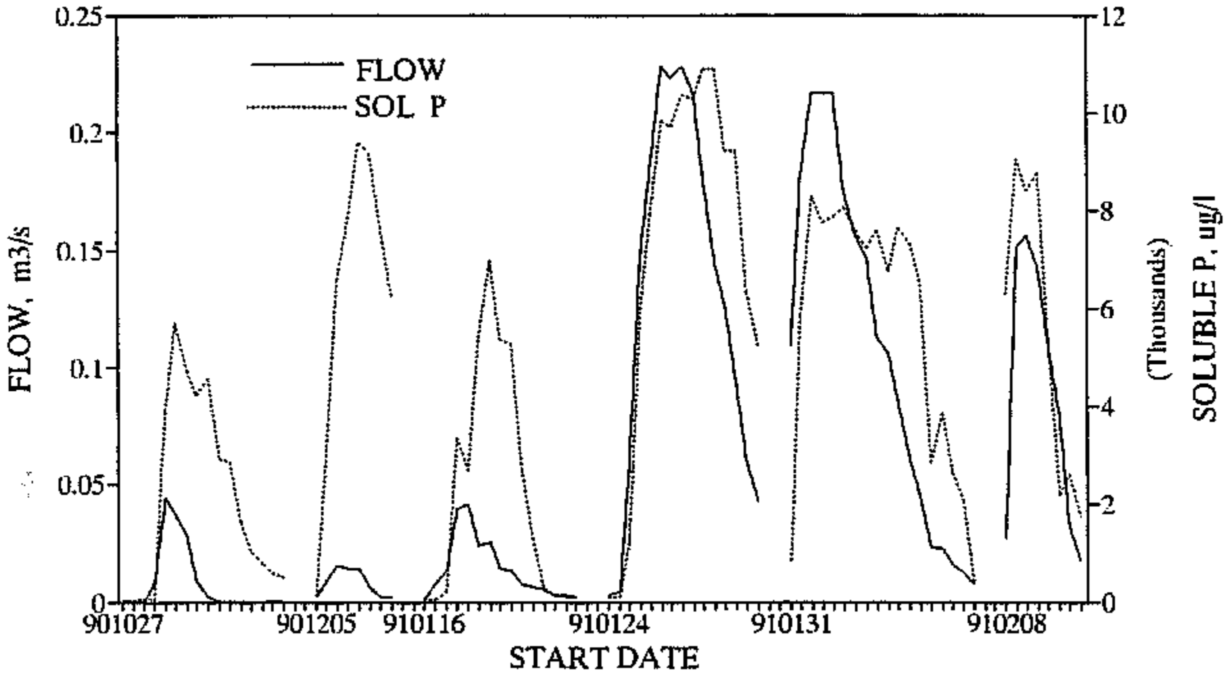
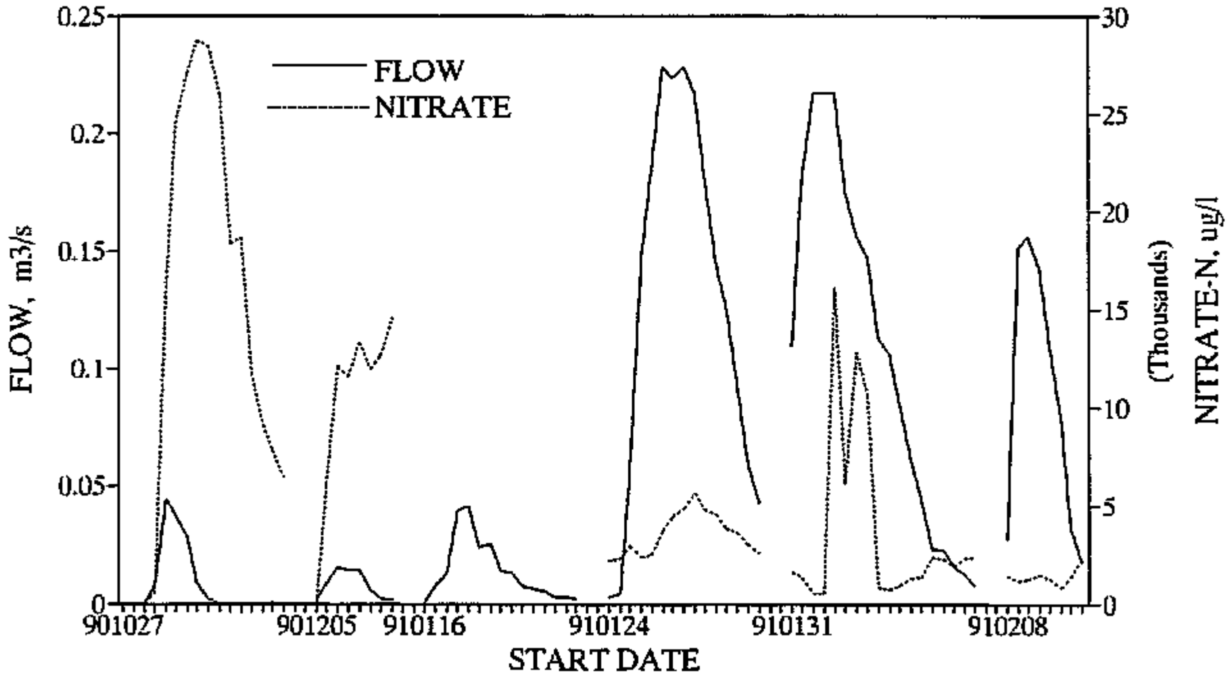


Figure 62: V7H010: Variation in nitrate concentrations with flow



On the other hand the nitrate concentrations for catchment V7H010 behaved in quite a different manner to soluble phosphorus. The results given in Figure 62 show a very large rise in nitrate concentrations with the first relatively small hydrograph of the season. Later, even larger hydrographs reflect much lower nitrate concentrations and the last one (910208) shows hardly any change in concentration. In a manner, this is a similar response to that shown for suspended solids, that is a "first flush" effect at the beginning of the season. But since nitrate is a soluble constituent, the lower concentrations during the large hydrographs could have been caused by dilution from rainfall. The process is obviously complex and no definitive answer can be given as to whether the nitrate store has been completely depleted without further monitoring.

For completeness, the same exercise was carried out on the limited results collected for the control catchment V1H028. Only four hydrographs are shown in Figures 64 to 67 as the main emphasis was on characterising runoff quality from the feedlot. General observations are given.

Suspended solids concentrations are responsive to flow but as observed for the other catchments, the response is not consistent with the magnitude of the hydrographs. Higher concentrations with lower peak flows at the beginning of the season and higher peak flows with lower concentrations later on can be seen. Conductivity displays an inverse relationship with flow and is most pronounced with the largest hydrographs. This trend was seen for the Cedara and Ntuze catchments. The change in soluble phosphorus concentrations with flow is greater than was the case for the Cedara and Ntuze catchments, but still there is no discernible pattern. In other words, it would be difficult to fit a soluble phosphorus relationship to flow. The variation in concentrations for nitrate with flow are vague and really insufficient analyses were conducted to observe any trends.

Basically this grassland catchment appears to have reacted, as far as flow-concentration relationships are concerned in a similar manner to the Cedara and Ntuze catchments. The particulate associated parameters are more susceptible to changes in flow than the soluble constituents which do not show as great a variation.

Figure 64: V1H028: Variation in susp. sol. concs. with flow

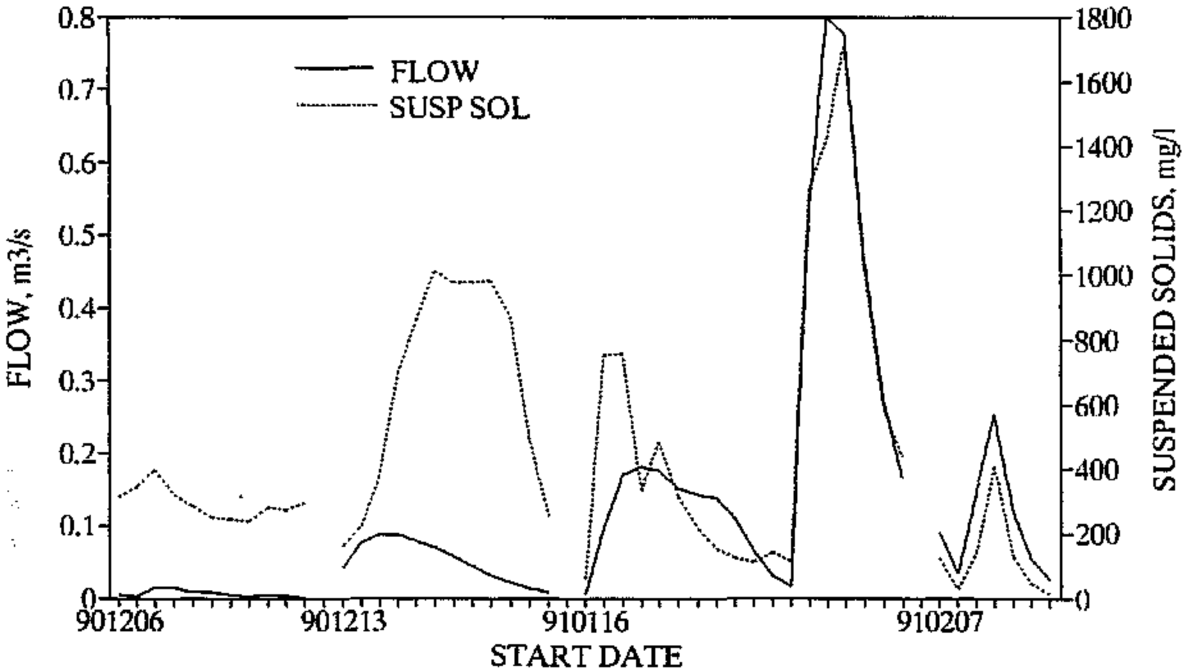


Figure 65: V1H028: Variation in conductivity levels with flow

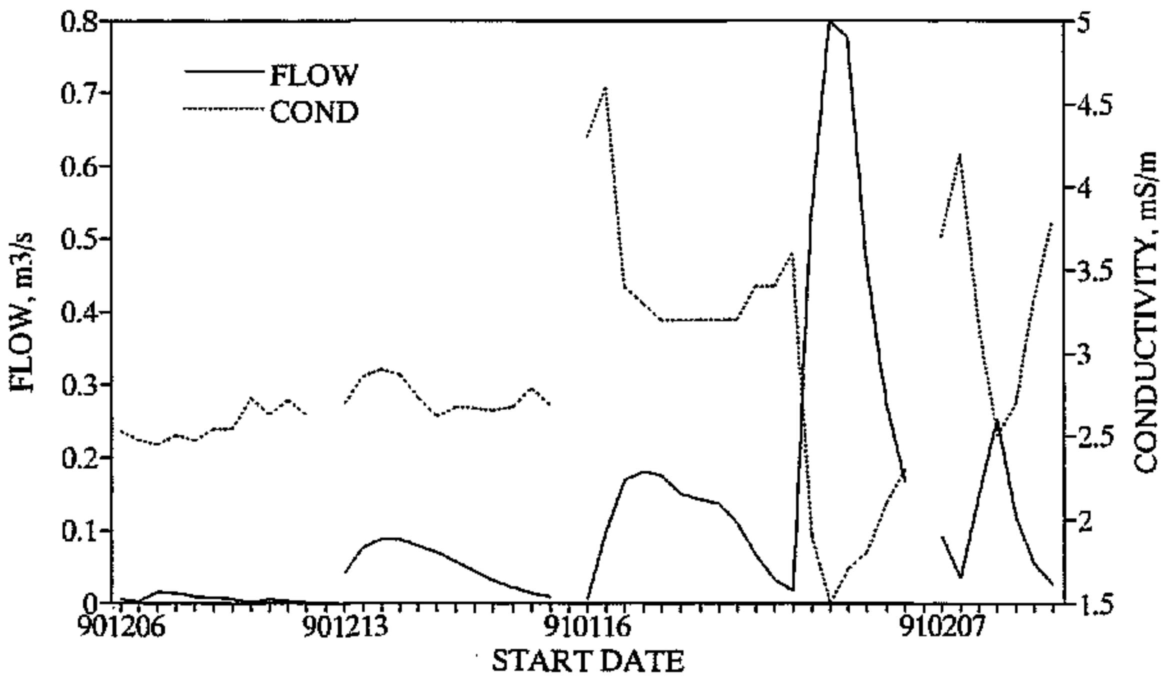


Figure 66: V1H028: Variation in soluble P concs. with flow

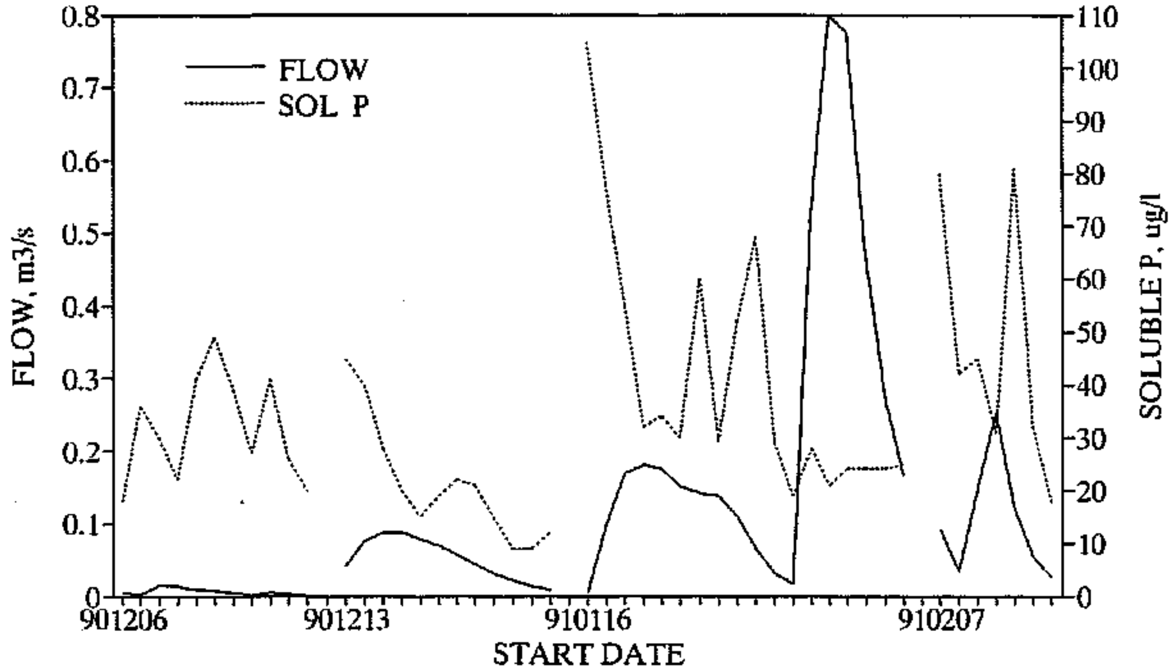
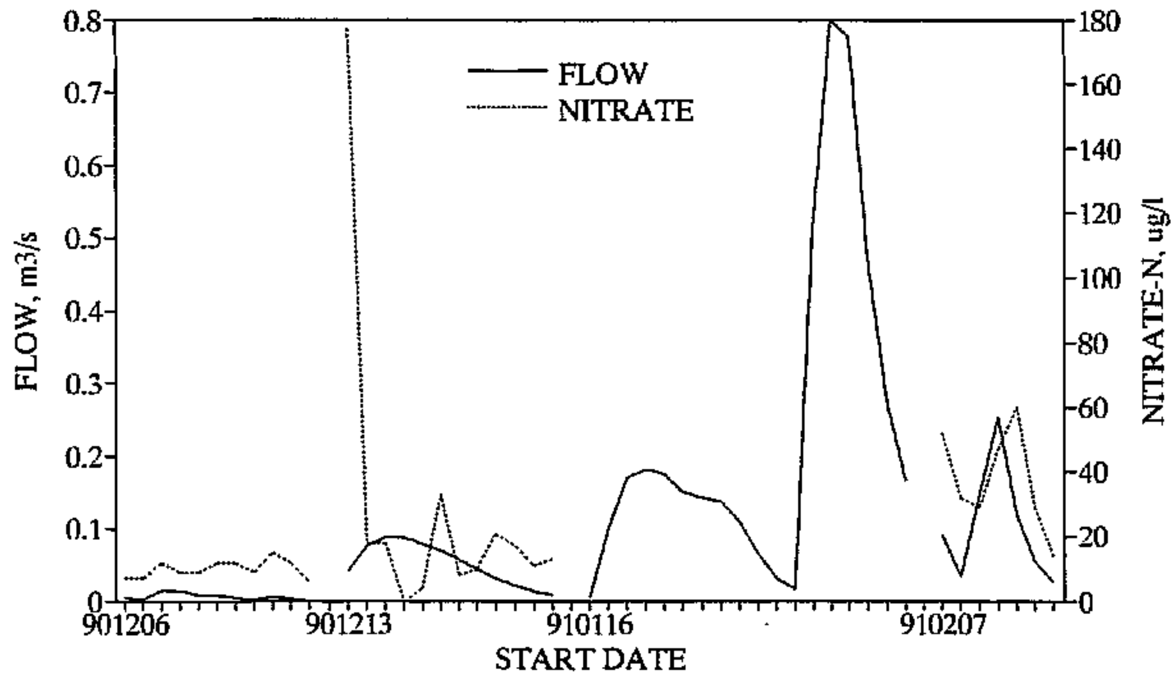


Figure 67: V1H028: Variation in nitrate concentrations with flow



6.6 Quality variations during hydrographs

As for the other catchments, the changes in concentrations during hydrographs was investigated. Only the results for conductivity and soluble phosphorus for the feedlot catchment, however, are presented as the results for suspended solids and nitrate for the catchment do not show any different findings to those observed for the Cedara and Ntuze catchments.

Where the Cedara and Ntuze catchments showed a negative relationship between conductivity and flow, a positive one was evident for the feedlot catchment, ie: increasing levels with flow. The path of changing conductivity levels with flow for six hydrographs is shown in Figure 68. For four of them the clockwise loop pattern, with some aberrations is evident, that is lower concentrations on the rising than on the falling limbs of the hydrographs. For the last hydrograph dated 910208, the reverse pattern is evident which may indicate depletion of the store of salts and dilution by rainfall. Otherwise it looks like high concentrations of dissolved salts are being leached out of the catchment.

The pattern for soluble phosphorus (Figure 69) is more consistent as shown by the clockwise loop for five of the six hydrographs. The fact that lower concentrations are found on the rising limbs of the hydrographs could be due to a sampling effect. As discussed earlier, the samples are taken from the V-notch as flow leaves the catchment, but there is a weir pond which provides a buffer effect for any incoming high concentrations. In the case of both conductivity and phosphorus this buffer effect could be confounding real flow-concentration relationships. Only if samples of flow were taken before entering the weir pond could this issue be resolved. It is considered that both dissolved salts and phosphorus are stored in the surface/soil layers of this catchment and are leached out with rainfall. To simulate phosphorus concentrations in runoff a model would need to take this factor into account.

Figure 68: V7H010: Changes in conductivity levels with flow

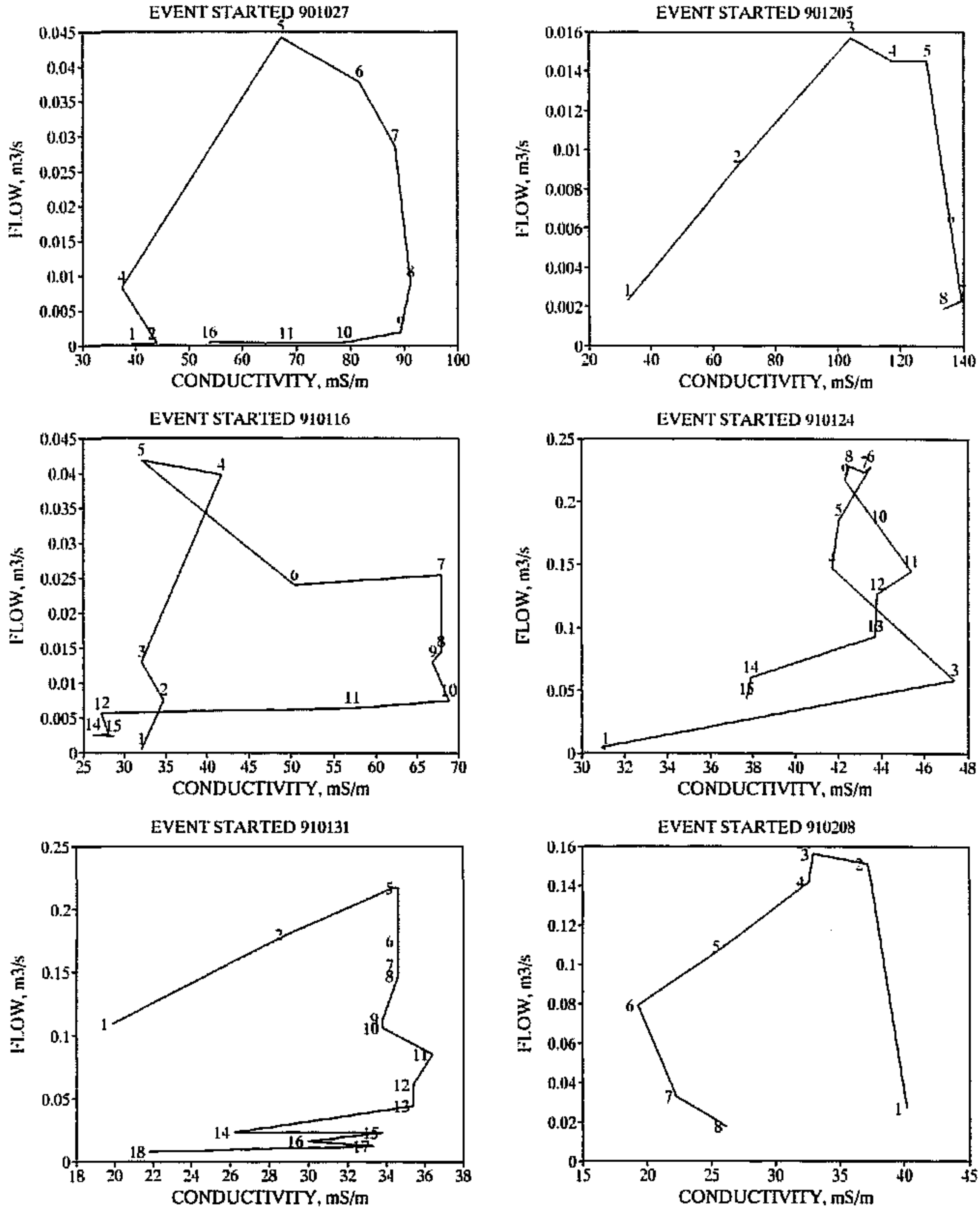
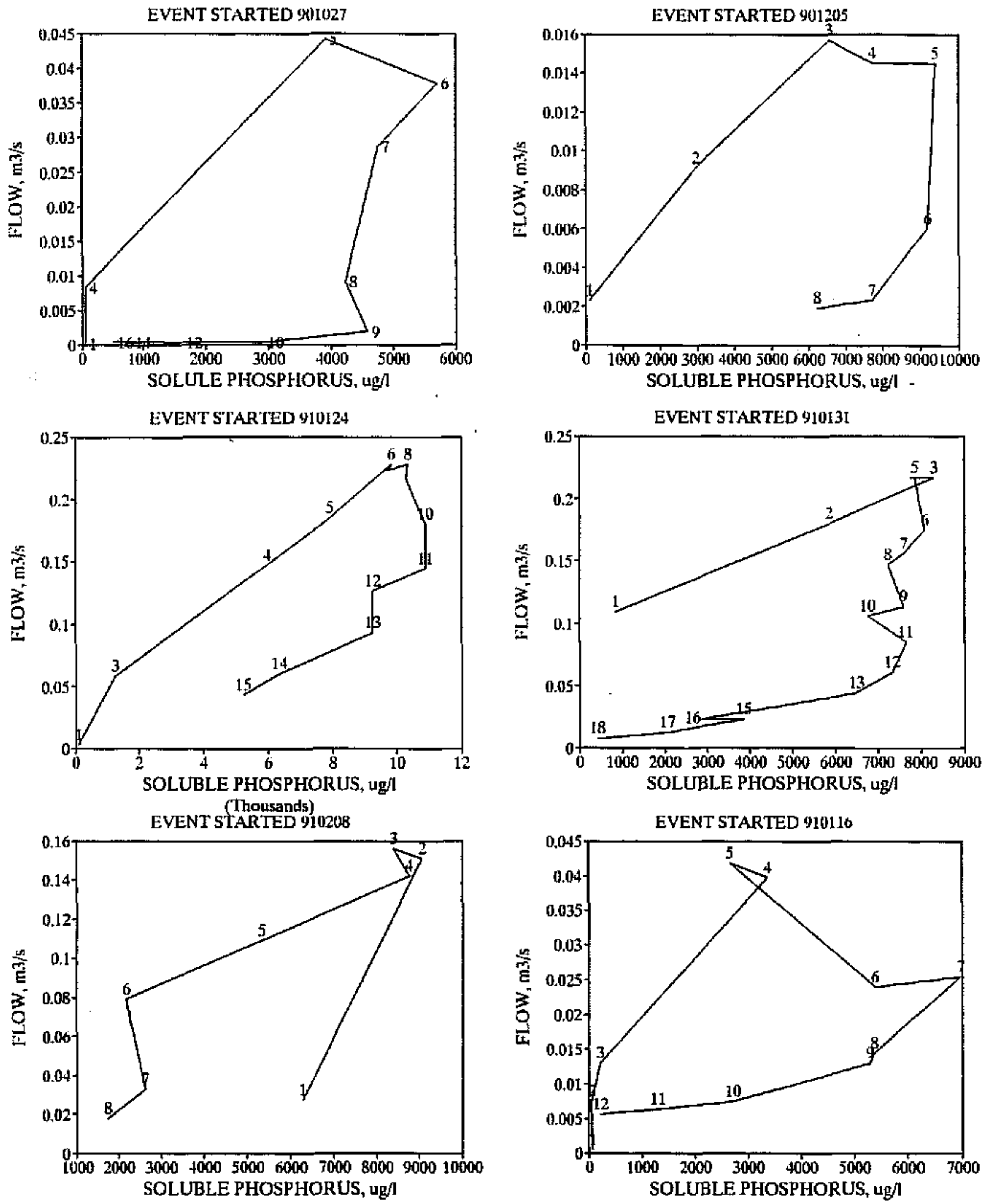


Figure 69: V7H010: Changes in soluble P concs. with flow



6.7 Correlation between water quality variables

A correlation analysis between flow and water quality variables was carried out and the results are shown in Table 19.

Table 19: Correlation coefficients between flow and water quality variables and between variables for catchments V7H010 and V1H028

V7H010	SS	Turb	Cond	SP	TP	NO3	NH3	SKN	TKN
Flow	0,60	0,31	-0,31	0,70	0,56	-0,24	0,27	0,24	0,45
SS		0,80	0,01	0,42	0,54	0,32	0,74	0,40	0,84
Turb			0,01	0,27	0,41	0,45	0,86	0,33	0,63
Cond				0,24	0,25	0,67	-0,05	0,62	0,34
SP					0,72	0,02	0,29	0,70	0,62
TP						0,17	0,23	0,56	0,62
NO3							0,17	0,40	0,43
NH3								0,46	0,73
SKN									0,80

V1H028	SS	Turb	Cond	SP	TP	NO3
Flow	0,69	0,37	-0,51	-0,10	0,60	0,27
SS		0,88	-0,56	-0,37	0,97	-0,24
Turb			-0,41	-0,41	0,92	-0,26
Cond				0,53	-0,60	0,11
SP					-0,38	0,43
TP						-0,22

Reasonably strong positive relationships for flow with suspended solids, soluble and total phosphorus are shown for catchment V7H010. Surprisingly, conductivity displays a negative relationship with flow whereas as seen earlier conductivity levels rose sharply with flow. This anomaly is most likely due to a lag effect caused by the weir pond. Similar correlations with flow may be seen for catchment V1H028 except that the inverse relationship between flow and conductivity is stronger. As expected, both catchments have good correlations between suspended solids and turbidity at 0,80 and 0,88. Other strong relationships can be used for predictive purposes, eg: between SKN and TKN.

6.8 Summary and discussion

Runoff quality from the disused feedlot catchment and the grassland catchment, which was selected as a control, was monitored for one wet season. Examination of past rainfall records showed that little rainfall occurred during the winter months and this pattern was verified by the short runoff period.

Very high phosphorus, nitrate, Kjeldahl nitrogen and chemical oxygen demand concentrations, of the order of that for raw sewage were found in runoff from the feedlot during hydrographs, but not in baseflow samples. Compared to runoff quality from the grassland catchment, loads for the monitoring period were 100 times higher for soluble phosphorus, 50 times higher for nitrate and 9 times higher for chemical oxygen demand. Runoff from catchments with this land-use could be detrimental to receiving waters in certain circumstances.

Changing flow rates during hydrographs strongly influenced concentrations of suspended solids, conductivity, soluble phosphorus and nitrate in a positive manner. For suspended solids, conductivity and nitrate a "first flush" effect at the beginning of the season was shown but for soluble phosphorus high concentrations were observed throughout, indicating an almost unlimited source. Soluble phosphorus levels were closely associated with the colour intensity of samples, showing a common source and a leaching mechanism. The response of pollutant concentration to changes in flow for catchment V1H028 was similar to that observed for the Cedara and Ntuze catchments.

Examination of individual hydrographs showed a repetitive pattern for changes in soluble phosphorus concentrations, ie: lower values on the rising than on the falling limbs of the hydrographs. This behaviour is thought to have been caused by a buffer effect in the weir pond. If it was possible to sample flow into the pond then a more direct relationship with flow may be found. Correlation analysis between the water quality variables gave reasonable correlations between some for both catchments. These relationships could be used to predict one constituent from another after a regression analysis to establish predictive equations.

7 DISCUSSION

The data obtained in these studies is considered to be of value for a number of reasons. Firstly, it is new information on runoff water quality from the catchments studied. An earlier grab sampling programme (Simpson, 1988) which was carried out at weekly intervals on the Cedara catchments produced results mainly representative of base flow conditions, except on the odd occasion when a sample was taken at some stage, either rising or falling limb of a hydrograph. The mean water quality, that is arithmetic means calculated for the grab sampling programme in 1988 is quite different to the means found in the current investigation, which involved continuous flow related sampling throughout hydrographs. As an example, some results for the two different studies on catchments U2H016 and U2H018 are compared below in Table 20:

Table 20: Comparison between results for grab and flow interval sampling

Variable		U2H016		U2H018	
		Grab	Flow	Grab	Flow
Suspended solids,	mg/l	12	29	23	35
Conductivity,	mS/m	14,8	12,7	6,9	6,9
Soluble P,	µg/l	8	21	6	16
Total P,	µg/l	22	49	27	48
Nitrate-N,	µg/l	620	333	852	521

If the results of the present study are taken as being the most accurate, which is a reasonable assumption, then the grab sampling study grossly underestimated suspended solids, soluble and total phosphorus concentrations, but overestimated nitrate concentrations. Conductivity levels on the other hand are far closer, in fact identical for catchment U2H018. The implication here is that if water quality means derived from grab sampling programmes for catchments are used to drive quality in models or just for calculation of export coefficients, then large errors can be incurred. Although continuous sampling studies are expensive in terms of the number of samples analysed, specialist equipment required and labour for development and servicing, the results are far more reliable for both the characterisation of runoff water quality from catchments and the calculation of pollutant washoff loads. Water quality models cannot realistically be either tested or calibrated without this type of information.

As shown in earlier sections of the report, concentrations for most constituents except soluble phosphorus (not in the case of catchment V7H010) were strongly influenced by changes in flow. This information can be used as input to models on the one hand and for calibration of models on the other. In the simplest form the empirical flow-concentration relationships derived for the catchments can be used to generate quality at all flows. Although this method could lead to overestimates during extended flow since there is no limit on the pollutant source, various factors could be built in to reduce loads/concentrations during extended flow, eg: the inclusion of time or volume from start of event as a negative exponent in the equation. A better method of simulating runoff quality would be to use a set of algorithms that (a) continuously accumulate pollutant loads on catchment surfaces during dry periods (b) remove or mobilise pollutants from the store with rainfall/runoff rate being the driving force (c) mix concentrations from surface flow, interflow and groundwater, if the information is available to give the final runoff quality. The Hydrological Simulation Program - FORTRAN (HSPF) model, (Donigian et al, 1984) contains this type of philosophy in the algorithms that generate quality and is well suited for the purpose. Synthesis of the data for the catchments clearly indicated that buildup of pollutants in the catchments during dry periods was occurring resulting in high concentrations at the beginning of the wet seasons and at the start of hydrographs.

The variation in quality for a number of constituents was shown to follow the shapes of the hydrographs quite well but regression analysis of quality on flow produced lower than expected R^2 values with appreciable unexplained variances. Examination of concentration paths in relation to flow during hydrographs showed some erratic behaviour with patterns of lower concentrations on the rising than the falling limbs of the hydrographs and vice versa. The reason for this behaviour could be due to a buffer effect on concentrations in the pond ahead of the weir V-notch where samples were taken, or in other words different concentrations at the inlet and outlet of the pond. If at all practical it is recommended that in future studies sampling of the incoming flow to the weir basin should take place in preference to sampling at the V-notch itself.

Since this study was basically concerned with the effect of land-use on runoff water quality, it is tempting to compare the results of all six catchments studied. This cannot, however, really be done because the sampling programmes for each study were not exactly the same. Between each pair of catchments, the methods and period of study were identical and therefore valid comparisons between them can be made. The mean runoff quality from the Cedara catchments was calculated from samples taken both during baseflow and during hydrographs to give overall means and export coefficients. On the other hand, for the Ntuze catchments, only samples taken immediately before, during and after hydrographs were analysed. Consequently, the means for these catchments really represent only hydrograph flow quality and exclude baseflow. The means for the Ntabamhlope catchments were calculated in a similar manner, as the main purpose was to characterise differences in quality between the land-uses during stormflow. Nevertheless, a comparison of flow weighted mean runoff qualities taken from Tables 5, 6, 11, 12, 16 and 17 is given in Table 21 below, but the above differences in approach must be borne in mind.

Table 21: Comparison of flow weighted mean runoff quality between catchments

Variable		U2H016	U2H018	W1H016	W1H031	V7H010	V1H028
Susp. sol.	mg/l	29	35	120	85	280	150
Turbidity	NTU	19	19	23	9	37	77
TDS (calc)	mg/l	85	46	102	97	263	23
Soluble P	μg/l	21	16	17	10	4690	39
Total P	μg/l	49	48	107	89	5967	68
Nitrate-N	μg/l	333	521	256	110	4162	77
Sol. Kjel-N	μg/l	266	231	392	416	7145	469
Tot. Kjel-N	μg/l	434	430	1253	1355	10298	720

Note: Total nitrogen for V7H010 = 14 460 μg/l

The feedlot catchment, V7H010, stands out as having by far the highest concentrations of the nutrients, nitrogen and phosphorus. The levels are more comparable to domestic sewage than to the other catchments. For example, data taken from Straub, 1989, for a medium strength domestic sewage gives a suspended solids level of 220 mg/l, a TDS of 500 mg/l, a total phosphorus of 8 000 μg/l and a total nitrogen of 40 000 μg/l. The levels in runoff from catchment V7H010 are not very different being the same order of magnitude. Clearly runoff from this catchment has a high pollution potential.

Comparisons between the other catchments show that the Cedara ones have the lowest suspended solids, total phosphorus and soluble and total Kjeldahl nitrogen concentrations, due in large part to the lowering influence of baseflow results in the calculations. The TDS levels estimated from conductivity are most likely a reflection of catchment geology and soil types. Concentrations of the soluble constituents are not so different with catchment V1H028 being the highest for soluble phosphorus, the Cedara catchments intermediate and the Ntuze catchments the lowest. Clearly, the activities in the Cedara catchments (smallholdings and forestry) and catchment W1H016 (settlements and subsistence farming) produce the highest nitrate concentrations compared to the less disturbed and more natural catchments W1H031 and V1H028. To make realistic comparisons between catchments requires, however, requires similar sampling and analysis programmes.

As to transferability of the results to other catchments, there is no reason why this should not be done, but with the proviso that land-use and other physical attributes in the catchment are similar. For example, runoff from a forested catchment with a lower average slope than that for U2H018, 29%, would not be expected to produce as high suspended solids concentrations or turbidity levels.

8 CONCLUSIONS

Summaries have been given at the end of the chapters on results presented for each pair of catchments and therefore the conclusions will be limited to more concise statements.

1. For the Cedara catchments, comparison of mean runoff quality between the 1988/89 and 1989/90 years for catchment U2H016 showed a major difference for suspended solids, up 100% and a lesser rise for turbidity, up 40%. The differences for catchment U2H018 for the same periods were lower at 30% to 40% for suspended solids, particulate phosphorus and nitrogen while the variation for other constituents was less. The variation was attributed to different rainfall cycles and is considered normal.

2. Comparison of mean runoff quality between the Cedara catchments showed U2H018, the forested one, to be higher for suspended solids (20%), particulate phosphorus, particulate nitrogen and nitrate but lower for dissolved salts (50%) and soluble phosphorus. The higher average topographical slope and consequently the erosion potential for catchment U2H018, 29% compared to 16% for U2H016, is considered the reason for the greater solids associated pollutant concentrations. The higher soluble phosphorus concentration for catchment U2H016 is considered due to a land-use effect, ie: smallholdings, crop raising.

3. The variation in export coefficients between years for the Cedara catchments was less than the variation for quality because total runoff in the second year was lower but concentrations higher. This variation is considered to be quite normal for catchments.

4. Catchment U2H018 had far higher export coefficients than U2H016, for example 2,5 times higher for nitrate and 3 times higher for suspended solids, mainly because of the higher total runoff from the catchment over the two year period, ie: 468 mm compared to 240 mm.

6. Comparison of weighted mean runoff quality during hydrographs from the Ntuze catchments showed that the disturbed catchment W1H016, with a land-use partly under subsistence farming and agriculture, had far higher suspended solids, turbidity, soluble phosphorus and nitrate concentrations than the control catchment W1H031, a protected grassland. Levels ranged from almost 50% higher for suspended solids to more than 250% for nitrate. The results reflect a distinctive land-use effect since all other attributes for the catchments are similar. Conversely, dissolved organic carbon and volatiles for suspended materials were greater for the control catchment. This was attributed to natural processes.

7. For the Ntabamhlope catchments, concentrations of soluble and particulate phosphorus, nitrate, soluble Kjeldahl nitrogen and chemical oxygen demand in runoff from the disused feedlot catchment, V7H010, were very much higher than those for the control catchment, V1H028, being an order of magnitude or higher for some. The levels are comparable to those found in domestic sewage. Runoff from this type of land-use could be detrimental to receiving waters.

8. The above results satisfy one of the objectives of the project, that is characterisation of runoff water quality and loads from catchments with different land-uses.

9. For all catchments, concentrations for suspended solids, turbidity, conductivity, particulate phosphorus, and nitrate but excluding soluble phosphorus, except in the case of catchment V7H010 were highly responsive to changes in flow during hydrographs. Conductivity had an inverse relationship with flow for all catchments with the exception of V7H010 where increasing conductivity with flow was found. The magnitude of the responses relative to the peaks of the hydrographs was not consistent, showing a varying relationship through the wet season. Higher concentrations were observed at the beginning of the wet seasons, indicating a "first flush" of pollutants that had built up on surfaces during the dry season.

10. Closer examination of the path of quality changes in relation to flow changes during hydrographs showed different "looped patterns" for constituents for all catchments. For some, concentrations were higher on the rising than on the falling limbs of the hydrographs, that is different concentrations at similar flow rates, and for others the reverse pattern was evident. The reason for this behaviour could be due to a "first flush" effect on the one hand (higher concentrations on the rising limbs) or in other cases to dilution of incoming higher concentrations to the weir basin on the other hand (lower concentrations on the rising limbs). Sampling of incoming rather than outgoing flow to weir basins would probably give better relationships between the two variables.

11. Regression analysis of the water quality variables on flow using four different models, linear, multiplicative, exponential and reciprocal, showed that no single one gave the best fit for predicting any particular constituent. For catchment U2H016 the strongest relationships with flow were found for conductivity, suspended solids and turbidity with R^2 values (explained variance) of 81%, 74% and 66% respectively. The relationships for catchment U2H018 had lower R^2 values, the highest being 45% for conductivity and generally poorer relationships were found for all of the other constituents tested. The best relationships for the Ntuze catchments was found for conductivity at 61% and 50% for W1H016 and W1H031 respectively. The regression equations may be used to predict quality from flow but the accuracy will be dependent on the strength of the relationships.

12. Some strong correlations were found between water quality variables showing that one may be confidently predicted from another, eg: particulate phosphorus from suspended solids for catchments U2H016 and U2H018, total phosphorus from suspended solids for catchments W1H016, W1H031 and V1H028 with coefficients ranging from 0,95 to 0,99. The correlations between suspended solids and turbidity were not as high with coefficients from 0,67 to 0,88, being lowest for the Ntuze catchments. Continuous measurement of conductivity will not give very reliable predictions of other variables such as suspended solids, since generally poor correlations were found, eg: the highest coefficient was 0,71 for catchment U2H016 but for

the others values from 0,22 to 0,56. Variable relationships were found for the other soluble constituents.

13. The foregoing data analysis on relationships between concentrations and flow has indicated the modelling approach which should be adopted for simulation of water quality in the model being developed for the Mgeni Catchment by the University of Natal, ie: a model that generates pollutants continuously and removes them by rainfall/runoff processes from a store. The data is available for testing/calibrating the model. This satisfies the second project objective.

14. The changing land-use in catchment W1H016, increasing settlement by subsistence farmers and some expansion of agriculture, together with the natural catchment, W1H031, makes this combination ideal for long term monitoring to assess the effects of development on runoff quality and loads. The results have shown a distinctive land-use/water quality effect. This satisfies the third project objective.

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APPENDIX A: DATA LOGGING SYSTEM

A.1 Logger programme (Sharp basic)

AN EXPLANATION OF THE PROGRAMME AND ALTERNATIVE STRATEGIES FOR DIFFERENT OPERATIONS

```
 1 REM LOGP16.LST,U2H016,881028,START AT 0m,(LF-FL)/LF<.1
 2 REM VARIABLE SAMPLING RATE DEPENDENT ON FLOW(IF USED). END OF YEAR CHECK
 3 REM TH=THRESH FLOW, V1=SLOW SAMPLING RATE, V2=FAST SAMPLING RATE, AA=FLAG FOR
   SAMPLING 2 SAMPLES/BOTTLE, IE: TO GIVE SAME NO. TO 2 CONSECUTIVE SAMPLES
 4 TH=0.2, :V1=600 :V2=300 :IT=0.01 :SN=1 :AA=0  auto input of variables
 5 MP=STATUS 2                        sets memory pointer at the beginning
 6 DIM F(255)                         reserves an array of 256 places for F
 7 DIM SV$(0)*30  reserves 30 characters for string SV$ (the saved string)
 8 DIM FT$(0)*30  reserves 30 characters for string FT$ (the fetched string)
15 INPUT "LOGGING OR PLAYBACK?(L/P)",RS$  place input into RS$
16 IF RS$="L"THEN 20                  data logging mode
17 IF RS$="P"THEN 8000                data playback mode
18 IF RS$="C"THEN 20                  loop mode to continuously read fl
19 GOTO 15                            return if unrecognised char input
20 FOR I=0TO 255                      read 256 data bits into the array
26 READ F(I)                          F, can be more than 256 but not
27 NEXT I                             less the specified dimension
30 IF RS$="C"THEN 3000                jump to calibration loop
31 DATA 0,.00001,.00002,.00005,.00008,.00013,.00019,.00026
32 DATA .00035,.00045,.00057,.00071,.00086,.001,.0012,.0014
33 DATA .0017,.0019,.0022,.0025,.0028,.0031,.0035,.0039
34 DATA .0043,.0047,.0052,.0057,.0062,.0067,.0073,.0079
35 DATA .0085,.0092,.0099,.0106,.0113,.0121,.0129,.0137
36 DATA .0145,.0155,.0164,.0173,.0183,.0193,.0204,.0215
37 DATA .0226,.0238,.025,.0262,.0275,.0287,.0301,.0314
38 DATA .0329,.0343,.0358,.0373,.0389,.0404,.0421,.0437
39 DATA .0455,.0472,.049,.0508,.0527,.0546,.0565,.0585
40 DATA .0605,.0626,.0647,.0669,.069,.0713,.0736,.0759
41 DATA .0783,.0807,.0831,.0856,.0882,.0908,.0934,.096
42 DATA .0988,.102,.105,.108,.112,.117,.122,.128
43 DATA .134,.141,.148,.155,.163,.17,.179,.187
44 DATA .195,.205,.214,.223,.232,.242,.252,.262
45 DATA .272,.283,.294,.305,.316,.327,.338,.35
46 DATA .362,.374,.386,.398,.41,.423,.436,.449
47 DATA .462,.475,.488,.502,.516,.53,.544,.558
48 DATA .572,.586,.602,.617,.633,.652,.67,.69
49 DATA .712,.733,.755,.777,.8,.82,.847,.871
50 DATA .895,.921,.948,.976,1.01,1.04,1.07,1.1
51 DATA 1.14,1.17,1.21,1.24,1.28,1.31,1.35,1.39
52 DATA 1.43,1.47,1.51,1.55,1.59,1.63,1.67,1.71
53 DATA 1.75,1.8,1.84,1.88,1.93,1.97,2.02,2.06
54 DATA 2.11,2.16,2.2,2.25,2.3,2.35,2.39,2.44
55 DATA 2.49,2.54,2.6,2.66,2.72,2.79,2.86,2.92
56 DATA 2.99,3.06,3.14,3.21,3.28,3.36,3.43,3.51
57 DATA 3.59,3.67,3.75,3.83,3.91,4,4.08,4.17
```

```
 58 DATA 4.26,4.34,4.43,4.52,4.61,4.71,4.8,4.9
 59 DATA 5,5.08,5.18,5.27,5.37,5.47,5.57,5.67
 60 DATA 5.76,5.87,5.97,6.07,6.17,6.27,6.38,6.48
 61 DATA 6.59,6.69,6.8,6.9,7.01,7.12,7.23,7.34
 62 DATA 7.45,7.56,7.67,7.79,7.9,8.02,8.14,8.25
 90 RESTORE   returns to first data statement
100 INPUT "VOLUME BETWEEN SAMPLES",VL   volume in m3 between samples
120 INPUT "INTERVAL AS .MMSS",IT        time interval between reads, min sec
122 IX=INT (IT*100)*60+(IT*10000)-(INT (IT*100))*100  converts IT to seconds
130 INPUT "FIRST SAMPLE NUMBER",SN                     can be 1 or other
200 LT=TIME                        read current time and put in var LT
210 NT=INT (LT*100)/100            remove seconds from LT and put in NT
220 GOSUB 5300                     subroutine to read flow rate
250 LF=FL                          current flow becomes last flow (update)
260 SV$(0)=STR$ (NT)+","+STR$ (FL)  combine NT and FL as string var in SV$
270 GOSUB 5000                     subroutine to save SV$ in memory
280 IF FL<TH THEN LET VL=V1        for slow sampling rate
281 IF FL>=TH THEN LET VL=V2       for faster sampling rate
285 IF ABS (TIME -LT)<ITTHEN 2000  *start of loop* is it time to do a fl read
    above 2 lines only used if variable sampling rate used, otherwise line 285
    becomes 280
286 IF ABS (TIME -LT)>(IT+0.1)THEN 1000  for change in hr or day or yr goto
                         for yr change -ve result made +ve and prog can cont
290 LT=TIME                         it is time for fl read, take current time
295 HR=0                            set flag to 0, an hr read can be taken
300 GOSUB 5300                      subroutine to read flow rate
310 CV=CV+(LF+FL)/2*IX  add flow vol for last period to CV, mean fl x seconds
320 IF CV<VL THEN 500   if not time for sample then check for significant change in flow
330 LF=FL               make current flow last flow
340 CV=CV-VL            subtract vol interval from CV, overflow carried forward
345 NT=INT (LT*100)/100                       remove sec from LT
350 SV$(0)=STR$ (NT)+","+STR$ (LF)+","+STR$ (SN)  make string of NT,LF,SN
360 GOSUB 5000                                subroutine to save string
370 GOSUB 5400                                subroutine to operate sampler
380 SN=SN+1                                   update sample number
    if 2 samples per bottle then 380 changed and 382 put in
380 IF AA=1 THEN LET SN=SN+1  only if flag set change sample number
382 AA=ABS(AA-1)  changes AA between 0 & 1 on every pass, -ve number made +ve
390 GOTO 280                       return to beginning loop
500 PAUSE LF;FL                    display last fl, current fl
504 IF ABS (LF-FL)/LF<0.1THEN 280  check if a significant change in flow since last one
510 LF=FL                          make current flow = FL
512 MN=INT (100*(LT-INT (LT)))     extract minutes only from time LT
520 SV$(0)="M"+STR$ (MN)+","+STR$ (FL) string with M in front then min and fl
530 GOSUB 5000                         subroutine to save in memory
540 GOTO 280                           return to beginning loop
1000 PT=TIME                     routine if change in hr between time and LT
1010 A=INT (100*(PT-INT (PT)))+60   extract min from PT and add 60
1020 B=INT (100*(LT-INT (LT)))      extract min from LT
1030 IF (A-B)>=INT (IT*100)THEN 290  find difference and if >= to IT, then do fl read
2000 BC=TIME                        routine for hour read, take current time
2005 IF HR=1THEN 2100               if flag = 1 then an hr read already taken
```

```
2010 AB=BC-INT (BC)                    remove month, day, hr from BC, leave .MMSS
2020 IF AB>0.0005THEN 2100             if more than 5 sec past hr, jump otherwise
2030 GOSUB 5300                        subroutine to read flow
2035 NT=INT (BC)                      remove min and sec, will be 0 as an hr read
2040 SV$(0)=STR$ (NT)+","+STR$ (LF)  make string of time and flow reads
2050 GOSUB 5000                        subroutine to save string, save hour read
2055 HR=1                      set flag to 1, no further hr record till reset
2060 GOTO 280                  return to beginning loop
2100 ST$=INKEY$                ST$ is any key entered on keyboard
2120 IF ST$="S"THEN 2200       if it is an S then jump to end
2130 ST$=""                    if not reset entry to nil
2140 GOTO 280                  return to beginning loop
2200 SV$(0)="END OF DATA"      S seen on keyboard, make this string in SV$
2210 GOSUB 5000                subroutine to save string in memory
2220 GOTO 10000                goto end
3000 GOSUB 5300                subroutine to read flow
3010 GOTO 3000                 loop for continuous flow reads
5000 PAUSE "RECORDING DATA"    subroutine to save a string, display message
5008 FOR I=1TO LEN (SV$(0))     set loop iterations to length of string
5010 SV=ASC (MID$ (SV$(0),I,1))  convert first character in string to ASCII character
5030 POKE MP,SV                 put character into memory
5040 MP=MP+1                    advance memory pointer so as not to overwrite
5050 NEXT I                     goto next character in string
5055 POKE MP,13                 end of string so enter a CR
5056 MP=MP+1                    advance memory pointer
5060 IF MP>=(STATUS 3-100)THEN 5100  check if memory nearly full
5090 RETURN                            return to where came from
5100 SV$(0)="END OF MEMORY"            enter this string into SV$ if memory full
5110 FOR I=1TO LEN (SV$(0))            for the length of the string
5120 SV=ASC (MID$ (SV$(0),I,1))        save character by character
5130 POKE MP,SV                        in memory
5140 MP=MP+1                           advance memory pointer
5150 NEXT I                            next character
5155 POKE MP,13                        enter a CR
5160 GOTO 10000                        goto end
5200 FT$(0)="":SC=0         subroutine to read from memory, empty FT set SC
5210 FT=PEEK MP             read character from memory into FT
5220 MP=MP+1:SC=SC+1        advance memory pointer and counter
5230 FT$(0)=FT$(0)+CHR$ (FT)  assemble character in string FT$, convert ASCII to string
5240 IF FT=13THEN RETURN      if CR seen then exit
5250 IF SC=40THEN RETURN      if string has 40 character exit (safety valve)
5260 GOTO 5210                loop to next character in memory string
5300 POKE# &1001,1            subroutine to read flow, switch on power to potentiometer
5310 PAUSE "READING FLOW"     display message
5320 POKE# &1000,0            address a/d channel 1
5330 AD=PEEK# &1000           put this value (0-255) into AD
5331 POKE# &1000,0
5332 AE=PEEK# &1000           read a/d for 2nd time
5333 POKE# &1000,0
5334 AF=PEEK# &1000           read a/d for 3rd time
5335 AD=(AD+AE+AF)/           calculate mean of 3 readings
5340 FL=F(AD)                 read the ADth flow value from array F
```

```
 5350 PAUSE "FLOW = ";FL;AD    display flow and array number (0-255)
 5360 POKE# &1001,0            switch off power to potentiometer
 5370 RETURN                   return to where came from
 5400 POKE# &1001,2            subroutine to operate sampler, close relay
 5410 PAUSE "OPERATING SAMPLER"  display message
 5420 POKE# &1001,0              open relay
 5430 RETURN                     return to where came from
 8000 SETCOM 2400,8,N,1          routine to set communication to PC
 8001 OUTSTAT 0                  "              "
 8003 SETDEV DO                  "              "
 8009 GOSUB 5200                 goto subroutine to read from memory
 8010 PRINT FT$(0),CHR$ (10)     print string to PC with a line feed
 8015 IF LEFT$ (FT$(0),1)="E"THEN 10000  if first character is an E goto end
 8020 GOTO 8009                          loop to next string to be read
10000 PAUSE "END"                        print message
10001 END
```

TO PUT IN VL, IT AND SN AUTOMATICALLY TO AVOID ERROR

DELETE LINES 120 AND 130
CHANGE LINE 100 TO:
100 VL="enter vol":IT=.01:SN=1   flow reads at 1 min. sample no. at 1

TO AVOID SAMPLING AT LOW FLOWS, IE: ONLY ACCUMULATE FLOW ABOVE A SET RATE

ADD IN LINE 305

```
305 IF FL < "a particular rate" THEN 500  this jumps the calculation of flow
                                          since the last min. and addition to the
                                          cumulative flow etc. and sends the prog.
                                          to check for a significant change in flow
```

TO CHANGE SAMPLE INTERVAL ACCORDING TO FLOW, NEED TO PUT IN SOME CONDITIONS
AT THE BEGINNING OF THE LOOP IE: AT 280 AND SO MUST CHANGE THOSE LINE NUMBERS

CHANGE 280 TO 285
CHANGE 281 TO 286
TO DO THIS JUST NEED TO GET CURSOR TO THE LINE NUMBER AND CHANGE TO WHAT YOU WANT. THIS THEN GIVES A DUPLICATE LINE IE: 280 WILL STILL EXIST.
TO REMOVE A LINE TYPE IN LINE NUMBER AND PRESS ENTER.
AT 280 ENTER: IF FL<0.1 THEN LET VL=500
AT 281 ENTER: IF FL>0.1 THEN LET VL=250
THIS ALLOWS FOR RETURN OF FLOW BELOW A THRESHOLD TO A LOWER SAMPLING RATE.

A.2 Logger interface

The interface between the Sharp PC 1500A used as a data logger was manufactured by The Division of Production Technology, CSIR, according to the requirements given to them by the project leader.

Functional description

The data logger and interface devices are powered by an external 9 V battery (Sonnenschein Dryfit A200, 9,5 Ah batteries used). The interface regulates the supply voltage to 5 V on the output connector for the potentiometer. The regulated voltage can be switched on and off under software control by Relay 2. Relay 1 is used as a normal switch and is also software controllable.

The input signal from the sensor (potentiometer) is connected to channel 1 of the interface and can have any value between 50 mV and 4,5 V. The gain can be adjusted by the trimpot in the interface for different fullscale input voltages.

The interface consists of an analogue to digital converter with 16 input channels of which only 6 are used. The scan rate of the A/D converter is 20 channels per second. To address any input channel the following statements should be used:

```
POKE# &1000,CH          (select the input channel)
LET A = PEEK# &1000     (read input channel data)
```

In the POKE# statement "CH" represents one of the six channel numbers and can be any value between 00 and 05. In the PEEK# statement the digital value is read and stored in the variable A. The value of A can be any number between 0 and 255.

The interface also consists of an 8 bit output port of which only 2 lines are used in this application. To address this port the following statement should be used:

```
POKE# &1000, DATA       (write digital word out on port)
```

where "DATA" can be any value between 0 and 255.

To switch Relay 1 and Relay 2 see following table:

DATA	RELAY1	RELAY2
00H 0	OFF	OFF
01H 1	OFF	ON
10H 2	ON	OFF
11H 3	ON	ON

Circuit description

The interface can be divided into 4 parts:

Decoding circuit
A/D converter circuit
Output control circuit
Battery charger circuit

The address decoding is formed by U2, a 4051 CMOS analog multiplexer, U4a, a 4093 NAND gate, R2 and R3. U2 and U4 are configured in such a way to control U1 and U3. Depending on the inputs O/D, R/W, ME1, A0 and A15, data is written to the output port or to the A/D convertor and also read from the A/D convertor.

The A/D convertor circuit is formed by U1, a 16 channel analogue to digital convertor, U5, a LM10CN operational amplifier, U4b, U6 and associated components. U5, R4 and R5 form the reference circuit for the A/D convertor. U4, R6 and C3 forms the clock circuit for the A/D and U6 the Gain amplifier circuit. The gain is determined by VR1 and R7 and the gain can be adjusted by VR1.

The output control port is formed by U3, a 74HC573 Octal latch enabled from U2 pin 12. U3 pin 18 is used to switch RL1 on and off with Q1. D1 is the feedback protection diode connected across the coil of RL1. The contact of RL1 is connected to pin 13 and 14 of the output connector. U3 pin 19 controls RL 2 in the same manner. U7, a low power 5 V voltage regulator is connected in series with the contacts of RL2. The 9 V input is switched by RL2 to U7 and the 5 V output of U7 is connected to pin 12 of the output connector.

Q3, R10 and ZD1 form the charger circuit to the PC1500A logger and is connected to the Vbat terminal of P1.

Interface between data logger and PC

When the data logger was brought in from the field it was connected to a SHARP RS232, CE-158 interface which was connected to a serial port on the PC. The software package CROSSTALK was used.

Settings in CROSSTALK were as follows:

```
SPeed     =   2400
DAta      =   8
POrt      =   1 or 2
PArity    =   N
STop      =   1
DEbug     =   OFF
TAbex     =   OFF
INfilter  =   ON
LFauto    =   OFF
BLankex   =   OFF
OUtfilter =   ON
CWait     =   DELAY 10
LWait     =   DELAY 20
```

To transfer data from the logger to the PC, the following procedure was carried out:

In command mode in CROSSTALK, type "CA" (capture mode) and enter address where data is to be stored (file name).
Then on data logger type:

```
SETCOM 2400,8,N,1
CONSOLE 0,0,1
OUTSTAT 0
SETDEV PO
LLIST
```

The data is transferred.

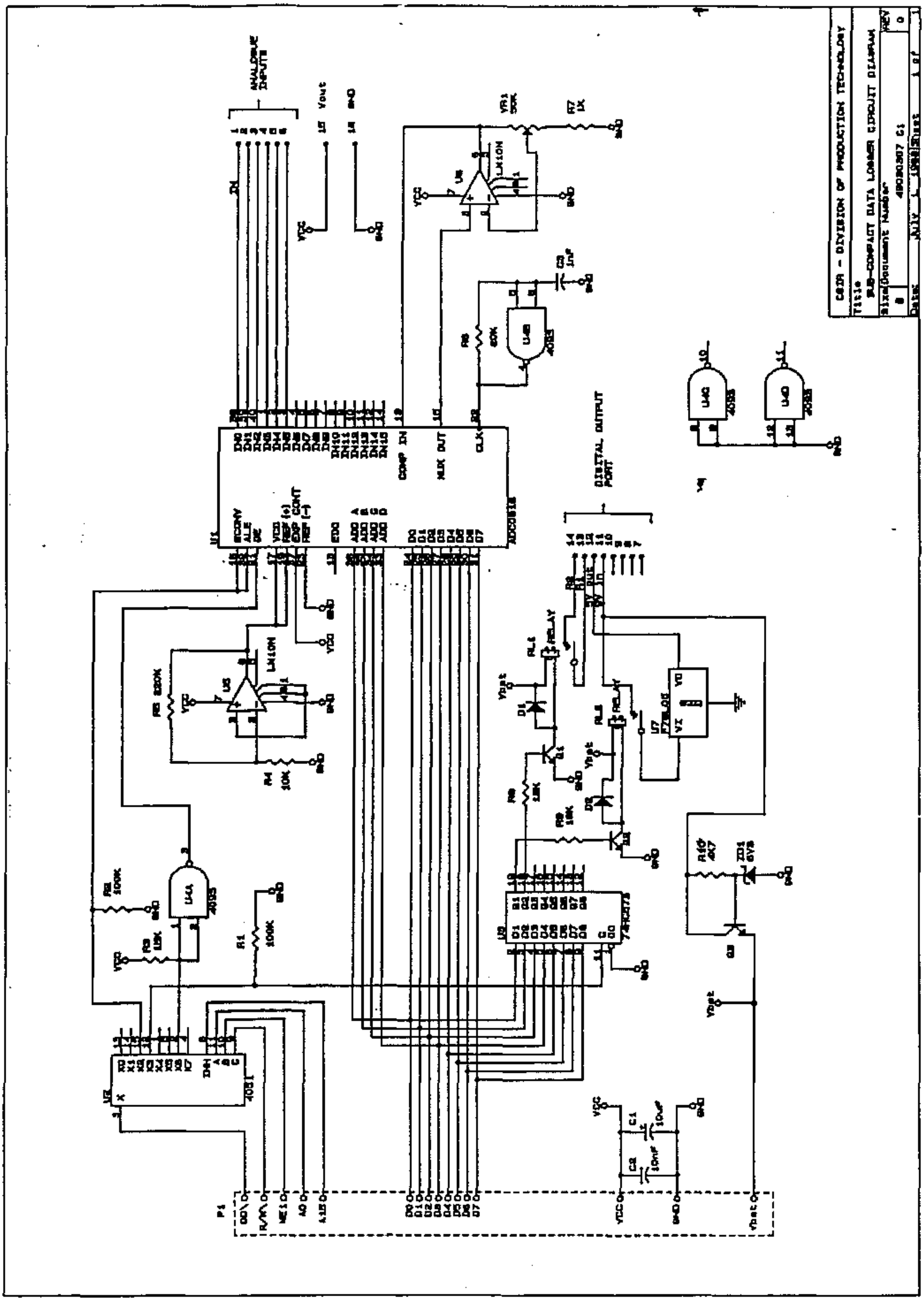
To load a programme from the PC to the data logger:
On data logger (in programme mode) type:

```
NEW
SETCOM 2400,8,N,1
OUTSTAT 0
SETDEV CI
CLOADa
```

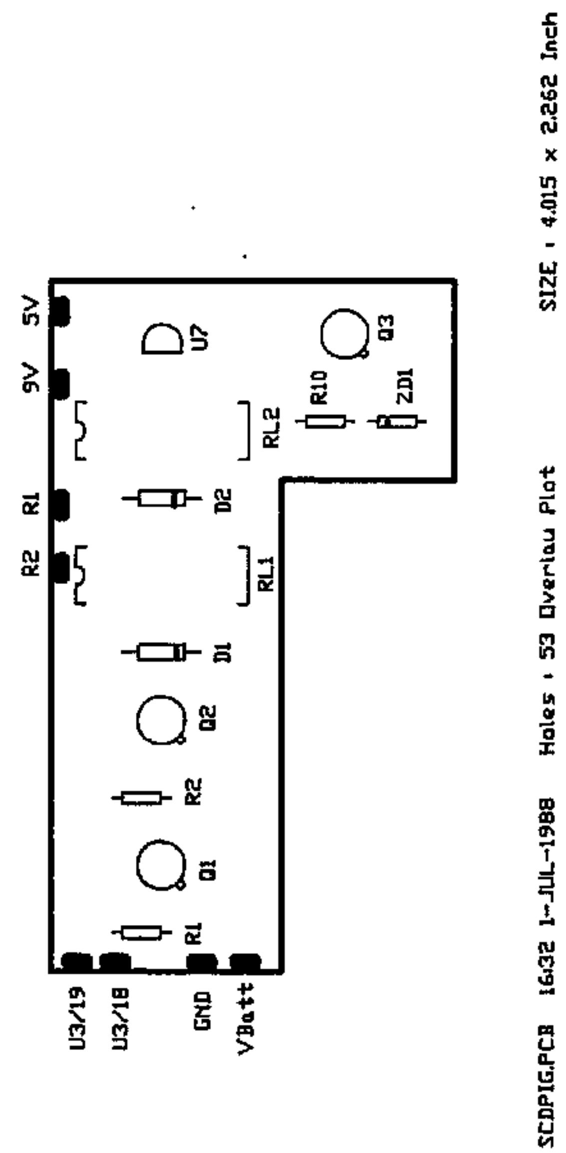
A "busy" will come up on data logger.

On PC turn off "CA" by typing CA if already on.
Type SE (for send) and then enter the filename of the programme to be sent.

The circuit diagram for the interface is given in the following two figures.


CSIR - DIVISION OF PRODUCTION TECHNOLOGY
SUB-COMPACT DATA LOGGER CIRCUIT DIAGRAM

Interface circuit diagram (continued)



A.3 Sampler modification

The Isco, Model 1680 automatic water sampler had to be modified because the pump time cycle at its maximum was insufficient time to pump the water from the weir V-notch via the tubing to fill the sample bottle. A printed circuit board was designed to increase all pumping cycles by factors of 2 or 3 times.

This should be read in conjunction with the circuit diagrams of the ISCO sampler instruction manual. The modification consists of a piggy back pcb containing two IC's and a dummy wire wrap socket. The modification is effected by removing IC21 on the Switch Printed Circuit Board and inserting the piggy back board into the IC21 socket position. Care should be taken that the piggy back board is plugged in correctly by ensuring that the IC21 socket pin 1 and piggy back pcb blank socket pin 1 correspond (An indent exists in the sockets at the pin 1 end). Pump cycle times of 1, 2 and 3 times may be obtained by placing the shorting link provided on the piggy back pcb across the appropriate period multiplier select pins.

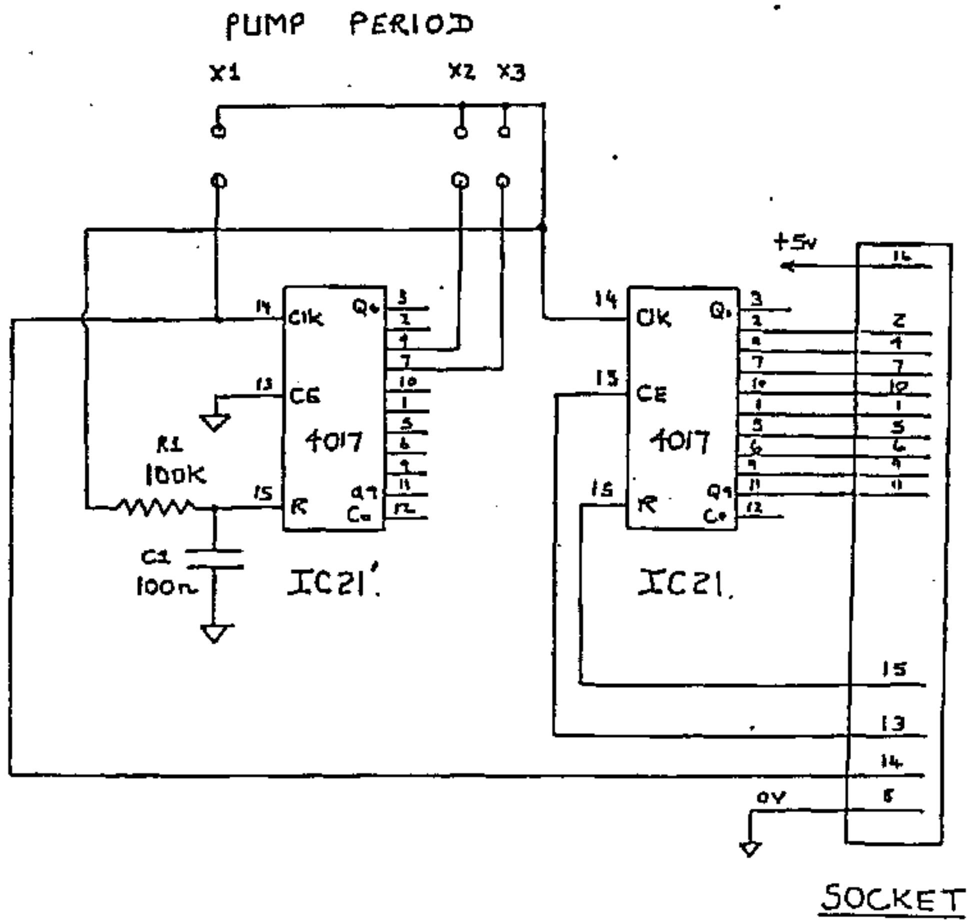
Piggy back pcb description

The piggy back pcb contains three 16 pin IC sockets. The centre dummy wire wrap socket is used as a connector and plugs into the unmodified IC21 position. The pcb contains IC21 as well as a predivider, designated IC21'. The circuit diagram is shown in Figure 1.

Incoming pump revolution pulses from IC17B pass through the predivider, IC21', which divides the number of incoming pulses by 2 or 3. This is achieved by connecting either the Q2 or Q3 output of the 4017 decade counter to its rest line. Resistor R1 and capacitor C1 ensure a reset pulse width, and hence clock output pulse of sufficient duration to drive IC21. In the "times 1" position, the output of IC17B is connected directly to the CLK input of IC21, which is the condition of the sampler in the unmodified state.

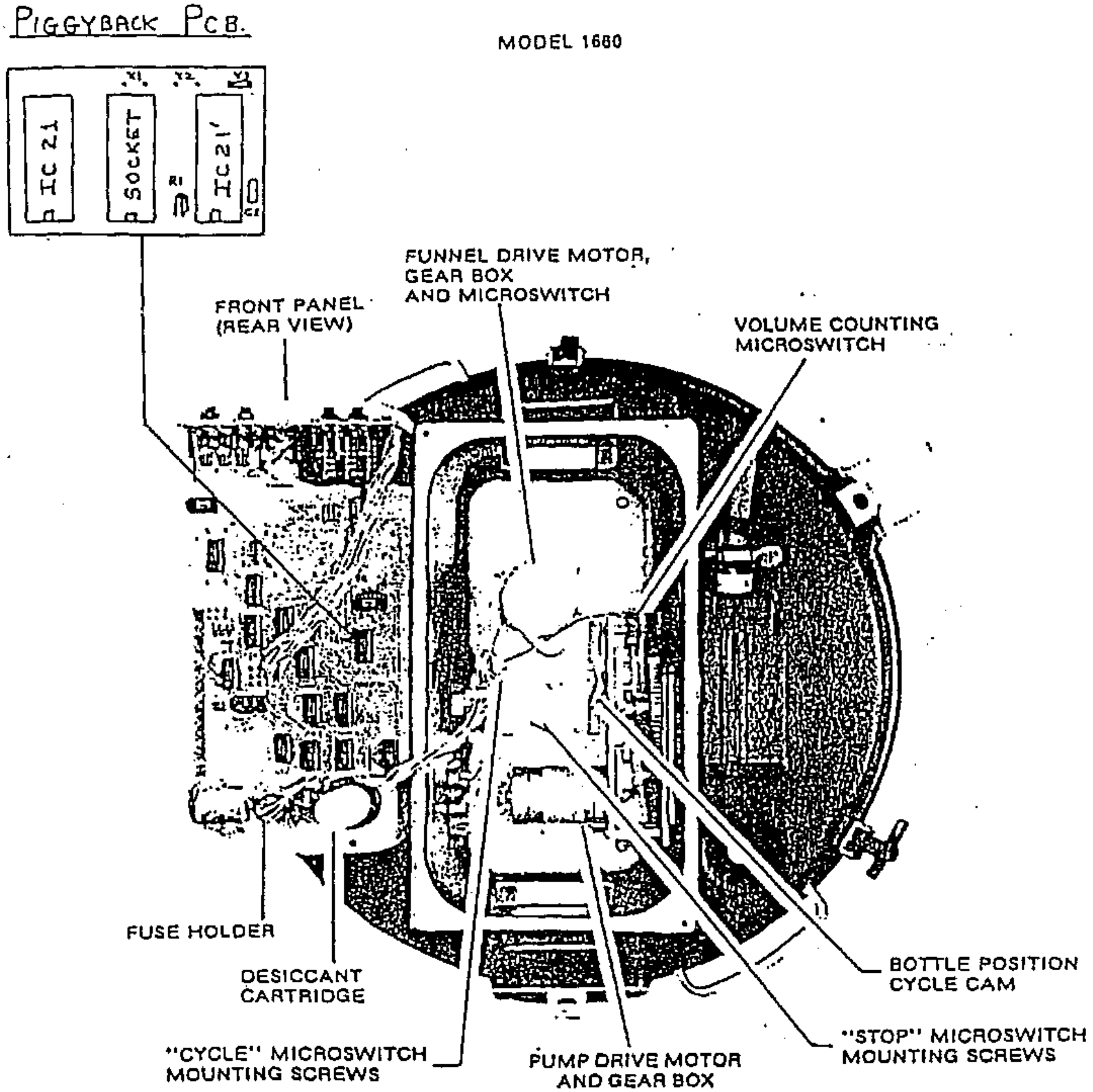
The sampling cycle consists of a number of states, these being pre-purge, line fill, bottle fill and final purge state. The length of each pump state is controlled by counting pump shaft revolutions. The pre-scaler piggy back pcb modification divides the shaft revolution count by 1, 2 or 3, and hence the time of each sample cycle state is divided accordingly.

The location of the board within the sampler is shown in the second figure entitled "Modification Detail".



Piggyback Pcb Circuit Diagram

Figure 1



PIGGY-BACK PCB

MODIFICATION DETAIL.

APPENDIX B: ANALYTICAL DATA

The analytical data is available as an ASCII file from the Computing Centre for Water Research, University of Natal, P O Box 375, Pietermaritzburg, 3200. An example of the format of the data is given below. An explanation of abbreviations used in the data tables is as follows:

DATE	YYMMDD
TIME	HHMM (sometimes HH.MM)
SN	(First one) Sample number for particular run
FLOW	Flow rate in m^3/s
SN	(Second one) The sample or composite sample analysed
SS	Suspended solids, mg/l
TURB	Turbidity, NTU
COND	Conductivity, mS/M
TPF	Total phosphorus filtered, μg/l as P
TPU	Total phosphorus unfiltered, μg/l as P
CL	Chloride, mg/l
NO3	Nitrate, μg/l as N
KNF	Kjeldahl nitrogen filtered, μg/l as N
KNU	Kjeldahl nitrogen unfiltered, μg/l as N
SO4	Sulphate, mg/l
V INT	Volume interval between samples, m^3
COMP	Denotes results for a composite sample

Note: Where composite samples were prepared, the flow rates for the individual samples making up the composites are given.

CEDARA CATCHMENTS ANALYTICAL DATA (EXAMPLE)

U2H016

DATE	TIME	SN	FLOW	SN	SS	TURB	COND	TPF	TPU	CL	NO3	KNF	KNU	SO4	V INT
881018	2306	1	0.011	1	14	11	16.9	32	44	7.8	821	367	471	12.5	500
881019	1222	2	0.01	2	9	10	16.1	39	42	8	496	212	343	12.4	500
881020	221	3	0.01	3	5	8	16.5	26	39	7.4	353	169	319	12.8	500
881020	1620	4	0.01	4	8	8	16.5	29	41	7.7	281	205	316	13	500
881021	619	5	0.01	5	5	8	17.2	35	45	7.3	319	197	332	13	500
890224	2117	6	0.009	6	12	10	16.3	38	51	7.8	371	270	310	13.3	500
881022	1008	7	0.011	7	11	10	16.3	36	49	7	373	224	262	13.8	500
881023	49	8	0.009	8	13	10	16.3	59	74	7.5	382	259	317	12.8	500
881023	1622	9	0.009	9	7	7	16.3	62	69	7.2	299	250	261	12.8	500
881024	845	10	0.009	10	9	9	16.9	42	50	7.6	527	241	246	13.3	500
881025	236	11	0.007	11	9	8	17.4	75	79	7.7	338	230	288	13.2	500
881026	415	1	0.0073	1	6	7.3	17	50	72	6.8	------	------	------	------	500
881026	2316	2	0.0079	2	3	5.8	17.1	25	33	6.3	------	------	------	------	500
881027	1730	3	0.0079	3	6	6.5	16.9	34	47	6.4	------	------	------	------	500
881028	1312	4	0.0073	4	4	6	17.2	40	53	6.5	------	------	------	------	500
881029	1112	5	0;0062	5	5	7.1	17.3	54	72	6.8	------	------	------	------	500
881030	918	6	0.0073	6	4	6.7	17.3	31	44	6.9	------	------	------	------	500
881031	627	7	0.0067	7	5	8.5	17.2	37	52	6.7	------	------	------	------	500
881101	511	8	0.0057	8	5	8	17.3	70	87	6.6	------	------	------	------	500
881102	944	1	0.0062	1	8	5	17.8	27	51	6.2	------	------	------	------	500
881103	827	2	0.0062	2	7	5.3	17.7	39	63	6.4	------	------	------	------	500
881104	326	3	0.0073	3	5	6	17.7	21	35	6.4	------	------	------	------	500
881104	2315	4	0.0062	4	4	6	17.5	24	45	6.4	------	------	------	------	500
881105	2148	5	0.0057	5	11	5	17.5	29	52	6.4	------	------	------	------	500
881106	2145	6	0.0057	6	5	4.9	17.6	53	62	6.2	------	------	------	------	500
881107	2032	7	0.0052	7	5	4.1	17.6	68	75	6.4	------	------	------	------	500
881108	2250	8	0.0052	8	6	4.3	17.7	78	82	6.4	------	------	------	------	500
881109	2312	9	0.0062	9	4	4	18	57	76	6.3	------	------	------	------	500
881111	1125	1	0.0052	1	2.7	3.2	14.9	42	60	6.7	51	183	430	------	500
881112	1353	2	0.0052	2	3.3	3.2	15	42	60	6.7	65	146	445	------	500
881113	1743	3	0.0043	3	5.3	4.4	15.7	84	155	6.7	204	161	348	------	500
881115	211	4	0.0039	4	4.7	5.6	15.2	94	158	6.7	275	146	333	------	500
881116	513	5	0.0067	5	6.7	6.7	15.5	55	62	6.7	308	153	238	------	500
881117	155	6	0.0067	6	4	7.2	15.8	30	48	6.7	632	191	302	------	500
881118	858	1	0.0073	1	6.7	5.7	17.3	39	47	7.5	------	------	------	------	500
881119	739	2	0.0057	2	6.7	4.9	17.1	46	67	7.7	------	------	------	------	500
881120	1140	3	0.0052	3	8	6	17.1	67	93	7.4	------	------	------	------	500
881121	1609	4	0.0047	4	12	8	17.2	78	103	7	------	------	------	------	500
881122	1951	5	0.0047	5	11.3	7.9	17.6	66	96	7.7	------	------	------	------	500
881130	2052	1	0.0092	1\4	16	3.6	14.7	54	91	6.3	384	265	564	------	500
881201	1200	2	0.0092	------	------	------	------	------	------	------	------	------	------	------	500
881202	622	3	0.0079	------	------	------	------	------	------	------	------	------	------	------	500
881203	13	4	0.0079	------	------	------	------	------	------	------	------	------	------	------	500
881203	1740	5	0.0085	5\6	10	2.8	15.8	26	48	6.4	179	101	235	------	500
881204	1039	5	0.0079	------	------	------	------	------	------	------	------	------	------	------	500
881204	1651	7	0.362	7	272	45	11.2	20	269	5	595	370	1535	------	500
881204	1714	8	0.316	8	451	64	7.8	112	542	4.7	813	586	------	------	500
881204	1742	9	0.272	9	421	78	6.7	45	539	4.3	838	639	2730	------	500