FINAL REPORT TO THE
WATER RESEARCH COMMISSION

THE DEVELOPMENT OF AN URBAN COMPONENT OF THE ACRU MODEL

by

PMU SCHMITZ AND G DU T DE VILLIERS

Department of Geography and Environmental Studies
University of Durban-Westville, Durban, South Africa

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EXECUTIVE SUMMARY

1. Introduction

The *ACRU*- model was originally developed as an agrohydrological model by the Agricultural Catchments Research Unit of the Department of Agricultural Engineering at the University of Natal in Pietermaritzburg. The model is designed to model sediment yield, crop yield, irrigation water demands, supply, etc. The *ACRU*-model is a physical conceptual model which uses daily input values such as rainfall and temperature and revolves around daily multi-layered soil water budgeting. *ACRU* can either be used in a lumped or distributed form. When using the model in a distributed form the streamflow from cells above the cell of interest is taken into account for the streamflow from the cell of interest (Schulze, 1989a, Tarboton and Schulze, 1992, Schulze 1995).

The *ACRU*-model was developed to function on catchments with an urban land use comprising less than 20 percent. Working on the Mgeni catchment, Tarboton and Schulze (1992) modified the model to operate on catchments with more than 20 percent urban land use. The aim of this project is to develop or integrate existing urban models as sub-models for *ACRU*. It will enable *ACRU* to operate on a fully urbanized catchment in terms of runoff, hydrograph development and water quality simulations from non-point sources. The models that are to be integrated into *ACRU* are the *WASHMO*-

model for hydrograph simulation, and the washoff and accummulation equations used in the *SWMM, BMPSOFT* and *HSPF* water quality models.

2. Objectives.

The following objectives were set for this project:

2.1 The incorporation and/or refinement of existing models capable of simulating urban flow patterns.

2.2 The development and refinement of sub-models that can simulate water quality loads from different urban land uses.

3. Methodology.

The project can be divided into two main categories. The first category involves the incorporation and refinement of models into the existing *ACRU* modeling structure whilst the second category involves the collection of rainfall data and flow data measured at the weir in the Palmiet River.

Water samples were collected on a weekly basis at ten different points along the Palmiet River and its tributaries for a period of two years from 1 October 1992 to 30 September 1994. Rainfall data were collected for the same period at the University of Durban-Westville, using a syphon and standard rain gauge. At the weir situated in the Palmiet River at the University of Durban-Westville, which is one of the ten sample points, water samples on a weekly basis as well as on days of high flow events were collected. All the collected samples were sent to the Waste Water Treatment Works of the Municipality of Pinetown for water quality analysis.The water samples from high flow events were collected with the aid of an ISCO sampler, which took a 200ml sample with every 5cm rise or fall in the river flow level. Three high flow events were sent to Umgeni Water for analysis of water quality changes over a hydrograph. All recorded data were sent to the Department of Agricultural Engineering for digitizing purposes and the digitized data were downloaded onto the computer at the Computing Centre for Water Research (CCWR).

Data collected by Simpson, 1986 on the Pinetown catchment were used to test the model on a fully reticulated catchment. Verification runs were done to test and calibrate the model against the collected data in order to give realistic outputs from the different simulation runs.

4. Results of the project.

The following results were established:

i) It was established that by incorporating the*WASHMO*-model into the *ACRU*-model, it became possible to generate realistic hydrographs from urban catchments. The *WASHMO*-model was altered to accommodate runoff from pervious as well as connected (adjunct) and unconnected (disjunct) impervious areas. Adjunct and disjunct impervious areas in this report have the same terminological meaning as in Tarboton and Schulze (1992). The *ACRU*-model was also changed to be used in conjunction with the *WASHMO* section as a single event storm model. This enables *ACRU* to be used for design storm purposes similar to the *SCS*-models.

ii) It was established that the *ACRU*-model in its existing form (Tarboton and Schulze, 1992) can simulate runoff on a daily basis from fully urbanized catchments.

iii) After the inclusion of accumulation and washoff equations *ACRU* is capable of simulating non-point pollution from urban areas with a higher degree of accuracy from fully reticulated urban areas than from natural streams.This is due to the fluctuations in chemical loads in the baseflow component of the streamflow.

5. Recommendations and further research.

The following recommendations are made:

i) It is recommended that the models are to be tested on other catchments in order to exclude any bias towards a particular catchment. This will improve the model's capacity to do realistic simulations in terms of hydrograph development and water quality.

ii) It is recommended that further refinements should be made to represent natural streams more accurately in terms of water quality loads in the baseflow component as well as to accommodate chemical constituents attached to sediments. This will enable the model to give more accurate water quality simulations from urban catchments with natural streams.

iii) Further research is recommended to develop subroutines that will enable the *ACRU*-model to simulate changes over a hydrograph, so as to facilitate the first flush effect.

iv) Finally, the establishment of a data base for accumulation rates of different pollutants in different regions of southern Africa is recommended. This can then be used to assess the impact of urbanization on rural catchments.

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Mr H Maaren (Chairman)	Water Research Commission
Mr HC Chapman	Water Research Commission
Mr TJ Coleman	University of the Witwatersrand
Dr MC Dent	Computing Centre for Water Research
Mr GJ Grobler	Department of Water Affairs and Forestry
Prof BE Kelbe	University of Zululand
Ms M Pillay	Umgeni Water
Mr D Simpson	Umgeni Water
Mr D Huyser (Committee Secretary)	Water Research Commission

TABLE OF CONTENTS

1 INTRODUCTION

1.1 BACKGROUND

The *ACRU* (acronym for **A**gricultural **C**atchments **R**esearch **U**nit)-model was orginally developed in the 1980's as an agrohydrological model by the Agricultural Catchments Research Unit which is situated in the Department of Agricultural Engineering of the University of Natal, Pietermaritzburg. The need for an agrohydrological model for Southern African conditions came to the fore during research done by Schulze in 1983 on an agrohydrological and agro-climatological atlas for Natal (Schulze, Angus, Lynch and Smithers, 1995). The *ACRU*-model is a physical-conceptual, multipurpose model that embraces the physical processes in a catchment, outputting these processes into runoff elements, reservoir yields, irrigation water demands and supply, the effect of land use changes, etc. (Schulze,Angus, Lynch and Smithers, 1995).

The *ACRU*-model was essentially developed to operate on catchments with 20 percent or less urban areas within a catchment. Since then the model has been adapted to incorporate catchments with more than a 20 percent urban area. This was attempted in a Water Research Commission funded project on the Mgeni Catchment by Tarboton and Schulze in 1992 (Tarboton and Schulze, 1992). According to Schulze, Angus, Lynch and Smithers (1995) typical applications of the *ACRU*-model are design flood estimation, irrigation water demand and supply, crop yield and primary production modelling and ground water modelling. The *ACRU*-model has also been used for the following assessments: water resources assessments, the assessment of impacts of land use changes on water resources, assessments of hydrological impacts of wetlands as well as the assesment of potential impacts on crop production and hydrological responses due to global warming (Schulze, Angus, Lynch and Smithers ,1995).

The aim of the present project is to develop sub-models which could be used in *ACRU* to operate on fully urbanized catchments, as well as to develop hydrographs and to simulate water quality loads from nonpoint sources in a catchment. In this context, developing sub-models means the development of subroutines that will then form part of the existing *ACRU* model.

1.2 OBJECTIVES OF THIS PROJECT

The following objectives were set for this project:

1.2.1 The incorporation and/or refinement of existing sub-models capable of simulating urban flow patterns.

1.2.2 The development and refinement of sub-models that can simulate water quality loads from different urban land uses.

1.3 HYDROLOGICAL MODELLING IN GENERAL

Hydrological models can be broadly classified into three distinct categories, namely stochastic, empirical and deterministic models (Ward and Robinson, 1989 and Alexander, 1990). Stochastic models are also known as probabilistic models that take into consideration the chance of occurance or probability distribution of hydrological variables such as streamflow or rainfall (Shaw, 1988 and Ward and Robinson, 1989). According to Ward and Robinson (1989:288) stochastic models make little reference to their physical linkages with the hydrological 'reality' but focus strongly on the generation of synthetic runoff series to accommodate the variations in runoff over time.

According to Ward and Robinson (1989:288) most of the stochastic models attempt to accommodate three main assumptions when generating these synthetic runoff series, namely: **i)** that the recorded historical sequence of streamflows is extremely unlikely to recur, **ii)** that it is unlikely that the maximum possible flood for a given stream is included within the historical record, meaning that there is always a possibility that the highest recorded flood will be superceded by an extreme event in the future, and **iii)** that the stream flow exhibits persistence, meaning it will show a grouping of wet and dry years reflected in the levels of stream flow. An example of stochastic modelling is the autoregressive integrated moving average (*ARIMA*) models (Ward and Robinson, 1989). The *Thomas-Fiering* model (as discussed in Shaw ,1988) is another example of a stochastic model which is a group of regression models working on monthly flow data. Both these models combine any direct serial correlation properties of a data series with the smoothing effects of an updated running mean through the series (Shaw, 1988:371).

Empirical models described in Alexander (1990) are models that are based on maximum recorded floods on a world-wide basis. According to Ward and Robinson (1989) the distinction between empirical and deterministic models, which will be discussed in more detail later, depends on how much consider-ation is given to the physical processes that act on the input variables to produce runoff from a catchment as an output. Alexander (1990) outlines the distinction between the two on the basis of the return period of a flood, namely a return period of 200 years up to the probable maximum flood. The two empirical models most often used in South Africa are the Creager method and the regional maximum flood method. The Creager method is based on historical maximum floods experienced in catchments of similar size to that of the catchment under consideration (Alexander, 1990). The regional maximum flood method was developed by Kovacs in the 1980's and is based on the Francou and Rodier method developed in the 1960's (Alexander, 1990). The K-values used in the regional maximum flood method were revised after the 1984 Domoina floods by Kovacs in 1988 (Alexander ,1990).

The third category of hydrological models is the deterministic hydrological models. These models simulate the physical processes operating in the catchment to convert rainfall and other precipitation forms into runoff. Catchment characteristics such as slope, channel slope, soil types, infiltration, land cover and antecedant soil moisture all have an influence on the amount of runoff available as well as on the shape of the flood hydrograph (Ward and Robinson, 1989 and Alexander, 1990).

According to Alexander (1990) the rainfall-runoff models' structure consists mainly of modules that determine the catchment response time, the rainfall intensity over the catchment that corresponds with the catchment's response time, and the proportion of the rainfall (determined by catchment characteristics such as soil type and antecedant soil moisture conditions) that contributes directly to runoff from the catchment.

Deterministic models according to Alexander (1990) must meet the following requirements: they must provide accurate estimates in terms of runoff; the results must be consistent, meaning that when other users use the model on similar problems the results must be of a similar nature; they must be applicable to a wide variety of situations; and must not produce questionable results in extreme situations. Lastly they must be generally accepted in practice and widely used.

Examples of deterministic models are the Rational Method developed by Mulvany in 1850 (Shaw, 1988), the Unit Hydrograph Method introduced by Sherman in 1932, which he defined as the hydrograph of surface runoff resulting from effective rainfall in a unit of time produced uniformly in space and time over the whole catchment (Sherman, 1942 as given in Shaw, 1988), and the Lag-Routed Hydrograph Method. Alexander (1990) gives a summary of these three models. The S-Curve model discussed in Hughes and Beater (1987) is an improvement on the implicit source area model developed by Hughes in the early 1980's. The concept of the model is that the proportion of the amount of rainfall that contributes to runoff varies throughout the storm in relation to the soil moisture content of the catchment (Hughes and Beater, 1987).

The Simple Antecedent Moisture (SAM) model is an extended version of the Isolated Event Model (IEM4) and uses an exponential relationship in the form of an assymetrical S-curve function between the initial soil moisture loss at the start of a storm and the proportion of the total rainfall contributing to runoff. The difference between the IEM4-model and the SAM-model is that the runoff potential is constant throughout a storm event (Hughes and Beater, 1987). The Augmented Hydrograph model was presented by Mandeville in 1983 (Hughes and Beater, 1987). The model uses an intermediate hydrograph with the same volume as the gross rainfall hyetograph - the augmented hydrograph - and this is input together with the antecedent conditions. From this, the runoff ratio is established to form the flow hydrograph (Hughes and Beater, 1987).

The Runoff Routing model was developed in the 1970's at the department of Civil Engineering at Monash University in the USA. The model is a general rainfall-runoff and streamflow routing model. The model can take into account the effects of the storage capabilities of retarding basins, lakes, dams and flood plains on the flow hydrograph. The model operates on a sub-catchment basis and is an isolated event model that does not take evapotranspiration, existing soil moisture and groundwater redistribution into consideration. The model is thus essentially an overland flow model (Hughes and Beater, 1987). These models are discussed in more detail in Hughes and Beater (1987).

Another example of a deterministic model is the **S**tormwater **M**anagement **M**odel (*SWMM*) which was developed under contract for the Environmental Protection Agency of the United States between 1969 and 1971 with regular improvements. It was fully documented in 1982 by Huber and his fellow authors (Green and Stephenson, 1986). The model is constructed of blocks performing specific functions such as modelling runoff and receiving water. Green and Stevenson, 1986 give a summary of the different blocks as well as of the model as a whole.The *SWMM*-model is designed for urban catchments. Another urban runoff model discussed in Green and Stephenson (1986) is the **ILL**udas **U**rban **D**rainage **A**rea **S**imulator (*ILLUDAS*) model. The *ILLUDAS*-model computes hydrographs from paved and grassed areas separately and combines them to produce a combined hydrograph. If tributaries flow into the reach under observation their hydrographs are then combined with the hydrograph of the reach to produce the runoff from the catchment. Restriction in flow can be input by the user and the model will store the excess flow and release it over a longer period. If detention basins are needed the model calculates the storage requirements. The model can also do stormwater design by determining the required pipe sizes. If more than one node is used in the model, the model will route the hydrograph to the next design point and give the results from each reach until the outfall is arrived at. The model will then print the outfall hydrograph (Green and Stephenson, 1986).

Kinematic models are another type of deterministic model in use and are based on kinematic theory of flow, meaning that overland flow in its natural, unregulated state is hydraulically classified as unsteady, non-uniform flow where the velocity and flow depth vary in both time and space (Green and Stephenson, 1986:68). The two-dimensional kinematic model *KINE 2* was developed in 1982 by Constantinides and is discussed in Green and Stephenson, 1986. The *WITWAT*-model developed by Green and Stephenson (1986) and the *WITSKM*-model developed by Coleman and Stephenson (1990) are examples of models using kinemtic theory.

Other deterministic models in use are those models which are based on the United States Department of Agriculture's Soil Conservation Service (*SCS*) model. These *SCS*-models use the standard *SCS* procedures adapted for South African conditions (Schulze and Arnold, 1979; Schmidt and Schulze, 1987). Here the runoff from a catchment is a function of rainfall, initial abstraction (the part of the rainfall that is intercepted, filling depression storages plus the quantity of infiltration before the start of runoff) and the potential maximum retention of the soil which is a function of the runoff curve number (Schmidt and Schulze, 1987). The runoff curve number is determined by the soil type's storm flow potential and land use characteristics (Schmidt and Schulze, 1987). A PC-based version called *SCS-SA* was published by Schulze, Schmidt and Smithers in 1993 (Schulze, Angus, Lynch and Smithers, 1995)

The other model using the *SCS* procedures is the *ACRU*-model (Schulze, 1989 and 1995) which gives refinements to the amount of rainfall available. For example, it uses net rainfall as opposed to gross rainfall. Net rainfall is obtained by subtracting the amount of rainfall that is intercepted by land cover (vegetation and other surfaces) from the gross rainfall (Schulze, 1995:10-3). Another refinement is the coefficient of initial abstraction that changes on a monthly basis in *ACRU* due to changes in vegetation cover and land use management as well as the characteristics of the site under discussion. In addition, the potential maximum retention of the soil is seen in *ACRU* as a soil water deficit calculated from the multi-layer soil water budgeting techniques, as opposed to being a function of the curve number in the original *SCS*-model. Finally, the *ACRU*-model includes a variable, critical soil depth, in conjunction with the potential maximum retention of soil, which is not used in the *SCS*-model, and a stormflow response coefficient which provides for delayed stormflow caused by delayed interflow. This delayed stormflow is then carried over to the next day (Schulze, 1995:10-3,4).

The Watershed Storm Hydrograph (*WASH)* model (Ward, Haan and Tapp, 1979) and the Watershed Storm Hydrograph - Multiple Options (*WASHMO*) model (Ward, Wilson, Bridges and Barfiled 1980) are models that are also based on the *SCS* procedures. The *WASH*-model uses the *SCS* triangular hydrograph procedure for estimating the time to peak and peak flow rate for a unit hydrograph and the shape of the hydrograph is determined from Haan's dimensionless unit hydrograph equation (Ward, Haan and Tapp, 1979). The *WASHMO*-model is an improvement on the *WASH*-model where the user has the option of three different hydrographs, namely **i)** Haan's dimensionless unit hydrograph, **ii)** TVA double triangle unit hydrograph and **iii)** user defined inputs (Ward,*et al*, 1980).

From the above discussion on different hydrological models it was decided to use the *WASHMO*-model for inclusion into the *ACRU*-model since both models are based on the modelling procedures used by the original *SCS*-model. Haan's dimensionless unit hydrograph is used in *WASHMO* and was developed for urban catchments (Campbell, Ward and Middelton, 1987).

1.4 WATER QUALITY MODELS

Since the start of the industrial revolution, water has been used by industrializing societies for an increasing range of purposes. Water has been used for industrial purposes, transport, streams for waste water returns, etc. This abuse of water has led to increased concern for the quality of water (Shaw, 1988). This problem is already being addressed very seriously in developed countries, using modern technology and strict laws to keep the water bodies in a healthy state. In developing countries the collection and treatment of water is not advanced and in some small settlements the collection point for water and the discharge point for effluent are in close proximity. In larger cities in the Third World with inadequate sanitation facilities, dangers from waterborne diseases are serious (Shaw, 1988). Increasing industrialization in general has also led to more pollution of water resources. Research is more and more focussed on the impact of waste water that contains toxic materials from industry on the receiving water bodies.

Of particular concern are those chemicals that cannot be abstracted by normal treatment processes at waste water treatment plants (Shaw, 1988). The problem is wider than simply treating waste from point sources, such as a pipe or channel discharging the effluent from industries or sewerage outfalls directly into the stream. With industrialization the atmospheric pollution levels increase and the pollution returns to the earth's surface via dry or wet fallout. This source of pollution is known as non-point source pollution since these pollutants are washed off from the catchments into the receiving water bodies, either directly as overland flow or via a stormwater drainage system.

According to Shaw (1988) there are three main water quality features in streams, rivers and lakes, namely physical, chemical and biological. Solids or physical features range from minute particles to tree trunks and boulders, depending on the discharge and flow velocity. The colour, taste and odour of the water as well as turbidity and temperature form part of the physical features of water quality. Examples of chemical water quality features are dissolved oxygen, biochemical oxygen demand, nitrogen, phosphurus, heavy metals and chlorides. Parasites such as Schistosoma and bacteria such as Echerichia coli are examples of biological water quality features.

Due to the shortage of water quality data, the hydrologist makes use of mathematical modelling techniques to generate data. These models are based on well researched catchments and then transfered to catchments where there is little or no data available. Some models model the complex physical, chemical and biological processes in rivers (Shaw, 1988), whilst others are used to assess the impact of different actions and decisions in river basin management (Ward and Robinson, 1989).

According to Coleman (1992) water quality modelling ranges between statistical methods and deterministic models. Statistical methods used are mostly regression analyses that examine the relationships between the catchment, runoff from the catchment and pollutant characteristics (Coleman, 1992). According to Coleman (1992), when using statistical methods, the modeller has to rely on local data, but it gives a useful first estimate of pollution loads from an urban catchment.

Deterministic water quality modelling attempts to model the processes taking place in a catchment. These processes can be divided into three groups, namely the buildup, meaning the accumulation of dust and dirt on the catchment; the washoff; and the transport of the pollutants through a drainage system (Coleman,1992). Simpson (1986) made use of the statistical approach to simulate pollutants from the Pinetown catchment. The data from this catchment are also used in the present study but this time using the deterministic modelling approach.

1.5 STUDY AREAS.

Two catchments were selected for this project namely the Pinetown Catchment and the Palmiet River Catchment. Although the Pinetown Catchment is a sub-catchment of the Palmiet River Catchment the two catchments will be treated as two seperate catchments. This is due to time frames of the collected data from the catchments. The Pinetown Catchment's data was collected by Simpson between 1982 and 1985 (Simpson, 1986), and the data collected for the Palmiet Catchment between 1992 and 1994. Another reason for the seperation is that the Pinetown Catchment is used as the basis for model linkage and improvements. Once the models performed adequately on the Pinetown Catchment they were used on the Palmiet Catchment where further refinements were made where necessary. The models used for the project and improvements will be discussed in the next chapter.

2. MODEL DEVELOPMENT AND LINKAGE

2.1 INTRODUCTION TO THE *ACRU*-MODEL.

The *ACRU*-model was developed from research which aimed at determining the evapotranspiration over a distributed catchment in the Natal Drakensberg in the early 1970's. This was followed by research on an agrohydrological and agroclimatological atlas for Natal which further contributed to the model's development. The *ACRU*-model was then improved by individuals and groups of individuals to its present state (Smithers and Schulze, 1995).

The *ACRU*-model is based on the following concepts (Schulze, 1989:AT2-1,2 and Smithers and Schulze, 1995:AM1-2,6): it is a physical conceptual model by which the physical processes are idealised and represented explicitly, and the variables used in the model are mostly estimated from physical characteristics of the catchment. The *ACRU*-model is a multi-purpose model, as it integrates various water budgeting and runoff-producing components of the terrestrial part of the hydrological cycle in design hydrology, crop yield modelling and reservoir yield simulation, etc.

The *ACRU*-model functions on daily time steps using daily climatic data such as rainfall. The more cyclic, conservative and less sensitive variables such as temperature, are inputted as monthly values and then converted internally by

ACRU into daily values. By doing this the model makes maximum use of available data. Intra-daily information such as rainfall distribution is obtained by synthetic desegregation of data within the model. *ACRU* is a multi-layer soil water budgeting model (see figure 2.1) designed to be sensitive to land use changes as well as to other changes such as temperature, rainfall, etc.

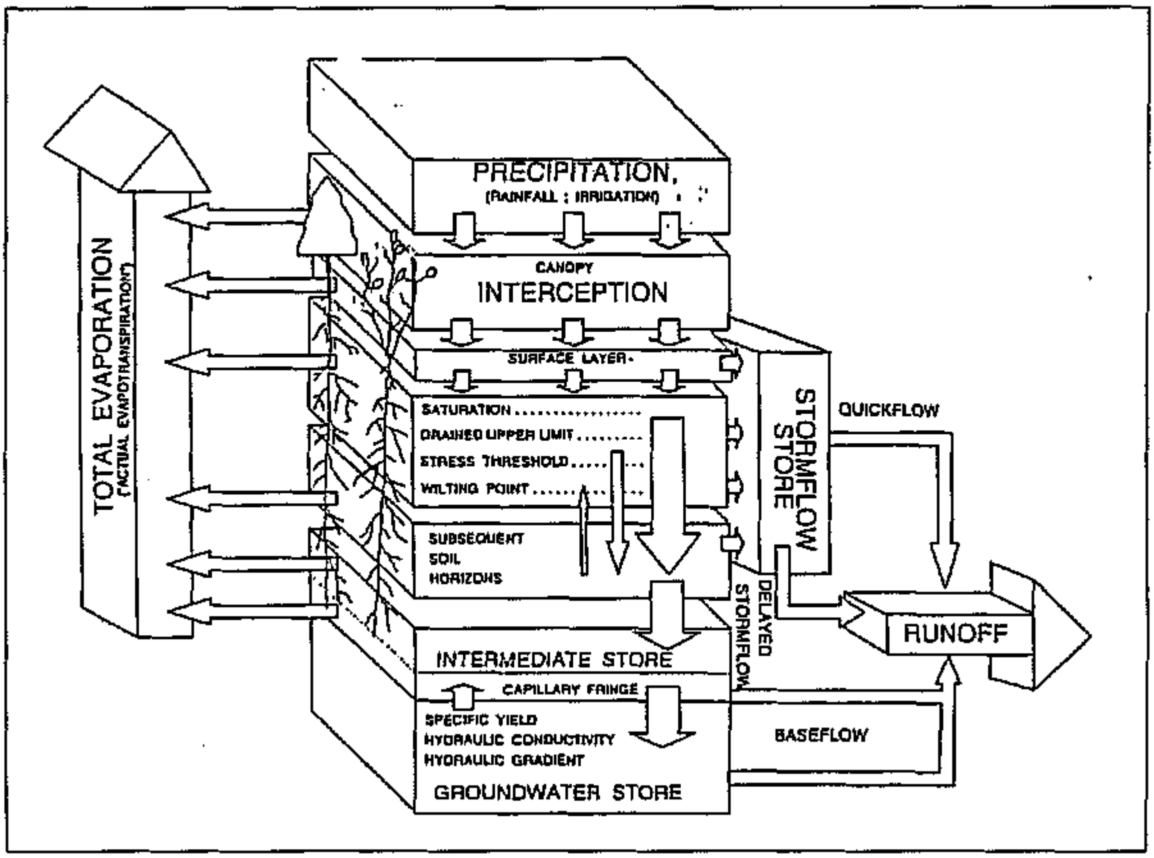


Figure 2.1. The general structure of the *ACRU* agrohydrological model (From Smithers and Schulze, 1995, pAM1-4).

The model is further a multi-level model which enables it to incorporate different pathways, depending on the availability of data and/or the specific components the user wants to simulate eg. runoff or crop yield modelling (Schulze, Angus, Lynch and Smithers, 1995).

ACRU is designed to operate as a point or lumped catchment model with catchment sizes in the lumped mode ideally not exceeding 30 square kilometers. In the lumped version *ACRU* cascades from one catchment to the next. Output from each sub-catchment can be obtained if the user so wishes. Inputs to each of the sub-catchment can vary to suit different simulations and outputs. To simulate changes over time the *ACRU*-model makes provision for the usage of dynamic input options to cater for the chosen changes, whether land use, land cover, etc., over time. Both abrupt and gradual changes can be modelled (Schulze, Angus, Lynch and Smithers, 1995).

Data is keyed into *ACRU* via the *ACRU Menubuilder*, which incorporates a Decision Support System to aid the user with inputting data. To aid the user further with the data input the ACRU Input Utilities were developed to help the user to prepare the data and information needed to do a simulation run. The *ACRU 3.00 Version* also makes use of an Outputbuilder for selection of variables that the user wants in the output and further analysis. This is done in conjunction with the *ACRU Output Utilities* (Schulze, Angus, Lynch and Smithers, 1995). Figure 2.2 gives a summary of the concepts of the *ACRU* model.

2.2 THE *WASHMO*-MODEL

2.2.1 Introduction to the *WASHMO*-Model.

According to Middleton, Ward and van Schalkwyk (1984) the *WASHMO*

(*WA*tershed Storm *H*ydrograph *M*ultiple Options) model was developed at the Agricultural Engineering Department at the University of Kentucky.

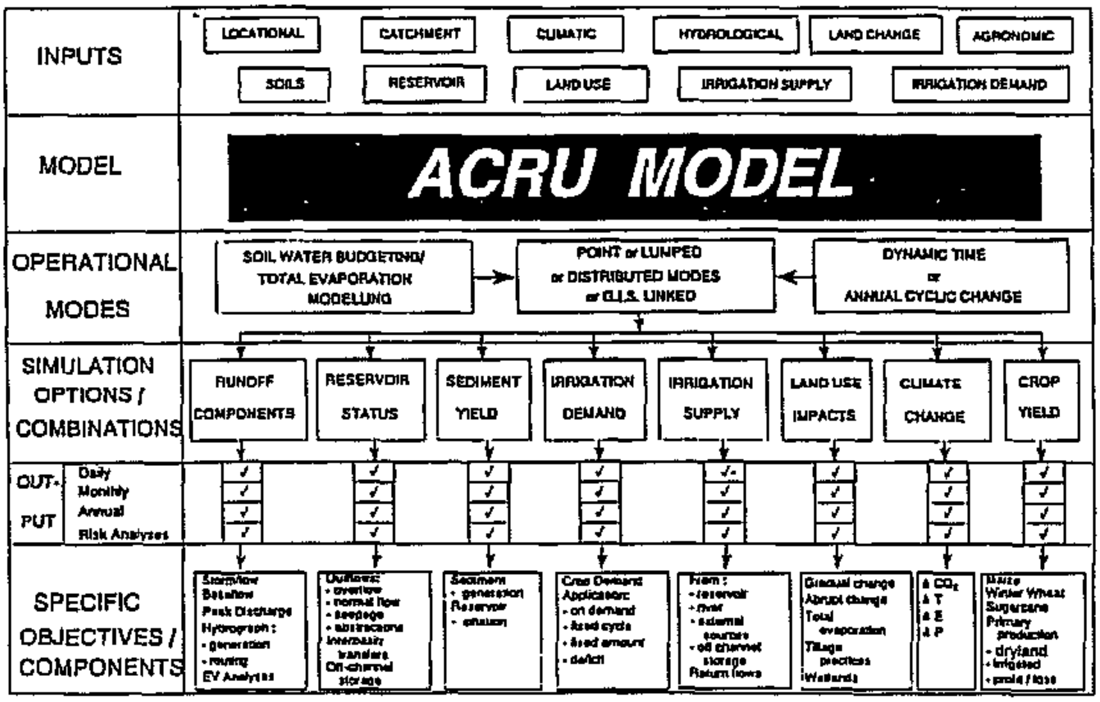


Figure 2.2. The concepts of the *ACRU* -model (From Smithers and Schulze, 1995, AM1-3).

The model is a modified version of the original *WASH*-model which then only consisted of Haan's unit hydrograph (Ward, Haan and Tapp, 1979). The *WASHMO* model is based on the United States Department of Agriculture's Soil Conservation Service (*SCS*) procedures for small watersheds. The surface runoff is determined by the *SCS Curve Number* method (Middleton, Ward and van Schalkwyk, 1984). It is suitable to be linked up with *ACRU* since its peakflow simulation is also based on the *SCS* procedures (Schulze, 1989; Smithers and Schulze, 1995).

The *Curve Number* in the *SCS*, *WASHMO* and *ACRU* models is an indicator of the runoff potential of an area and varies with soil type, landuse and soil moisture conditions. For the theory and development of the curve numbers and their applications under South African conditions the reader is refered to the work of Schmidt and Schulze (1987).

In *WASHMO* the rainfall data can be distributed through the selection of various synthetic rainfall distributions, namely *SCS Type I, SCS Type II* and the input of the user's own actual rainfall distribution (Middleton, Ward and van Schalkwyk, 1984). For this project, a further four synthetic rainfall distributions were added to take into account South African conditions. These four distributions and the own actual rainfall distribution will be discussed in more detail in section 2.2.3.2.

WASHMO has been developed to use unit hydrograph procedures and the user has a choice of three approaches. These approaches are: Haan's unit hydrograph, Double Triangle hydrograph and user defined inputs. These different options will be discussed in more detail in the next three sections.

2.2.2 Hydrograph development in *WASHMO*.

In this section the two different hydrograph developments in *WASHMO* are discussed. The two hydrographs are Haan's Unit Hydrograph which is used for urban areas and the TVA double triangle hydrograph for rural areas.

2.2.2.1 Hydrograph development: Haan's Unit Hydrograph.

This unit hydrograph is recommended for use in urban areas (Tapp,1981). The shape of Haan's unit hydrograph is determined from Haan's dimensionless unit hydrograph equation, developed in 1970 (Ward, Haan and Tapp, 1979). The equation as used in *WASHMO* is:

$$Q_t(t) = Q_p * 35.31* ((t/T_p) * \exp(1.0 - t/T_p))^{C3}$$

where:

$Q_t(t)$ = the hydrograph ordinate at time t

Q_p = peak flow in cubic meters per second

t = time in hours

T_p = time to peak in hours

C3 is found from the following relationship:

$$C3 = 6.2747 * ((Q_{mm}/25.4) * T_p)^2 + 0.3232 * (Q_{mm}/25.4 * T_p)$$

where:

Q_{mm} = peak flow rate in millimeters per hour

Q_p is determined from the following equation:

$Q_p = (5.318 * A)/T_p$

where:

A = area in square kilometers

Q_{mm} is determined from Q_p by the following equation:

$Q_{mm} = (Q_p * 3.58)/A$

T_p is determined as:

$T_p = T_L + D/2.0$

where:

T_L = time lag of catchment in hours

D = time increment of rainfall event in hours

T_L is determined as follows,

$T_L = 0.0084 * (L/0.3048)/((Y^{0.5}) * (100.0 - 0.67AG - 0.9F - 0.8V)$

where:

L = hydraulic length in meters

Y = average overland flow as a percentage

AG = % agriculture

F = % forest

V = % veld

D is determined as:

$$D = (2 * T_L)/7.0$$

2.2.2.2 Hydrograph development: TVA double triangle unit hydrograph.

The TVA double triangle unit hydrograph in the *WASHMO*-model is based on the work of Overton and Troxler in 1978 and Overton and Crosby in 1979 (Ward, Wilson, Bridges and Barfield, 1980). The response time of the double unit hydrograph (TLX) in hours is determined as:

$$TLX = 1.25 * T_L + 1.25 * T_L * (0.01 * F + 0.003 * AG + 0.005 * V)$$

The above equation is based on double triangle unit hydrograph shapes as determined by Overton and Troxler in 1978 (Ward, *et al*, 1980). According to Ward, *et al* (1980) in Tapp (1981:113) Overton and Troxler treated lag time as the time between 50 percent of the runoff and 50 percent of the rainfall. In *WASHMO* TLX it is treated as being synonymous with the lag times of Overton and Troxler (Ward, *et al* 1980).

The time to the first peak (T_1) of the double triangle is calculated as follows:

$$T_1 = MT_1 * 0.05$$

MT_1 is calculated from:

$$MT_1 = (T_L+0.05) * 20.0$$

The time to the second peak (T_2) of the double triangle is determined from:

$$T_2 = MT_2 * 0.05$$

MT_2 is calculated from:

$$MT_2 = 32.0 * TLX$$

All these values are in hours.

The peak of the TVA double triangle hydrograph (UP) in millimeters per hour and the peak of the second triangle (UR) in millimeters per hour are determined from the following equations:

$$UP = 18.288/TLX$$

$$UR = 0.2 * UP$$

The ordinates of the hydrograph over time t for the TVA double triangle unit hydrograph are calculated by the following equations:

$$Tx = Tx + D$$

where Tx time increment in hours of the unit hydrograph is determined by the rainfall increment D.

If Tx is less than T_1 then the ordinate is calculated by:

$$Q_t(t) = UP * Tx * A/(T_1 * 25.19)$$

If Tx is greater than T_1 the ordinate is determined by:

$$Q_t(t) = ((T_{23} * 1.164) - Tx) * 9.728 * UP * A/(0.9917 * ((T_{23} * 1.164) - T_1)$$

T_{23} is determined from:

$$T_{23} = (UP * T_2 - UR * T_1)/(UP - UR)$$

If Tx is greater than T_2 the ordinate is determined as follows:

$$Q_t(t) = (0.0526 * UR * T_3 - (UR/25.4) * Tx) * 247.1 * A/(0.9917 * ((T_3 * 1.325) - T_2)$$

T_3 is determined from:

$$T_3 = (2.0 + T_{23} * (UR - UP))/UR$$

The TVA double triangle unit hydrograph is recommended for agricultural and forested catchments (Ward, *et al*, 1980).

2.2.3 Improvements and changes made in the *WASHMO*-model.

For the *WASHMO*-model to be incorporated into the *ACRU*-model some changes had to be made for the model to fit within the *ACRU* structure and to improve the model's performance. The improvements and changes made in the model will be discussed in this section.

2.2.3.1 Pervious and impervious areas.

Urban areas consist of paved and unpaved areas that contribute to runoff from an urban area. Provision was made for impervious areas in the original *SCS*-model through the use of Curve Numbers (Schulze and Arnold, 1979) but the *SCS* model does not make provision for connected and unconnected impervious surfaces. This was addressed by the Soil Conservation Service in the release of Technical Report No.55 in 1986 (United States Department of Agriculture, 1986). This concept is used by Tarboton and Schulze (1992) for Mgeni Catchment project.

Since the *WASHMO*-model is based on the *SCS* procedures this concept has been incorporated into *WASHMO*.

The terms "connected" and "unconnected" are synonymous with **ADJIMP** and **DISIMP** *in ACRU* as discussed in Tarboton and Schulze (1992). Runoff from connected impervious surfaces enters the stream via storm drainage systems, and runoff from unconnected impervious areas flows unto pervious surfaces where it infiltrates and/or contributes to the runoff from pervious areas (see figure 2.3).

WASHMO makes use of synthetic or recorded rainfall distributions to generate excess rainfall for runoff during a storm event. These distributions are discussed in section 2.2.3.2. To determine excess runoff from a catchment *WASHMO* calculates a rainfall excess table using the initial abstraction (I_a) of the soil in millimeters as calculated by the *SCS* procedures. In this version the initial abstraction is calculated for the pervious section with the standard *SCS* procedures using the curve number (CN) or from the soil moisture deficit as calculated in *ACRU*. The concept and calculation of soil moisture deficit in *ACRU* is decribed in Schulze (1989 and 1995). For the impervious surfaces an initial abstraction of 1 millimeter is assumed before any runoff can occur. This is the value used by Tarboton and Schulze (1992) as a default value for depression storage of the impervious areas.

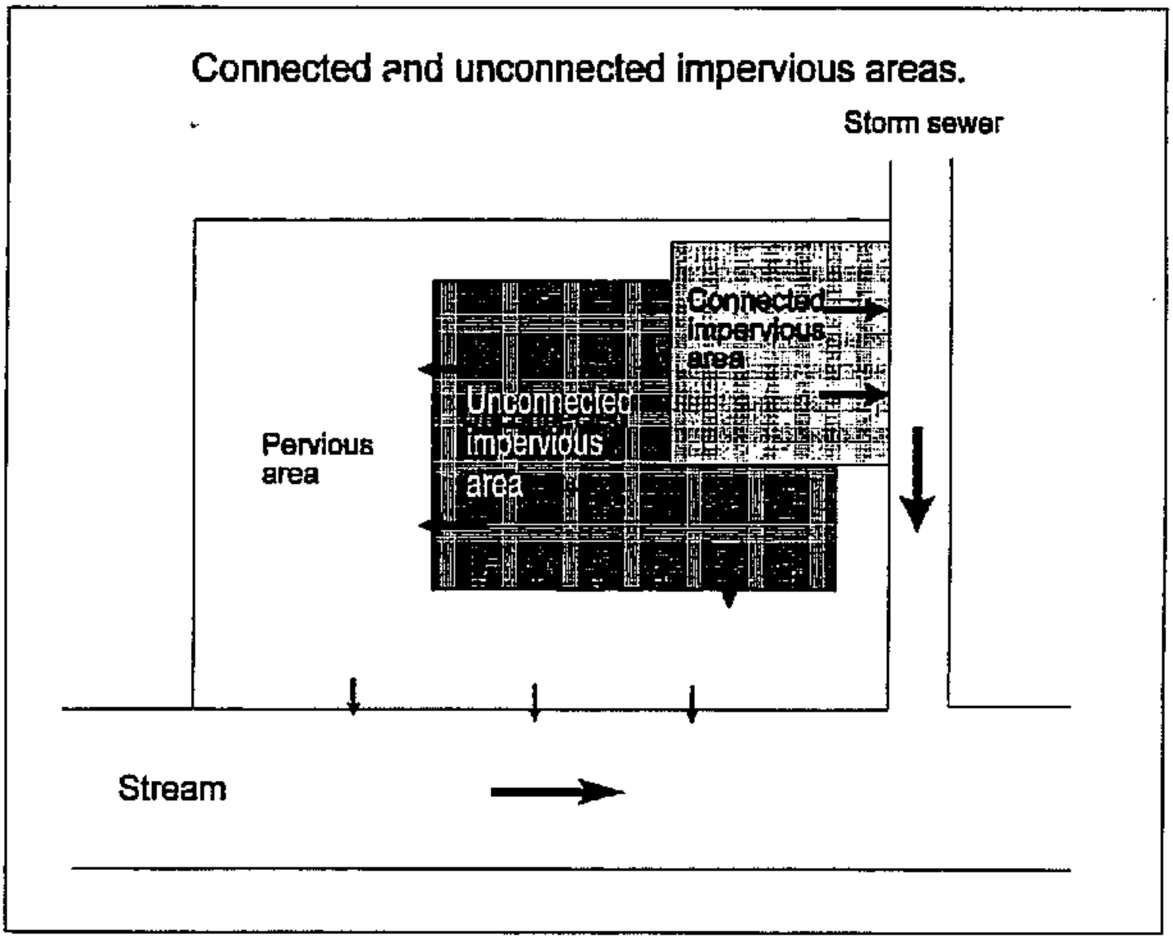


Figure 2.3 The concept of connected and unconnected impervious surfaces (Adapted from Tarboton and Schulze, 1992, figure 5.2 p42)

The catchment is divided into pervious and impervious surfaces and the impervious surfaces are then further sub-divided into connected (adjimp) and unconnected (disimp) impervious surfaces. The catchment or sub-catchment equals 100% which is then divided into percentage pervious, connected and unconnected impervious surfaces. The division of the impervious areas into connected and unconnected surfaces is based on the same principle as discussed in Tarboton and Schulze (1992).

Runoff (excess rainfall) is calculated as follows:

$$Q_{imp} = P - 1$$

$$P_{per} = P + (Q_{imp} * DISIMP)$$

$$Q_{per} = ((P_{per} - I_a)^2)/((P - I_a) + S)$$

$$Q = ((Q_{per} * PERSUR) + (Q_{imp} * ADJIMP)) / 100$$

where

Q_{imp} = runoff from impervious section of the catchment.

P_{per} = precipitation for pervious section of the catchment including the runoff fraction from unconnected (DISIMP) areas.

Q_{per} = runoff from pervious section of the catchment.

Q = runoff from the catchment including the runoff connected (ADJIMP) areas.

PERSUR = percentage pervious surfaces in the catchment.

If the rainfall is less than the initial abstraction for the pervious areas only the impervious areas contribute to the runoff from the catchment.

2.2.3.2 The development of synthetic rainfall distributions for South African rainfall events for use in the *WASHMO*- model.

As mentioned in section 2.2.3.1 *WASHMO* uses synthetic rainfall distributions to determine the rainfall pattern for the generation of stormflow.The rainfall distribution is determined as the ratio of accumulated rainfall to the total rainfall (Schulze and Arnold, 1979) over time. In the *SCS* and *WASHMO* models the storm duration is taken as 24 hours. In *WASHMO* the 24-hour storm is fractionised into 12 minute intervals, each interval showing the ratio of accumulated rainfall to the total rainfall.

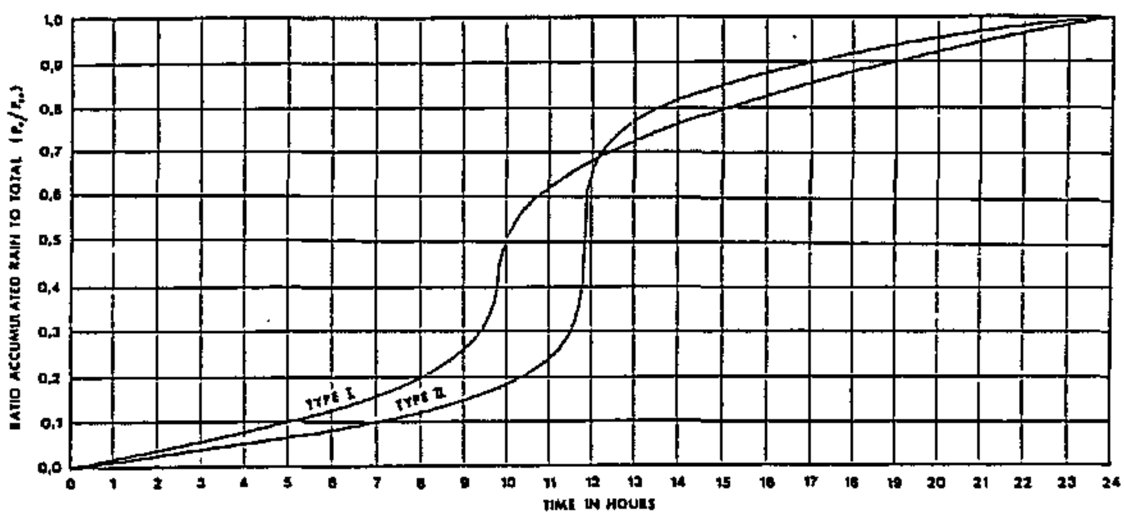


Figure 2.4 The two synthetic rainfall distributions as used in the *SCS* model (From Schulze and Arnold,1979:32, Fig 1.8.1).

Figure 2.4 shows the rainfall distribution for the original *SCS*-model. Appendix A gives the ratios for each storm rainfall distribution over 24 hours as used in *WASHMO*. If the storm duration is less than 24 hours, *WASHMO* determines mathematically the synthetic rainfall distribution by selecting the different ratios needed for the shorter storm. Schulze and Arnold (1979) immediately recognised the need to develop synthetic rainfall distributions for Southern Africa and this was done by Wedepohl (1988) as cited in Schmidt and Schulze (1987). To improve the modeling capability of the *WASHMO*-model that is linked into *ACRU*, the four southern African synthetic rainfall distributions are added. The ratios for the 12 minute intervals are calculated from the equation given in (Schmidt and Schulze, 1987:66):

$$R = (a * D)/(b + D)^c$$

where:

R = ratio of D-hour to one day storm depth

D = duration for which ratio is to be calculated

a,b and c are regression constants.

These regression constants are given in Table 2.1.

Table 2.1 The regression constants for the four Southern African synthetic rainfall distributions from Table 1.11.2 in Schmidt and Schulze (1989:67)

Distribution type	a	b	c
1	0.29935	0.059	0.62
2	0.45321	0.100	0.75
3	0.73402	0.230	0.90
4	1.01330	0.320	1.00

The ratios used for the *WASHMO*-model are calculated from the middle of the day to correspond with the exponential increase of intensity peaking at mid-time of the one day storm, as well as with the exponential decline in intensity of the storm until the end of the storm (Schmidt and Schulze, 1989:68). R was calculated at a 0.4h interval divided by 2 to determine the ratios at 0.2h intervals before and after the peak intensity. In *WASHMO,* the time of peak intensity was taken as 12h with 0h and 24h the starting time and end time respectively of the storm. Figure 2.5 shows the four different distributions at 0.2h intervals.

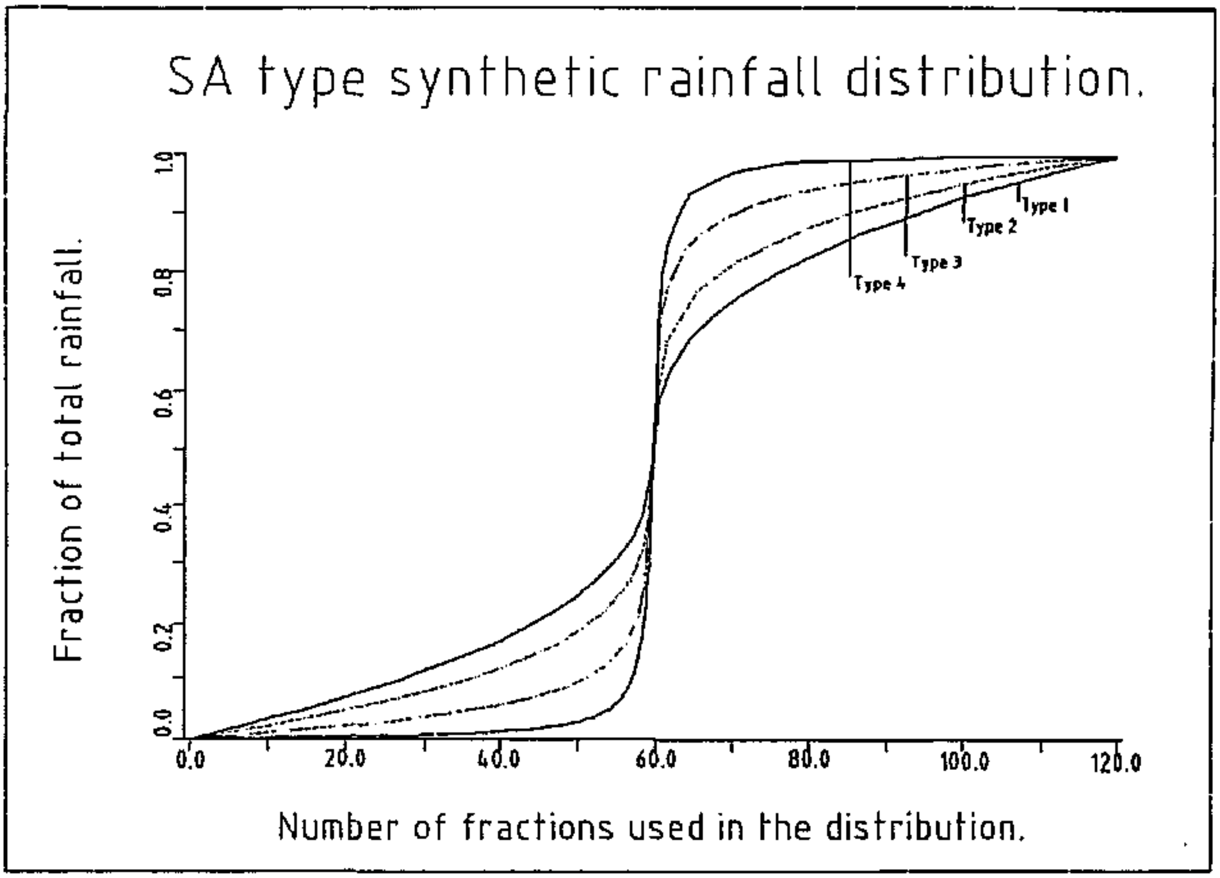


Figure 2.5 The four different synthetic rainfall distributions as used in the *WASHMO*-model adapted from Wedepohl (1988).

2.2.3.3 Own rainfall distribution.

WASHMO was designed with the option of an own rainfall distribution input, however the *WASHMO* model could only accept a 3 min rainfall interval for its own rainfall distribution (Tapp, 1981). In *ACRU, WASHMO* was developed to accept any rainfall time interval.

2.3.4 *ACRU* as a single event storm for design purposes

The *WASHMO*-model was developed as a single event storm hydrograph model. Design storms of a certain return period are used in areas where no runoff records are available to aid in the construction of structures or in the delimitation of floodlines. For design purposes, rainfall with certain return periods is used to produce a flood event of the same return period. With the linkage of the *WASHMO*-model into *ACRU* the *ACRU*-model was changed to act as a single event storm hydrograph model if required. This could only be done by using the *WASHMO* option in *ACRU*.

2.3 THE WATER QUALITY MODEL (ACRU-NPS)

2.3.1 Introduction.

As discussed in section 1.4 there are two approaches to water quality modelling namely, the statistical and the deterministic approach. The non-point source model linked into *ACRU* is a deterministic water quality model. The aim of the development of a NPS model is to provide a model that is easy to use to simulate urban impact on water quality (Schmitz, De Villiers and Schulze, 1993). Nonpoint pollution has its sources in atmospheric deposition, agricultural activities, runoff from developing and fully urban areas (Todd, Bedient, Haasbeek and Noell, 1989). According to Baan and Berbee (1989) a study was undertaken in the Netherlands which showed that in spite of strict legislation concerning point pollution, water quality did not improve to expected levels. It was discovered that nonpoint sources do have a significant impact on the water quality. Due to the above reason it was decided to use a non-point source model (*ACRU-NPS*) as a water quality model in *ACRU.*

The daily runoff generated by *ACRU* is used to wash the material from the catchment during days of rainfall. Only the quick flow component is used for the washoff process. The model also makes provision for water quality simulations involving base flow. If base flow is included in the water quality simulation the concentrations, either a single value or a monthly value to accommodate seasonal changes, are inputted for each pollutant. In the next section the accumulation and washoff pollutants as used in *ACRU* are discussed.

2.3.2 Accumulation and washoff of pollutants

Several models such as the *NPS* model (Donigian and Crawford, 1976), the *HSPF*-model (Johanson, Imhoff, Kittle and Donigian, 1984), the *BMPSOFT* -

model (Kuo, Cave and Loganathan, 1988) and the *SWMM*-model (Wanielista, 1979 as referenced in Kuo, Cave and Loganathan, 1988) use the principle of mass accumulation on the catchment surface during dry and also on wet days and the fraction of the mass washed off from the surface by runoff. The fraction of the mass washed off is directly proportional to the amount of runoff. In *ACRU-NPS*, as in the *HSPF*-model, the washoff is determined from pervious and impervious areas and the total load is achieved by correcting each value by the percentage of pervious and impervious areas in the catchment (Schmitz, de Villiers and Schulze, 1993). Washoff from these surfaces is treated as a seperate entity and then mixed to give a single output value as a concentration in mg/l or as an export value in kg/interval. A mass balance equation is used to do the mixing of the pollutants:

$$C_3Q_3 = C_1Q_1 + C_2Q_2$$

where

C_1, C_2 and C_3 = the concentration of the pollutants in mg/l or the export value in kg.

Q_1, Q_2 and Q_3 = discharge in cubic meters or runoff in mm.

It is assumed that on the day when rainfall occurs, washoff occurs at the end of the day, thus providing for accumulation of pollutants on rainy days as well. The accumulation of pollutants, both on dry and wet days, is determined as follows, using the relationships developed for the *HSPF*-model (Johanson, *et al*, 1984).

For pervious areas:

$$A_{per} = A_{cc} + AS_{per} * (1,0 - R_{per})$$

where:

A_{per} = accumulated mass at the end of the day (kg/ha) on the pervious surface.

A_{cc} = accumulation rate of pollutant (kg/ha per day)

AS_{per} = A_{per} at the start of the interval

R_{per} = unit removal rate of the stored constituent per day from pervious areas.

for impervious areas:

$$A_{imp} = A_{cc} + L_{dep} + AS_{imp} * (1,0 - R_{imp})$$

where

A_{imp} = accumulated mass at the end of the day (kg/ha) on the impervious surface.

A_{cc} = accumulation rate of pollutant (kg/ha per day)

AS_{imp} = A_{imp} at the start of the interval

R_{imp} = unit removal rate of the stored constituent per day from impervious areas.

L_{dep} = deposition of pollutants from vehicles in kg/ha per day

The unit removal rate applies to the removal of pollutants during dry days by wind, street sweeping, etc.

The unit removal rate is computed as follows:

$R_{per} = A_{cc}/A_{lim}$

where

A_{lim} = the asymptotic limit for A_{per} as time approaches infinity (kg/ha), if no washoff occurs (Johanson, *et al*, 1984)

The same equation is used for impervious surfaces.There are different ways to describe the build-up of pollutants between storm events. These build-up relationships can either be linear, power functions, exponential or Michaelis-Menton (Coleman,1992). Since the atmospheric fallout is captured in containers allowing virtually no removal of accumulated material, the build-up of material can be seen as linear (Johanson, 1993). An asymptotic limit can be imposed on a linear build-up rate (Huber, Heany, Nisi, Dickenson and Polman, 1982) so as to facilitate removal of build-up material using the removal equation of the *HSPF*-model by Johanson, *et al* (1984). The asymptotic limit was set for fourteen days after the last storm event which is close to the number of days established by Sartor and Boyd (1972, as cited in Huber, *et al*, 1982) for non-linear build-up of material reaching an asymptotic limit.

Due to the high number of motor vehicles present in urban areas, especially in the commercial and industrial areas, it was decided to include deposition from motor vehicles into the daily accumulation of pollutants on impervious surfaces. The deposition from motor vehicles, adapted from Ahmed and Schiller (1980), is calculated as follows:

$$L_{dep} = D_{rate} * T_{dens} * A_{xles}$$

where

D_{rate} = deposition rate in kg/ha per axle.

T_{dens} = traffic density per day

A_{xles} = average number of vehicle axles.

The washoff of pollutants from the catchment surfaces is determined by the following two equations as used by Kuo, Cave and Loganathan (1988:128). These equations were based on the equations used in the *SWMM*-model (Kuo, Cave and Loganathan, 1988) and similar equations for the washoff of pollutants are used in the *HSPF*-model by Johanson, *et al* (1984). Kuo, Cave and Loganathan (1988) based these equations on the following assumptions:

a. That a uniform runoff of 12.7mm/h (0.5 inch/h) will washoff approximately 90 percent of the initial pollutant load in one hour from impervious surfaces

b. That a uniform runoff of 12.7mm/h will washoff approximately 50 percent of the initial load from pervious surfaces.

These equations are:

$$W_{imp} = A_{imp} * (1.0 - EXP(-4.6 * R * t))$$

$$W_{per} = A_{per} * (1.0 - EXP(-1.4 * R * t))$$

where:

W_{per}/W_{imp} = mass washed off from surface after time t in kg/ha

A_{per}/A_{imp} = initial loading in kg/ha

R = runoff rate in mm/h

if R is not known it can be determined as follows:

R = (runoff depth over time t(mm))/t.(h)

The first equation is developed for impervious areas and the latter equation for pervious areas.

For the daily time step section of the *ACRU-NPS*-model the equation has been changed such that the time increment is omitted to facilitate full washoff if the rainfall is high enough. The two equations are rewritten as follows:

$$W_{imp} = A_{imp} * (1.0\text{-}EXP(-4.6 * Q_{imp})$$

$$W_{per} = A_{per} * (1.0\text{-}EXP(-1.4 * Q_{per})$$

Q_{imp} and Q_{per} are determined by *ACRU*'s existing structures.

2.3.3 Percentage contribution of atmospheric fallout to the pollutant loads from a catchment.

Simpson in his research on Pinetown from 1982 to 1985 estimated the contribution of atmospheric fallout to runoff loads by comparing the mean concentrations for bulk fallout and runoff loads. These estimates are given as percent atmospheric fallout contribution to the runoff loads (Simpson, 1986:90).

The percentage contribution from atmosperic fallout to runoff loads is included as an input variable in the non-point source model in *ACRU* to facilitate the catchment's own input to the pollution loads. After the washoff from both surfaces has been mass balanced, the pollution load from atmospheric fallout is corrected by the percentage contribution to the runoff load using the following equation:

$$P_{load} = W_{tot}/(C_{\%}/100.0)$$

where

P_{load} = the runoff load from the catchment including atmospheric fallout contributions kg/ha per day

W_{tot} = total washoff from both surfaces kg/ha per day

$C_{\%}$ = percentage contribution of atmospheric fallout to runoff loads.

2.4 LINKAGE INTO THE *ACRU*-MODEL

For both the *WASHMO* and the non-point source model, subroutines were written and linked into *ACRU*. The input values needed to run these subroutines were added to the *MENU* that *ACRU* uses to read in input values. Further subroutines were written to facilitate output from these subroutines. The subroutines are called from the *ACRU* main program. In the next chapter the respective study areas which were used in this project are discussed.

3 STUDY AREAS.

3.1 INTRODUCTION

Two study areas were selected for this project namely, the Palmiet River Catchment and the Pinetown Catchment. As discussed in section 1.5 these two catchments are treated as seperate entities. In this chapter, each of these catchments will be discussed in terms of the physical landscape and land use.

3.2 THE PALMIET RIVER CATCHMENT

3.2.1 Location

The Palmiet River Catchment is situated approximately 13km to the west of Durban, between 29° 46.7' and 29° 50.2' South and 30° 50.2' and 30° 57.1' East. The river begins at Fields Hill just to the northwest of Pinetown CBD, then winds its way through Pinetown, including the CBD, through Westville, past the University of Durban-Westville to where it enters the Mgeni River close to the N2 viaduct near Springfield Flats. The area of interest is the Palmiet River from Fields Hill down to the weir at the University of Durban-Westville. The size of the catchment is 20.3 square kilometers. Figure 3.1 gives the location of the Palmiet River Catchment in KwaZulu-Natal.

3.2.2 Topography

The topography of the Palmiet Catchment is undulating and dissected by the river except in the Pinetown CBD where it is relatively flat. The lowest point of the catchment is 78m above mean sea level at the weir at the University of Durban-Westville, and the highest point is 542m at Fields Hill. Figure 3.2 shows the Palmiet River Catchment topography.

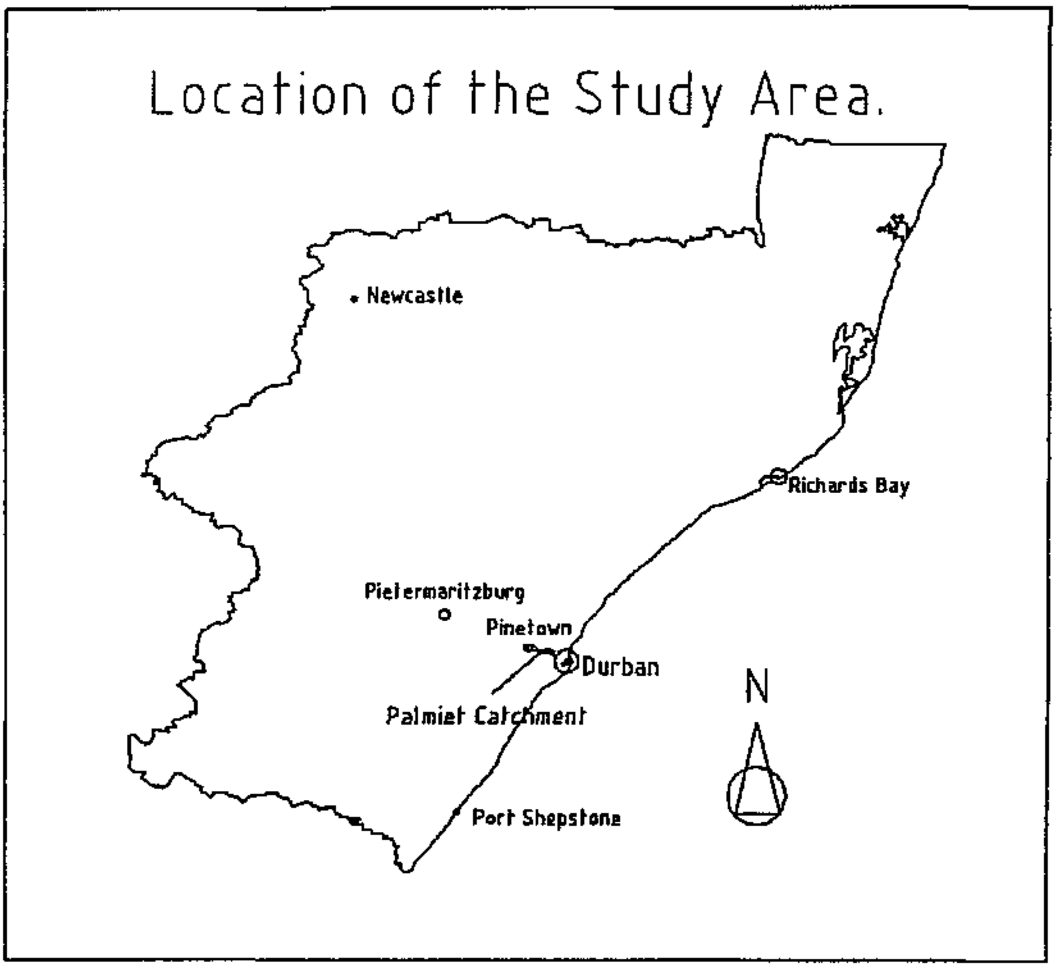


Figure 3.1. The location of the Palmiet River Catchment in KwaZulu-Natal.

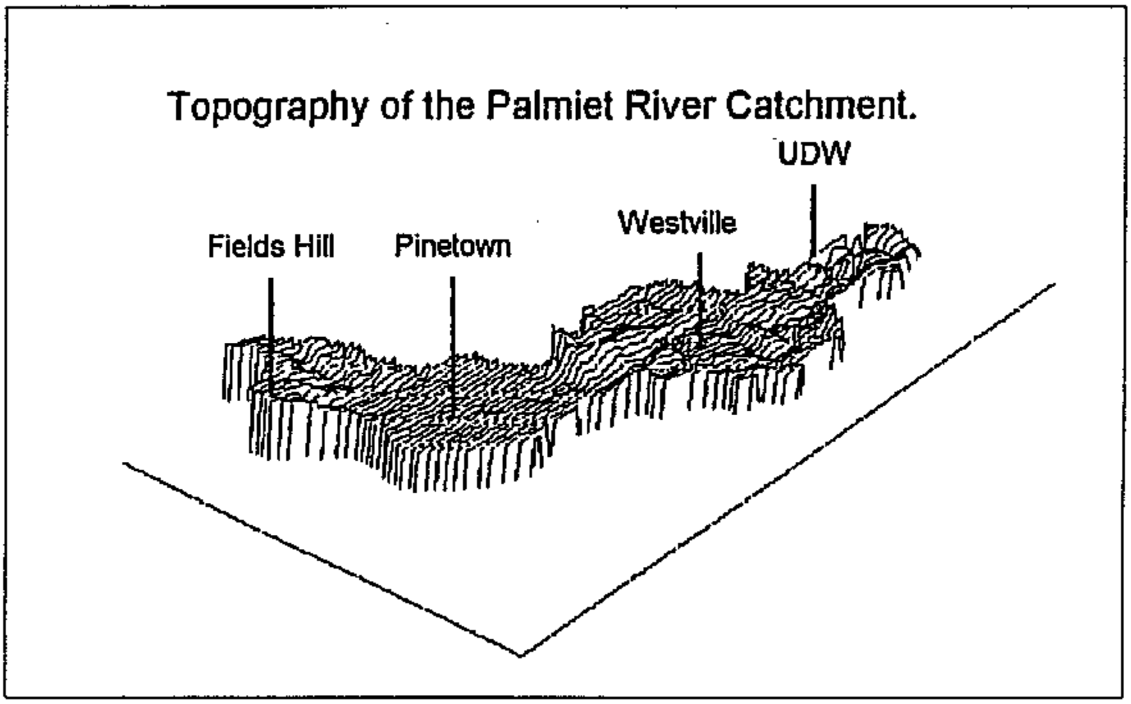


Figure 3.2 Topography of the Palmiet Catchment.

3.2.3 Hydrology

The Palmiet Catchment was subdivided into ten sub-catchments, each of them chosen according to the dominant land use (e.g. commercial, residential, etc.). The water quality sampling points are located at the outlet of each sub-catchment, so as to be representative of the influence of different landuses on the quality of the water in each catchment (see figure 3.3). The different landuses in each of these sub-catchments will be discussed in the next section.

Figure 3.3 also shows the main streams of interest to this project. The hydraulic length of the main channel is 15330m.

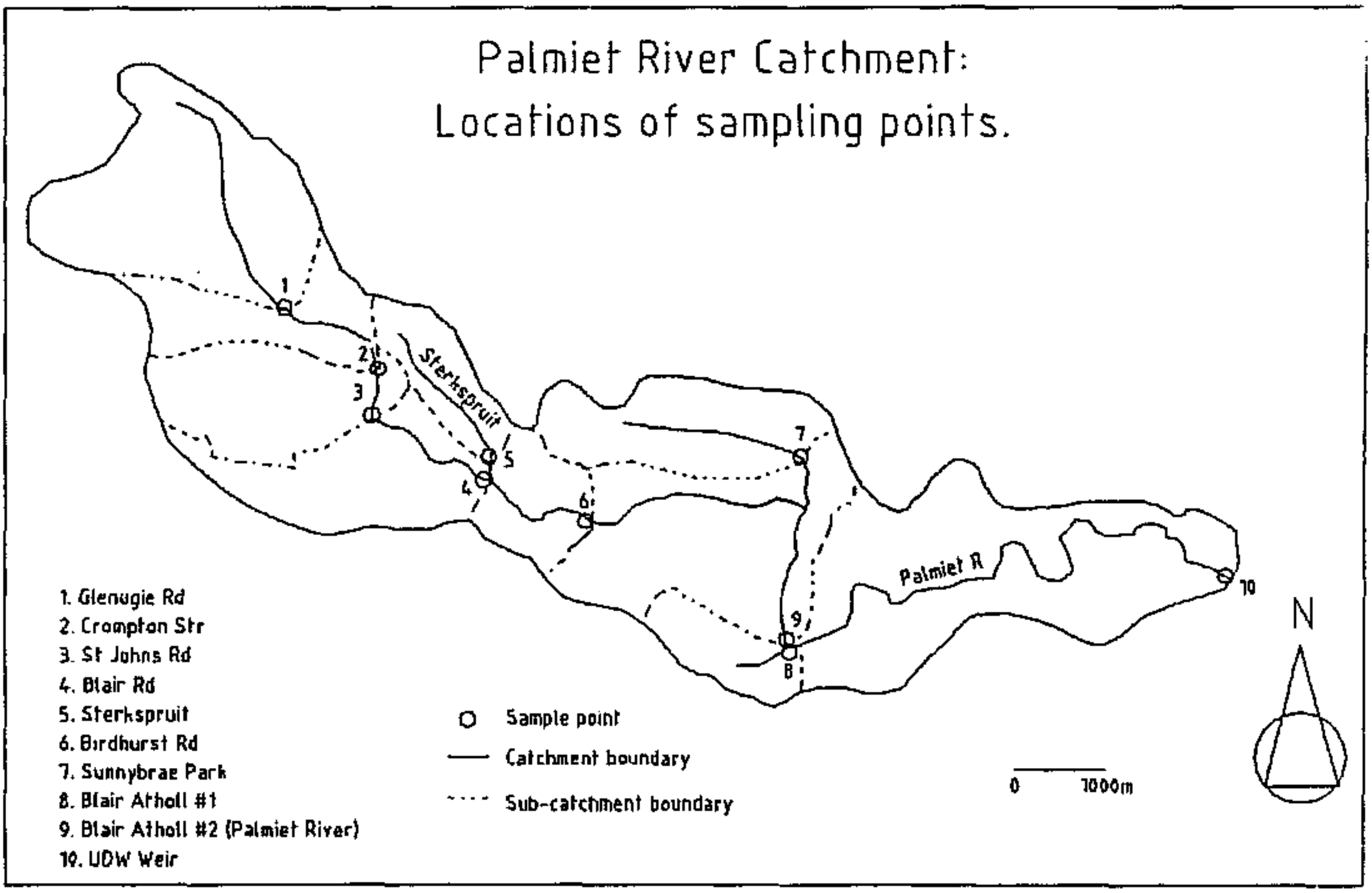


Figure 3.3 Hydrology and sub-catchments of the Palmiet River Catchment.

3.2.4 Soil types

The soil data for the land types in the Palmiet River Catchment were obtained from the Institute for Soil, Climate and Water (ISCW) in 1993. Figure 3.4 shows the different land types within the Palmiet River Catchment. According to ISCW

(1993) a **land type** is an area displaying marked uniformity of terrain, soil pattern and climate. The soil types within each land type will now be discussed. The source of this discussion is ISCW (1993) unless referenced otherwise.

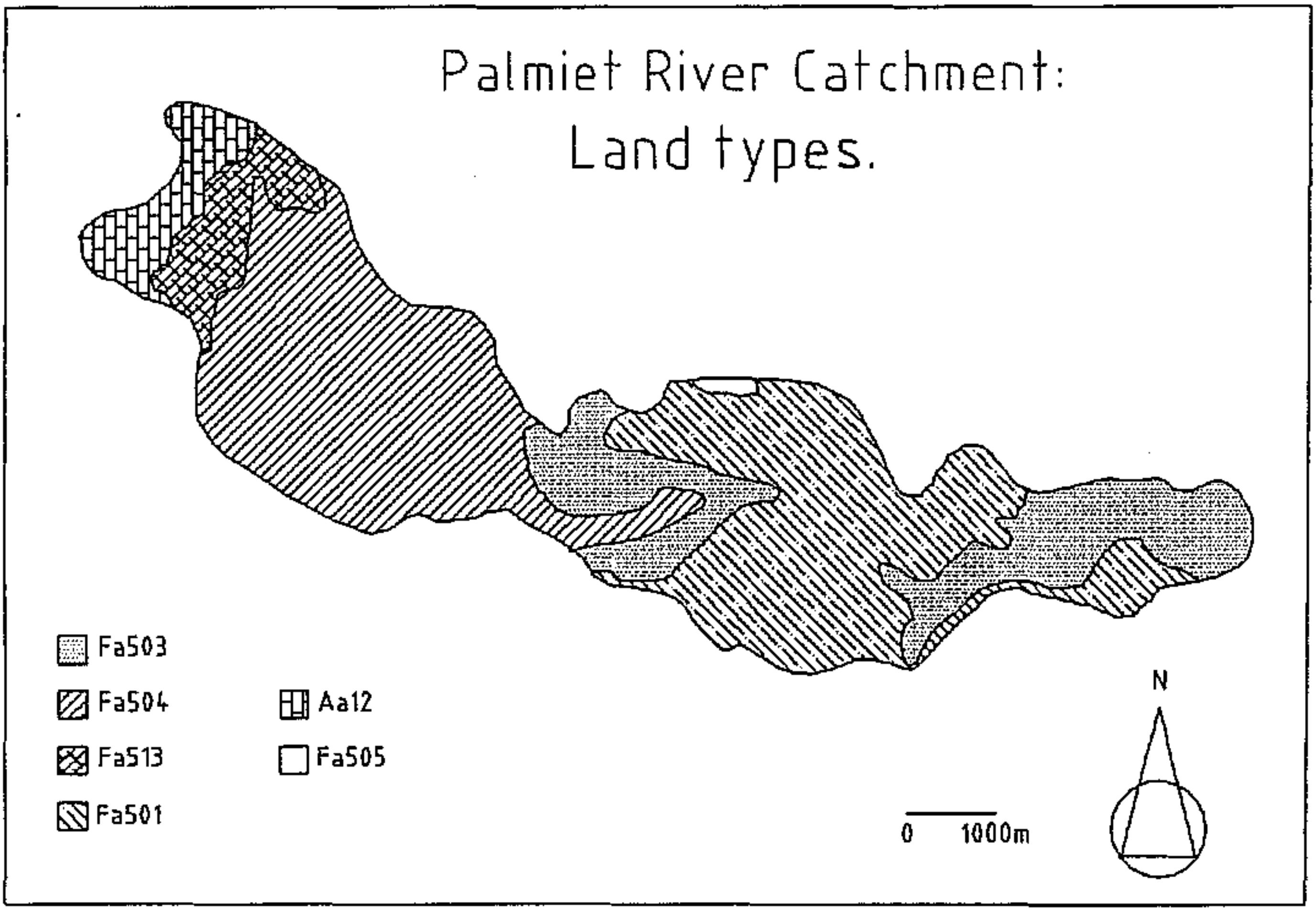


Figure 3.4 Different land types in the Palmiet River Catchment

Land type Aa12:

The dominant soils in this land type are the Fountainhill (Ia10) and Sprinz (Ia12) soil series from the Inanda Soil Form and Nomanci (No10) and

Lusiki (No11) series from the Fountain Hill Soil Form. These soils have a humic topsoil, the texture varying from medium sandy loam to medium sandy clay loam to clay. The soil depth varies from 300mm to more than 800mm.

Land type Fa513:

The dominant soils in this land type are Cartref (Cf21) and Cranbrook (Cf22) from the Cartref Soil Form as well as the Platt (Gs14) and Trevanian (Gs17) series from the Glenrosa Soil Form and Mispah (Ms10). The texture from all these soil series varies from loamy medium sand to sandy clay loam. These soils are very shallow, less than 500mm in depth. This can be attributed to the topography since they occur on the slopes of Fields Hill.

Land type Fa504:

This land type covers the biggest part of the Palmiet River Catchment. This is also the part of the catchment where Pinetown's CBD is located. About 40 percent of the area has a slope of less than 8 percent. The dominant soils are from the Cartref Soil Form (Cartref (Cf21), Cranbrook (Cf22), Grovedale (Cf30) and Kusas (Cf31)) and from the Glenrosa Soil Form (Gs14 and Gs17). The soils have a depth of between 300mm and 500mm. The soil texture varies from medium to coarse sand to sandy loam to sandy clay loam.

Land type Fa503:

The soils are from the Cartref Soil Form (Rutherglen (Cf11), Arrochar (Cf12, Cf21 and Cf22), Glenrosa Soil Form (Gs14, Gs17) and Williamson (Gs16) and Mispah (Ms10). The soil texture varies from medium to fine sand, loamy sand, sandy loam to sandy clay loam. Ms10 is very shallow, to a depth of less than 300mm, while the soil depth for the rest varies between 300mm to 800mm.

Land type Fa501:

The soil texture in this land type varies from medium sandy loam to sandy clay and has a soil depth that varies between 300mm and 800mm. The soil types are Gs16, Gs17, Cf21, Cf22 and Msinga (Hu26) and Doveton (Hu27) from the Hutton Soil Form.

Land type Fa505:

The soil texture varies between medium to coarse sand to sandy clay loam with depth varying between 300mm to more than 800mm. The soil types are Levubu (Oa34) and Jozini (Oa36) from the Oakleaf Soil Form (Gs17, Cf21, Cf22, Cf30 and Cf31). Due to the terrain there are insignificant amounts of bottomland soils (ISCW, 1993).

3.2.5 Vegetation.

The vegetation in the Palmiet Catchment varies from remnants of sub-tropical coastal forest and grassland, most dominant in the Palmiet Nature Reserve, to a mixture of indigenous and exotic trees and shrubs and lawns in the built-up areas of the catchment. Disturbed areas in the catchment have a high number of alien and invasive alien plants.

3.3 THE PINETOWN CATCHMENT

3.3.1 Location

The Pinetown Catchment is located in the western upper part of the Palmiet Catchment within Pinetown's municipal area and is about 16km to the west of Durban. The geographical location is 29° 48' South and 30° 52' East and comprises 0.915 square kilometers (Simpson, 1986).

3.3.2 Topography

The topography of the Pinetown Catchment is relatively flat with a slope average of 2,5 percent. The height varies from between 317m at the outlet of the catchment to 360m above mean sea level (Simpson, 1986). Figure 3.5 shows the topography of the Pinetown Catchment.

3.3.3 Hydrology

The catchment is fully reticulated for stormwater and is fully seperated from the foul sewer system (Simpson, 1986). The hydraulic length of the reticulation system is 1720m (Simpson, 1986).

3.3.4 Soil types

The only soil types present in the Pinetown CBD are those discussed in the land type Fa504 in section 3.2.4.

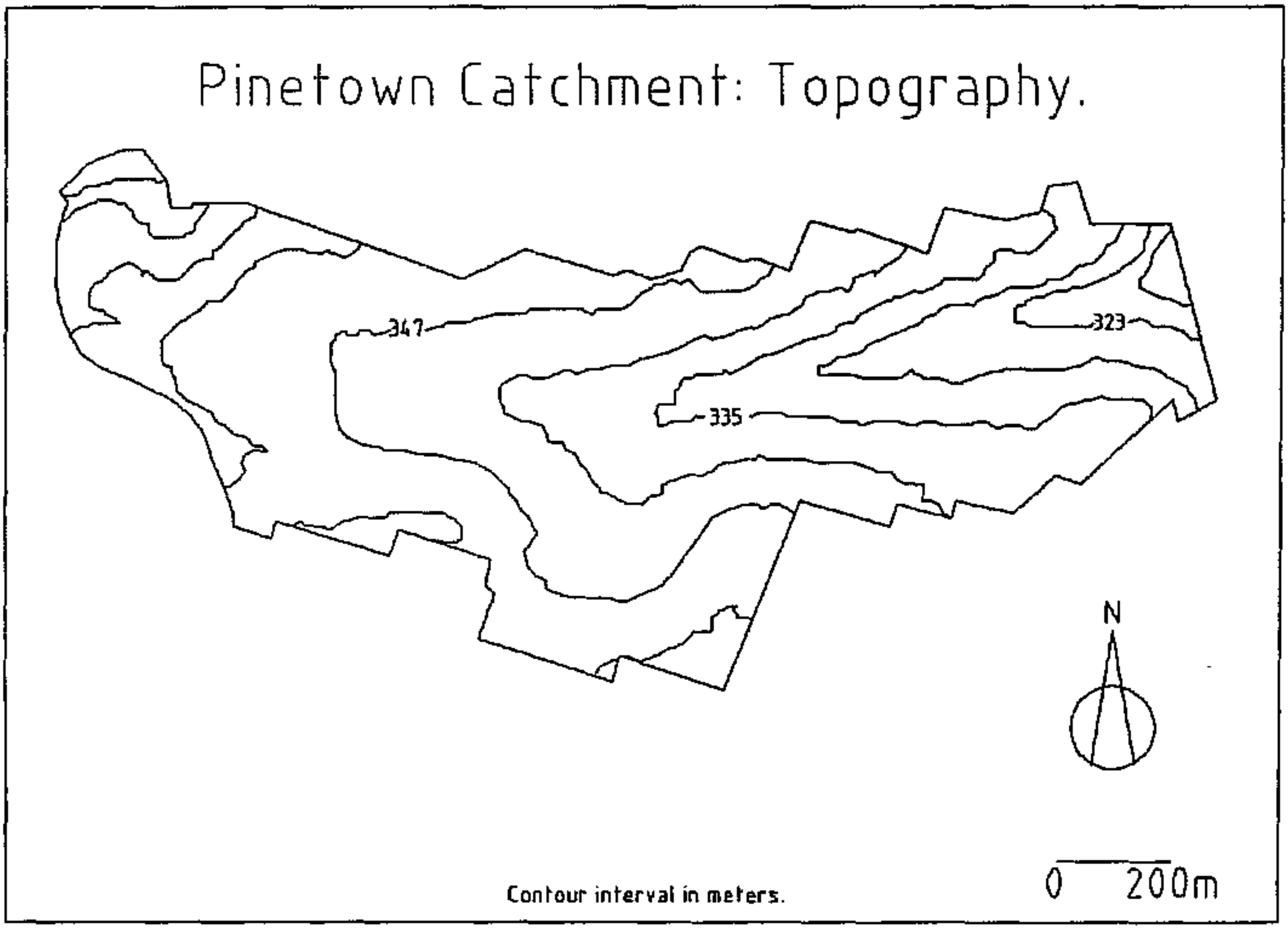


Figure 3.5. The topography of the Pinetown Catchment (From Simpson, 1986:116, fig.43)

3.3.5 Vegetation

Vegetation in the Pinetown catchment consists mainly of indigenous and exotic trees and shrubs and lawns in the built-up areas. Most of the open spaces in the

Pinetown catchment are maintained open spaces with cut lawns and trimmed beddings. Other open spaces in the catchment are disturbed areas with grass as well as indigenous trees and shrubs, benign aliens and invasive alien plants.

3.4 LAND USE

3.4.1 Palmiet River Catchment

Figure 3.6 shows the general land use in the Palmiet Catchment with table 3.1 showing the different land uses in more detail for each subcatchment.

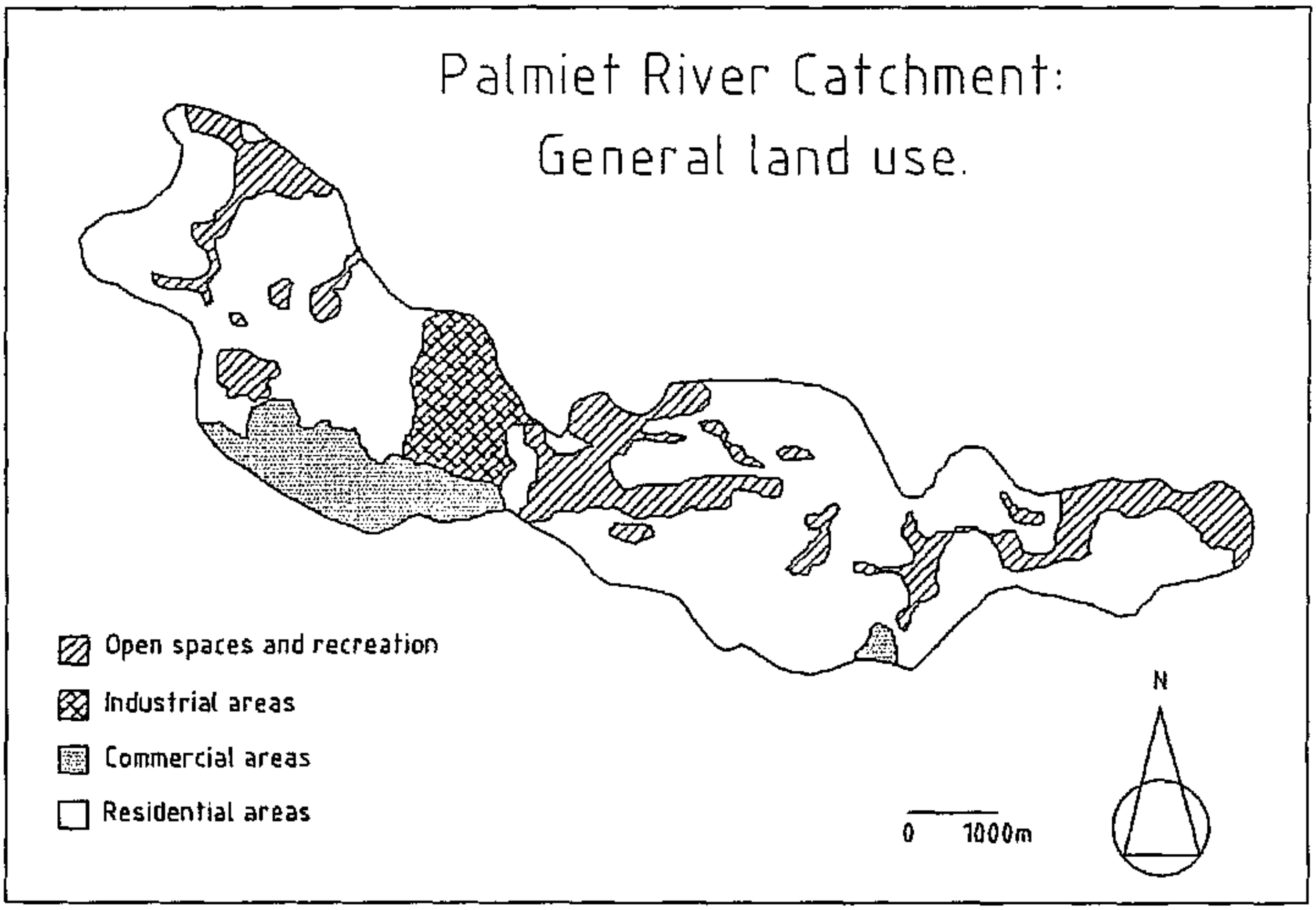


Figure 3.6 General land use in the Palmiet River Catchment.

3.4.2 Pinetown Catchment

According to Simpson,1986 the land use in the Pinetown Catchment consists of 30 percent commercial, 19 percent light industrial and 51 percent consists of multiple and single residential areas and parkland. Figure 3.7 shows the different landuses in the Pinetown Catchment.

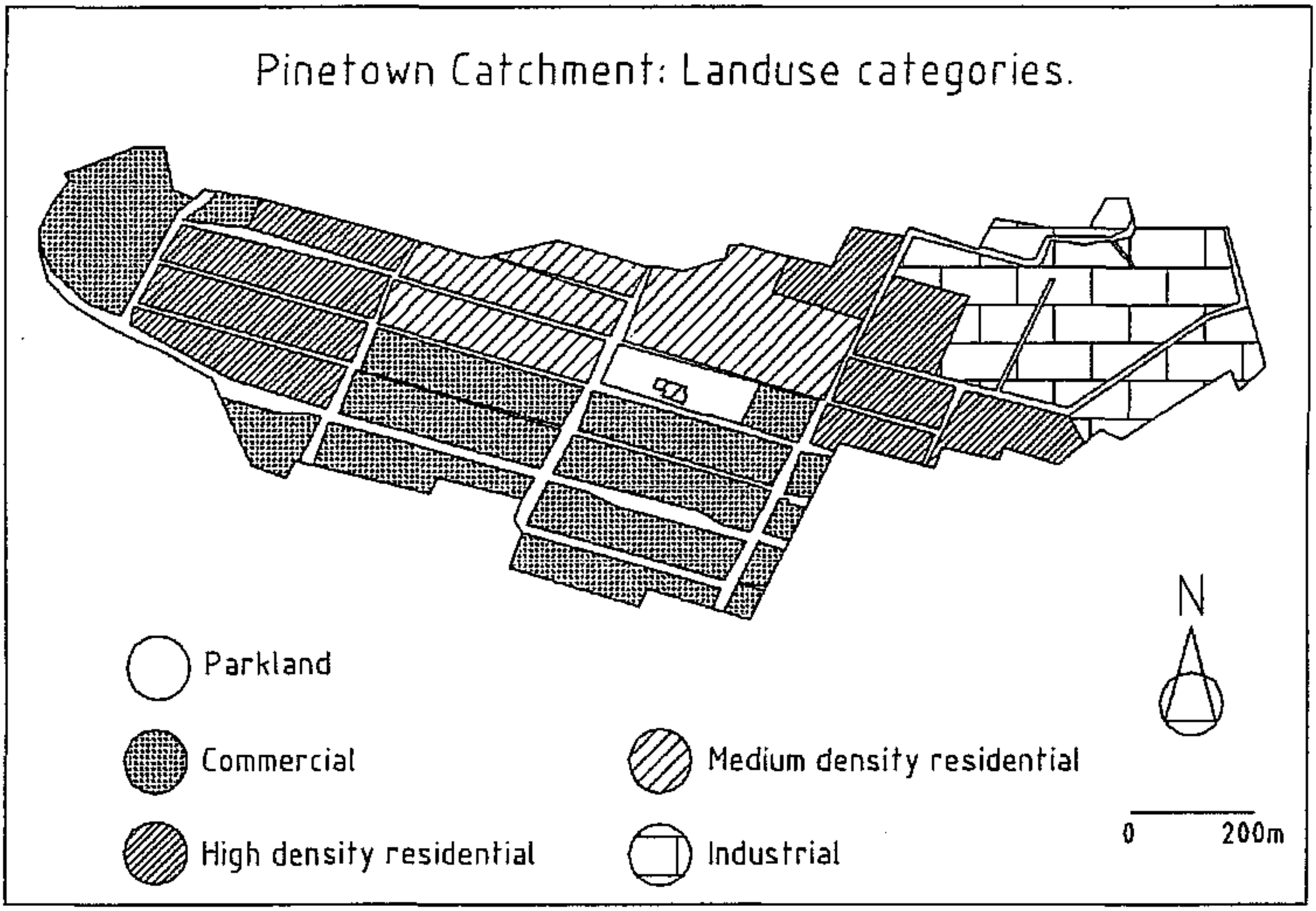


Figure 3.7. Different landuses in the Pintown Catchment (From Simpson, 1986:9, fig.2)

In this chapter the two different study areas used in this project were discussed in terms of their natural and cultural landscape. In the next chapter the data that were collected during the project period will be discussed.

Table 3.1 Landuse in the sub-catchments of the Palmiet River Catchment.

Sub-catchment	Land use (units = square kilometers)	
Glenugie Rd	Residential: Medium	1.254
	Low	1.023
	Open spaces/Recreational	1.023
	Total:	3.300
Crompton Str	Residential: Medium	0.333
	Industrial	0.387
	Open spaces/Recreational	0.180
	Total:	0.900
St Johns Rd	Residential: High	0.088
	Medium	0.704
	Industrial	0.572
	Commercial	0.528
	Open spaces/Recreational	0.308
	Total:	2.200
Blair Rd	Residential: Medium	0.060
	Industrial	0.800
	Commercial	1.140
	Total:	2.000
Sterkspruit	Industrial	0.658
	Open spaces/Recreational	0.042
	Total:	0.700
Birdhurst Rd	Residential: Medium	0.528
	Open spaces/Recreational	0.572
	Total:	1.100
Sunnybrae Park	Residential: Medium	1.748
	Open spaces/Recreational	0.552
	Total:	2.300
Blair Atholl #1	Residential: Medium	1.200
	Total:	1.200
Blair Atholl #2 (Palmiet River)	Residential: Medium	3.100
	Total:	3.100
UDW	Residential: Medium	2.765
	Commercial	0.035
	Open Spaces/Recreational	0.700
	Total:	3.500

4. DATA COLLECTION AND ANALYSIS.

4.1 INTRODUCTION

The data for rainfall, stream flow and water quality were collected between October 1992 and September 1994. Each of these factors will be discussed below in further detail in terms of location of instruments and the method of collection and analysis.

4.2 RAINFALL

A siphon recording rain gauge with weekly charts collected rainfall data on a weekly basis. A standard rain gauge was used to register daily rainfall and was also used as a control rain gauge. The standard rain gauge provided backup daily rainfall values in case of a breakdown of the recording rain gauge. Both rain gauges were set up on the terrain of the University of Durban-Westville's meteorological station. Figure 4.1 shows the position of the rain gauges. The recorded charts were sent to the Department of Agricultural Engineering to be digitized. The digitized rainfall data were used for the simulation runs on the Palmiet Catchment.

Figure 4.2 shows the monthly rainfall values for the period October 1992 to September 1994. The second year (October 1993 to September 1994) shows a higher rainfall than the first year. The annual totals are 530mm and 1054mm for October 1992 to September 1993 and October 1993 to September 1994 respectively. The low values in the first year coincide with the severe drought experienced in 1992 and 1993. The mean annual rainfall at Durban International Airport is 1018 mm (Weather Bureau, 1984), suggesting that the second year shows a normal rainfall total for the region, whilst the first year only received approximately half of the mean annual rainfall amount.

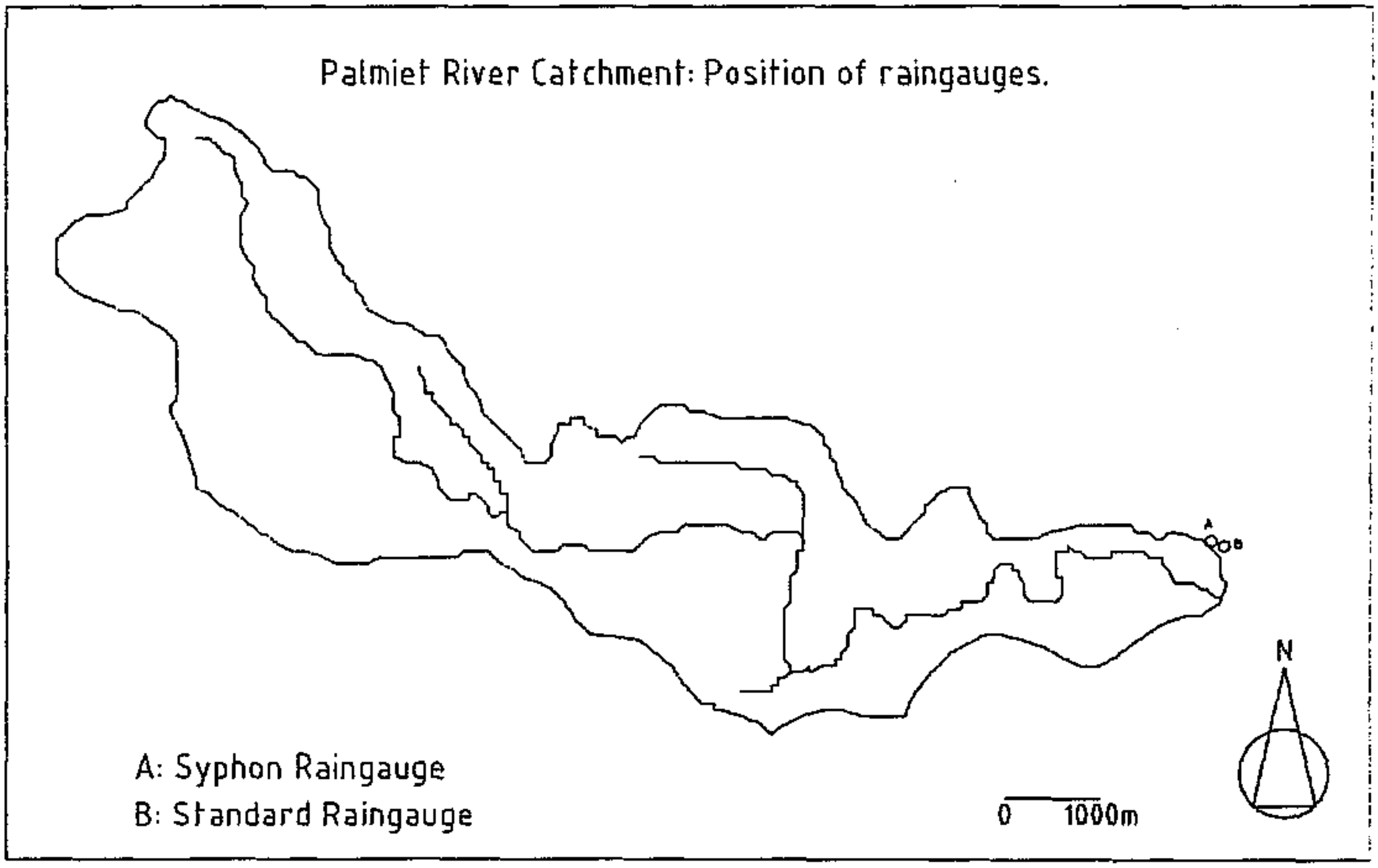


Figure 4.1 The location of the raingauges in the Palmiet Catchment.

The daily rainfall data used in the Pinetown Catchment were obtained from the Computing Centre for Water Research (CCWR) and the individual storm distributions at a two minute interval were obtained from Simpson, 1986.

4.3 STREAMFLOW

Streamflow was recorded at a rectangular weir constructed in the Palmiet River on the campus of the University of Durban-Westville which is situated in the lower part of the catchment.

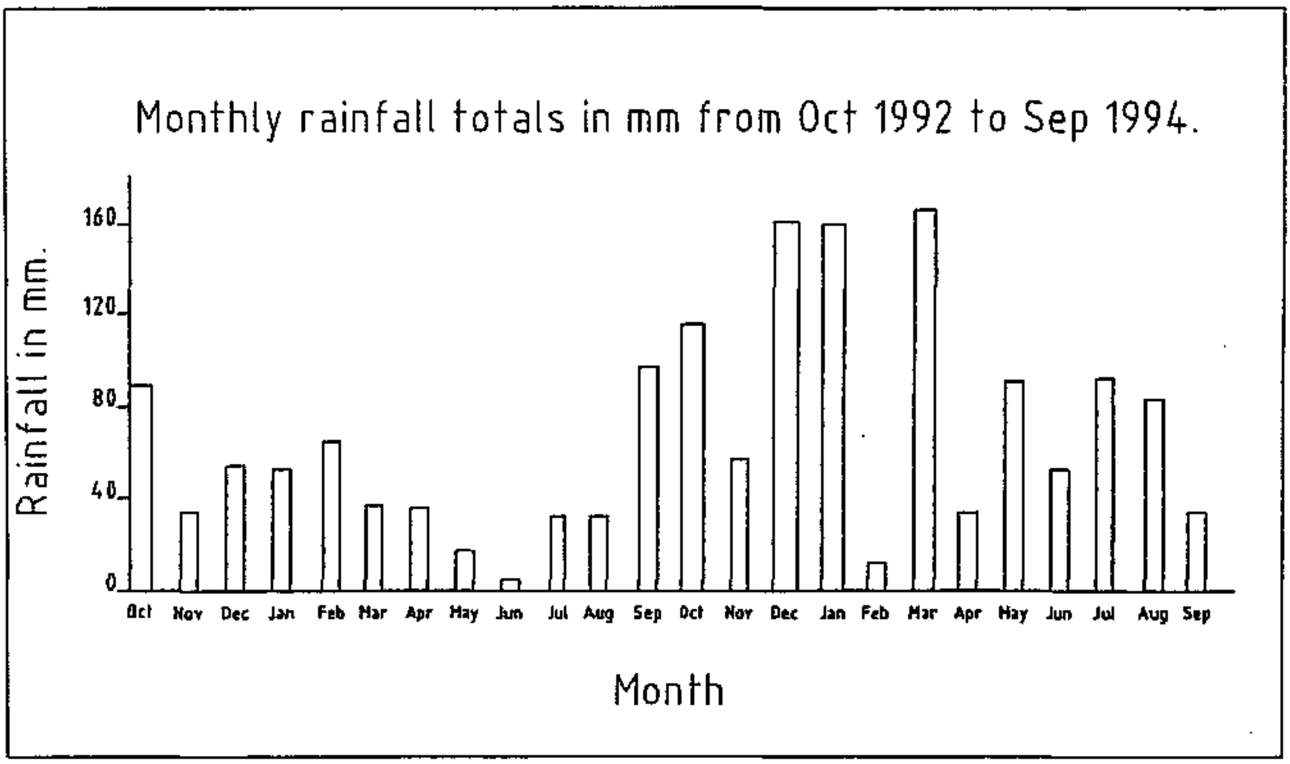


Figure 4.2 Monthly rainfall totals in mm from October 1992 to September 1994.

The streamflow was recorded on an OTT flow level recorder using a six week roll chart. The recorded charts were also sent to the Department of Agricultural Engineering at the University of Natal, Pietermaritzburg for digitizing purposes. The flow at the other sampling points in the Palmiet River was established using a 1 liter beaker for the smaller tributaries and a 5 liter bucket with a stop watch. The filled beaker or bucket, divided by the time it took to fill it in seconds, gave the flow in liters per second. It should be noted that the flow values are not as accurate as those taken at the weir, but this method gives a reasonable estimate of the flow, which is necessary when grab samples are taken. Figure 4.3 gives the accumulated monthly runoff from the Palmiet Catchment at the UDW weir and shows clearly the wet and dry seasonal flow. The runoff is distinctly lower in the first year (October 1992 to September 1993) than the second year (October 1993 to September 1994) due to the drought experienced in 1992 and 1993.

4.4 WATER QUALITY

4.4.1 Selected water quality constituents.

Although there are a large variety of constituents that can cause pollution in water resources it was decided to use only ten different parameters that are most common to urban areas. These ten parameters are: Chemical Oxygen Demand (COD), Chlorides, Nitrogen, Total Phosphorus, Suspended Solids, Total Dissolved Solids (TDS). The following constituents are all heavy metals: Chromium (Cr), Copper (Cu), Zinc (Zn), Nickel (Ni), Lead (Pb) and Iron (Fe). These ten constituents also form part of Pinetown Municipality's water sampling programme in detecting pollution from several sources in the Palmiet Catchment.

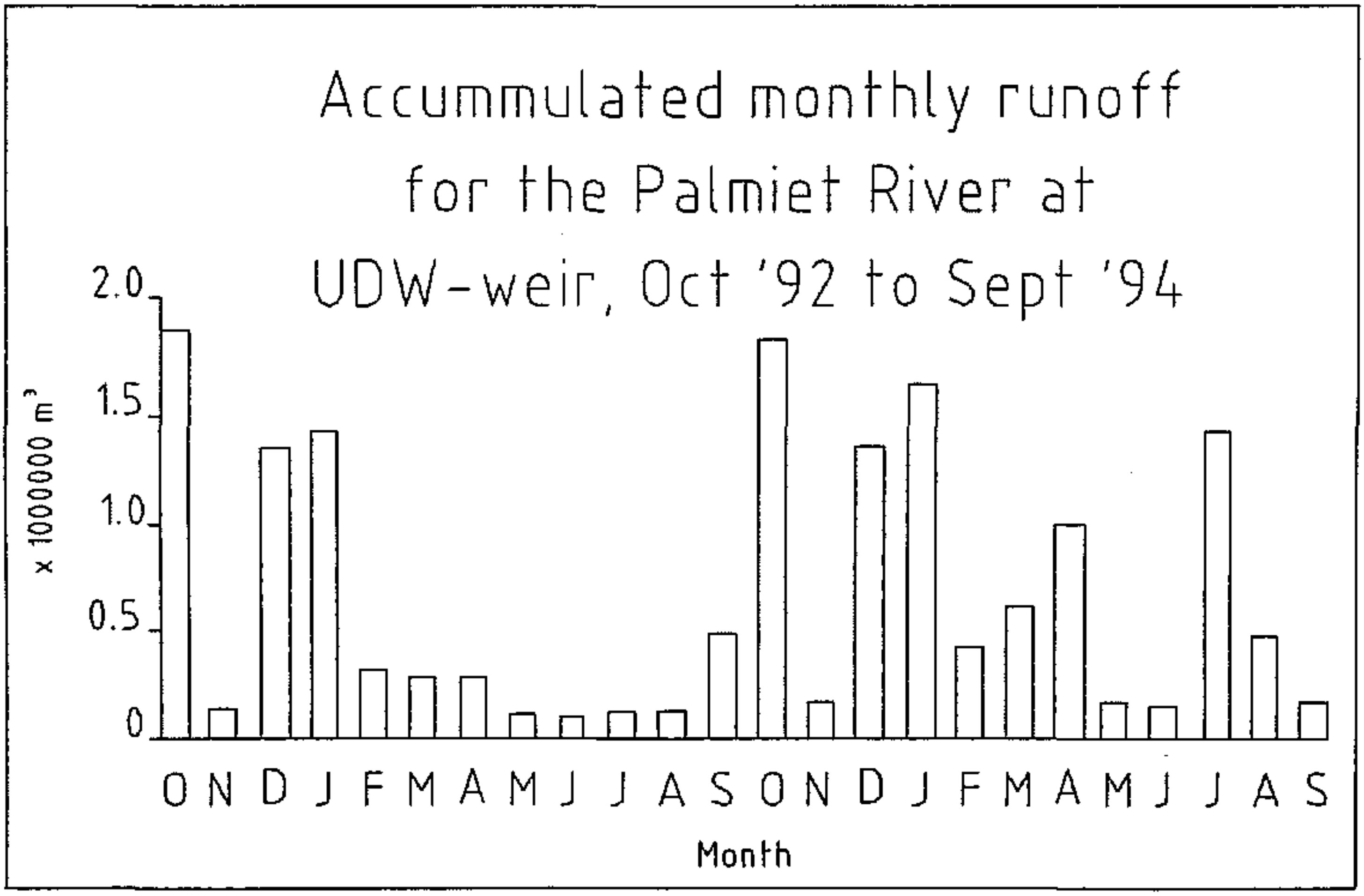


Figure 4.3 Accumulated monthly runoff from the Palmiet River Catchment at UDW weir from October 1992 to September 1994

4.4.2 Water sampling methods.

Water samples were collected by two methods. The first method was the use of grab samples once a week from the sampling points given in figure 3.3. Each of the sampling points was chosen to represent certain dominant land use types such as commercial, medium density residential or industrial landuse. The different land uses are given in Table 3.1. The reason for this was to establish baseflow values for each of the twelve constituents over a period of two years. These values were then compared with the high flow values, which are discussed in section 4.5.3. The analysis was done by the Waste Water Treatment Works of the Pinetown Municipality. A total of 88 samples were collected at each point.

High flow samples were collected at the weir at the University of Durban-Westville only. These samples were collected with an ISCO-sampler. The sampler was programmed to collect a sample when the stream level rose or fell by 5cm. This method was followed in order to establish changes in water quality over a hydrograph. Three of these storm events were analysed by Umgeni Water and will be discussed in section 4.5.4. For the other storm events a composite sample was taken and analysed by the Pinetown Municipality. The results from these samples are discussed in the next section.

4.5 DATA ANALYSIS

4.5.1 Monthly base flow water quality data.

Table 4.1 gives the different monthly base flow water quality values for twelve different constituents. Total phosphorus (TP) testing was only done on the last four sampling points, viz. Sunnybrae Park (SBP), Blair Atholl 1(B/Atholl#1) and Blair Atholl 2 (B/Atholl#2 - the Palmiet River) and the weir at the University of Durban-Westville (UDW). The first six sampling points, viz. Glenugie Road (Glenugie), Crompton Street (Crompton), St Johns Road (St Johns), Blair Road (Blair Rd), Sterkspruit (S/Spruit) and Birdhurst Road (Birdhurst) (see also figure figure 3.3), form part of Pinetown Municipality's ongoing monitoring program, which does not include the testing of total phosphorus. To avoid duplication, the data from the Pinetown Municipality were directly incorporated into the data collected at the last four points during the duration of this project.

One of the features of the non-point source model is the inclusion of monthly base flow water quality values for streams to include the effect of base flow on the water quality of the stream. Johanson, *et al*, 1984 used monthly baseflow water quality values or a single value to facilitate this effect. Since the non-point source model is based on the HSPF model it was decided to include these values to simulate water quality during the non-rainfall events. The aim of establishing a monthly base flow water quality data base is to make provision for monthly changes in water quality. To illustrate the monthly changes,suspended solids, chloride and copper will be used as examples in the discussion.

For suspended solids (SS) from Table 4.1 and Fig 4.4 it is difficult to find a common trend based either on seasonal fluctuations or amongst the sampling points along the Palmiet River. During certain months of the year there is a high concentration of SS, while the other months show a lower concentration for each of the ten sampling points. This irregular pattern could be ascribed to earthmoving activities in the Sterkspruit and Blair Rd areas. The residential areas, Glenugie, Birdhurst Rd, Sunnybrae Park, Blair Atholl #1 and #2 and UDW show however a more uniform trend than the other sampling points. The higher concentrations in the winter months could be related to the low flows (see Figure 4.3). Another possible reason to account for the high values of SS can be related to the dumping of garden refuse into the stream channel by property owners bordering the stream. This practice was observed at several places along the stream during fieldwork.

At most of the sampling points, the lowest chloride concentrations appear during February, March and April (see Fig 4.5). This can be attributed to the higher flows during this period. Although January shows a high flow and concentration, this can be ascribed to the chlorides entering the streams via the pool cleaning activities in the residential areas.

Table 4.1 Palmiet River: Average monthly water quality values (Oct 1992 - Sept 1994) at 10 sampling points.

Glenugie	Month												
Chemical (mg/l)	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Annual Average
COD	36	21	23	19	49	41	19	12	19	34	19	21	26.1
Cl	52	55	55	55	54	48	49	50	50	52	51	58	52.5
Nitrate	1	1.1	1.8	1.3	1.1	0.8	1.1	1.4	1.6	2.6	1.2	1.4	1.383
TP													
Sus Sol.	197	225	207	190	214	178	179	169	170	197	204	202	194.3
TDS	260	244	250	226	264	240	219	218	233	257	237	250	241.6
Cr	0.007	0.013	0.030	0.022	0.012	0.023	0.008	0.018	0.015	0.017	0.018	0.011	0.016
Cu	0.015	0.019	0.035	0.017	0.055	0.025	0.089	0.038	0.030	0.026	0.023	0.067	0.037
Zn	0.007	0.016	0.021	0.015	0.037	0.047	0.018	0.142	0.080	0.030	0.008	0.025	0.037
Ni	0.002	0.004	0.003	0.003	0.007	0.011	0.026	0.037	0.009	0.005	0.010	0.004	0.010
Pb	0.015	0.008	0.007	0.005	0.013	0.008	0.039	0.015	0.003	0.014	0.008	0.006	0.012
Fe	0.350	0.520	0.610	0.590	0.580	0.920	0.880	0.630	0.420	0.450	0.520	0.480	0.554

Clompton	Month												
Chemical (mg/l)	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	Annual Average
COD	36	29	31	24	29	35	20	18	24	29	20	24	27.1
Cl	68	53	54	60	57	48	45	51	66	58	58	62	56.7
Nitrate	0.6	0.9	1.4	1.1	0.8	0.9	1.0	1.3	1.4	1.8	1.3	0.5	1.083
TP													
Sus Solids.	236	315	247	225	240	193	360	291	211	231	264	249	255.2
TDS	267	244	261	243	271	236	233	240	250	274	254	291	255.3
Cr	0.005	0.013	0.008	0.041	0.016	0.015	0.010	0.011	0.016	0.013	0.017	0.014	0.015
Cu	0.030	0.013	0.019	0.047	0.065	0.026	0.033	0.068	0.043	0.013	0.010	0.024	0.033
Zn	0.040	0.127	0.053	0.114	0.057	0.045	0.042	0.031	0.076	0.075	0.037	0.037	0.061
Ni	0.023	0.085	0.195	0.083	0.045	0.025	0.050	0.048	0.023	0.068	0.116	0.045	0.067
Pb	0.016	0.011	0.005	0.029	0.006	0.006	0.014	0.006	0.003	0.004	0.010	0.009	0.010
Fe	0.330	0.530	0.720	0.880	0.610	0.700	0.660	0.520	0.630	0.660	0.640	0.670	0.648

St Johns	Month												
Chemical (mg/l)	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Annual Average
COD	47	79	65	19	39	48	43	39	56	56	67	41	49.9
Cl	61	49	58	60	62	52	57	60	69	66	61	64	61.6
Nitrate	0.8	1.4	1.8	1.4	1.0	1.2	1.4	1.4	2.0	1.8	1.0	1.5	1.392
TP													
Sus Solids.	250	282	287	271	310	236	253	308	319	345	289	288	286.5
TDS	288	277	291	305	312	274	285	328	332	332	291	315	302.6
Cr	0.012	0.009	0.006	0.043	0.021	0.024	0.006	0.028	0.026	0.026	0.025	0.007	0.020
Cu	0.081	0.045	0.066	0.026	0.067	0.084	0.056	0.156	0.024	0.031	0.027	0.048	0.061
Zn	0.068	0.210	0.225	0.469	0.204	0.196	0.332	0.622	0.456	0.745	0.543	0.462	0.378
Ni	0.013	0.018	0.038	0.002	0.027	0.014	0.047	0.039	0.040	0.014	0.032	0.055	0.028
Pb	0.020	0.012	0.017	0.008	0.014	0.012	0.023	0.009	0.009	0.018	0.016	0.015	0.014
Fe	0.540	0.700	0.960	0.670	0.790	1.290	0.660	0.870	0.920	1.110	0.960	0.820	0.841

Table 4.1. Continued

Blair Rd	Month											
Chemical (mg/l)	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	Annual Average
COD	136	35	64	23	28	40	45	34	50	94	77	158	65.3
Cl	62	47	45	63	60	53	54	74	80	70	67	68	61.9
Nitrate	1.2	1.0	1.6	1.3	0.7	1.0	0.8	1.3	1.8	1.6	0.8	0.5	1.125
TP													
Sus Solids.	402	345	294	300	310	256	287	322	348	398	361	522	345.3
TDS	342	274	319	298	312	288	319	360	367	346	309	343	323.9
Cr	0.006	0.008	0.006	0.023	0.005	0.022	0.009	0.016	0.009	0.094	0.024	0.028	0.021
Cu	0.089	0.013	0.015	0.063	0.050	0.033	0.044	0.033	0.028	0.048	0.031	0.015	0.038
Zn	0.088	0.125	0.142	0.042	0.109	0.143	0.204	0.218	0.281	0.297	0.592	0.347	0.216
Ni	0.019	0.011	0.025	0.022	0.013	0.018	0.016	0.008	0.015	0.005	0.018	0.011	0.015
Pb	0.013	0.009	0.017	0.008	0.012	0.009	0.014	0.010	0.007	0.010	0.008	0.016	0.011
Fe	1.790	0.740	0.620	0.620	0.790	0.680	0.840	0.920	1.300	1.310	2.140	2.320	1.206

S/Spruit	Month											
Chemical (mg/l)	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Annual Average
COD	84	42	36	20	29	51	55	37	35	49	36	27	41.8
Cl	38	48	42	32	77	30	38	38	47	49	44	50	43.8
Nitrate	0.6	0.9	1.3	0.7	0.9	1.6	1.4	0.8	1.9	1.7	0.6	1.3	1.142
TP													
Sus Solids	249	228	207	219	210	212	367	408	260	274	253	213	265.8
TDS	253	253	322	247	236	233	319	425	274	296	274	552	307
Cr	0.011	0.013	0.013	0.005	0.014	0.024	0.016	0.059	0.016	0.031	0.038	0.067	0.026
Cu	0.020	0.021	0.014	0.012	0.008	0.032	0.056	0.054	0.044	0.024	0.020	0.014	0.032
Zn	0.280	0.674	0.473	0.310	0.397	0.452	0.499	0.550	0.781	0.872	0.653	0.849	0.558
Ni	0.018	0.004	0.005	0.009	0.010	0.011	0.025	0.041	0.069	0.013	0.013	0.100	0.027
Pb	0.011	0.006	0.008	0.017	0.005	0.007	0.014	0.003	0.016	0.024	0.050	0.011	0.014
Fe	0.740	0.520	0.530	0.700	0.580	0.720	0.850	0.420	0.720	0.670	1.030	0.560	0.670

Birchhurst	Month											
Chemicals (mg/l)	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Annual Average
COD	41	46	43	28	26	42	34	37	48	36	35	42	38.2
Cl	61	41	42	59	53	46	50	65	70	64	64	64	56.6
Nitrate	0.6	1.0	1.1	0.9	0.4	0.6	0.6	1.0	0.8	1.6	0.8	0.7	0.858
TP													
Sus Solids	277	279	262	271	263	237	249	309	292	331	270	297	279.8
TDS	315	274	319	292	298	278	315	353	346	350	315	339	316.2
Cr	0.003	0.013	0.011	0.015	0.008	0.033	0.013	0.029	0.012	0.023	0.022	0.007	0.016
Cu	0.012	0.012	0.017	0.009	0.168	0.046	0.187	0.093	0.055	0.018	0.018	0.012	0.054
Zn	0.085	0.179	0.171	0.141	0.157	0.151	0.120	0.480	0.153	0.191	0.475	0.171	0.205
Ni	0.022	0.009	0.010	0.020	0.011	0.009	0.060	0.013	0.027	0.007	0.018	0.007	0.019
Pb	0.020	0.009	0.010	0.015	0.014	0.007	0.020	0.005	0.006	0.008	0.004	0.009	0.011
Fe	1.430	0.700	0.680	0.850	0.650	0.690	0.650	0.800	1.200	1.080	1.150	1.000	0.907

Table 4.1 Continued

SBP	Month												
Chemical (mg/l)	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Annual Average
COD	51	52	65	47	43	36	35	40	41	60	37	63	47.5
Cl	76	66	64	60	51	48	45	62	68	67	68	76	62.6
Nitrate	1.1	1.2	1.5	1.4	0.9	0.8	0.9	1.1	2.1	0.5	0.5	0.6	1.050
TP	0.6	0.8	0.5	0.3	0.2	0.1	0.1	0.3	0.3	0.8	0.4	1.0	0.450
Sus Solids.	309	221	240	226	239	197	232	263	283	309	317	418	271.2
TDS	274	261	256	222	226	188	199	247	260	237	278	261	242.4
Cr	0.004	0.005	0.010	0.006	0.008	0.012	0.005	0.012	0.016	0.017	0.010	0.010	0.010
Cu	0.009	0.015	0.016	0.016	0.011	0.005	0.004	0.012	0.008	0.009	0.009	0.007	0.010
Zn	0.016	0.032	0.057	0.036	0.033	0.026	0.020	0.021	0.043	0.036	0.028	0.040	0.035
Ni	0.005	0.006	0.008	0.003	0.006	0.008	0.006	0.009	0.006	0.004	0.007	0.013	0.007
Pb	0.008	0.009	0.013	0.023	0.005	0.009	0.005	0.014	0.022	0.007	0.004	0.009	0.011
Fe	0.630	0.590	0.840	0.870	0.390	1.110	0.950	0.630	0.910	1.310	0.870	1.100	0.833

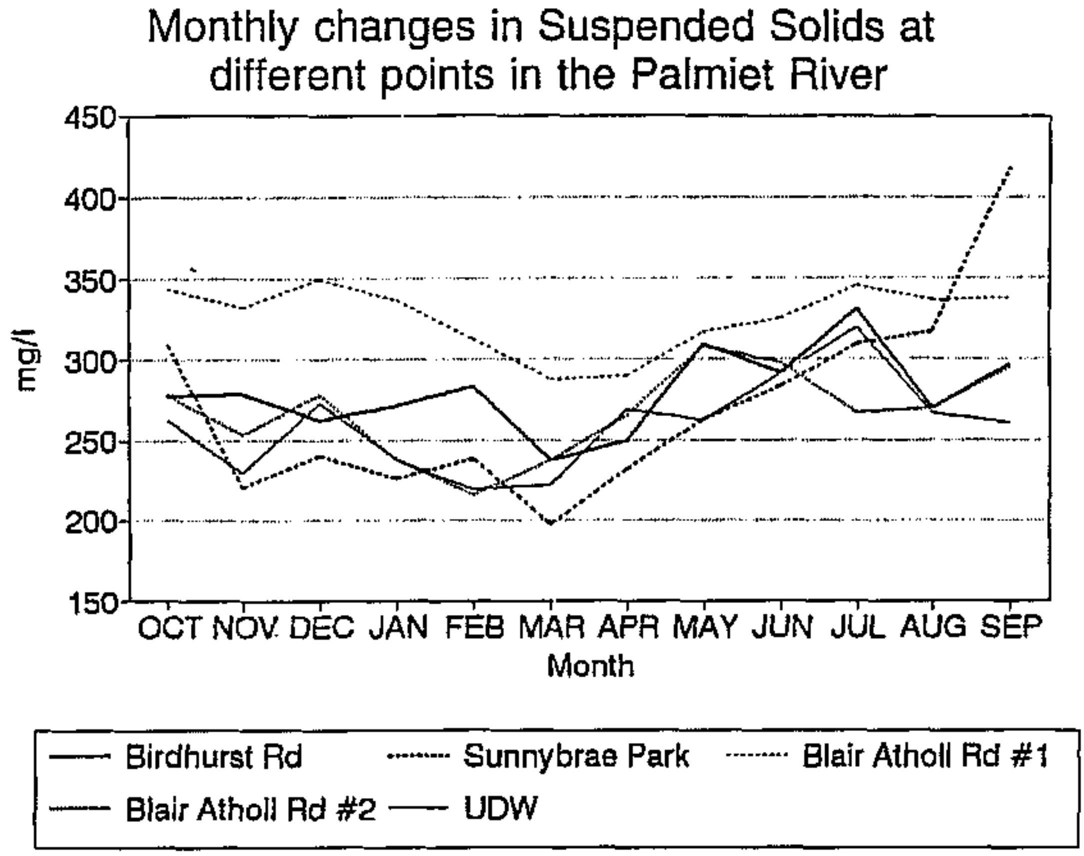
B/Atholl#1	Month												
Chemical (mg/l)	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Annual Average
COD	43	48	49	44	41	42	30	31	57	62	37	56	45.0
Cl	87	79	82	80	61	61	64	71	67	73	69	91	73.5
Nitrate	1.6	2.0	2.3	2.0	0.9	0.8	1.8	1.7	2.3	2.3	1.5	1.7	1.758
TP	3.1	0.6	0.4	0.8	0.3	0.2	0.4	0.4	0.3	0.3	0.3	0.7	0.650
Sus Solids	344	332	349	338	313	288	290	317	325	345	336	338	326.1
TDS	329	352	339	301	322	282	276	305	319	332	305	336	316.5
Cr	0.014	0.005	0.005	0.006	0.011	0.016	0.006	0.014	0.017	0.015	0.009	0.007	0.010
Cu	0.010	0.028	0.014	0.014	0.014	0.005	0.006	0.013	0.015	0.006	0.011	0.009	0.012
Zn	0.003	0.029	0.029	0.070	0.022	0.041	0.001	0.011	0.164	0.026	0.029	0.020	0.040
Ni	0.006	0.006	0.004	0.004	0.004	0.012	0.005	0.036	0.004	0.006	0.008	0.010	0.009
Pb	0.014	0.015	0.007	0.028	0.007	0.008	0.006	0.007	0.012	0.003	0.009	0.008	0.010
Fe	0.060	0.140	0.270	0.310	0.170	0.440	0.310	0.220	0.560	0.340	0.450	0.120	0.283

B/Atholl#2	Month												
Chemical (mg/l)	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Annual Average
COD	49	38	59	53	35	33	33	34	47	55	42	52	44.2
Cl	63	57	66	53	42	44	57	55	62	53	53	64	55.8
Nitrate	1.1	1.0	1.5	1.1	1.1	0.8	1.9	1.6	2.0	1.6	1.8	1.0	1.375
TP	1.5	0.4	0.3	0.7	0.3	0.2	0.2	0.5	0.2	0.3	0.5	0.7	0.481
Sus Solids.	278	253	278	238	216	237	265	308	298	287	270	294	266.8
TDS	288	268	287	225	243	221	245	298	265	291	302	305	271.5
Cr	0.012	0.008	0.007	0.011	0.016	0.019	0.007	0.016	0.014	0.017	0.007	0.013	0.012
Cu	0.008	0.005	0.023	0.009	0.066	0.008	0.005	0.014	0.020	0.010	0.007	0.009	0.015
Zn	0.020	0.070	0.064	0.068	0.060	0.054	0.063	0.078	0.123	0.077	0.078	0.069	0.068
Ni	0.017	0.007	0.008	0.010	0.008	0.011	0.012	0.040	0.009	0.012	0.006	0.012	0.013
Pb	0.011	0.005	0.009	0.019	0.006	0.009	0.006	0.010	0.016	0.004	0.004	0.009	0.009
Fe	0.460	0.480	0.470	0.630	0.400	0.660	0.690	0.420	0.500	0.450	0.420	0.360	0.497

Table 4.1 Continued

UOW	Month												
Chemical (mg/l)	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Annual Average
COD	42	48	56	43	30	32	31	37	44	75	35	48	43.4
Cl	61	60	56	56	46	51	58	56	63	64	62	61	57.8
Nitrate	0.7	0.7	1.0	1.4	0.9	0.7	1.0	1.2	0.9	1.2	0.7	0.7	0.925
TP	0.3	0.5	0.3	0.4	0.2	0.1	0.2	0.3	0.2	0.2	0.6	0.5	0.317
Sus Solids	263	230	273	238	319	222	289	202	291	320	267	261	259.6
TDS	253	267	350	223	232	234	235	257	282	264	274	274	262.9
Cr	0.001	0.007	0.004	0.004	0.009	0.016	0.006	0.011	0.011	0.016	0.008	0.011	0.009
Cu	0.030	0.008	0.012	0.008	0.008	0.005	0.006	0.008	0.011	0.008	0.008	0.004	0.010
Zn	0.011	0.035	0.054	0.038	0.046	0.035	0.025	0.053	0.076	0.042	0.027	0.032	0.040
Ni	0.005	0.005	0.005	0.009	0.007	0.012	0.007	0.006	0.006	0.008	0.007	0.016	0.008
Pb	0.010	0.005	0.005	0.021	0.004	0.010	0.007	0.008	0.024	0.008	0.006	0.009	0.010
Fe	0.270	0.360	0.420	0.460	0.300	1.400	0.780	0.350	0.570	0.460	0.410	0.290	0.506

According to Figure 4.6 there is a difference between predominantly non-residential and predominantly residential areas in terms of fluctuation in Cu concentrations on a monthly basis. The non-residential areas such as the areas around Crompton Street, St Johns, Blair Rd, Sterkspruit and Birdhurst Rd show fairly high fluctuations between the months, when compared with the values of the residential areas. The only exception is Glenugie Rd, which is residential, where the same trend as in the non-residential areas occurred. A possible explanation is that the Arthur Hopewell Highway forms part of the sub-catchment's boundary and the higher copper content originates from the deposition of copper by motor vehicles from the rivets in clutchplates and brake shoes, which is then washed off into the Palmiet River. The primary sources of pollutants from motor vehicles are, according to Ahmed and Schiller (1980), oil, grease, tyre fragments, brake lining fragments and exhaust fumes.



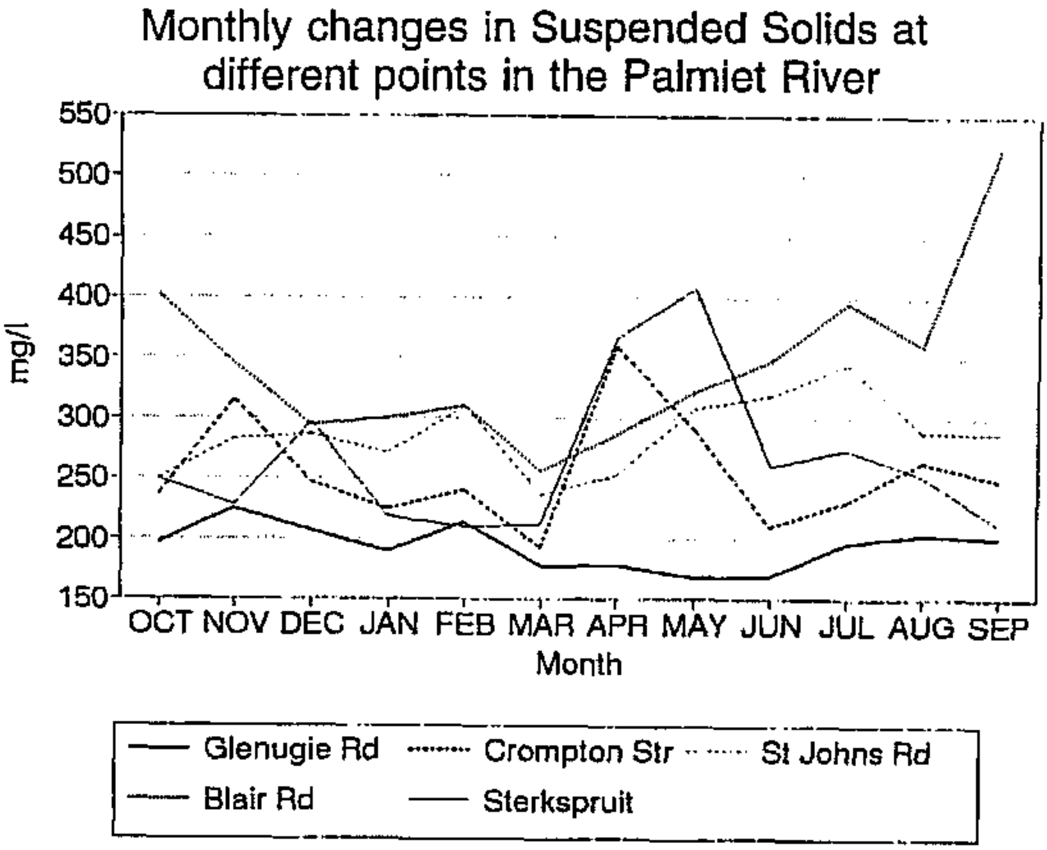
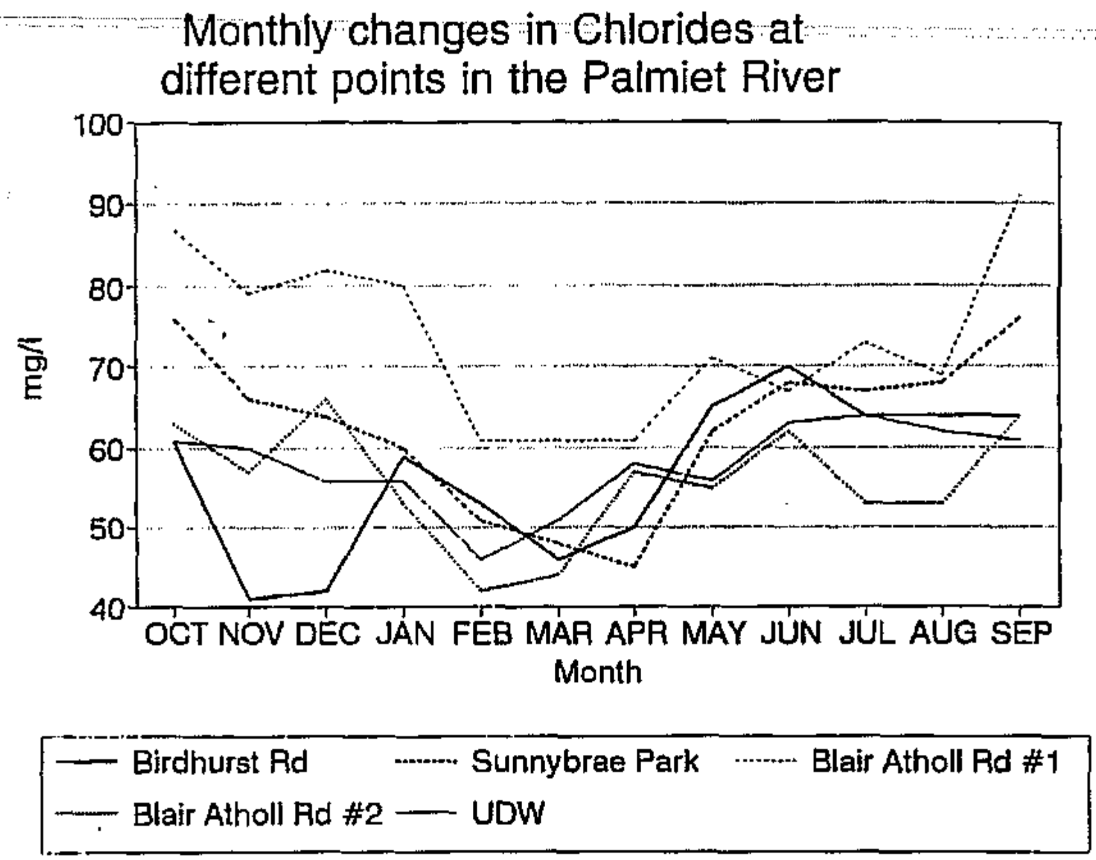


Figure 4.4 Monthly changes in Suspended Solids at different points in the Palmiet River.

(Average monthly values from Oct 1992 to Sep 1994).



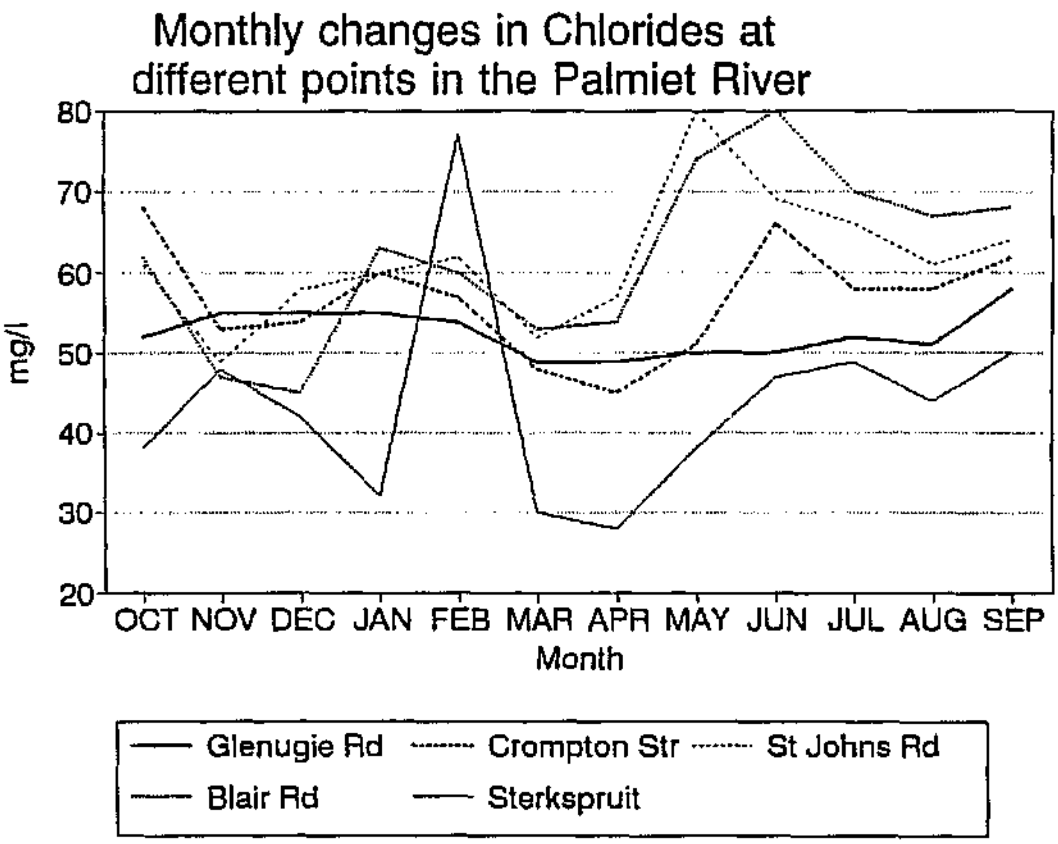
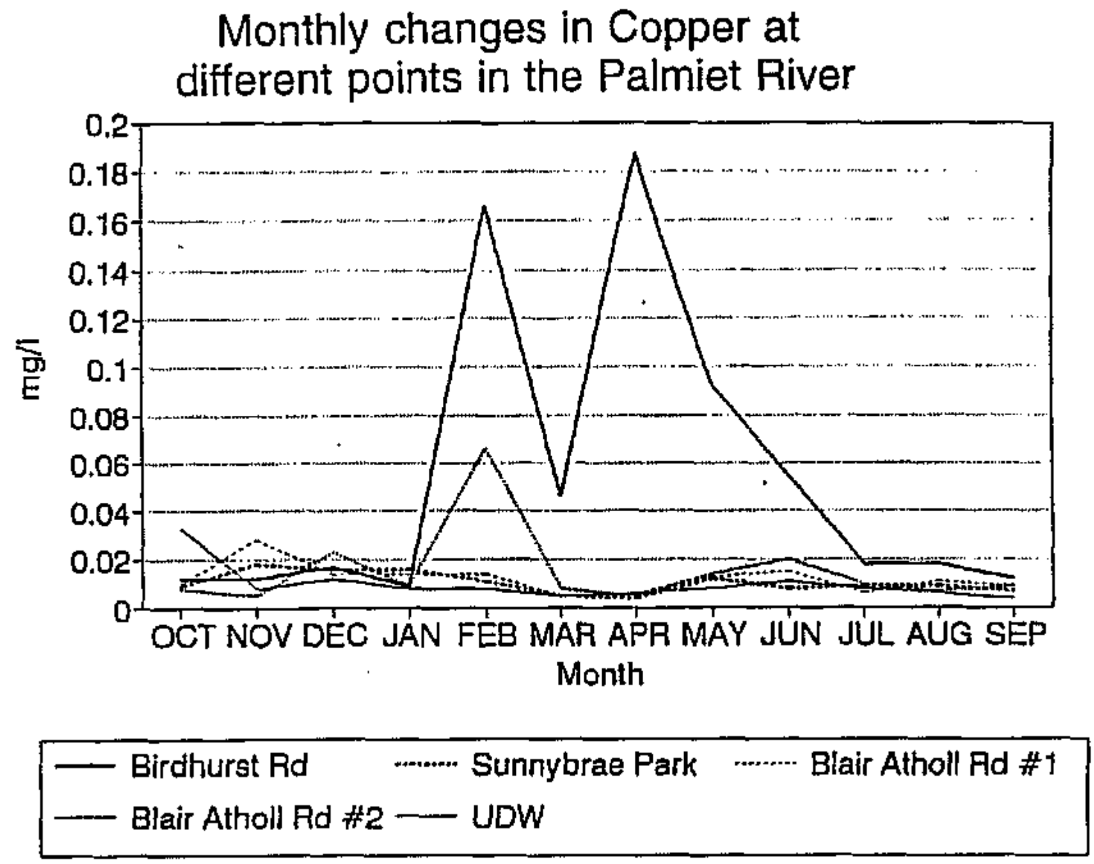


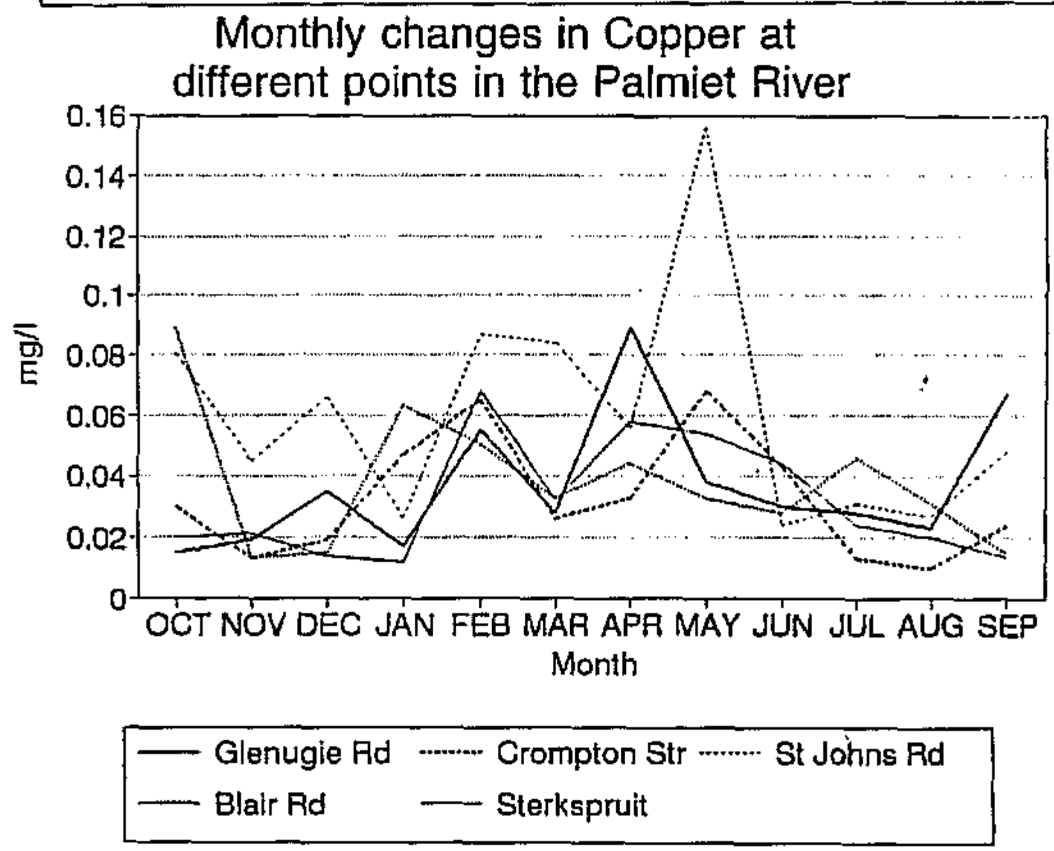
Figure 4.5 Monthly changes in Chlorides at different points in the Palmiet River. (Average monthly values from Oct 1992 to Sep 1994).

Another possible reason for the high copper content at Glenugie Road is leaching of copper in solution from the old landfill at the upper reaches of the Palmiet River. The old landfill was used for waste disposal by Kloof Municipality. The rainwater which is slightly acid infiltrates the landfill causing acid-reducing conditions corroding any copper and brass objects present in the landfill, thus causing the copper to go into solution. If the rainfall is sufficient, the copper in solution is flushed out from the landfill and enters the stream causing drastic rises in the copper content of the water (Dunlevey, 1995). Motor vehicles and spillages from other sources such as electro-plating facilities are the main sources for copper in the Palmiet River in the non-residential areas. The fairly constant trend of the copper content in the residential areas can be ascribed to the regular movement of traffic, and also to the settling of the copper onto the stream bed upstream from the residential areas. In addition, these areas are low risk areas in terms of accidential spillages.

4.5.2. Annual base flow data.

Table 4.2 gives the annual averages in mg/l of the constituents at sample points along the Palmiet River's main stream. In this discussion the tributaries are excluded to depict the changes of water quality in the main stream itself. The aim of this table is to explain the influence of land use patterns on the chemical contents in the receiving water bodies. The high nitrate content at Glenugie (see Fig. 4.7) is probably the result of the vehicular traffic on the highway as well as





4.6 Monthly changes in Copper at different points in the Palmiet River. (Average monthly values from Oct 1992 to Sep 1994).

Table 4.2. Palmiet River Main stream: Annual averages at 7 sampling points

Chemicals - Annual ave. (mg/l)	Glenugie	Crompton	St Johns	Blair Rd	Birdhurst	B/Atholl#2	UDW
COD	26.1	27.1	49.9	85.3	36.2	44.2	43.4
Cl	52.5	56.7	61.7	61.9	56.6	55.8	57.8
Nitrate	2.430	1.080	1.390	1.250	0.860	1.380	0.930
TP						0.480	0.320
Sus Solids.	194.0	255.0	287.0	345.0	280.0	267.0	260.0
TDS	242.0	255.0	303.0	324.0	316.0	272.0	263.0
Cr	0.016	0.015	0.020	0.021	0.016	0.012	0.009
Cu	0.037	0.033	0.061	0.038	0.054	0.015	0.010
Zn	0.037	0.061	0.378	0.216	0.205	0.068	0.040
Ni	0.010	0.067	0.028	0.015	0.018	0.013	0.008
Pb	0.012	0.010	0.014	0.011	0.011	0.009	0.010
Fe	0.554	0.646	0.841	1.205	0.907	0.497	0.508

the use of garden fertilizers in the residential area. All the other constituents (see Fig. 4.7) show an increase in the industrial and commercial areas, and a decline when passing through residential areas.

4.5.3 Base flow data against high flow data.

Table 4.3 shows the data from 12 high flow events, giving the chemical constituents in mg/l and the flow in liters per second. These are composite samples taken with the ISCO sampler at the UDW weir. Some of the water quality values are lower than the annual average values for base flow. This is attributed to the fact that little has been washed off from the catchment during that event and dilution occured which lowered the concentration of that particular constituent.

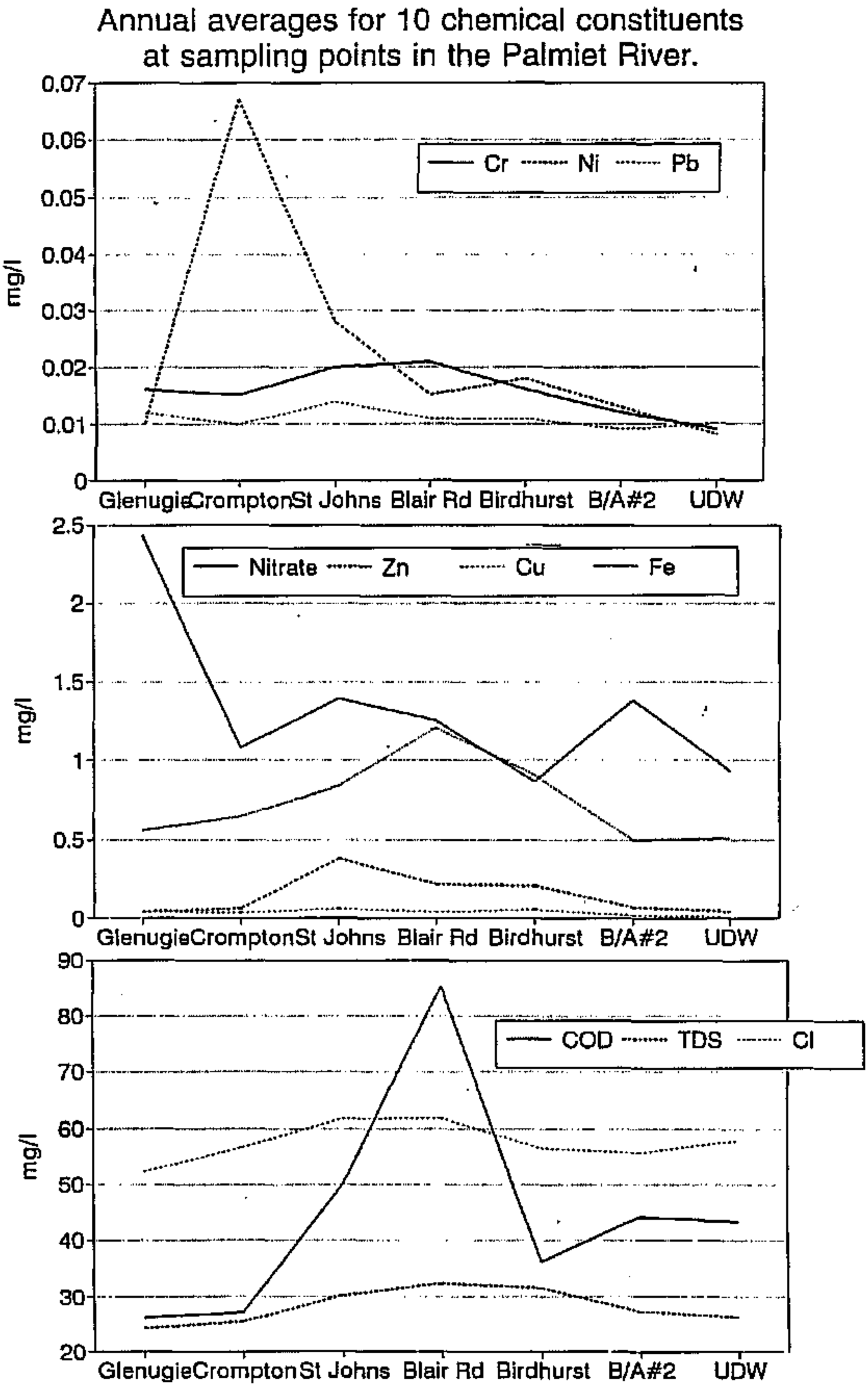


Figure 4.7. Annual averages for 10 chemical constituents at sampling points in the Palmiet River.

Table 4.3. High flow vs Baseflow values at UDW Weir.

Chemicals (mg/l)	Date										Annual Average
	12/11/92	16/11/92	11/12/92	12/12/92	09/01/93	08/02/93	03/03/93	15/03/93	27/04/93	11/08/93	
COD	51	18	76	46	58	37	21	76	20	30	43
Cl	84	54	47	50	65	26	56	32	52		58
Nitrate	2.0	1.0					3.4	0.2	1.0	1.0	0.93
TP	0.84	1.1	0.2		0.9	0.19		0.03	0.21	0.31	0.32
Sus Solids.	291	248	193	189	280	209		740	278	531	260
TDS	301	247	212	205	192	151	212	158	233	212	263
Cr	0.013	0.015	0.003	0.010	0.001	0.003	0.010	0.001	0.023	0.045	0.009
Cu	0.003	0.015	0.030	0.003	0.015	0.001	0.005	0.010	0.015	0.015	0.010
Zn	0.010	0.040	0.033	0.048	0.003	0.001	0.001	0.035	0.120	0.250	0.040
Ni	0.003	0.008	0.003	0.005	0.003	0.003	0.001	0.001	0.018	0.003	0.008
Pb	0.008	0.001	0.003	0.001	0.001	0.008	0.001	0.050	0.035	0.103	0.010
Fe	0.240	1.040	0.035	0.033	0.110	0.580	0.450	1.620	2.800	3.290	0.508
Flow (l/s)	797	952	652	952	8780	5708	4165	531	625	2305	

4.5.4 Hydrograph water quality sampling.

Three high flow events' samples were sent to Umgeni Water for chemical analysis of the different constituents. Table 4.4 (a to c) shows the change in concentration, while Figure 4.8 (a to c) shows the different hydrographs and the points on the hydrograph where samples were taken. In all three of the events, the first flush effect can be clearly detected.

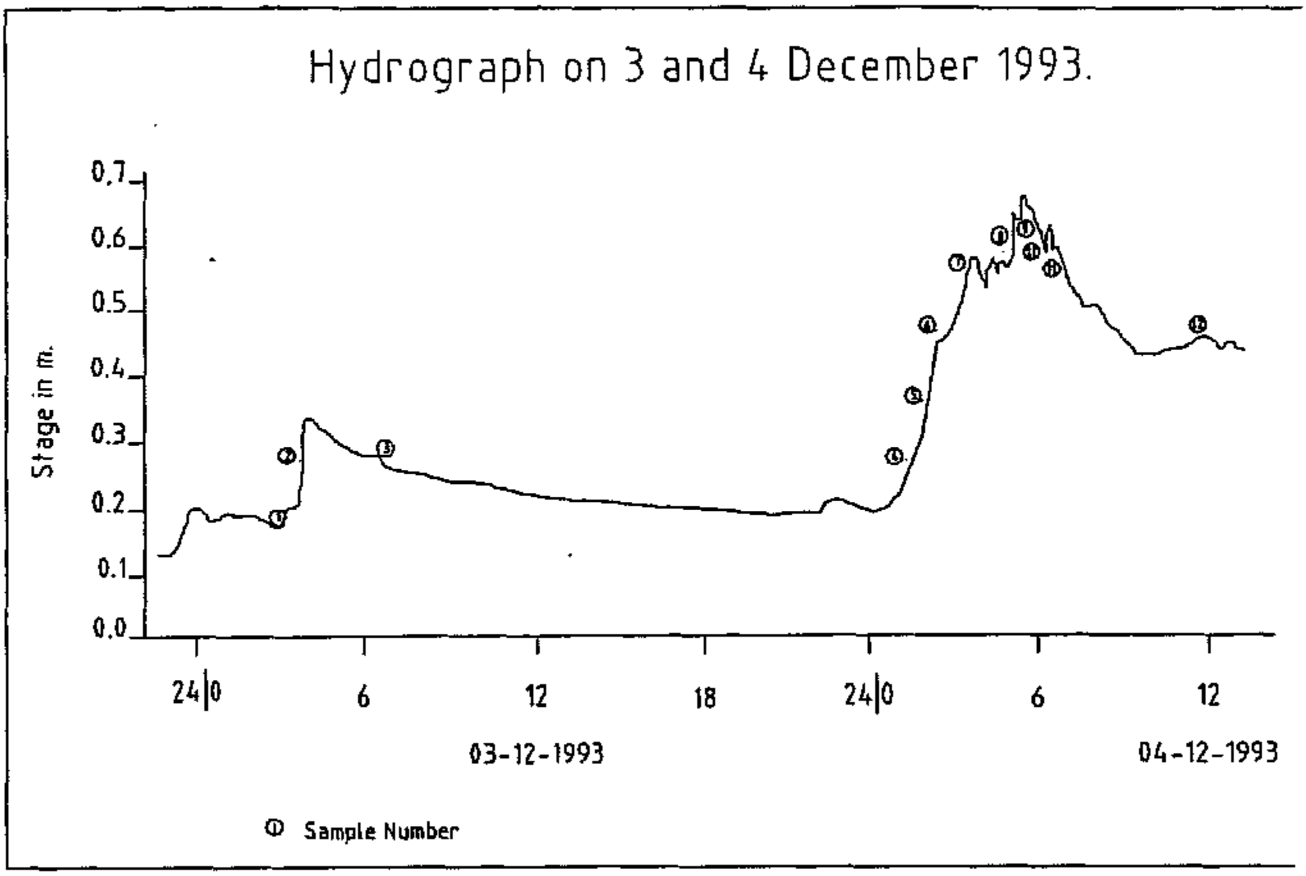


Figure 4.8a. Hydrograph on 3 and 4 December 1993.

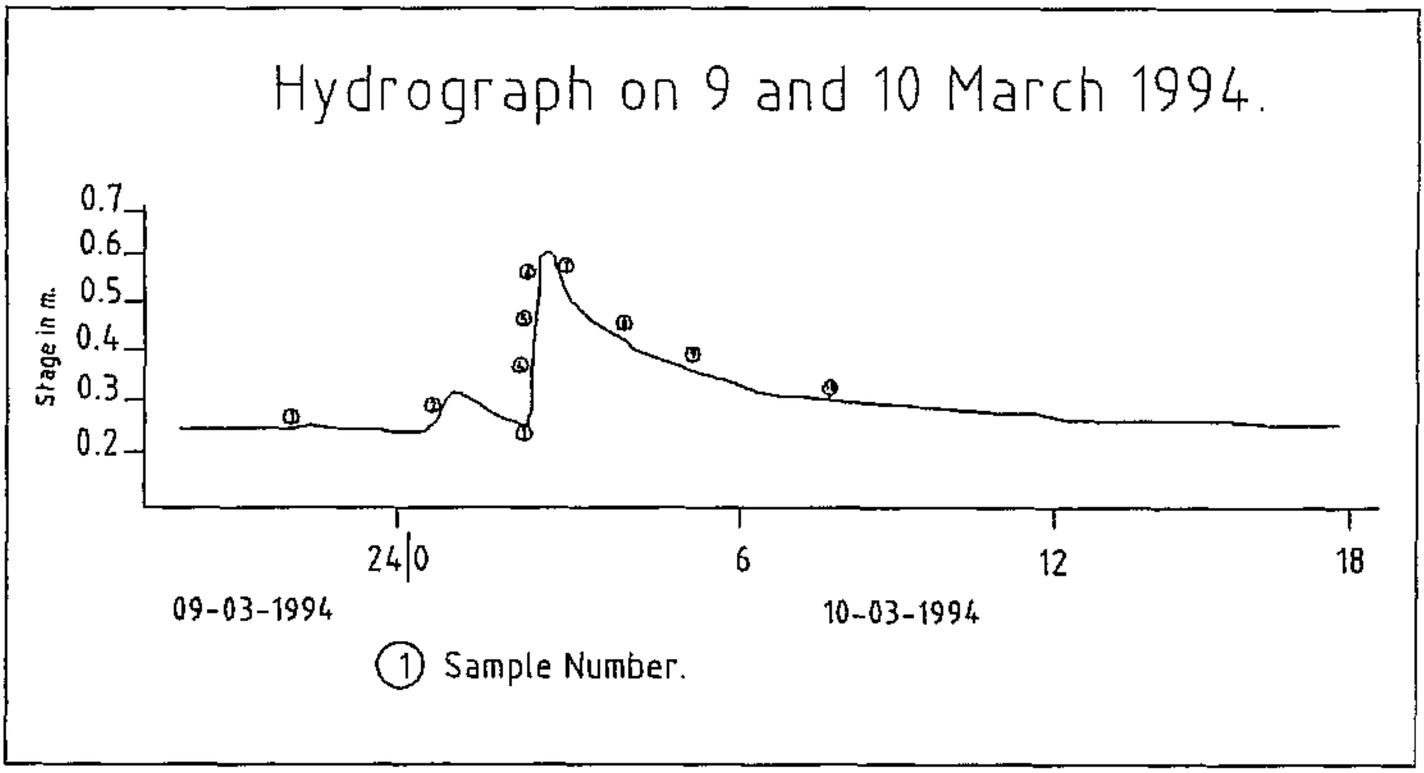


Figure 4.8b. Hydrograph 9 and 10 March 1994

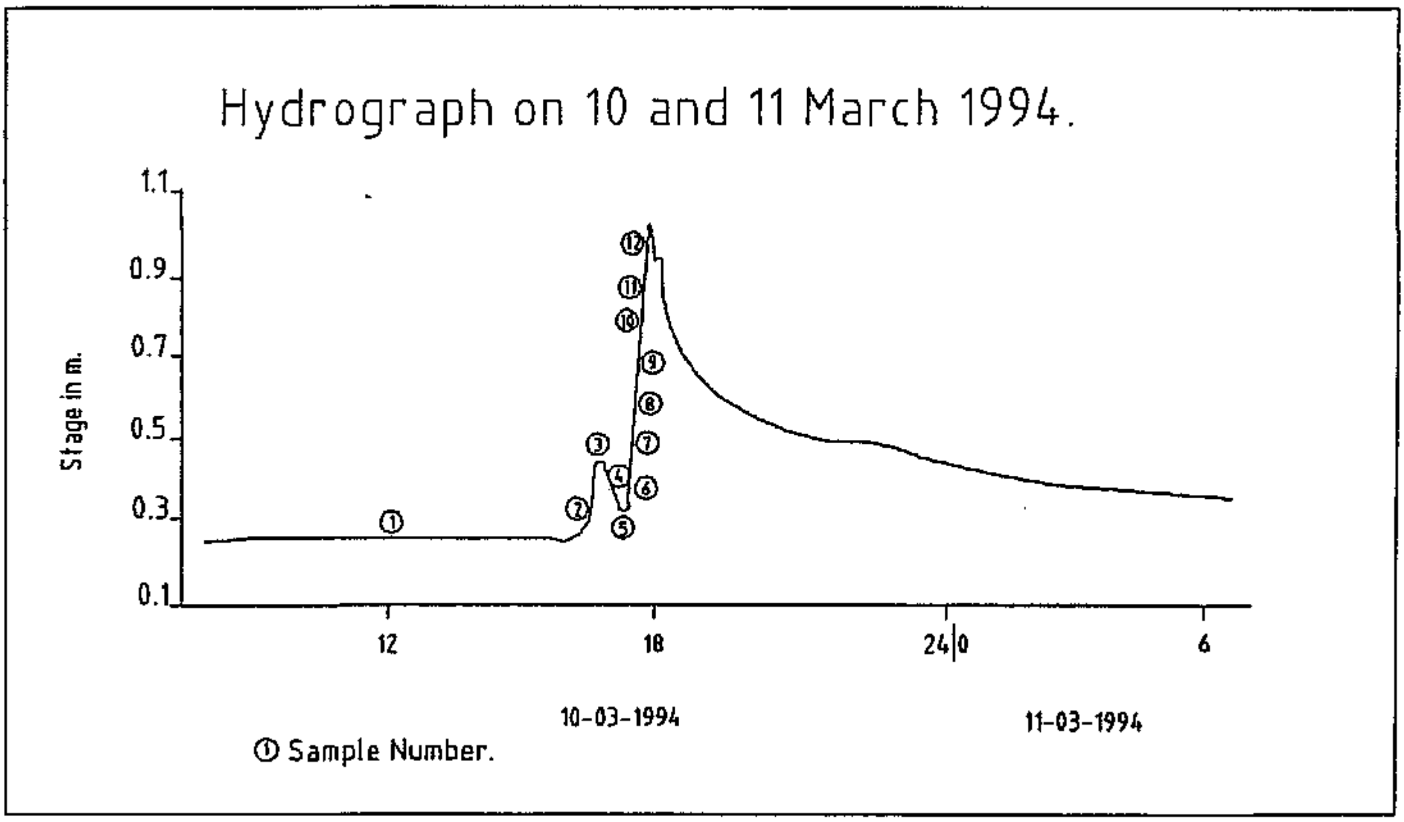


Figure 4.8c. Hydrograph on 10 and 11 March 1994

4.5.5 Weekly fallout rates at the University of Durban-Westville.

Weekly bulk fallout rates were collected on the roof top of the Science Building of the University of Durban-Westville and the analysis was done with a Hach DR2000 spectro-photometre. Table 4.5 shows the weekly fallout rates as well as corresponding constituents from Simpson, 1986. The reason for this procedure was to compare the differences between the two sites since both are in a residential setting.

Table 4.4. Changes in concentrations over a hydrograph for 3 events.

Date	04/12/93						
Sample #	SS mg/l	TP ug/l	NO3 mg/l	Cu mg/l	Cr ug/l	Pb ug/l	Zn mg/l
1	293	456	1.37	< 0.02	0.8	2.9	0.26
2	341	514	1.54	< 0.02	1.7	2.8	0.34
3	618	1187	1.71	0.03	4.3	3.9	0.66
4	276	479	1.56	< 0.02	1.1	1.3	0.29
5	367	505	1.33	< 0.02	1.5	2.1	0.32
6	130	234	0.87	< 0.02	< 0.5	< 1.0	0.12
7	82	173	0.89	< 0.02	< 0.5	< 1.0	0.08
8	96	206	0.96	< 0.02	< 0.5	< 1.0	0.10
9	77	159	0.88	< 0.02	< 0.5	< 1.0	0.06
10	30	117	0.74	< 0.02	< 0.5	< 1.0	0.04
11	18	98	1.25	< 0.02	< 0.5	< 1.0	0.02
12	18	139	0.88	< 0.02	< 0.5	< 1.0	0.02

Date	09/03/94						
Sample #	SS mg/l	TP ug/l	NO3 mg/l	Cu mg/l	Cr ug/l	Pb ug/l	Zn mg/l
1	64	88	0.94	0.03	11.5	< 1.0	0.40
2	503	463	0.66	0.06	35.5	7.0	0.18
3	810	1088	0.56	0.05	67.5	20.0	0.42
4	199	1462	0.34	0.05	84.0	26.0	0.68
5	242	462	0.63	0.04	47.0	50.1	0.29
6	127	411	0.66	0.03	42.5	37.0	0.29
7	140	252	0.76	< 0.02	27.9	26.0	0.13
8	62	279	0.85	0.04	24.5	36.0	0.14
9	88	289	0.86	< 0.02	27.0	29.5	0.17
10	94	255	0.94	0.03	19.5	24.0	0.13

Date	10/03/94						
Sample #	SS mg/l	TP ug/l	NO3 mg/l	Cu mg/l	Cr ug/l	Pb ug/l	Zn mg/l
1	186	459	0.28	0.03	34.5	56.5	0.28
2	220	203	0.22	< 0.02	16.0	21.0	0.07
3	569	511	0.16	< 0.02	21.5	25.5	0.11
4	1133	1702	0.28	0.03	84.5	64.0	0.69
5	1044	1513	0.29	< 0.02	56.5	64.0	0.32
6	929	1067	0.20	< 0.02	71.0	59.0	0.28
7	1126	1239	0.18	0.02	72.0	79.0	0.39
8	1070	1281	0.21	0.03	73.5	82.0	0.48
9	1506	1669	0.14	< 0.02	67.0	55.0	0.28
10	835	1904	0.27	0.08	167.0	155.0	0.95
11	1489	1253	0.14	< 0.02	64.0	61.0	0.29
12	894	759	0.42	0.04	100.0	101	0.54

Table 4.5. Weekly fallout rates for selected constituents.

Constituent	UDW: kg/ha.wk	Simpson, 1986: kg/ha.wk
Chloride	0.8600	0.8000
Copper	0.0220	0.0022
Chromium	0.0060	0.0040
Lead	0.0090	0.0110
Nitrogen	0.2300	0.2800
Zinc	0.4100	0.0160
Suspended Solids	7.0000	6.1000
Phosphorus	0.1070	0.0120

Chlorides, chromium, lead, nitrogen and suspended solids compare well. The differences in results in copper, zinc and phosphorus might be ascribed to emissions on the University of Durban-Westville's campus.These values may therefore not be a true reflection of general fallout rates for residential land use, yet it is important to simulate the impact of a university on its immediate environment in terms of pollutant deposition and washoff, leading to eventual contamination of water bodies.The stormwater runoff from a university will eventually end up in a water body via its storm water drainage system.

In this section the collection and analysis of the data were discussed. The data can be grouped into four main groups namely rainfall, water quality samples taken on a weekly basis and water quality samples during high flow events. The latter were collected either as a composite sample or as hydrograph water quality samples. The fourth group is the collection of weekly fallout rates at the University of Durban-Westville. The data formed part of the simulation runs for model verification, discussed in the next chapter.

5 MODEL APPLICATIONS

5.1 INTRODUCTION

In this chapter the model applications will be discussed. Since the Pinetown Catchment was used as a driver catchment when testing the improvements and changes made in the different models, the results from this catchment will be discussed first. This is followed by the applications done on the Palmiet River Catchment.

5.2 THE PINETOWN CATCHMENT (1982 to 1985)

5.2.1 Water quality simulations.

Water quality simulations in terms of annual export loads in kg/ha.a were done on the Pinetown Catchment. No base flow simulations were done since it is a fully reticulated catchment. Table 5.1 gives the simulation results as well as the observed values for the three corresponding years of Simpson's research period from 16-09-1982 to 15-09-1985.

The results were also plotted on a logarithmic chart (see figure 5.1) and it is evident that the model closely simulates the observed values, except for chlorides in years 2 and 3 where the model under-simulated the chloride values. In year 2 the model over-simulated the zinc value.

Table 5.1 Observed vs Simulated Values for the Pinetown Catchment in kg/ha.a.

Constituent	1982/9/16 to	1983/9/15	1983/9/16 to	1984/9/15	1984/9/16 to	1984/9/15
	Observed	Simulated	Observed	Simulated	Observed	Simulated
TDS	179	171	479	540	444	407
SS	479	458	1629	1749	1574	1416
TP	1.9	1.7	3	3	3.2	2.7
TN	7.1	6.1	17	18	15	15.7
Cl	23	21	50	35	51	29.6
Pb	0.66	0.73	1.4	1.3	1.9	1.2
Zn	1.3	1.8	2.1	6.3	2.3	2.6
Fe	15	11	36	37	38	24
Cr	0.18	0.17	0.44	0.3	0.38	0.26
Cu	0.11	0.1	0.23	0.2	0.26	0.15

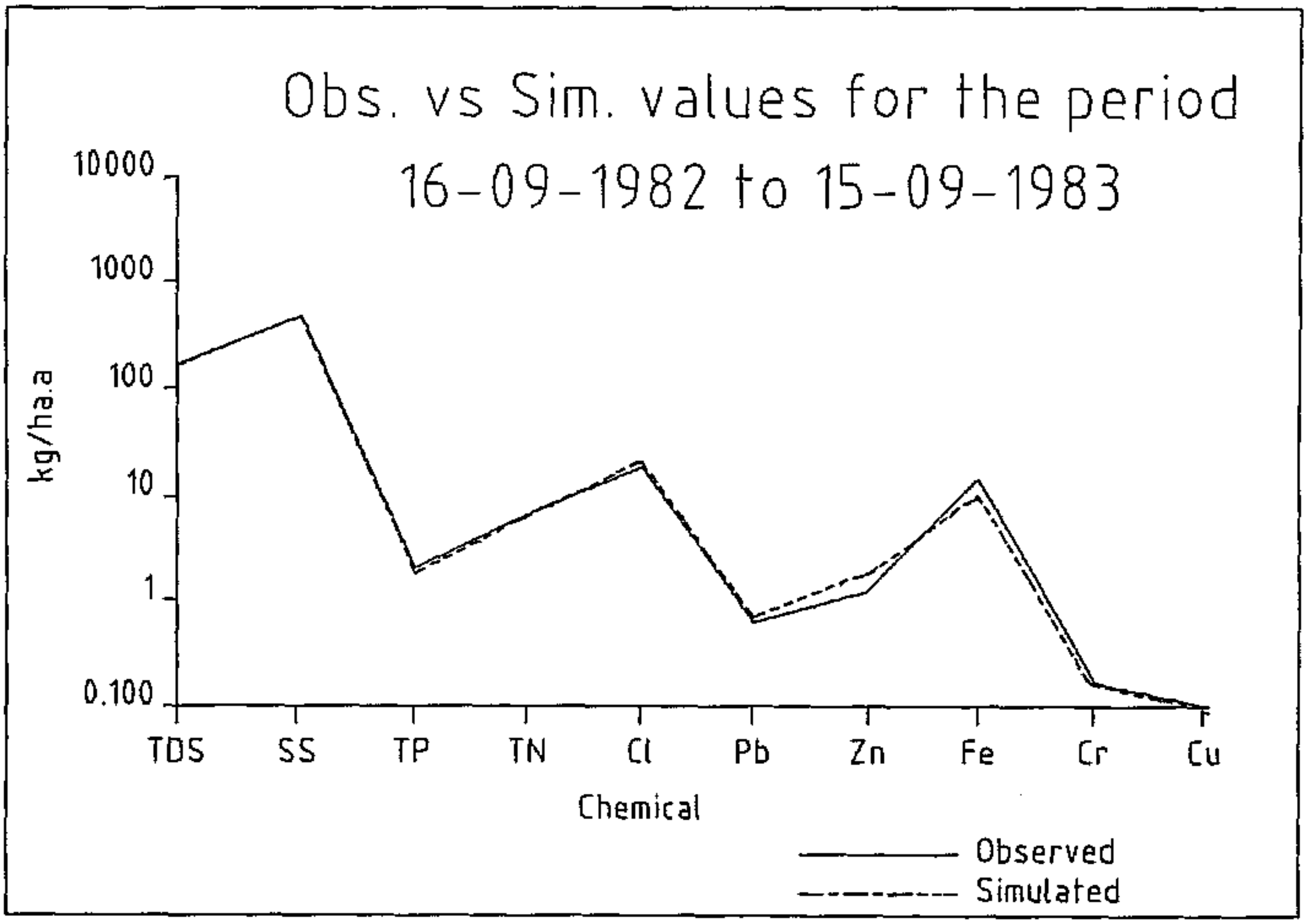


Figure 5.1a Observed vs Simulated Values for the Pinetown Catchment in kg/ha.a from 16-09-1982 to 15-09-1983

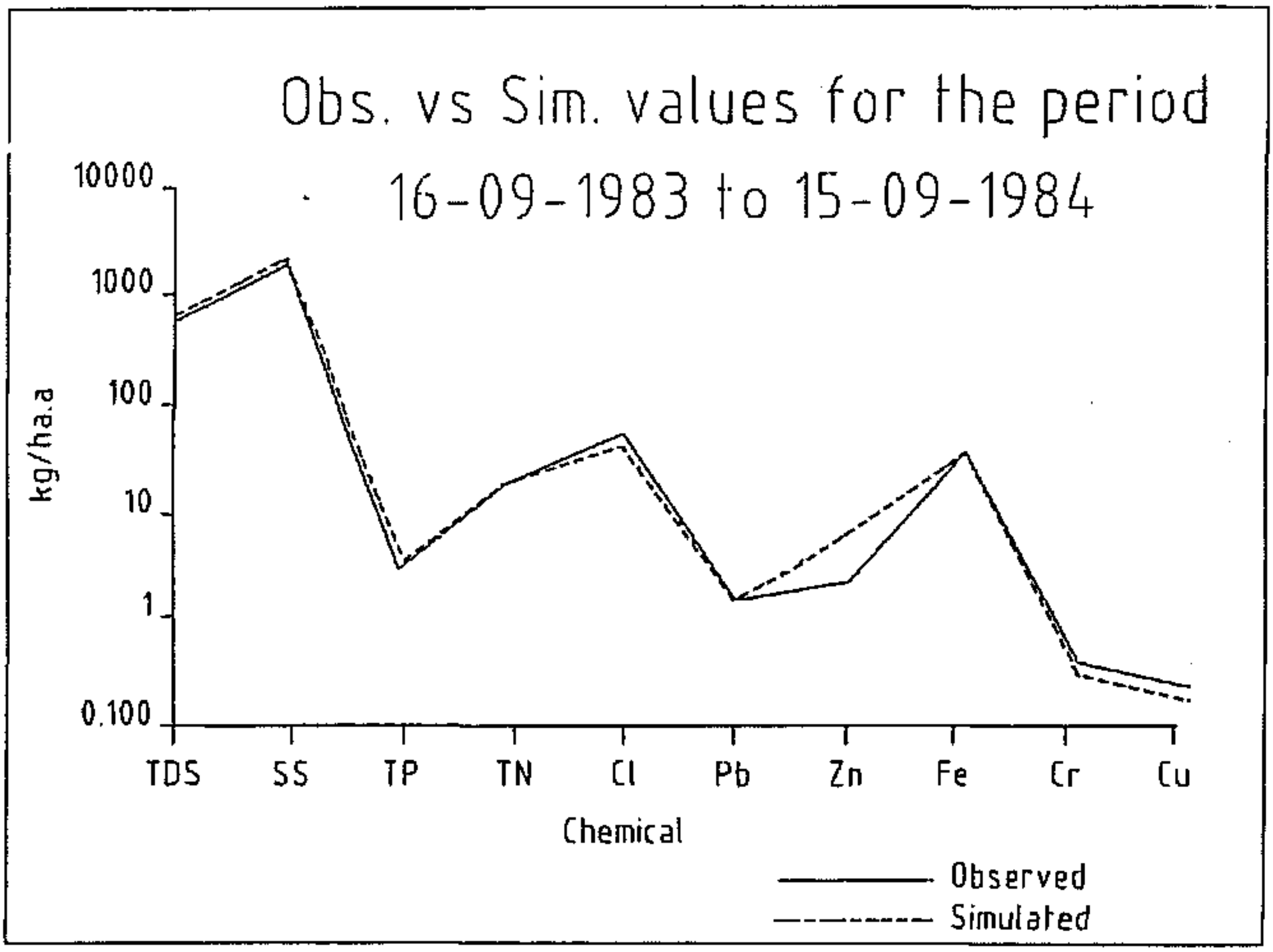


Figure 5.1b Observed vs Simulated Values for the Pinetown Catchment in kg/ha.a from 16-09-1983 to 15-09-1984

5.2.2 Hydrograph simulations.

Eleven rainfall events from Simpson's 1986 study were used to test the *WASHMO* model's incorporation into *ACRU*. Since these rainfall events are single storm events *ACRU* was run as a single event storm hydrograph model.

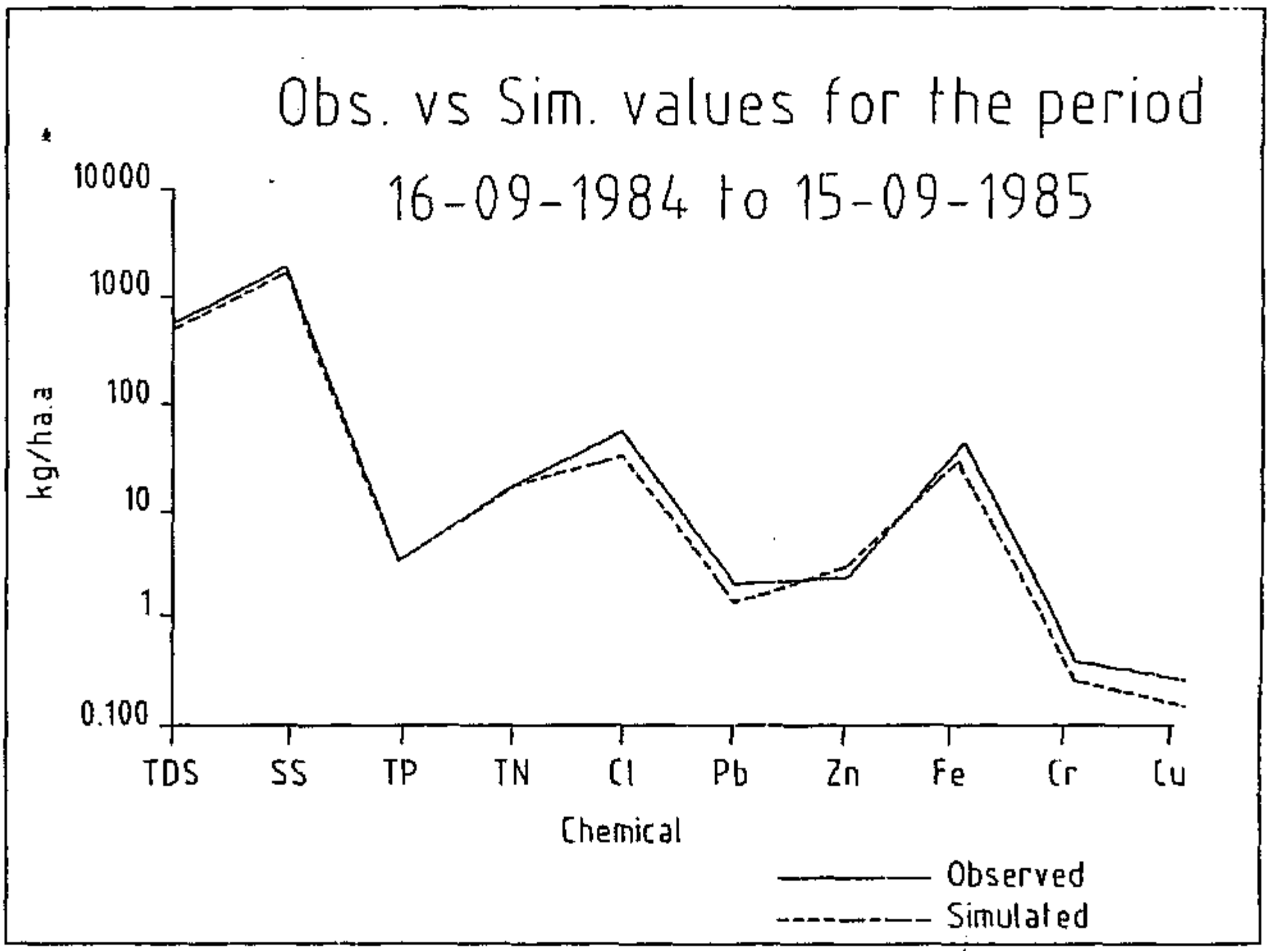


Figure 5.1c Observed vs Simulated Values for the Pinetown Catchment in kg/ha.a from 16-09-1984 to 15-09-1985

The rainfall increment is at a two minute interval and the same interval is used for *WASHMO's* own rainfall distribution option in *ACRU*. Figures 5.2 (a) to (k) show the observed and simulated hydrographs together with the rainfall distribution over the two minute interval. Since the simulations were done to represent actual catchment conditions the antecedent soil moisture content was used for the CN of the pervious section of the catchment, as described in Schmidt and Schulze, 1987.

The model under-simulated the flow in six events (Fig.5.2 (a),(d),(e),(g),(i) and (k)) and over-simulated in the other events. This can also be clearly seen in the graph in Figure 5.3 comparing observed peakflow and simulated peakflow. Storm events A to K represent the same storm event as in Figure 5.2 (a) to (k). A product-moment correlation analysis was done using the six actual flow and simulated values, giving a correlation coefficient of 0.954. This indicates a high positive correlation between the two values which implies that the model is capable of simulating runoff effectively. The only exception is the rainfall event of 1984-04-16 (event S117 in Simpson,1986) where the outflow nearly reached full pipe flow.

The *WASHMO*-model is not designed at the present stage to accommodate pipe flow, although the model makes provision for flow of water through a concrete pipe or concrete channel. However, it is not adapted for pipe diameters that restrict the flow through the pipe.

5.3 THE PALMIET CATCHMENT (1992 to 1994)

5.3.1 Runoff simulations.

The *ACRU* model was used to simulate runoff from the Palmiet Catchment on a daily basis, using the existing structures in *ACRU* for pervious and impervious

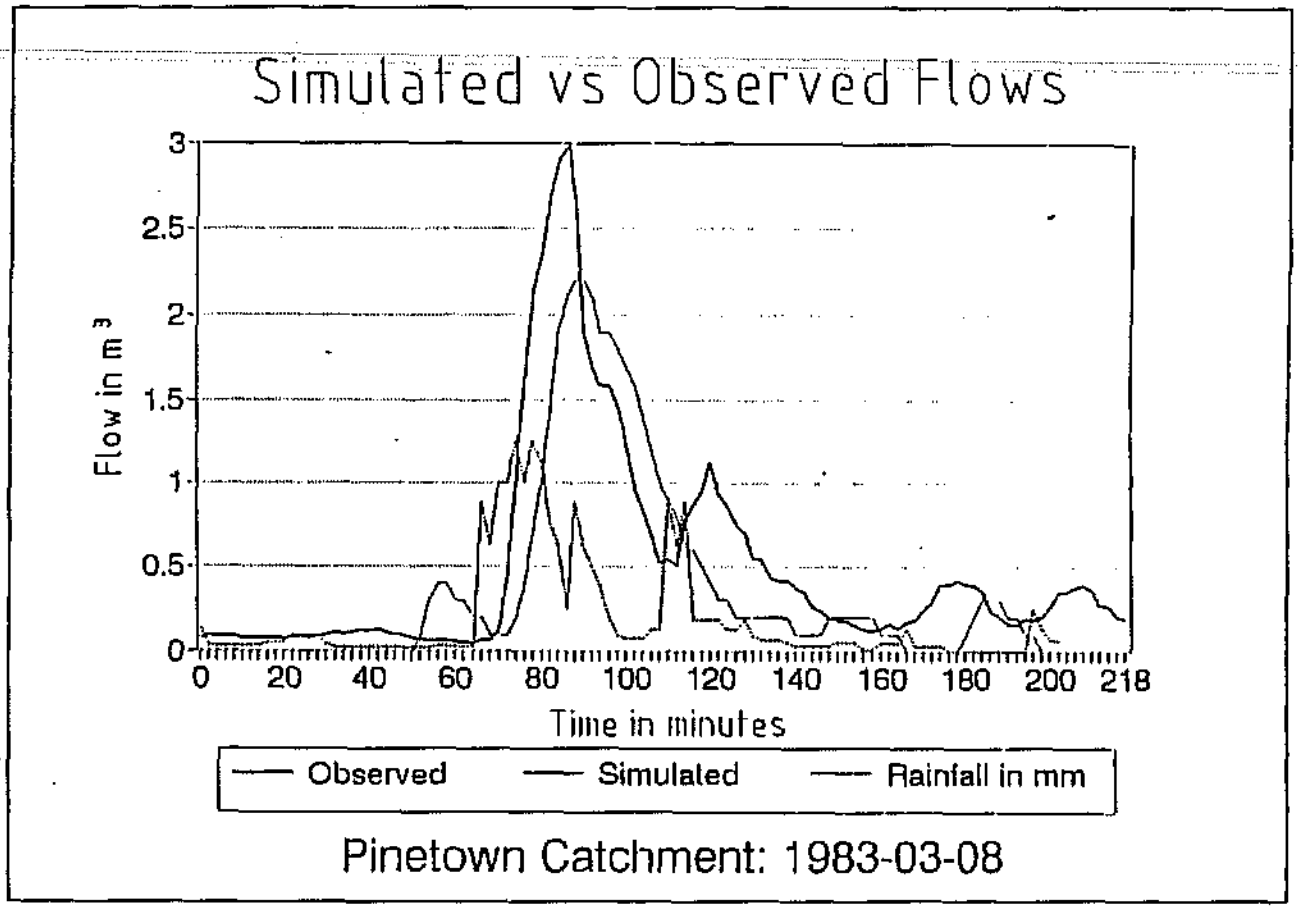


Figure 5.2a. Simulated vs Observed flow in the Pinetown Catchment.

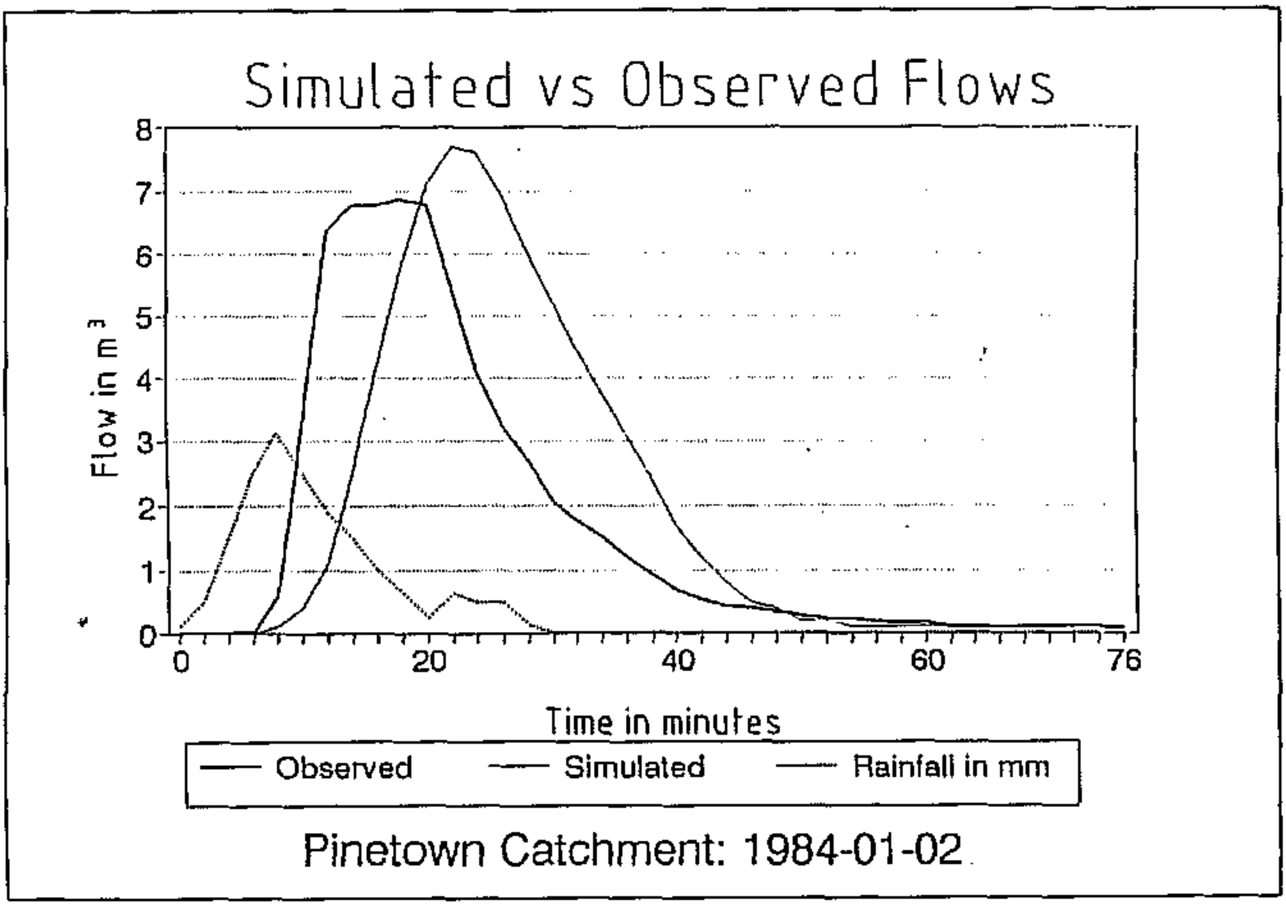


Figure 5.2b. Simulated vs Observed flow in the Pinetown Catchment.

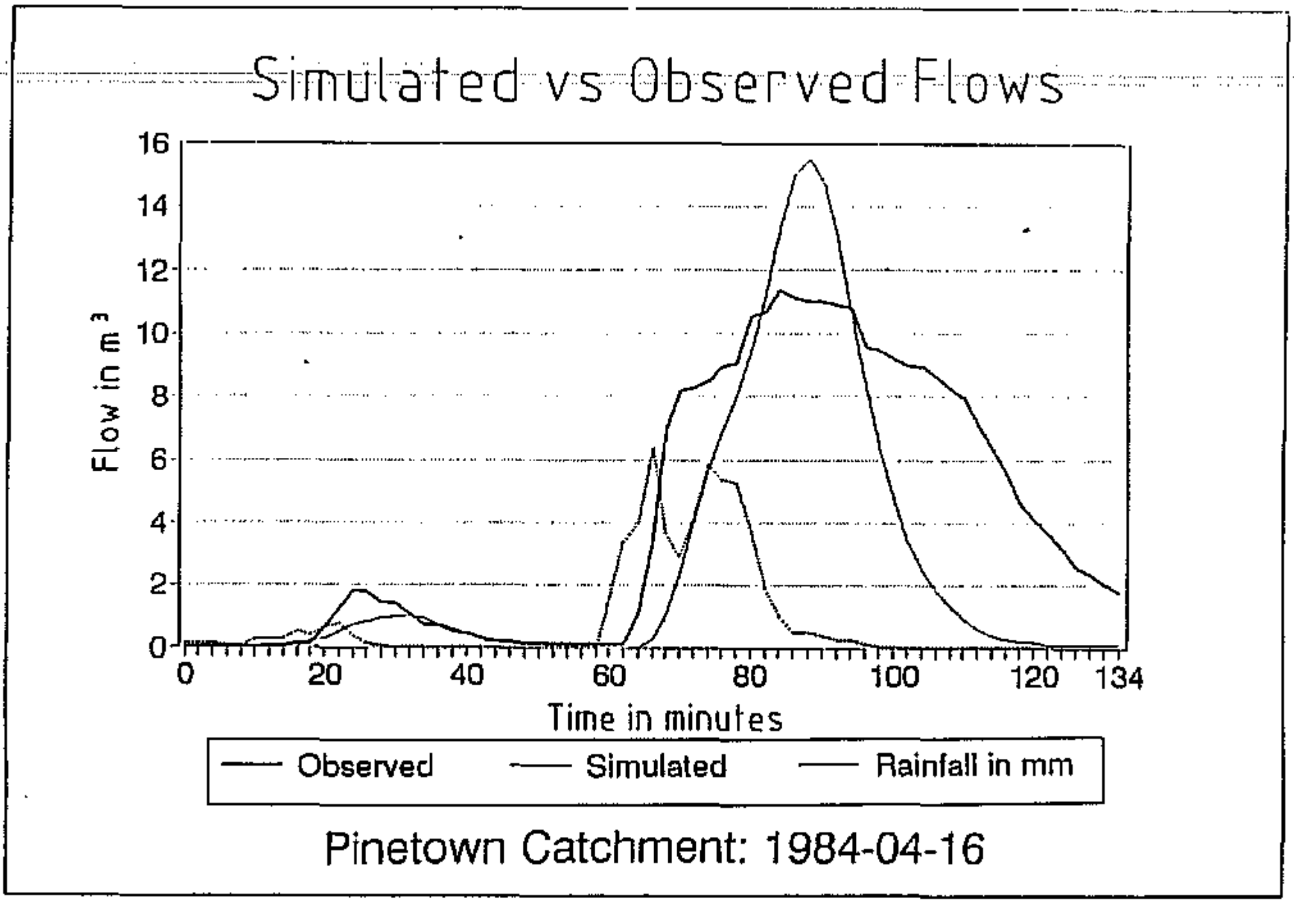


Figure 5.2c. Simulated vs Observed flow in the Pinetown Catchment.

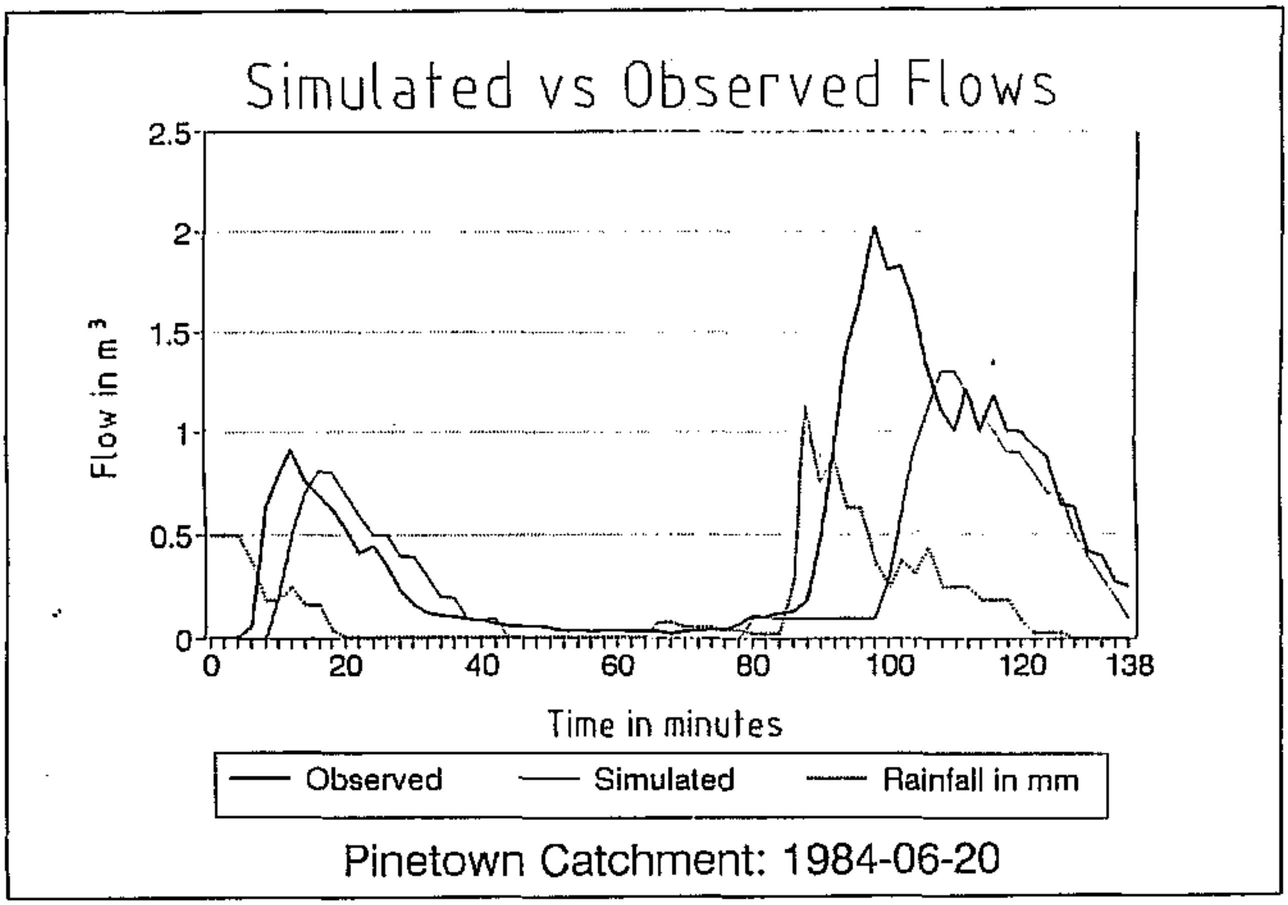


Figure 5.2d. Simulated vs Observed flow in the Pinetown Catchment.

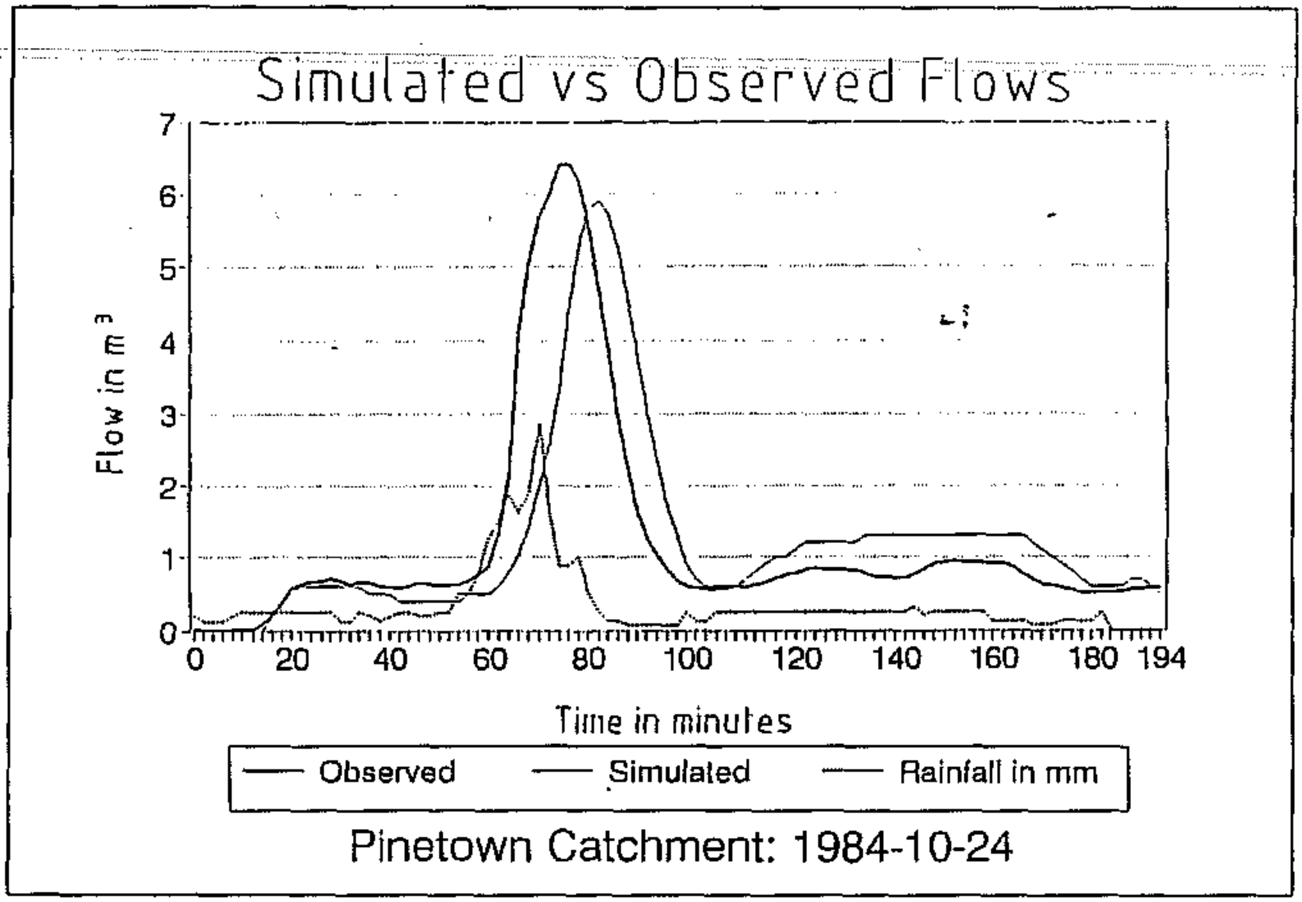


Figure 5.2e. Simulated vs Observed flow in the Pinetown Catchment.

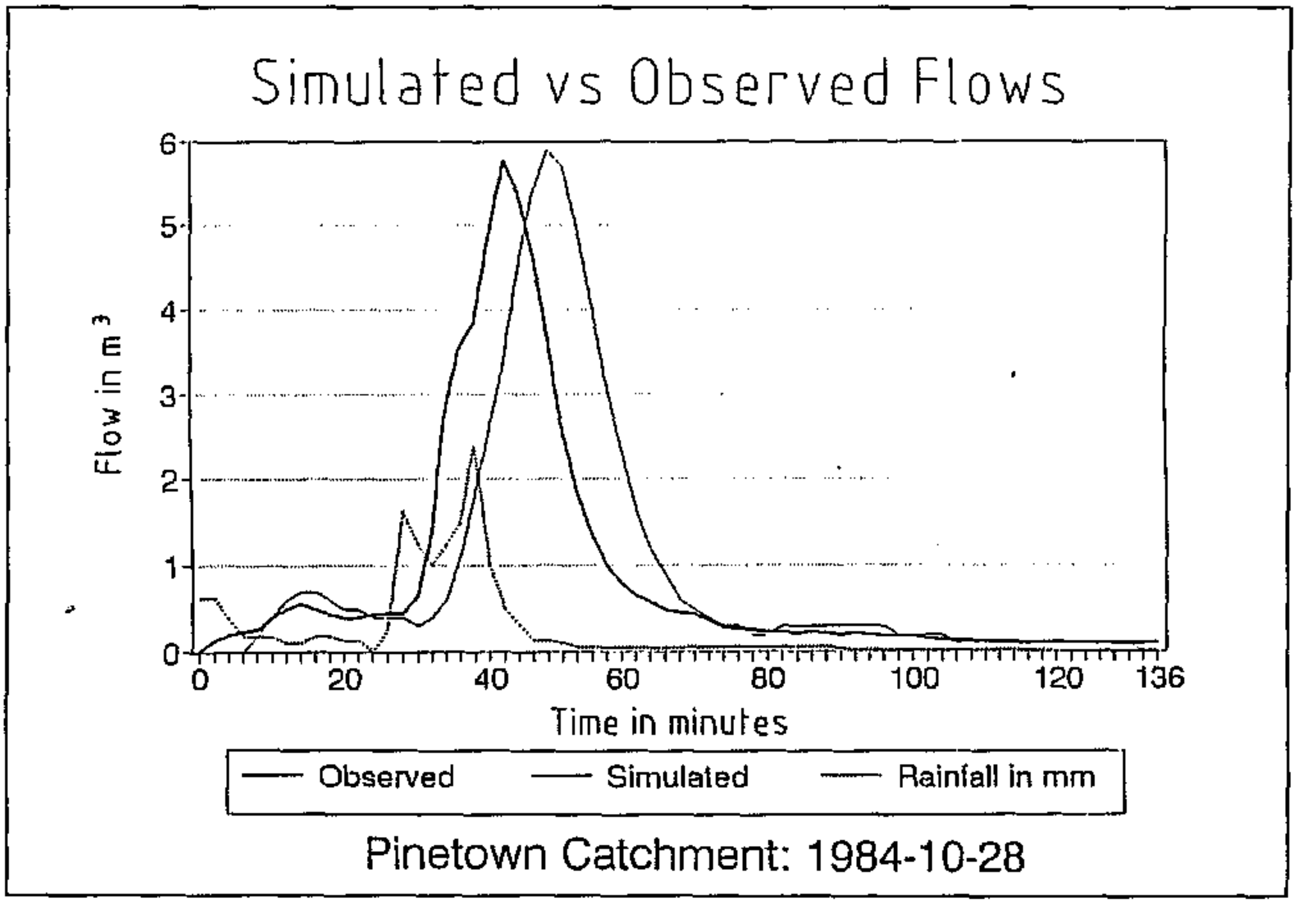


Figure 5.2f. Simulated vs Observed flow in the Pinetown Catchment.

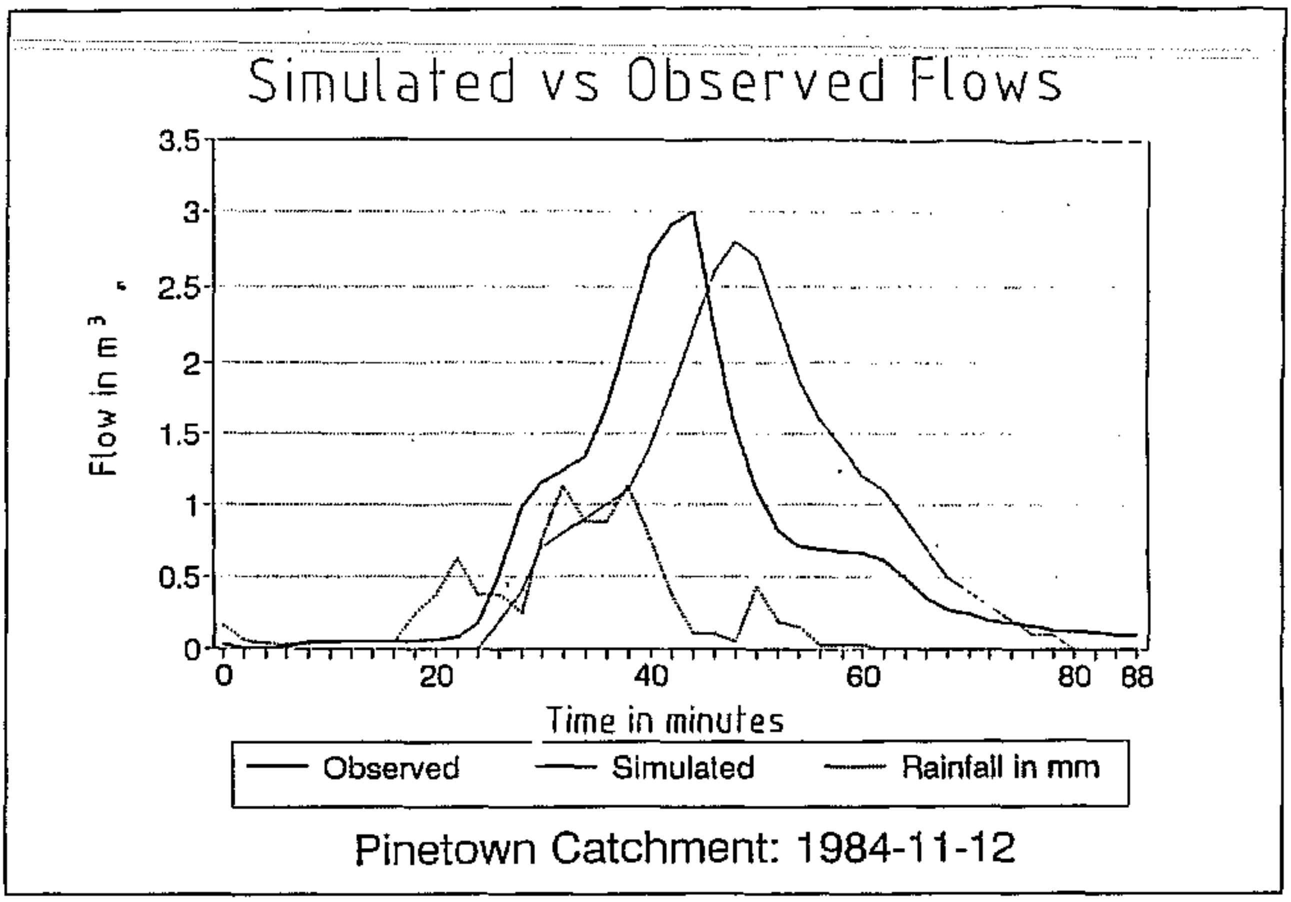


Figure 5.2g. Simulated vs Observed flow in the Pinetown Catchment.

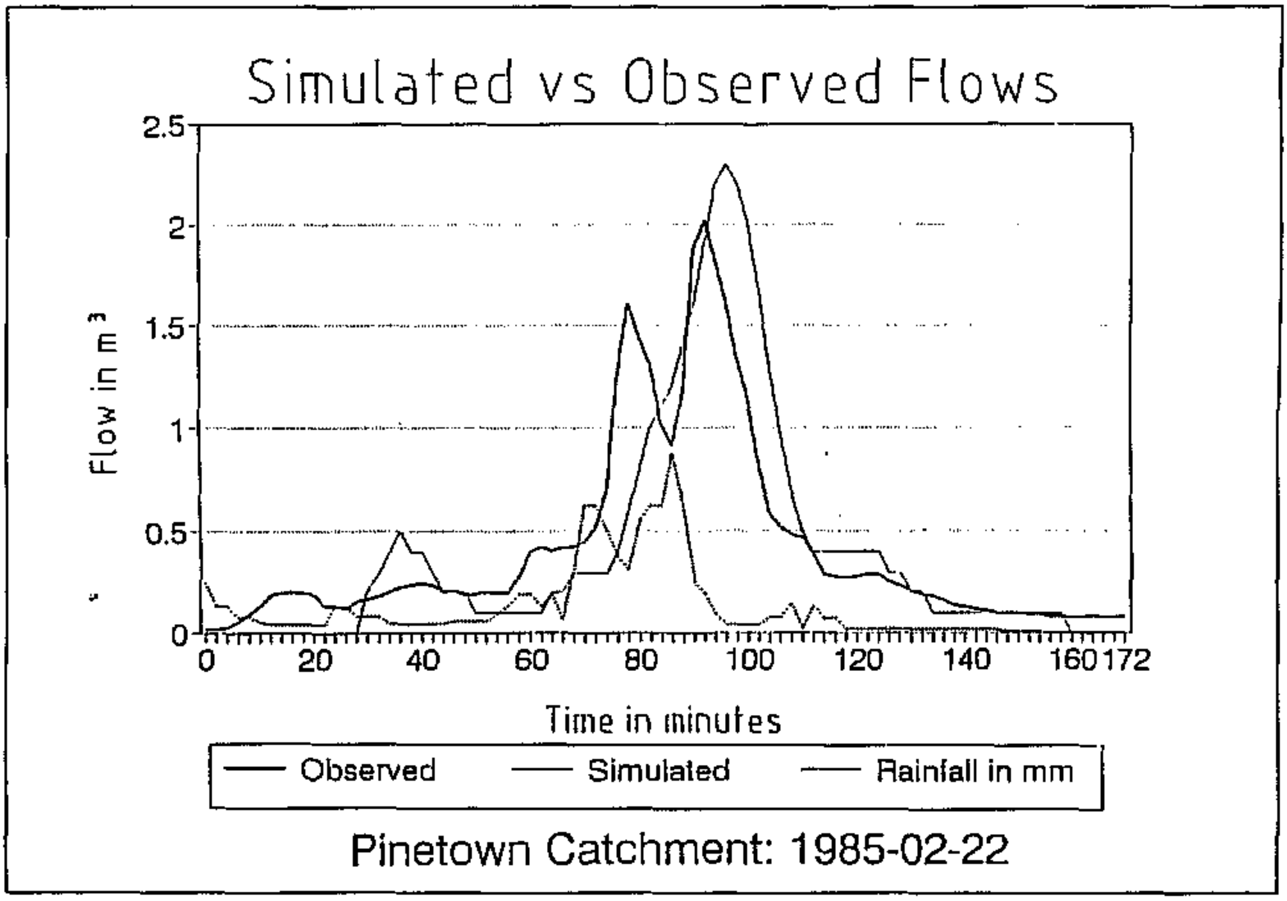


Figure 5.2h. Simulated vs Observed flow in the Pinetown Catchment.

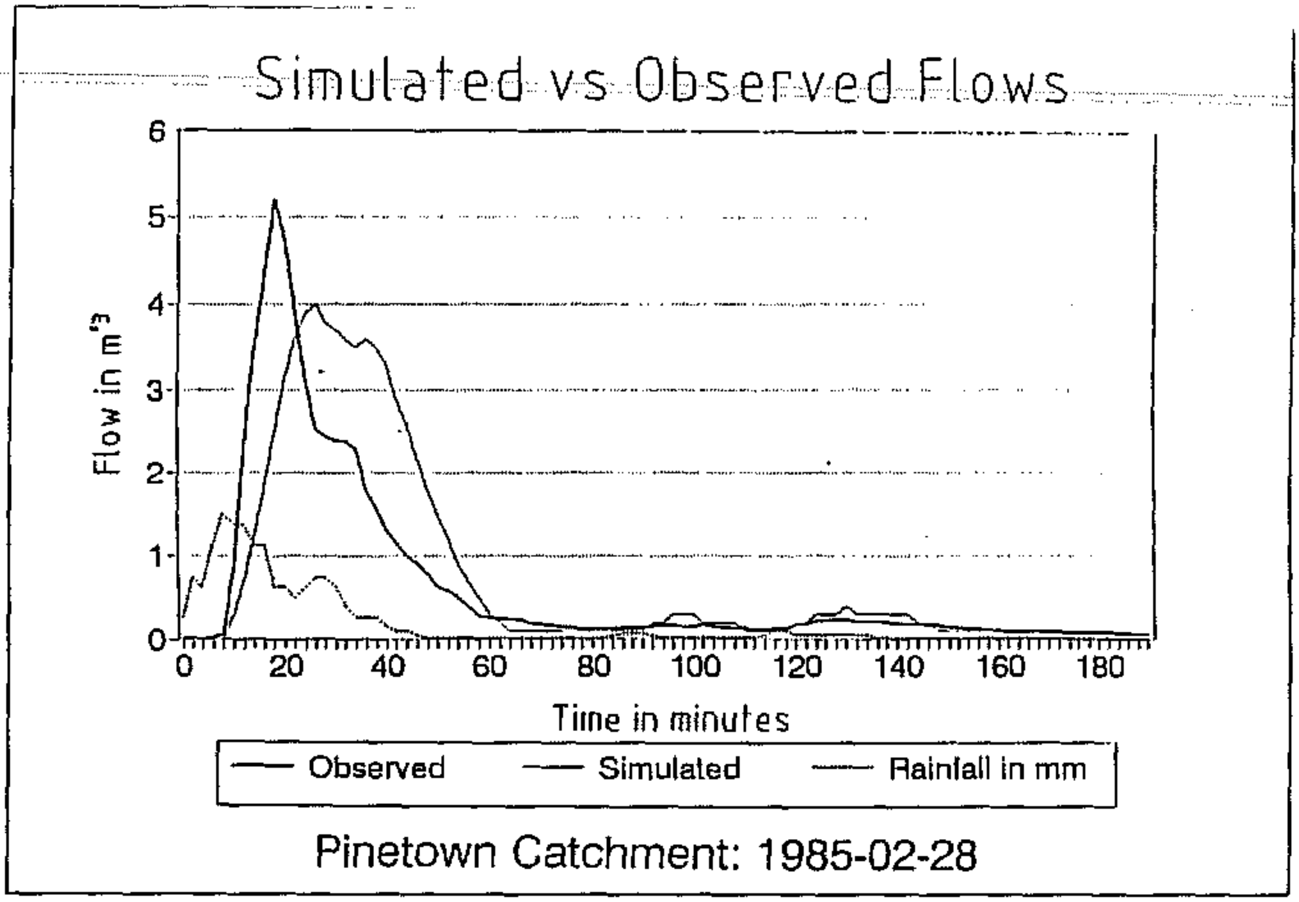


Figure 5.2i. Simulated vs Observed flow in the Pinetown Catchment.

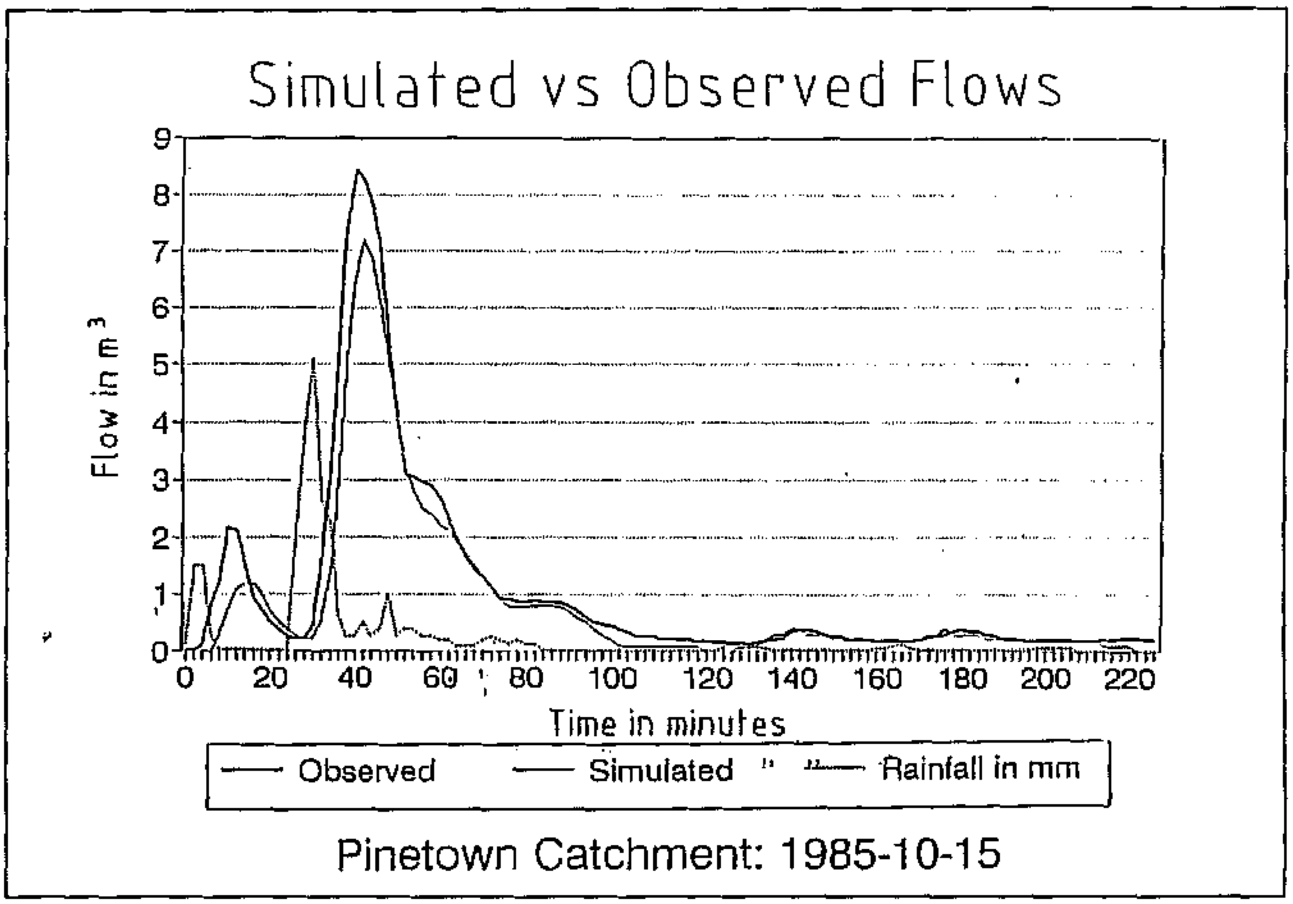


Figure 5.2j. Simulated vs Observed flow in the Pinetown Catchment.

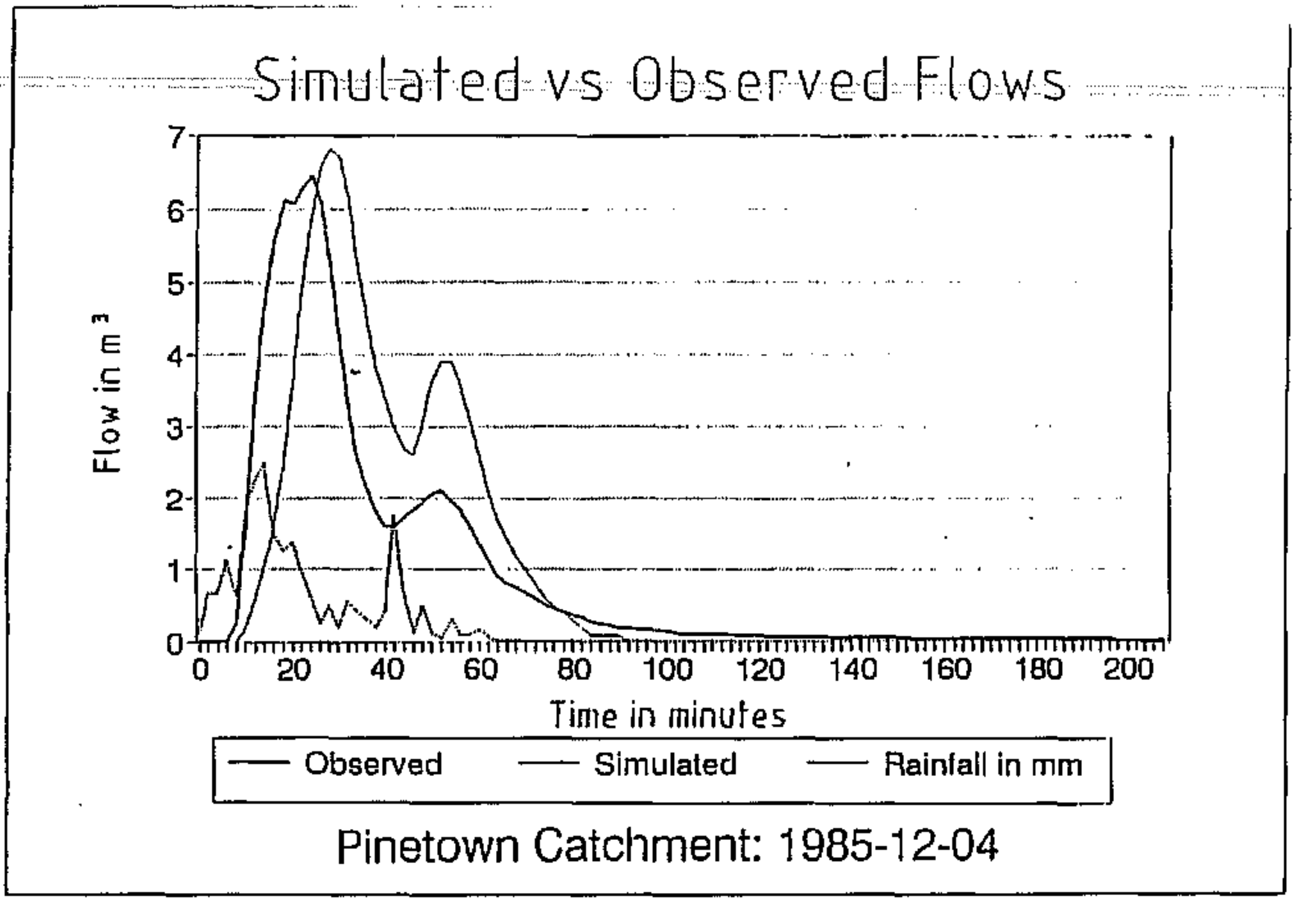


Figure 5.2k. Simulated vs Observed flow in the Pinetown Catchment.

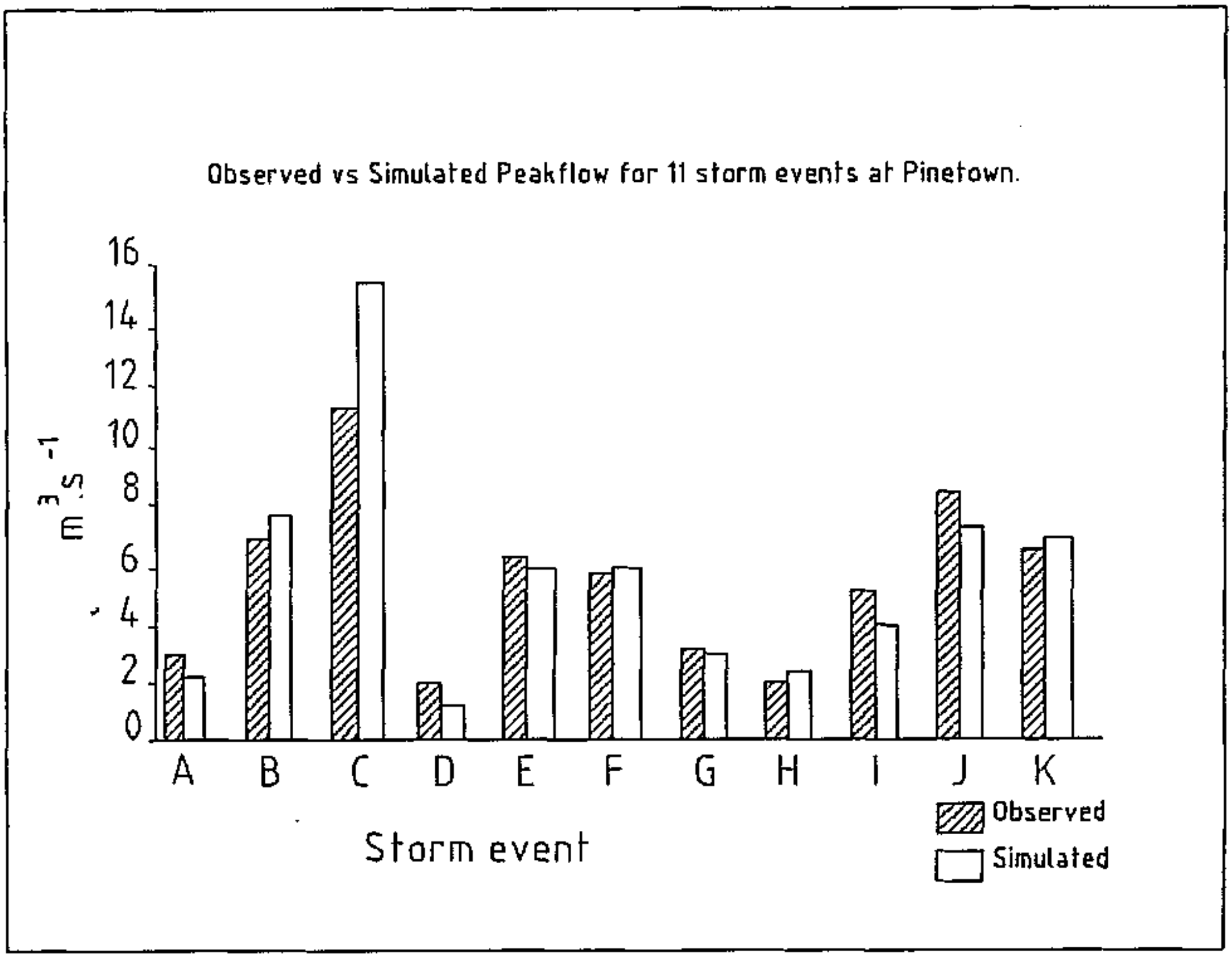


Figure 5.3 Observed vs Simulated peakflow for the 11 storm events at Pinetown.

surfaces as developed by Tarboton and Schulze (1992). This was done to determine if it was necessary for further improvements to be made in *ACRU* for runoff simulations from a fully urbanized catchment. Table 3.1 gives the breakdown of land use in each subcatchment. The land use in the Palmiet River Catchment can be summarized as follows: the total catchment size is 20.3 square kilometers of which residential areas form 11.64; open spaces, including nature reserves and sport and recreation, 4.55; industrial areas 2.4 and commercial areas 1.71 square kilometers respectively. Table 5.2 gives the monthly accumulated flow in cubic meters for both the actual and simulated flow and Figure 5.4 gives a scatter diagram of simulated vs. observed runoff

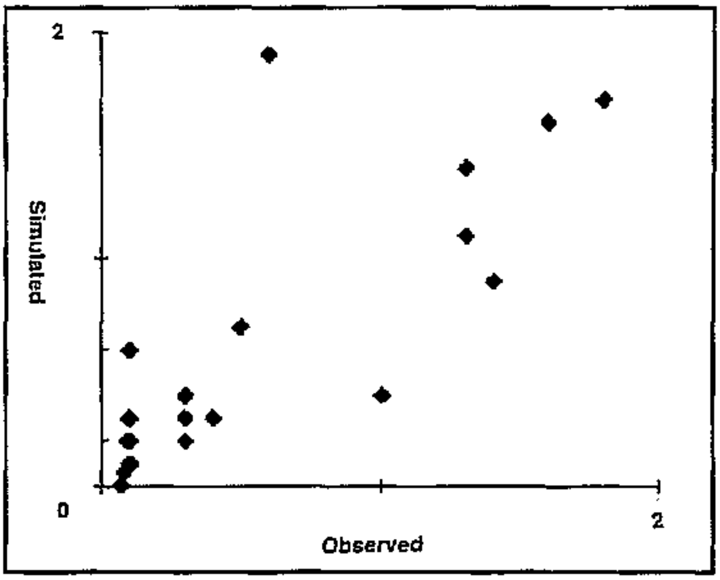


Figure 5.4 Scatter diagram of simulated vs observed monthly runoff values from January 1993 to September 1994, in the Palmiet River Catchment.(units = x 1000 000 m^3)

Table 5.2. Monthly discharge in cubic meters from Jan 1993 to Oct 1994.

Discharge:	Simulated vs	Observed
Units =	x1 000 000	cubic meters
Month	Simulated	Observed
Jan 93	0.90	1.40
Feb 93	0.40	0.30
Mar 93	0.20	0.30
Apr 93	0.30	0.30
May 93	0.06	0.08
Jun 93	0.01	0.07
Jul 93	0.20	0.09
Aug 93	0.20	0.10
Sep 93	0.70	0.50
Oct 93	1.70	1.60
Nov 93	0.60	0.10
Dec 93	1.40	1.30
Jan 94	1.60	1.60
Feb 94	0.30	0.40
Mar 94	1.90	0.60
Apr 94	0.40	1.00
May 94	0.10	0.10
Jun 94	0.30	0.10
Jul 94	1.10	1.30
Aug 94	0.30	0.40
Sep 94	0.09	0.10

values. When applying the product-moment correlation to assess the relationship between observed and simulated values the correlation coefficient (r) is 0.802 which is also reflected in the scatter diagram of Figure 5.4. *ACRU* in some instances over-simulated the runoff and in other months under-simulated it. Taking the high correlation coefficient into consideration the *ACRU* model is capable of simulating runoff from a fully urbanized catcnment.

5.3.2 Water quality simulations

Scatter diagrams were compiled for some of the chemical constituents analyzed in the ten selected storm events. The chemicals used were COD, Cl, N, suspended solids, Cr, Cu, Zn, Pb and Fe. Daily accumulation rates were used to simulate the build-up of pollutants which were then available for washoff. Table 5.3 gives the export values from the catchment in kg/ha.day for ten selected storm events. Figure 5.5 shows the scatter diagram for COD, Cl and suspended solids.From these scatter diagrams and Table 5.3 it is evident that the model does in some instances over-simulate (e.g. suspended solids in event 9/1/93) and under-simulate (e.g. suspended solids in event 11/8/93), but in general the model gives a good reflection of the actual situation. This is confirmed by Table 5.4, where there is a good correlation between the observed and simulated values except for chromium (Cr) and nitrogen (N) which show a low negative correlation indicating either strong over-simulation or under-simulation.

5.4 CONCLUSION

It is evident from the above discussions that the models linked into *ACRU* performed satisfactorily on the two catchments. The existing structure in *ACRU* in terms of urban areas with pervious and impervious surfaces is sufficient to model daily, monthly and annual runoff from fully urbanized catchments. However the original structure of *ACRU* is not sufficient to model the above on smaller time steps than a day. The new structure in *ACRU* (*WASHMO* and *NPS*), in terms of hydrograph generation as well as daily, monthly and annual water quality simulation from urban areas, is able to simulate events in a catchment sufficiently. In terms of water quality simulations, the model performs better on reticulated catchments which minimize base flow than on natural streams with base flow components, as indicated by the selected storms in section 5.3.2. Guidelines for setting up the *ACRU-NPS* and *WASHMO* models will be discussed in Appendices A and B.

Table 5.3. Export values in kg/ha.day for selected storm events.

Date	12/11/92		16/11/92		11/12/92		12/12/92		09/03/93	
Chemicals (kg/ha.day)	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed
COD	1.0	2.0	2.0	1.0	1.0	2.0	1.0	2.0	23.0	17.0
Cl	1.0	2.0	1.0	2.0	0.4	1.0	0.4	2.0	10.0	19.0
Nitrate	0.033	0.08	0.041	0.041						
Sus. Solids.	6.0	10.0	9.0	10.0	4.0	5.0	4.0	8.0	107	75
TDS	1.0	6.0	2.0	1.0	1.0	1.0	1.0	1.0	19.0	6.0
Cr	< 0.001	< 0.001	0.001	0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.009	0.001
Cu	< 0.001	< 0.001	< 0.001	0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.004	0.004
Zn	0.002	< 0.001	0.002	0.002	0.001	0.001	0.001	0.002	0.027	0.010
Pb	0.001	0.002	0.001	< 0.001	0.001	< 0.001	0.001	< 0.001	0.017	0.014
Fe	0.020	0.010	0.030	0.040	0.010	0.001	0.010	0.001	0.400	0.100

Table 5.3. Continued

Date	08/02/93		08/03/93		15/03/93		27/04/93		11/06/93	
Chemicals (kg/ha day)	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed
COD	3.0	6.0	1.0	0.1	4.0	2.0	3.0	1.0	2.0	2.0
Cl	1.0	4.0	0.3	0.3	2.0	1.0	1.0	1.0		
Nitrate			0.018	0.016	0.109	0.010	0.070	0.030	0.06	0.06
Sus. Solids.	14.0	32.0			20.0	18.0	13.0	7.0	11.0	32.0
TDS	2.0	2.0	1.0	0.1	4.0	1.0	2.0	1.0	2.0	1.0
Cr	0.001	0.001	< 0.001	< 0.001	0.002	< 0.001	0.001	0.001	0.001	0.003
Cu	< 0.001	< 0.001	< 0.001	< 0.001	0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.001
Zn	0.004	< 0.001	0.001	< 0.001	0.005	0.001	0.003	0.003	0.003	0.010
Pb	0.002	0.001	0.001	< 0.001	0.003	0.001	0.002	0.001	0.002	0.001
Fe	0.050	0.090	0.012	0.002	0.070	0.040	0.050	0.070	0.040	0.200

Table 5.4 Product-moment correllation coefficient between selected chemicals for the ten storm events shown in table 5.3.

Chemical	r
COD	0.955
Cl	0.973
N	-0.392
Suspended Solids	0.914
Cr	-0.180
Zn	0.633
Pb	0.986
Fe	0.561

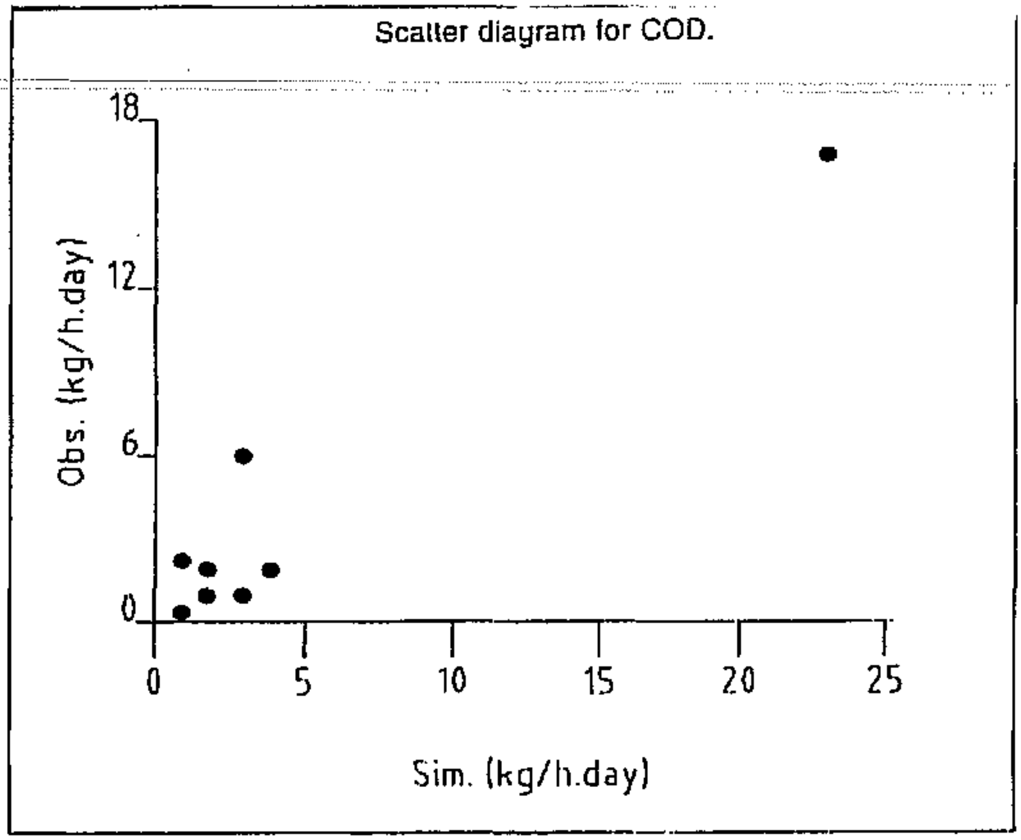


Figure 5.5a Scatter diagram of simulated vs observed daily water quality export values of COD for ten selected storm events.

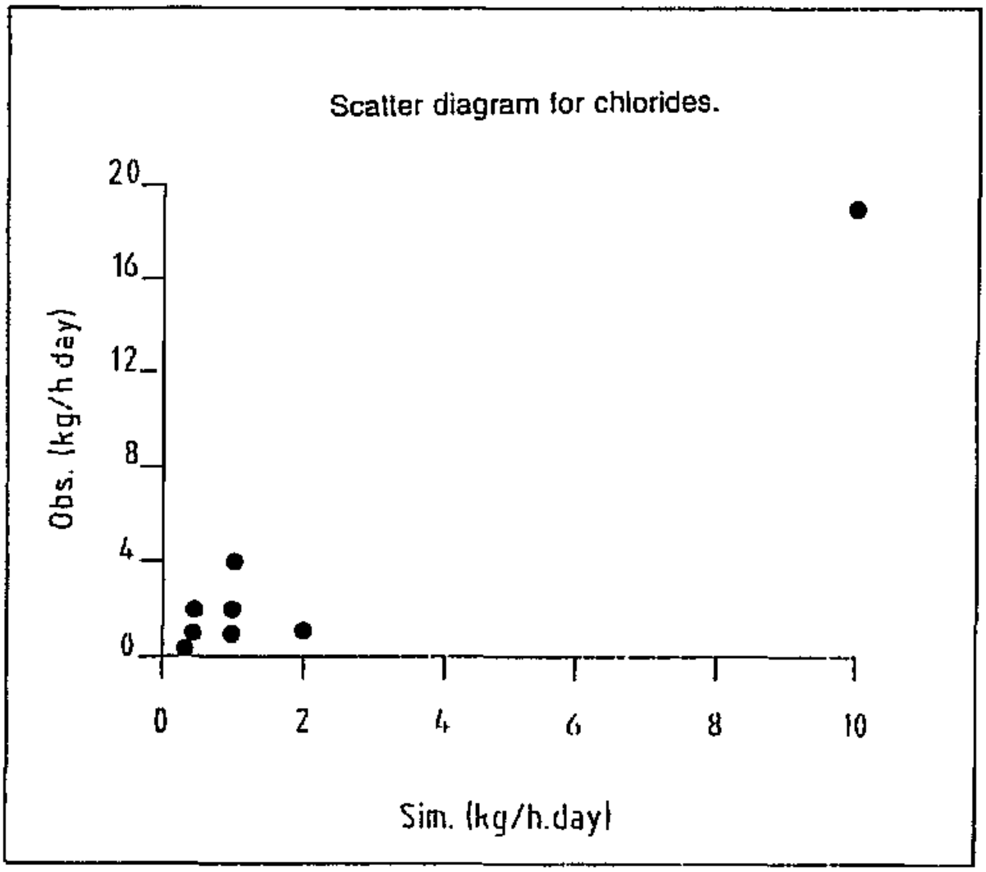


Figure 5.5b Scatter diagram of simulated vs observed daily water quality export values of Cl for ten selected storm events.

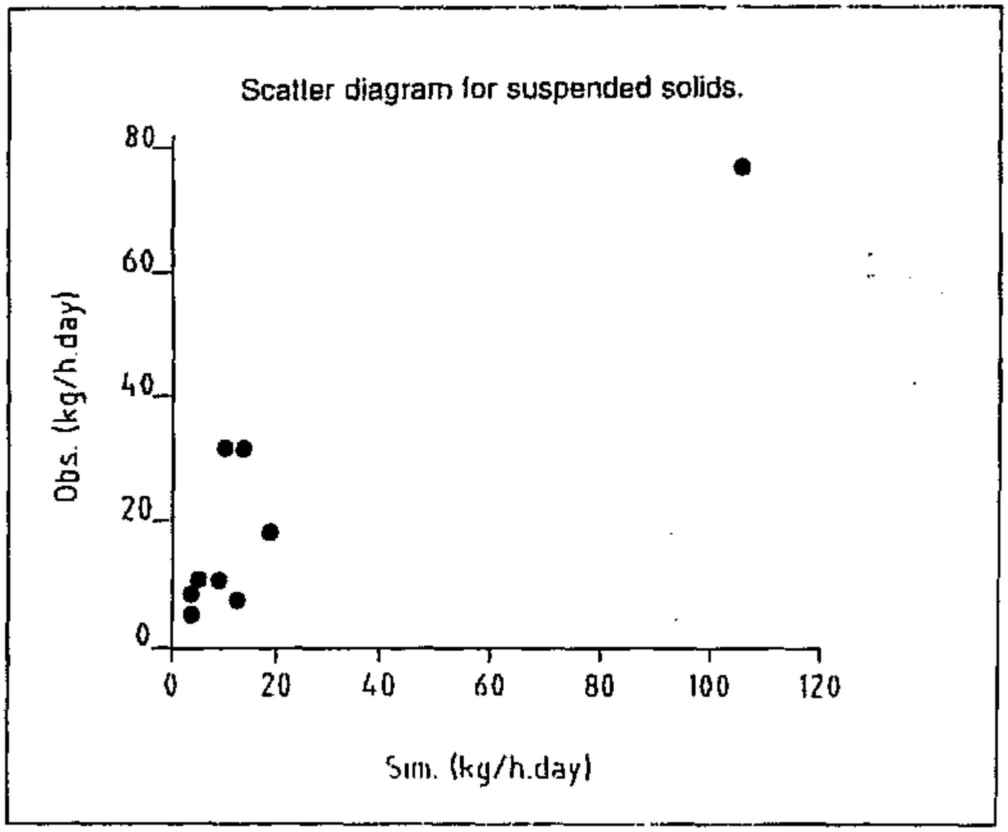


Figure 5.5c Scatter diagram of simulated vs observed daily water quality export values of suspended solids for ten selected storm events.

6 CONCLUSIONS, RECOMMENDATIONS AND FURTHER RESEARCH.

The objectives of this project were the incorporation and/or refinement of existing models capable of simulating urban flow patterns, and the development and refinement of sub-models that can simulate water quality loads from different urban land uses. These different models were discussed in Chapter Two and the applications in Chapter Five. The following conclusions can be drawn:

That the models in terms of urban runoff are capable of giving reasonably accurate representations. This was clearly shown by the models' capability of generating hydrographs from urban catchments which are fully reticulated (see section 5.2.2).

That the models are also capable of doing water quality simulations from urban catchments. The models performed better on a fully reticulated catchment than a natural catchment where base flow forms part of the water quality loads from the catchment. Since the biggest influence on receiving water bodies in terms of pollution from urban areas is the runoff from reticulated areas, the models can provide the necessary information needed to assess the impact on the catchment.

The following recommendations and suggestions for further research can be made:

6.1 It is recommended that the models are to be tested on other catchments in order to exclude any bias towards a particular catchment. This will improve the models' capacity to do realistic simulations in terms of runoff, hydrograph development and water quality.

6.2 It is further recommended that when the models are applied to a natural catchment with a base flow component, the models have to establish the base flow in the catchment first before simulations of water quality with a base flow component can be made. Once the base flow component is fully established then a more accurate water quality simulation can be conducted. If the user wants to simulate water quality from a reticulated catchment then this is not necessary since base flow is excluded from a reticulated system.

6.3 Further research possibilities are:

6.3.1 The further refinement of the models and the incorporation of a sediment routine to simulate suspended solids and total solids more accurately, as well as the influence of attached constituents which find their way to water courses via erosion.

6.3.2 The establishment of a database for accumulation rates of different pollutants in different regions of Southern Africa, which then can be used to assess the impact of urbanisation on catchments.

6.3.3 The development of sub-models to represent changes in water quality over hydrographs with the aim of simulating a first flush effect. The information can then be used to design retention ponds which are able to accommodate water with high concentrations of constituents. This will allow for proper management and the minimization of the impact of non-point pollution on a receiving water body.

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* A Waterlit Source

APPENDIX A: USER GUIDELINES FOR SETTING UP *ACRU-NPS*.

A.1 INTRODUCTION

ACRU was designed as a practical water management tool, but lacked an urban component for stormwater modelling and more particularly water quality simulations. This research contributed to the further development of *ACRU* by refining and then building the *WASHMO* model into it, and by making water quality simulations possible by adapting and incorporating the *NPS* water quality model into *ACRU*.

This and the next chapter deal with the instructions and information needed to run these models.

A.2 DIRECTORY

IWQLTY = The option to do water quality in *ACRU*.

Yes = 1 and No = 0

IQAMNT = Number of water quality constituents used.

IBMVAL = Monthly base flow water quality values available.

Yes = 1 and No = 0

IQNUM = The number the user assigns to link with the particular type of constituent used, when simulating water quality from a catchment. Eg. Suspended Solids = 1, COD = 2, Pb = 3, etc.

BSQLM(I) = These are the monthly base flow values for each constituent. (See section 6.3.4)

QUALID = The name of the constituent used.

BSQLA = A single base flow water quality value.

ACQOP = Accumulation rate of constituent in kg/ha per day (Johanson, et al,1984:190).

SQOLIM = Asymptotic limit for constituent buildup as time approaches infinity in kg/ha when no washoff occurs (Johanson, et al, 1984:190)

DEPRTE = Deposition rate of constituents from motor vehicles in kg/ha per axle.

TRFDNS = The number of vehicles per catchment per day.

AXLES = The average number of vehicle axles

PERCTB = Percentage of constituents produced by the catchment itself.

IWQOBD = Daily observed water quality values available. Yes = 1, No = 0.

IWQOBM = Monthly observed water quality values available. Yes = 1, No = 0.

IOBDWQ = Daily observed water quality values file. The file name for the particular catchment must be given.

IOBMWQ = Monthly observed water quality values file. The file name for the particular catchment must be given.

IWQPTD = Daily printout option of water quality values.

IWQPTM = Monthly printout option of water quality values.

IWQPTA = Annual printout option of water quality values.

A.3 EXPLANATIONS

A.3.1 IQAMNT

This states the number of constituents used between 1 and 10. If the user wants to use more than 10 constituents, the user must re-run ACRU with the remainder. This limitation is intended to save space and computation time.

A.3.2 IBMVAL

If the user has monthly base flow values available, they can be included for use as base flow values as long as the user takes the option to include base flow in the simulation runs.

A.3.3 IQNUM

This is the number assigned to a specific water quality constituent e.g. 1 is assigned to Chemical Oxygen Demand (COD), 2 to copper (Cu), etc. Any number between 1 and 10 can be assigned to any constituent. This is left to the user's own choice or preference. If the user has more than 10 constituents the first constituent for the next batch must start at one again.

A.3.4 BSQLM(I)

These are the base flow values for each constituent for each month of the year. This is done to incorporate seasonal changes in the concentration of a particular constituent. The values MUST be in mg/l.

A.3.5 QUALID

Here the names of the different constituents are given up to a maximum length of 10 characters.

A.3.6 BSQLA

A single base flow value can be given if IBMVAL=0 and this will then be used throughout the complete simulation run. The default value is 0.000mg/l.

A.3.7 ACQOP

The accumulation rate is derived from the amount of the constituent that reaches the surface through atmospheric fallout both on wet and dry days. If no values are available, the values given in Table A.1 can be taken as default values. However, collection of these values for the particular area of interest is recommended. The method of collection and analysis is discussed in Simpson (1986:31-3).

A.3.8 DEPRTE, TRFDNS and AXLES

This is an extra value that can be entered by the user. It is of more importance to commercial and industrial areas where there is a concentration of vehicular traffic than in residential areas. It is used along with traffic density, and expressed as the number of vehicles per day. Axles indicates the average number of axles, determined from the vehicle type, e.g. two per motorcar, 6 per horse and trailer. The number of axles is then divided by the number of vehicles to give the average number of axles per catchment. These values will be used for simulation of water quality in the impervious section of the *ACRU-NPS* model.

A.3.9 IWQOBD and IWQOBM

If daily or monthly observed water quality data is available it can be used for comparison with the simulated values. The user can use either one or both variables. The observed values will only appear as part of the water quality printouts.

A.4 EXAMPLES OF VALUES USED FOR WATER QUALITY SIMULATION.

A.4.1 Introduction

In this section some examples are given of the values used to run the water simulation in *ACRU* during this project. Some of these can be used as default values when local values are not available.

A.4.2 BSQLA and BSQLM(I)

These values are average base flow water quality values and will be used for all years included in the simulation run.

A.4.3 ASQOP and SQOLIM

Table A.1 shows the default values that can be used for ASQOP and SQOLIM if no actual values are available for the catchment concerned. Values are given for three different land uses namely residential, commercial and industrial.

These values were derived from Simpson (1986). The asymptotic limits are reached after 14 days. This assumption is made to represent 'real' catchment conditions (Schmitz, de Villiers and Schulze, 1993). It is recommended to use weighted averages to determine accumulation rates for catchments with a combination of different land uses, for example:

ACQOP = [(ACQOP*%RES.) + (ACQOP*%IND.) + (ACQOP*%COMM.)]/100

If open spaces occur the assumption is made that the accumulation rates are the same as in the predominant land use adjacent. These open spaces should then be included into the particular land use in order to determine the weighted average of the accumulation rates for a particular catchment.

A.4.2 PERCTB

Apart from atmospheric fallout the catchment generates its own contribution to the quality of its water resources. Simpson (1986) compared the mean concentrations for bulk fallout (wet and dry fallout) and runoff. These estimated contributions were expressed in percentages and are given in Table A.2.

Table A.1 Default values for ACQOP and SQOLIM fron selected constituents in kg/ha.

Constituent	Residential		Industrial		Commercial	
	ACQOP	SQOLIM	ACQOP	SQOLIM	ACQOP	SQLM
TDS	0.529	7.400	0.529	7.400	0.585	8.200
Suspended Solids	0.829	11.600	0.986	13.800	0.771	10.800
Sol. P	0.00024	0.0034	0.0003	0.0042	0.00037	0.0032
Particulate P	0.0013	0.0182	0.0016	0.023	0.0014	0.0188
Inorganic N	0.0140	0.190	0.0130	0.183	0.0142	0.199
Sol. organic N	0.0054	0.076	0.0048	0.068	0.0047	0.066
Particulate N	0.0067	0.094	0.008	0.112	0.0069	0.097
Total N	0.026	0.360	0.026	0.362	0.026	0.362
COD	0.600	8.400	0.710	10.000	0.490	6.800
Chloride	0.104	1.460	0.104	1.460	0.129	1.800
Sulphate	0.109	1.520	0.109	1.520	0.113	1.580
Copper	0.00026	0.0036	0.00029	0.0040	0.00034	0.0048
Cadmium	0.00010	0.0014	0.00007	0.00104	0.00010	0.0014
Lead	0.0014	0.0196	0.0014	0.0196	0.0018	0.0256
Zinc	0.0023	0.0318	0.0026	0.0362	0.0031	0.0440
Iron	0.028	0.394	0.030	0.414	0.027	0.380
Chromium	0.00071	0.010	0.00069	0.0096	0.00083	0.0116
Manganese	0.00059	0.0082	0.00086	0.0120	0.0012	0.0168

It is advisable to determine the percentage contribution of atmospheric fallout to runoff loads for the particular catchment in question, however if there is no data available, the data in Table A.2 can be used as a first estimate to assess the impact of fallout on the water quality of the urban catchment in question.

Table A.2 Percentage contribution of atmospheric fallout to pollutant loads inrunoff.

Constituent	Percentage
Suspended Solids	9.00
Total Dissolved Solids	20.00
Total Phosphates	8.20
Total Nitrates	21.00
Chlorides	51.00
Lead	19.60
Zinc	31.00
Iron	16.00
Chromium	29.00
Copper	31.00
Chemical Oxygen Demand	17.00
Sulphates	19.00
Manganese	26.00
Cadmium	30.00

A.4.3 DEPRTE

Table A.3 shows the deposition rates from vehicles in kg/ha.axle. These values can be used as default values if no values are available. These values were derived from Ahmed and Schiller (1980). The comment given in section A.4.2 applies to this section as well.

TableA.6.3 Deposition rates from vehicles in kg/ha.axle

Constituent	kg/ha.axle
Nitrogen	0.00000014
Phosperus	0.0000005
Copper	0.0000001
Chromium	0.00000007
Lead	0.0000098
Nickel	0.00000014
Zinc	0.0000012

APPENDIX B: USER GUIDELINES FOR SETTING UP *ACRU-WASHMO*

B.1 INTRODUCTION

This section deals with the information needed to run *ACRU-WASHMO*.

B.2 DIRECTORY

IWASHM	=	The option to use *WASHMO* in *ACRU* Yes = 1, No = 0.
IURFL	=	Rainfall type to be used for the simulation run.
RAIND	=	The design rainfall depth. To be used with option 2 of IURFL.
TIME	=	The storm duration in hours.
DELTAT	=	The time increment of the hydrograph in hours. Default value 0.2h.
CN2	=	The *SCS*-Curve Number for average conditions.
CNP	=	The *SCS*-Curve Number for average conditions of the pervious section of the catchment.

TA = Time to first peak in hours.

UP = Peak of first triangle in mm/h.

TB = Time to second peak in hours.

UR = Peak of second triangle in mm/h.

XINT = Time interval of own rainfall distribution in minutes.

NTYPE = Type of rainfall distributions used.

IUNIT = Unit hydrograph types.

Y = Catchment slope as a percentage.

SC = Channel slope as a percentage.

HDIFF = The distance of the sub-catchment from the total catchment's outlet.

ARF = Area reduction factor. Default value = 1.

NROUGH = Channel roughness.

ILAG = To use the lag times calculated either by *WASHMO* (ILAG=0) or by *ACRU* (ILAG=1). The first option is recommended for single event storms, while for the daily time step model the *ACRU* options are recommended since they have been developed for daily time steps.

B.3 EXPLANATIONS

B.3.1 IURFL

There are three rainfall type options that can be used in *ACRU-WASHMO*. Table B.1 gives the different options available. The user's attention is drawn to the fact that options 1 and 2 change the *ACRU* model from a daily time step model into a single event storm model.

TableB.1 Rainfall types available to *ACRU-WASHMO*.

Rainfall Type	Explanation
0	The daily rainfall option. It uses the rainfall files uesd by ACRU itself and is defined by the user as required by MENUBUILDER *program*.
1	The own rainfall distribution. Here the provides own rainfall distributions for each catchment. The user must also indicate the time interval used in the distribution.
2	The design rainfall option. The user can input a design storm value, e.g. for the 1:50 year design storm rainfall for *Durban* is 260*mm*.

B.3.2 TIME

The user must enter the duration of the rainstorm event in decimal hours, maximum 24 hours. It is advised that if the option 0 of IURFL is to be used, that the user should enter the average storm duration of the particular catchment to generate a more accurate hydrograph at the point of interest. For the other two options the TIME must be given. The default value is 24h.

B.3.3 CN2 and CNP

CN2 values are used when DISIMP and ADJIMP are unknown to the user. CNP is then equal to 0. CNP values are used when DISIMP and ADJIMP values are known to the user. The user then has the choice of using the open spaces, parks and cemetery option or the veld and woods/shrub options. CN2 then equals 0. The user must take cognisance of the fact that *ACRU-WASHMO* land cover is seperate from the land cover options available in *ACRU* which are given as crop numbers.

B.3.4 XINT

If the own rainfall distribution is used then the user must provide the time interval for the distribution. Some are at a 2 minute interval, while others are at a 5 minute interval. This is important since it is used by *ACRU-WASHMO* together with the storm duration to determine the shape of the hydrograph.

B.3.6 NTYPE

There are seven types of rainfall distributions that can be used in *ACRU-WASHMO*. The first six are synthetic rainfall distributions while the seventh indicates that the own rainfall distribution option is used. When IURFL equals 1 then NTYPE must be 7. Table B.2 gives the different rainfall distribution types.

Figure B.1 shows the distribution of the USA type rainfall distribution over southern Africa (Schulze and Arnold, 1979). Figure B.2 shows the distribution of the SA types (Smithers and Schulze, 1995).

Table B.2 Rainfall distribution types for *ACRU-WASHMO*.

NTYPE	Explanation
1	Original SCS Type 1 Curve (USA)
2	Original SCS Type 2 Curve (USA)
3	Schmidt-Schulze SA Type 1
4	Schmidt-Schulze SA Type 2
5	Schmidt-Schulze SA Type 3
6	Schmidt-Schulze SA Type 4
7	Own rainfall distribution

B.3.7 IUNIT

There are three types of unit hydrographs available to the user. The first option is Haan's unit hydrograph (IUNIT=0) which is recommended for urban catchments. The second option is the double triangular, TVA unit hydrograph

(IUNIT=1) recommended for rural areas. The third option (IUNIT=2) is the user's own parameters for the TVA unit hydrograph using TA, UP, TB and UR inputs.

B.3.8 NROUGH

This value depicts the roughness of a stream channel in a particular reach or catchment. If there is more than one channel type in a reach, then the roughness of the dominant channel type must be taken. Table B.3 shows the different channel types. *ACRU-WASHMO* will then convert it to the relevant roughness factor

Table B.3 The different channel types used by *ACRU-WASHMO*.

NROUGH value	Description
1	A natural stream
2	An unlined channel
3	A grassed water way
4	A concrete channel or pipe

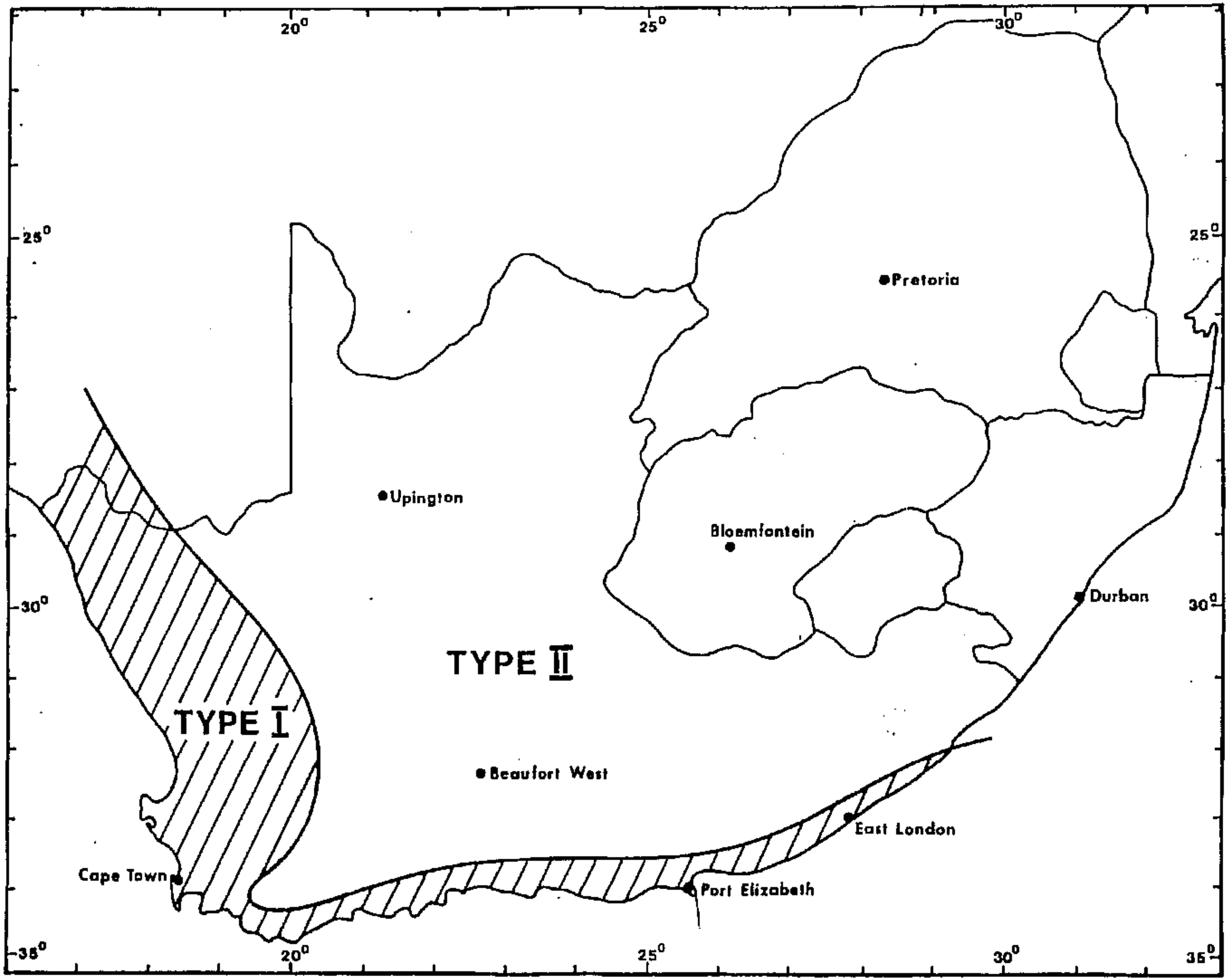

Figure B.1 Original SCS synthetic rainfall distribution over South Africa (from Schulze and Arnold, 1979)

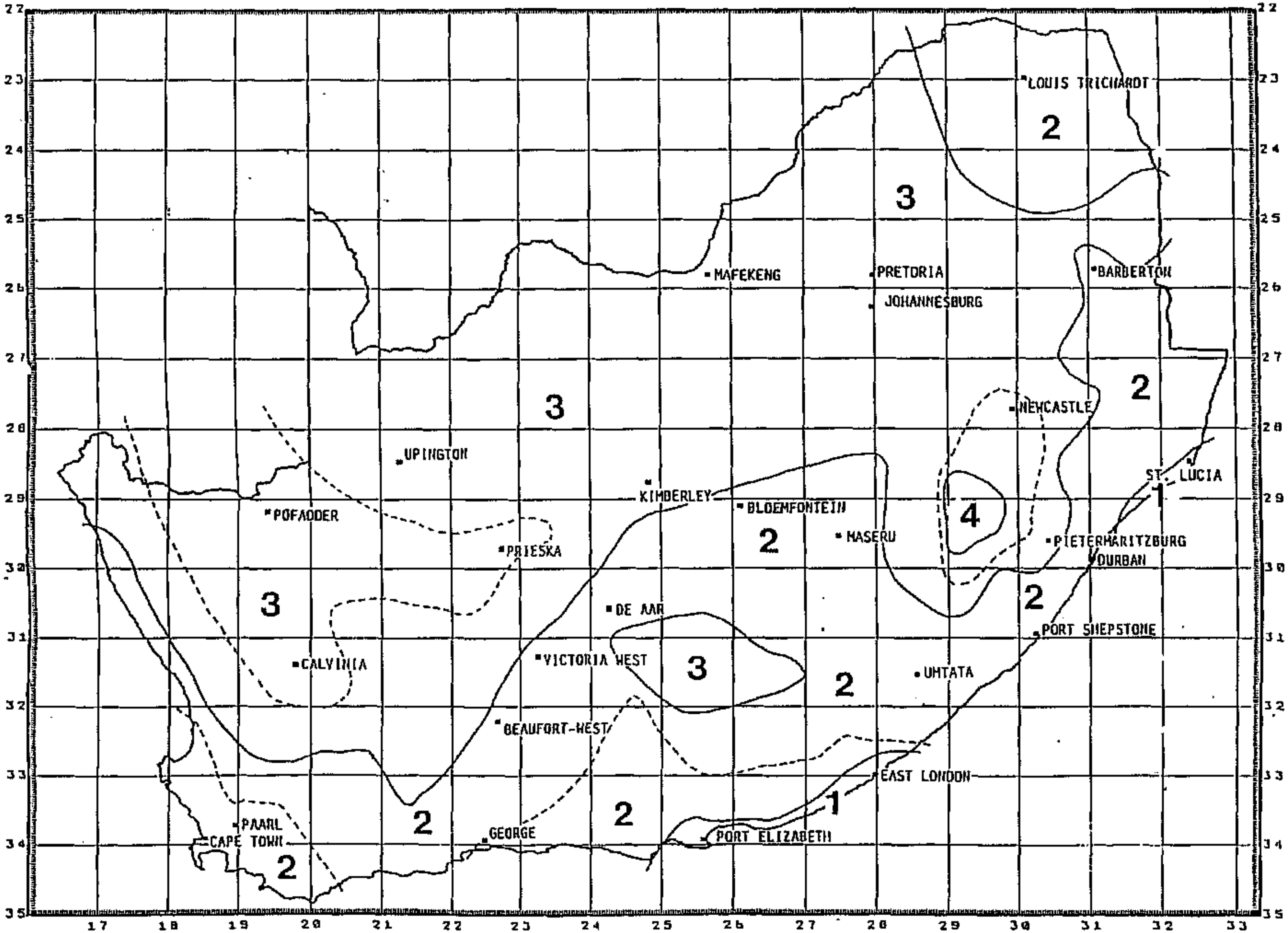

Figure B.2 Distribution of the four South African synthetic rainfall distributions (from Schmidt and Schulze, 1987)