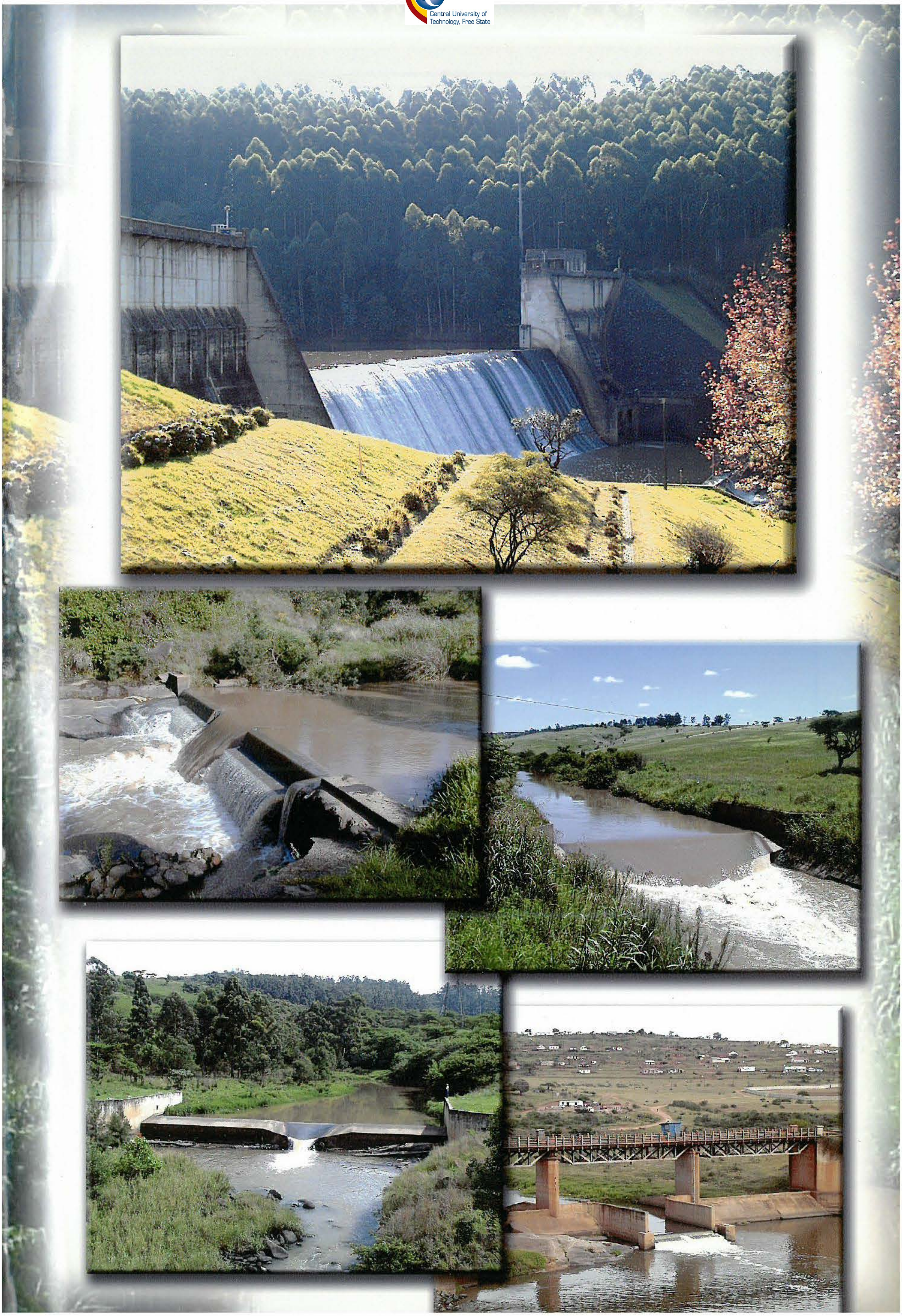

HSPF MODELLING OF THE

MSUNDUZI RIVER CATCHMENT

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April 2003

DECLARATION

I, OCKERT, JACOBUS GERICKE, hereby declare that this research project submitted for the degree MAGISTER TECHNOLOGIAE: ENGINEERING: CIVIL, is my own independent work that has not been submitted before to any institution by me or anyone else as part of any qualification.

2003-04-11

SIGNATURE OF STUDENT DATE

This study is dedicated to my late father, George Sebastiaan Gericke, whose support, love and faith in me will remain me always, as a lasting legacy.

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SUMMARY

Hydrological modelling, simulating surface runoff in a catchment, was a relatively new approach in South Africa in the mid seventies. The advent of hydrological modelling on a practical level in South Africa lagged that of other countries by several years at that stage. This delay could be ascribed to the fact that the awareness concerning surface water, draining concepts and hydrological modelling was only then becoming more prevalent in South Africa.

Today, following international trends, there is a growing number of hydrological modelling systems for integrated water resource management on a catchment basis in South Africa. Such systems are likely to be installed for operational use in ongoing learning, research, strategic planning and consensus building amongst role players in the Catchment Management Agencies (CMAs). These installed systems are poised to fundamentally change the way modelling is approached in South Africa. Hydrological models are the logical and irreversible response to the enormous forces, which have led to the revision of the National Water Act (NWA), 1998 (Act 36 of 1998) and the water resource management paradigms.

The *primary objective* of this modelling process is the application of the streamflow generation component of the Hydrological Simulation Program – Fortran (HSPF) model in order to provide hydrological information essential to those responsible for planning, development and management of the Msunduzi River Catchment. The *focus* of this modelling process is on the development and implementation of all input data and the testing of HSPF's continuous modelling system to correctly represent the hydrological components of the hydrological cycle.

The Msunduzi River Catchment forms an integral part of the southern portion of the Mgeni River Catchment. By 1985, the Mgeni River Catchment was already supplying water to 3.6 million people, industry and agriculture, which contribute 20% of South Africa's Gross National Product.

The margin of error in the simulated annual water balance varied between two and 11% during calibration, while it varied between five and 16% during the period of verification. There is a slight bias in the seasonal calibration for under-estimating the streamflow in the upper sub-catchments during the wet period and over-estimating the baseflow during autumn and follow-on dry periods. In the lower sub-catchments, the wet periods were over-simulated and the baseflow was correctly simulated during the dry period. The response time and interflow recession rates of the hydrographs were accurately simulated, except for some cases during autumn where the interflow recession rate was incorrectly simulated.

The over-simulation of the various single storm events (higher streamflow peaks) was the most consistent error that occurred during the period of calibration. This can probably be ascribed to the poor representation and areal distribution of precipitation data, which did not account accurately for the spatial variation in precipitation- and storm distributions.

Hydrological simulations are a prerequisite for further expansion of the model for water quality simulations. Therefore an accurate hydrological simulation forms an essential first step in developing a full HSPF application for a catchment. The fact that the Msunduzi River Catchment constitutes a substantial portion of the Mgeni River Catchment emphasises the importance of this project's results to help manage the hydrology and water quality of the larger Mgeni River Catchment of approximately 4000 km^2. HSPF can also be used to develop model parameters to test scenarios of future development within the catchment such as land-use changes, which may affect runoff and streamflow.

HSPF, together with other installed modelling systems, will enable CMAs to address the contradictory calls for affordable modelling at the same time as recognising greatly increased complexity, scalability, accessibility and integration. The successful implementation of the HSPF model will address the timeliness issues of today's fast moving world in which contentious water resource issues are becoming much more commonplace.

OPSOMMING

Hidrologiese modelering om oppervlakafloop te simuleer was in die sewentigerjare 'n betreklike nuwe benadering in Suid-Afrika. Suid-Afrika het toe 'n agterstand van 'n paar jaar beleef waar dit by die praktiese toepassing en implementering van hidrologiese modelering gekom het. Hierdie vertraging kan toegeskryf word aan die feit dat bewustheid rakende die beginsels rondom oppervlakwater, dreinering en hidrologiese modelering toe eers posgevat het in Suid-Afrika.

Volgens internasionale neigings, vandag, word hidrologiese modeleringsisteme vir geintegreerde waterhulpbronbestuur toenemend gebruik in opvangsgebiede in Suid-Afrika. Sulke sisteme sal waarskynlik gevestig word vir operasionele gebruik in voortgesette onderrig, navorsing, strategiese beplanning en om eenstemmigheid tussen die belangrikste rolspelers van Opvanggebiedbestuursowerhede te bevorder. Die reeds geimplementeerde sisteme is slaggereed om die huidige modeleringstegnieke in Suid-Afrika, wesenlik te verander. Hidrologiese modelle is die logiese en onomkeerbare gevolg van die oortuigingskrag wat die hersiening van die Nasionale Water Wet, 1998 (Wet 36 van 1998) en klemverskuiwing rondom waterhulpbronbestuur paradigmas, tot gevolg gehad het.

Die *primêre doelwit* van hierdie modeleringspoging is die toepassing van die hidrologiese komponent van die "Hydrological Simulation Program- Fortran (HSPF)" model om sodoende 'n sisteem daar te stel wat noodsaaklike hidrologiese inligting aan al die rolspelers van die Msunduzi Opvangsgebied betreffende beplanning, ontwikkeling en bestuur beskikbaar te stel. Die *fokus* van hierdie modeleringsproses is op die ontwikkeling en implementering van al die invoerdata en die toetsing van HSPF se kontinue modeleringsisteem om al die hidrologiese komponente van die hidrologiese siklus korrek weer te gee.

Die Msunduzi Opvangsgebied vorm 'n integrale komponent in die suidelike gedeelte van die Mgeni Opvangsgebied. In 1985 het die Mgeni Opvangsgebied alreeds water aan 3.6 miljoen mense, industrieë en die landbou, wat 20% bydra tot Suid Afrika se Bruto Nasionale Produk, voorsien.

Die foutgrens in die gesimuleerde jaarlikse waterbalans het gevarieer tussen twee en 11% tydens kalibrasie, terwyl dit tussen vyf en 16% gevarieer het tydens verifikasie. Die model se seisonale kalibrasie van die hoërliggende subopvangsgebiede is soms geneig om die piek stroomvloei tydens die nat periode te laag te simuleer en die basisvloei tydens herfs en die opeenvolgende droë periodes te hoog te simuleer. In die laerliggende subopvangsgebiede is die piek stroomvloei te hoog gesimuleer tydens die nat periode, terwyl die basisvloei in die droë periode korrek gesimuleer was. Die reaksietyd en tempo van intervloei van die hidrograwe is akkuraat gesimuleer; behalwe in sommige gevalle in die herfsmaande waar die intervloei-tempo verkeerd gesimuleer was.

Die oor-simulering van die verskeie eenmalige stormgebeurtenisse (hoër stroomvloei pieke) was die mees algemene fout tydens kalibrasieperiode. Dit kan moontlik toegeskryf word aan die swak verteenwoordigende oppervlakverspreiding van reënvaldata wat nie die onreëlmatige verandering en verspreiding van die reënval en donderstorms akkuraat kon verklaar nie.

Hidrologiese simulasies is 'n voorvereiste indien die model verder ontwikkel gaan word om waterkwaliteit te simuleer. Derhalwe vorm akkurate hidrologiese modelering die eerste noodsaaklike stap in die ontwikkeling van 'n volledige HSPF-toepassing in 'n opvangsgebied. Die feit dat die Msunduzi Opvangsgebied 'n groot gedeelte van die groter Mgeni Opvangsgebied uitmaak, beklemtoon die belangrikheid dat die resultate van hierdie projek sal bydra tot die effektiewe bestuur van die hidrologie en waterkwaliteit van die groter Mgeni Opvangsgebied van bykans 4000 km^2. HSPF kan ook gebruik word om model-parameters wat die impak van toekomstige ontwikkelinge soos veranderinge in grondbenutting wat moontlik afloop en riviervloei sal beinvloed, te ontwikkel.

HSPF, tesame met ander geïmplementeerde modeleringsisteme sal Opvanggebiedbestuursowerhede in staat stel om die uiteenlopende behoefte vir bekostigbare modelering, sowel as die omvang, toeganklikheid en integreerbaarheid daarvan, te besef en aan te spreek. Die suksesvolle implementering van die HSPF model sal alle toepaslike aspekte van belang in vandag se vinnige samelewing, waarvan kontroversiële waterhulpbronaangeleenthede so deel geword het, aanspreek.

TABLE OF CONTENTS

Page

LIST OF FIGURES

Page

LIST OF TABLES

LIST OF ANNEXURES

LIST OF PLATES

LIST OF ABBREVIATIONS

ACRU	Agricultural Catchment Research Unit
AGWETP	Evapotranspiration from Active Groundwater
AGWRC	Base Groundwater Recession Rate (/day)
AGWS	Active Groundwater Storage (mm)
ANNIE	Interactive Hydrological Analyses and Data Management
ARM	Agricultural Runoff Management Model
ARS	Agriculture Research Service
ASAE	American Society of Agricultural Engineers
BASINS	Better Assessment Integrating Point and Non-point Sources
BASETP	Evapotranspiration from Baseflow
BOD	Biochemical Oxygen Demand
CBD	Central Business District
CCWR	Computing Centre for Water Research
CEPS	Interception Storage (mm)
CEPSC	Interception Storage Capacity (mm)
CMAs	Catchment Management Agencies
CREAMS	Chemicals, Runoff and Erosion from Agricultural Management Systems
CRRAT	Ratio of maximum to mean velocity
CSIR	Council for Scientific and Industrial Research
DEEPFR	Fraction of infiltrating water, which is lost to deep aquifers
DELTH	Stream reach length change in elevation (m)
DO	Dissolved Oxygen
DSS	Data Storage System

EIA	Effective Impervious Area
EPA	Environmental Protection Agency
EPIC	Erosion Productivity Impact Calculator
ET	Evapotranspiration
FTABLEs	Function Tables to document the functional relationship between two or more variables (volume-discharge relationship for RCHRES operations)
GENSCN	Generalised Scenario Generator Software
GIS	Geographical Information System
GLEAMS	Groundwater Loading Effects on Agricultural Management Systems
GWVS	Initial Index to Groundwater Slope
HSP	Hydrological Simulation Program
HSPF	Hydrological Simulation Program – Fortran
HYDR	Flood routing, reservoir behaviour and analysis of dissolved constituents
IFWS	Initial Interflow Storage
IGWI	Inactive Groundwater
ILLUDAS	Illinois Urban Drainage Area Simulator
IMPLND	Impervious Land Segment
INFEXP	Exponent in Infiltration Equation
INFILD	Ratio of maximum or mean Infiltration Capacities
INFILT	Index of Mean Soil Infiltration Rate (mm/h)
INFLO	Inflow of water and constituents into RCHRES through a single gate
INTFW	Interflow Inflow Parameter
IOWDM	Input and Output for Watershed Data Management File

IRC	Interflow Recession Constant
IVOL	Volume of inflow
IWATER	Water Budget for impervious land segments
KINE 2	Two-dimensional Kinematic Model
KVARY	Non-linear groundwater recession rate (/mm)
LEN	Stream reach length (km)
LSUR	Length of assumed overland flow plane (m)
LZETP	Lower Zone Evapotranspiration Parameter
LZS	Lower Zone Storage (mm)
LZSN	Lower Zone Nominal Storage (mm)
MAP	Mean Annual Precipitation (mm)
MUTSIN	Multiple Time Series Sequential Input
NCH	Manning's *n* value for river channels
NFP	Manning's *n* value for flood planes
NPS	Non-point Source Runoff Model
NSUR	Manning's *n* for overland flow plane
NWA	National Water Act
NWRS	National Water Resource Strategy
OFLO	Outflow of water and constituents from RCHRES through multiple gates
PERLND	Pervious Land Segment
PEST	Parameter Estimation Program (non-linear)
PET	Potential Evapotranspiration
PETMAX	Temperature below, when evapotranspiration reduces to half (°C)
PETMIN	Temperature below where evapotranspiration is set to zero (°C)
PLS	Pervious Land Segment

PRSUPY	Precipitation on the RCHRES surface
PWATER	Water Budget of pervious land segments
PQUAL	Water Quality Constituents of pervious land segment
QUAL2E	Enhanced Stream Water Quality Model
RCHRES	Runoff Simulator in a Single Reach
RETS	Retention Storage (mm)
RETSC	Retention Storage Capacity (mm)
RMSE	Root-mean-square-error
ROUTE	Hydraulic Routing
ROVOL	Volume of total outflow
RUN	Interpreter or group of sub-programs, which read and interprets the User's Control Input (UCI)
SAWB	South African Weather Bureau
SEDMNT	Land Surface Erosion
SLSUR	Average slope of assumed overland flow plane (m/m)
SNOW	Snow accumulation and melt
SURS	Surface Detention Storage
SWAT	Soil and Water Assessment Tool
SWMM	Storm Water Management Model
SWRRB	Simulator for Water Resources in Rural Basins
TDS	Total Dissolved Solids
TEAMS	Time Series Extraction and Manipulation
UCI	User's Control Input
URBCELL	Cell Model applicable to Urbanised Areas
USDA	United States Department of Agriculture

USA	United States of America
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
UZS	Upper Zone Storage (mm)
UZSN	Upper Zone Nominal Storage (mm)
VOL	Volume at the end of the interval or Initial stream channel water volume ($M.m^3$)
VOLEV	Evaporation
WDM	Watershed Data Management
WITSKM	Witwatersrand Stormwater Kinematic Model
WITWAT	Witwatersrand Wave Approximation Theory Model
XSECT	Utility or program used in the conversion of river geometry data to volume-discharge relationships in FTABLEs

CHAPTER

1

INTRODUCTION

HSPF MODELLING OF THE MSUNDUZI RIVER CATCHMENT

1. INTRODUCTION

1.1 BACKGROUND

The Msunduzi River Catchment forms the southern portion of the Mgeni River Catchment. By 1985, the Mgeni River Catchment was already supplying water to 3.6 million people, industry and agriculture, which contribute 20% of South Africa's Gross National Product. In Water Plan 2025 (Horne Glasson Partners, 1989) it was predicted that, depending on future growth, the population in the whole area presently supplied by Umgeni Water could increase to between nine and twelve million by the year 2025 (Tarboton & Schulze, 1992: 1).

Concomitant with the population increase, anticipated future rural-, urban- and industrial development would increase the water demand in excess of available water resources, making effective water resource management within the Msunduzi River Catchment vital. This increase in water demand is likely to be accompanied by a decrease in water quality (Tarboton & Schulze, 1992: 1-2).

The above-mentioned factors that influence the hydrological response of a catchment as well as the different hydrological processes that occur are taken into consideration during hydrological modelling of the Msunduzi River Catchment. This specific hydrological modelling study is important, because it can be used to develop model parameters to test scenarios of future development within the catchment such as land-use changes, which may affect runoff and streamflow.

surface runoff, infiltration rates and subsurface pathways, mechanisms for water storage in the catchment and evapotranspiration (ET) rates.

- The model should be able to investigate a wide variety of conditions in the river, including the extremes of floods and low-flow periods.
- Realistic and objective simulation of daily streamflow in the Msunduzi River Catchment, over the past eight years from 1992 to 2000.
- The development of a Geographical Information System (GIS) containing the relevant spatial information for the Msunduzi River Catchment.

1.3 TYPICAL MODELS USED IN SOUTH AFRICA

Hydrological modelling simulating surface runoff in a catchment was a relatively new approach in South Africa in the mid seventies (Green & Stephenson, 1986: ii). The advent of hydrological modelling on a practical level in South Africa lagged that of other countries by several years at that stage. This delay could be ascribed to the fact that the awareness concerning surface water, draining concepts and hydrological modelling was only then becoming more prevalent in South Africa.

During the last two decades several models and their applications became more prevalent. Most of the models were developed in the early seventies and their application expanded during the last two decades to a level where they were verified against observed data. Although, due to the above-mentioned slow adoption, the demand is still limited to a few models and therefore the model availability is also restricted locally. Some of the most prominent models in use in South Africa together with their relative merits and applications are given in

Consulting engineers, water resource planners and hydrologists would use more complex hydrological simulation techniques if the appropriate technology has already been applied (Green & Stephenson, 1986: ii). These more complex computational techniques are used to determine viable surface water management policies, especially if the higher levels of urbanisation and population densities are taken into consideration (Coleman & Stephenson, 1990: 1).

1.4 HSPF: HISTORY AND PREVIOUS APPLICATIONS

1.4.1 History

The hydrological component of the HSPF model was developed in the early 1960's as the Stanford Watershed Model. In the 1970's, water-quality processes were added (USGS, 2002). A Fortran version incorporating several related models using software engineering design concepts was then developed. The Research Laboratories of the United States Environmental Protection Agency (USEPA) in Athens, Georgia funded these developments in the late 1970's.

In the 1980's, pre-processing and post-processing software, algorithm enhancements and use of the United States Geological Survey Watershed Data Management (USGS WDM) system were developed by the United States Geological Survey (USGS) and USEPA. An interactive version was developed by the USGS in the 1990's (USGS, 2002).

HSPF is currently in its 12th version (2001) and is widely used by consultants and government agencies in the United States of America (USA) and elsewhere, most notably Australia. The model is currently maintained by Aqua Terra Consultants and is supported by USGS and EPA. HSPF is an extension and improvement of three previously developed models:

- The EPA Agricultural Runoff Management Model (ARM) (Donigian & Davis, 1978);
- The EPA Non-point Source Runoff Model (NPS) (Donigian & Crawford, 1979) and;
- The Hydrological Simulation Program (HSP, including HSP Quality), a privately developed proprietary program (Aqua Terra Consultants, 2002).

The continuous simulation approach contained in these models is valuable in solving many complex water resource problems.

1.4.2 Previous Applications

According to Russo (Bicknell, Imhoff, Kittle & Donigian, 1996) HSPF is currently the most comprehensive and flexible model of catchment hydrology and water quality available. This model can simulate the continuous, dynamic event or steady-state behaviour of either hydrological or hydraulic and water quality processes in a catchment (Bicknell *et al.*, 1996: 2). The potential applications and uses of the model are comparatively large, including:

- Flood control planning and operations;
- Hydropower studies;

- Catchment planning;
- Storm drainage analyses;
- Water quality planning and management;
- Point and non-point source pollution analyses;
- Soil erosion and sediment transport studies;
- Evaluation of urban and agricultural best management practices;
- Fate, transport, exposure assessment, control of pesticides, nutrients and toxic substances and;
- Time-series data storage, analysis and display (Bicknell *et al.*, 1996).

HSPF is designed so that it can be applied to most catchments using existing meteorological- and hydrological data, soil- and topographical information, land-use, drainage-, physical- and man-made characteristics. Long, rather than short time-series records are preferred. Typical long time-series records include precipitation, waste discharges and calibration data such as streamflow and constituent concentration (Bicknell *et al.*, 1996).

There have been hundreds of applications of HSPF all over the world. The applications range from the 160580 km^2 tributary area of the Chesapeake Bay to experimental plots of a few hectares near Watkinsville, Georgia. Some specific examples of HSPF applications are summarised below:

Truckee-Carson River, California and Nevada:

The ability of HSPF to manage different categories of water ownership or -rights was used to simulate flow routing and reservoir- and river options. The aim was to provide simulations that allow comparison of the effects of alternative management practices or allocations on streamflow- or reservoir storages over long periods of time (Berris, Hess & Bohman, 2001).

Waterford River Catchment, Newfoundland, Canada:

Streamflow was simulated in this small watershed in Newfoundland, Canada. The purpose of the study was to determine the impact of increased urbanisation on streamflow. The model was calibrated against a scenario of future land-use change (primarily conversion of pervious to impervious land). The results verified that, by doubling the amount of impervious land could increase peak flows by about 20% (Ng & Marsalek, 1989: 117-124).

A later application investigated the effects of climate change on streamflow. Input temperature values were increased by up to 4% and precipitation was varied between 90% and 110% of its current value. The precipitation changes had a larger effect on the streamflow. Annual and seasonal streamflow fluctuations were directly proportional to precipitation changes (Ng & Marsalek, 1992: 257-272).

North Reelfoot Creek, Tennessee:

HSPF was used to simulate streamflow and sediment in a small catchment in Tennessee. The catchment is primarily agricultural. There are significant soil erosion and sedimentation problems in the catchment (Chew, Moore & Smith, 1991: 10-16).

Experimental Agricultural Catchment, Quebec:

Streamflow and atrazine concentrations in this small experimental catchment in Quebec were simulated (Laroche, Gallichand, Lagacé & Pesant, 1996).

Dade County, Florida:

Concentrations of non-point source pollutants (sediment, nutrients and pesticides) in surface runoff and groundwater were simulated. All simulations were performed using the PERLND (Pervious Land Segment) module only, because no instream processes were simulated (Tshirintzis, Fuentes & Gadipudi, 1996).

Dominican Republic: Hydropower Study:

An early application of HSPF in a hydropower study of the Rio Yaque del Norte Catchment for the Dominican Republic undertaken by Hydrocomp, Incorporated in 1980 (Donigian, Imhoff, Bicknell & Kittle, 1984: 131).

Clinton River Stormwater Management Study:

An early version of HSPF was used by the Macomb County (Michigan) Public Works Department to evaluate alternative stormwater management practices in the Clinton River Catchment (Donigian *et al.*, 1984: 133).

1.4.3 Applications in South Africa

The use of HSPF is a relatively recent occurrence in South Africa, the first applications taking place in the late 1980's (Johanson, 1989 & De Vos, 2002). Consulting engineers, water resource planners and hydrologists tend to use other models, because these models have been researched and experimented with during the last two decades.

The availability of resources and references with regard to HSPF water management is limited. Consultants undertook some of these studies and these references are only available from one of the parties involved. Therefore, most previous HSPF applications in South Africa lie outside the traditional scientific literature and are difficult or impossible to obtain.

The information obtained was either via personal communication or conversation and preliminary reports. The following applications occurred in South Africa:

Hlobane Colliery, Vryheid Coalfields, South Africa:

The purpose of this study was to determine the long-term water quality risks after the mine closure and to evaluate the effects of various water management actions. An integrated assessment approach was adopted that incorporated hydrological-, hydrogeological-, mineralogical- and geochemical assessment and modelling techniques to predict the volumes and qualities of water discharging from various points on the mine for the base case situation where no water management options were implemented (Hattingh, Pulles, Krantz, Pretorius & Swart, 2001: 2).

HSPF was used to obtain a water balance for the Hlobane 1 system in terms of the apportionment of mean annual precipitation to ET, streamflow and loss to the underground mine workings. A lack of reliable flow data (high flows) for the streams on top of the mountains as well as the difficult access to the area complicated this exercise. These data allowed for satisfactory calibration of parameters associated with base flow conditions such as the interflow recession rate and the active groundwater recession constant.

In the area of Hlobane II, HSPF could not be directly calibrated with observed surface flow, due to the fact that there were no defined streambeds, or mining induced fractures and subsidence areas existed. Therefore the same parameter set obtained at the Hlobane I system was used, and compared to the resultant ingress of water into the associated mine workings with that derived from flow measurements taken at the discharge from the workings.

Furthermore HSPF was used to model the catchments on the plains around Hlobane. The hydrology as well as water quality constituents were modelled. The impacts of mining induced water contamination were simulated by modelling total dissolved solids (TDS), sulphate (SO_4) and sodium (Na) concentrations as typical substances in the Manzana-, Tshoba- and Sithebe river catchments. After a successful iterative calibration process, the model was used to assess the benefit of various proposed management strategies and for the generation of discharge hydrographs in weekly time steps.

The results showed that model derived ingress rates correlated well with the difference in land-use characteristics observed between the two areas. In all instances the predicted water qualities improved over time, with the result that the current monitoring results for the key parameters involved (sodium, TDS and sulphate) represent the worst case in terms of future scenarios.

Rural Catchments of the Berg River Basin, Western Cape:

This study was undertaken to compare different non-point source water quality models, which are capable of simulating phosphorous production in rural catchments with a variety of land-use types. These four rural catchments were the Doring-, Kompanjies-, Leeu- and Twenty-Four River catchments in the Berg River Basin, Western Cape. (Matji & Görgens, 1999: 2-4).

The emphasis was on the link between management decisions and non-point source assessment techniques. HSPF was successfully applied to simulate the hydrology of these catchments and, at the time of writing, the simulation of phosphorous production was still under investigation.

Urban Catchment, Pinetown, Kwa-Zulu Natal, South Africa:

The purpose of this study was to simulate the hydrology, sediment and phosphorous in this highly urbanised catchment. This 90-hectare catchment is situated in the Central Business District (CBD) of Pinetown (Johanson, 1989: 104).

The Council for Scientific and Industrial Research (CSIR) was responsible for the collection of precipitation- and streamflow data from 1982 to 1987. Only three years of data were used. Daily evaporation data were also used.

A good fit between the daily observed- and simulated streamflow was obtained during the hydrological calibration. The simulation of the accumulated flow over time was 7% lower than observed streamflow overall. This could be ascribed to the fact that some of the observed baseflow was non-natural in origin, typical examples being leaking water mains and wash water from industries. These non-natural components were not included in the modelling attempt. Due to the fact that data from only two precipitation stations were used or available as input to the model, the overall model performance and agreement were considered accurate.

Sediment calibration is dependent on the hydrological simulation. The observed data for sediment were in the form of event loads. During the three-year simulation period there were about 240 precipitation events. The sediment simulation was calibrated until there was a good fit between observed data and simulated values. The simulation indicated that almost all the sediment came from impervious land, but it was not always the case in severe events.

Adsorbed phosphorous and dissolved phosphorous are dependent on the sediment calibration. The mechanisms involved in these two forms of phosphorous are different and therefore they were simulated separately. A close fit between the simulated accumulated quantities of the soluble- and total phosphorous and observed data were obtained, but the agreement for individual events was unacceptable.

Rural Catchment (Midmar) of the Mgeni River Catchment, Kwa-Zulu Natal, South Africa:

The purpose of this study was to simulate the hydrology and water quality of the Midmar Catchment, an important rural sub-catchment of the larger Mgeni River Catchment, which covers an area of 300 km^2. The Midmar Dam is also a very important water source and it is euthrophically sensitive (Johanson, 1989: 102, 106).

The Midmar Catchment consists of two sub-catchments. The Lions River in the north drains the one sub-catchment, while the Mgeni River drains the other sub-catchment in the south. Due to time constraints, only the Mgeni River sub-catchment was simulated. The Mgeni River sub-catchment, which covers an area of 299 km^2, was delineated into six pervious sub-catchments, taking all the land-use characteristics and regional variations in mean annual precipitation into consideration.

The period of 1980 through to 1985 was modelled. Daily precipitation data from five precipitation stations were selected. These daily precipitation data were disaggregated into hourly values by using data from three nearby precipitation stations at the Cedara Research Station. Daily evaporation- and streamflow data were also used (Johanson, 1989: 107).

The period of 1980 through to 1982 was used for hydrological calibration, while the period of 1983 through to 1985 was used for verification. The agreement between the simulated- and observed accumulated flow over time was considered accurate.

Comprehensive water quality data were only available in the Lions River sub-catchment. Due to time limitations, the water quality data were treated as if they are applicable to the Mgeni River sub-catchment. This assumption's error was not severe, due to the similarity in the land-use mix and precipitation data of these two sub-catchments.

A good fit between the observed and simulated accumulated suspended solids was obtained during the water quality calibration, except for the periods of 27 March 1982 and 14 February 1985. Poor streamflow simulations were also associated with these periods, thus resulting in the inaccurate modelling of individual events.

Maputo Iron Steel Project, Southern Africa:

This was a water demand study undertaken by Coleman and Van Niekerk (1997) as part of a draft report by Wates, Meiring & Barnard (1997) for Gibb Africa, Midrand, South Africa. Hydrology and water quality were simulated.

The Msunduzi River Catchment extends over a large area with numerous river reaches and relatively lower quality meteorological data, when compared to the above-mentioned applications in South Africa. Thus, it was necessary to spend much more effort on data collection (catchment-, hydrological- and meteorological data), interpretation of the data, model calibration and verification. Furthermore, the fact that the Msunduzi River Catchment constitutes a substantial portion of the Mgeni River Catchment emphasises the importance of this project's results to help manage the hydrology and water quality of the larger Mgeni River Catchment of approximately 4000 km^2.

1.5 AN OVERVIEW AND SUMMARY OF THE STUDY AREA

The Msunduzi River Catchment covers an area of 901 km^2. It is located in the province of Kwa-Zulu Natal, South Africa. Rising in the northwestern extremity of the catchment at an altitude of ± 1520 m above sea level near Ka-Nzakane and at an altitude of ± 1390 m above sea level near Mafunze in the southwest, the perennial Msunduzi flows 150 km (excluding tributaries) to its confluence with the Mgeni River at an altitude of ± 285 m.

Urban- and informal areas within the catchment include Pietermaritzburg and Cato Ridge on the southern catchment border. Vulindlela is the most important informal settlement in the Msunduzi River Catchment, just west of Pietermaritzburg (Tarboton & Schulze, 1992: 2). Precipitation over the catchment is highly variable with the mean annual precipitation ranging from in excess of 1186 mm to 684 mm.

The Department of Water Affairs and Forestry (DWAF) divides the Msunduzi River Catchment into the management sub-catchments of Henley, Inanda, Pietermaritzburg and Table Mountain as listed in Table 1.2.

Table 1.2: Management sub-catchments of the Msunduzi River Catchment

Management sub-catchments	Area (km^2)	Percentage-distribution (%)
Henley	220	25
Inanda	19	2
Pietermaritzburg	319	35
Table Mountain	343	38
Total:	**901**	**100**

The catchment data such as specific location, topography, geological data, land-use and vegetation, as well as the hydrological- and meteorological data are discussed in detail in Chapter 5.

1.6 THESIS SCOPE

This thesis describes the application of the streamflow generation component of HSPF and the development of the input data of the HSPF Msunduzi River Model. Chapter 1 describes the background of the study area, the objectives and scope of this modelling attempt and the history and previous applications of HSPF. Chapter 2 provides a literature review of hydrological modelling in general, the role of hydrological modelling in water resource management and the comparison between some of the different hydrological models available or in use in South Africa.

The development and structure of HSPF is discussed in Chapter 3. The parameters and calibration of the HSPF model, as well as the applicable array of model- performance statistics are discussed in Chapter 4.

Chapter 5 describes the preparation and development of input data (catchment-, hydrological- and meteorological data) for HSPF. Extensive analyses of catchment-, hydrological- and meteorological data were performed to ensure the best possible simulation was achieved. Chapter 6 presents the results concerning data collection, hydrological simulations, calibration, verification and analysis of model performance. Chapter 7 presents the conclusions and recommendations on the results discussed in Chapter 6.

CHAPTER

2

LITERATURE REVIEW: HYDROLOGICAL MODELLING IN GENERAL

HSPF MODELLING OF THE MSUNDUZI RIVER CATCHMENT

2. LITERATURE REVIEW: HYDROLOGICAL MODELLING IN GENERAL

2.1 HYDROLOGICAL MODELLING

2.1.1 Introduction

It is important to have a good understanding of hydrological principles before attempting to use any computer models to design stormwater systems and structures. All models have limitations and are designed for specific applications. Computer modelling can be one of the more effective and efficient methods for predicting the quantity and nature of runoff and the effectiveness of best management practices (Brach, 2000: 8.00-1).

Snyder and Stall (1965) defined a "model" as follows: "A model is simply the symbolic form in which a physical principle is expressed. It is an equation or formula, but with the extremely important distinction that it was built by consideration of the pertinent physical principles, operated on by logic and modified by experimental judgement and plain intuition".

Schulze (1995) expanded this definition to hydrological models by stating that a hydrological model can be defined as a mathematical model representing one or more of the hydrological processes resulting from precipitation and culminating in catchment runoff. A model provides a way of transferring knowledge from a study area to an area where hydrological information and decisions are needed, thus it represents a quantitative expression of the observation, analysis and prediction of hydrological responsiveness.

Furthermore, hydrological models are planning tools that ask "what if" questions. The model user asks the questions. The model developer anticipates the question and develops the capability to answer them through the model. Soundly structured hydrological models may therefore provide answers to "what if" scenarios where observed catchment data are not available, or studies have not yet been carried out (Dent, 2002). The model could provide information on the effect of land-management practices on quantity and quality of runoff, infiltration, lateral flow, both saturated and unsaturated subsurface flow, and deep percolation (De Coursey, 1991).

A model is most accurate when it is used with actual data and measurements. Observed data to varying degrees are used as part of individual components of the model. Errors associated with observed data will also impact the ability of the model to reliably produce the desired simulation (Brach, 2000: 8.20-1). The number of actual measurements applied to calibrate a model is important, because it will determine how accurate the model will predict future scenarios when no data are available (Dent, 2002).

Thus, the traditional, older water-resource analyses of historical records are clearly inappropriate planning tools in any changing technological environment. Historical patterns and trends should therefore be interpreted, not as predictors of the future, but rather as baselines against which the effects of changes can be compared. This is essential for effective planning and resource management (Brach, 2000: 8.10-1).

2.1.2 Types of Hydrological Models

Hydrological models can be classified as either optimising (decision theory, system analysis and operations research techniques) or non-optimising models (statistical-, empirical- and conceptual models). Statistical models are then divided into three categories, *viz.* regression and correlation-, probabilistic- and stochastic methods. Conceptual models may further be sub-divided into deterministic and parametric models. A parametric model is also deterministic in the sense that it includes some deterministic components, although the model parameters are not necessarily defined as measurable physical quantities (Green & Stephenson, 1986: 4). Figure 2.1 illustrates the classification of the various modelling approaches.

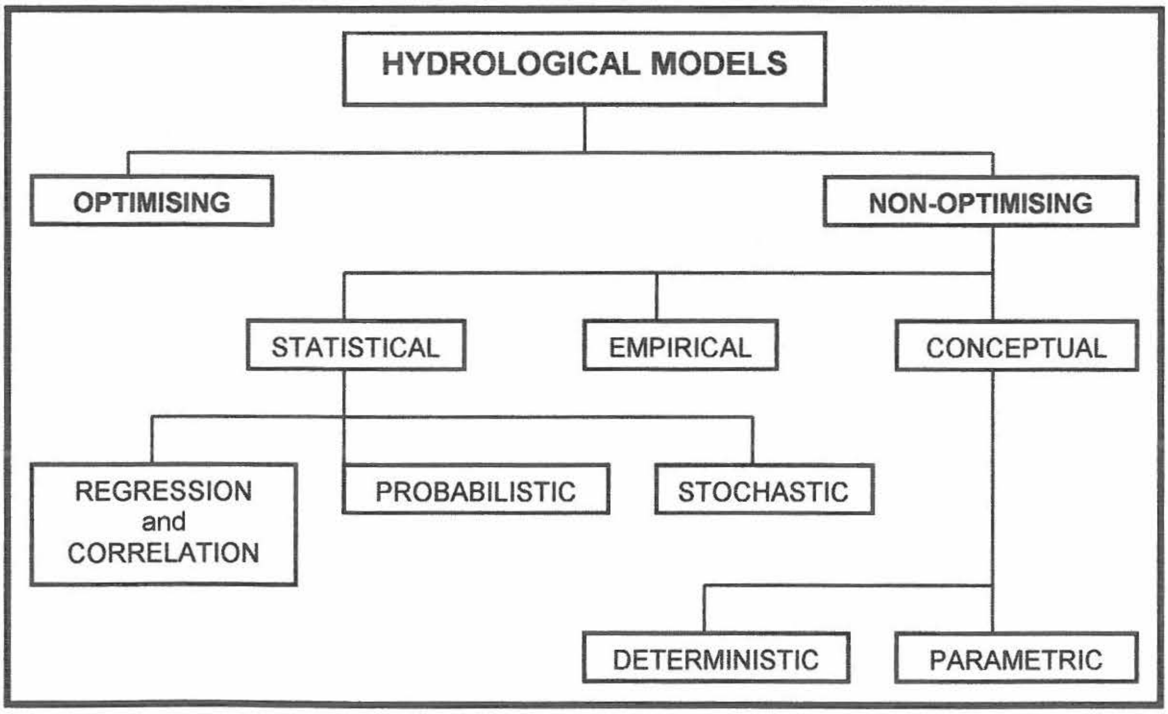

Figure 2.1: Classification of hydrological models (Green & Stephenson, 1986)

Stochastic: The random variables in these models use probability distributions and take the chance of occurrence or probability distribution of hydrological variables into consideration (Schmitz & De Villiers, 1997: 14). The sequence of events are treated as time-dependent and applied in extending hydrological forecasts, either as random or non-random data or the combination thereof (Green & Stephenson, 1986: 2).

Empirical: These models are formulated purely on observations. The output is generated from input based on experiments and observations, therefore it does not rely much on the physical processes involved (Green & Stephenson, 1986: 4).

Deterministic: The theoretical structure of these models are physically based, that is when all the governing physical laws are known and could be described by equations of mathematical physics (Green & Stephenson, 1986: 2). All the input variables in these models are considered to be free from random variation. In some cases it may include stochastic processes to add the dimension of spatial and temporal variability to some of the sub-processes (Hydrocomp, 2003: 195). Deterministic models can further be sub-divided as follows by making use of a set of criteria as presented by the ASAE (American Society of Agricultural Engineers):

- A *single-event model* represents a single runoff event occurring over a period of time ranging from about an hour to several days. The initial conditions in the catchment for each event must be assumed or determined and supplied as input data. The accuracy of the model output may depend on the reliability of these initial conditions. A single-event model may exclude one or both of the subsurface components, as well as evapotranspiration (Hydrocomp, 2003: 195 & Dent, 2002).

- A *continuous model* operates over an extended period of time, determining flow rates and conditions during both runoff periods and periods of no surface runoff. Thus the model keeps a continuous account of the basin moisture condition and therefore determines the initial conditions applicable to runoff events. These models utilise three runoff components: surface runoff, interflow and groundwater flow (Hydrocomp, 2003: 195).

- Precipitation and other meteorological data are the primary input for *complete* or *comprehensive models* and the output is simulated hydrographs. The model represents the hydrological processes, which significantly affect the runoff, while maintaining the water balance. This is achieved by solving the continuity equation (water balance) of precipitation, evapotranspiration (ET) and runoff, thus increasing the accuracy of the model. This represents one of the most important advantages of complete models over partial models.

- A *partial model* represents only a part of the hydrological processes concerned, and it does not take the heterogeneity of the catchment into consideration. The input- as well as the output variables is spatially averaged (Kienzle, Lorentz & Schulze, 1997: 5).

- A *calibrated parameter model* has one or more parameters that can be evaluated only by fitting simulated hydrographs to the observed hydrographs. Calibrated parameters are usually necessary if the catchment component has any conceptual component models. These models are data demanding and the transfer of ungauged catchments is problematic and speculative (Kienzle *et al.*, 1997: 5).

- In a *measured parameter model* all the parameters can be determined satisfactorily from known catchment characteristics, either by measurement or estimation (Hydrocomp, 2003: 196).
- *Lumped models* are structured to utilise average values of the catchment characteristics affecting runoff volume, thus the spatial variability of inputs, outputs or parameters are not explicitly taken into account. Averaging certain parameters also implicitly averages the process that being simulated. Non-linearity and threshold values can also lead to significant error (Hydrocomp, 2003: 196).
- *Distributed models* include spatial variation in inputs, outputs, and parameters. Normally, the catchment area is delineated into a number of reaches and runoff volumes are calculated separately for each reach. Models can be mistakenly classified as lumped, even though these models are able to represent spatial variability by subdividing the catchment into segments with representative "lumped" parameters for each segment (Hydrocomp, 2003: 196).
- *General models* are used without modifications to catchments of various types and sizes. These models have parameters, either observed or calibrated, which can adequately represent the effects of a wide variety of catchment characteristics. Conceptual models (with calibration parameters) are normally used to achieve this (Hydrocomp, 2003: 196).
- *Special purpose models* are applicable to a particular type of catchment in terms of topography, geology or land-use. Usually these models can be

applied to catchments of different sizes, as long as the characteristics of the catchments are the same (Hydrocomp, 2003: 196).

Any catchment can be divided into a number of sub-catchments. The unique hydrological and water quality characteristics of some of the homogeneous parts of these sub-catchments, as well as factors such as the lagging and attenuation of floods through river reaches and reservoirs should be taken into account (Kienzle *et al.*, 1997: 6 & Schulze, 1995: AT 2.9).

In order to represent hydrological processes realistically, the time step-interval of the model is important. Precipitation events normally occur over short periods, but it is the driving force on which the system's long-term streamflow is based (Kienzle *et al.*, 1997: 6).

2.1.2.1 Advantages of Hydrological Models

The advantages of using hydrological models are as follows:

- The model provides a frame of reference for a problem and it can point out information gaps and thus suggests needed research (Brach, 2000: 8.10-1).
- The model brings out the problem of abstraction in complex systems and uncovers questions that might not otherwise be raised. It promotes understanding and added insights into the different processes in the hydrological system.
- The model, once expressed, provides relatively easy manipulation of components and a basis for comparison (Schulze, 1995: AT 1.11).

- Time scales are significantly compressed. Observations made over many years in the physical system are reproduced in a much shorter period of time. This is also an advantage in certain circumstances; for example, one cannot build a dam and wait for 30 years or longer to see what happens (Dent, 2002).

2.1.2.2 Disadvantages of Hydrological Models

The disadvantages of using hydrological models are as follows:

- Most models are only effective under certain specified conditions.
- Models involve gross simplifications when representing the true physical system.
- Models use a number of mathematical or graphical representations ("lumped" model parameters) to describe various hydrological and hydraulic concepts (spatial heterogeneity of catchment), each of which is considered to be relevant to the overall hydrological response of the catchment (Brach, 2000: 8.10-2).

2.1.2.3 Model Selection

Catchment- and human-impact related considerations are the primary criteria in model selection. Additional to these criteria, management and administrative considerations (availability of technical support, costs, user-friendliness, version control and training) and technical capabilities (data set requirements and model capabilities) inform the process of model selection (Görgens, Tanner, Viljoen, Sami, Dennis *et al.*, 2002: 17).

Even though there are no clear rules for the process of model selection, the following simple guidelines can be stated:

- The simplest method that can provide the answer to your questions must be used.
- The simplest model that will yield adequate accuracy must be used.
- Model selection must appropriate for the problem, thus one should not try to fit the problem to a specific model (Hydrocomp, 2003: 196).

During the process of model selection, the following questions can also be asked:

- Which model is best for solving a particular problem in a particular location?
- What are the data requirements for both model and problem?
- What computer hardware and staff are required?
- What documentation is available?
- How much will it cost to apply the model?
- How accurate will the model be in representing the "real world"?
- Are there enough data available?
- What different kinds of models are available?
- Will it be applicable to land-use activities?
- Will it be applicable to broad geographic areas?
- How accurate will the prediction be?

(Görgens *et al.*, 2002: 18 & Brach, 2000: 8.10-3)

2.1.2.4 Model Verification

A model should generally be verified by running the model against known conditions to compare simulated versus observed results. During verification the data set used must not have been used before, during calibration. Monitoring error or interpretation of observed data can be one of the main sources of error in model verification. Precipitation can vary significantly within short distances, even fractions of a kilometre. If monitoring stations do not cover the entire catchment, assumptions must be made about the distribution of precipitation in the catchment (Brach, 2000: 8.10-4).

Grab samples do not show variability of concentration with flow unless flow data are correlated with concentration and a significant number of samples are taken. Any averaged or composite sample methods tend to disguise the extreme events.

Flow-weighted mean samples depend on good sample values for each representative unit of flow. Small flow-measurement errors or unrepresentative sample values can significantly affect any loading estimate. Systematic errors, such as using the highest possible values, may be desirable for "worst-case scenarios" but these values also tend to multiply in an unrealistic manner if not properly utilised (Brach, 2000: 8.10-4).

2.1.2.5 Sensitivity Analysis in Hydrological Modelling

The key task in any modelling study is the sensitivity analysis and interpretation of the model outputs. Since models are simply tools for a quantitative, systematic analysis of specific environmental problems or issues, they do not provide simple "yes" or "no" answers to managers, regulators or decision-makers. Rather, they usually provide detailed information about the expected response of the system to a given perturbation in order that a more informed objective decision could be made (Brach, 2000: 8.10-5).

The accuracy associated with the results of modelling studies depends on the model used, the accuracy of the input data, the characterisation of the environmental system being simulated, the expertise or experience and resources available to the model user. Most models are often more accurate in a relative sense, than in an absolute sense. That is, when models are used to compare alternatives (such as management- or control options), the relative differences predicted between alternatives are sometimes more reliable than an absolute value predicted for any one alternative (Brach, 2000: 8.10-5).

2.2 ROLE OF HYDROLOGICAL MODELLING IN WATER RESOURCE MANAGEMENT IN SOUTH AFRICA

The hydrological world is already interrelated and it is therefore not necessary to create its interrelatedness: the challenge is to enable organisations and scientific disciplines to achieve a measure of interrelatedness so as to better understand and hence manage within the hydrological world. This interrelatedness is explicitly recognised in the National Water Act (NWA), 1998 (Act 36 of 1998) and has resulted in institutional and management changes (Dent, 2001).

The National Water Policy and NWA (1998) form the foundation of the National Water Resource Strategy (NWRS). The objectives of water resource management of the NWRS in South Africa were revised and include the following changes:

- Ensuring security of supply for basic human needs;
- Protecting water resources;
- Ensuring equitable access to resources;
- Improving the efficiency of water use;
- Ensuring sufficient future water supplies to sustain health and economy and to promote a prosperous society;
- Ensuring equity in payment for water and;
- Honouring obligations to neighbouring countries (DWAF, 2002).

Another change is that, following international trends, there is a growing number of modelling systems for integrated water resource management on a catchment basis in Southern Africa. Such systems are likely to be installed for operational use in ongoing learning, research, strategic planning and consensus building amongst role players in the CMAs. These installed systems are poised to fundamentally change the way modelling is approached in Southern Africa. They are a logical and irreversible response to the enormous forces, which have led to the revision of the NWA and the water resource management paradigms (Dent, 2001).

Installed modelling systems will enable CMAs to address the contradictory calls for affordable modelling at the same time as recognising greatly increased complexity, scalability, accessibility and integration. Modelling systems are operationally successful because they address the timeliness issues which are important in today's fast moving world in which contentious water resource issues are becoming much more commonplace (Dent, 2001).

Water resource modelling systems perform processes on sequences of time-dependent data. Such systems must be flexible in terms of the temporal and spatial resolution of the processes being modelled. A key functional element of an installed modelling system is therefore a highly efficient time series management system (Dent, 2001).

The system should be able to model both quantity and quality both on the land and in the stream. It should be able to model both point and non-point sources of conservative and non-conservative pollutants. The system should be able to inter-operate with the functional modules of other systems. The networks of flows, abstractions, return flows, pumping and release regimes within a catchment are often complex. The flows in each reach or branch of the network will often be allocated to persons or institutions. It is therefore important that the modelling system keeps track of the water ownership or allocation categories (Dent, 2001).

The primary objective of this modelling process is the application of the streamflow component of the HSPF model. In future studies, the objective will expand to encompass water resources management at a catchment level as part of the greater Mgeni River Catchment, including water quality modelling and water allocation simulation as a management tool, taking the objectives of water resource management of the NWRS into consideration.

The installed modelling system framework must keep track of all the above-mentioned factors in a functional, flexible and robust manner and it should be capable of modelling the responses to conditional anthropogenic interventions. According to Russo (Bicknell *et al.*, 1996) HSPF is the most comprehensive model in the category of continuous water budgeting models.

Therefore, the HSPF model was used in this hydrological modelling study of the Msunduzi River Catchment. However, this does not mean that HSPF is the best model to use in all circumstances, but compared to other hydrological models locally available it possessed the best combination of features for the present and future investigations.

2.3 COMPARISON OF HYDROLOGICAL MODELS IN GENERAL

According to Hydrocomp (2003) physically based, continuous water budgeting models are the most accurate models currently available. The comparison, relative merits and application of some of these models in the continuous water budgeting category are discussed below.

2.3.1 ACRU Model

The acronym ACRU is derived from the Agricultural Catchment Research Unit within the Department of Agricultural Engineering of the University of Natal in Pietermaritzburg, South Africa. The model has been verified widely on data from Southern Africa and the United States of America (USA) (Schulze, 1995: AT 2.1).

Important features:

- It is a physical conceptual model. The model conceives of a system in which important processes and couplings are idealised. Physical processes are represented explicitly.

- This multi-purpose model integrates the various water budgeting and runoff-producing components of the hydrological system, taking all the aspects of risk analysis into account. These aspects of risk analysis can be integrated with simulated soil moisture changes antecedent to design events.
- The "heart" of the ACRU model is a daily multi-layer soil water budgeting system. The model simulates the components and processes of the hydrological cycle affecting the soil water budget, like the soil water deficit antecedent to a precipitation event on a daily basis (Kienzle *et al.,* 1997: 10).
- The critical response depth of the soil depends mainly on the dominant runoff-producing mechanism. Stormflow is split into quickflow (same day response) and delayed stormflow with a "lag". This “lag” is a surrogate for simulating interflow and is dependent on soil properties, catchment size and the drainage density. Therefore the model has been developed into a versatile total evaporation model, which takes all the above-mentioned factors into consideration (Schulze, 1995: AT 2.2-2.6).
- ACRU has been designed as a multi-level model. Multiple options or alternative pathways in many of its routines are characteristic. These options are dependent on the users needs or the level of available data or the detail of output required. Various methods, taking the level of data input into account, can be used to determine most of the hydrological components. Typical components are reference potential evaporation, interception losses, values of soil water retention constants, total evaporation, leaf area index, components of the peak discharge estimation, hydrograph routing and reservoir storage area relationships.

- ACRU's operation is either as a point or as a lumped small catchment model. ACRU can also operate as a distributed cell-type model. This distributed cell-type model can also be linked to a Geographic Information System (GIS) in order to integrate geographically spatial information for input into the model and to display output from the model (Schulze, 1995: AT 2.2-2.4).

Important applications:

- The ACRU model can be used for the estimation of design runoff as a consequence of the non-stationarity of catchment responses over time. The ACRU model can also illustrate potential changes in runoff responses to design precipitation under conditions of anthropogenically induced global climate change (Schulze, 1995: AT 2.8- 2.11).
- ACRU can be applied as a designing tool in hydrology, crop yield modelling, reservoir yield simulation and irrigation water demand or -supply, regional water resources assessment and planning optimum water resource utilisation (Kienzle *et al.,* 1997: 8).
- ACRU can be applied on a minute-by-minute grid of latitude and longitude of the area, when regional water resource assessment is of any concern. The total of the simulated streamflow at each grid point is then determined. By doing this, the regional production of runoff in average, wet and drought-stricken years can be estimated (Schulze, 1995: AT 2.8-2.11).

According to Schulze (1995) the components of the water budget are integrated with the different modules available in the ACRU model to enable output of:

- Reservoir yield analysis.
- Sediment yield analysis.
- Determination of the hydrological response of wetlands.
- The effect of water abstractions from streams on the catchment's water yield.
- The hydrological impact of afforestation.
- The effect of gradual or abrupt land-use and management changes.
- The effects of enhanced atmospheric CO_2 levels on transpiration suppression and hence on crop yield and water resources.
- The depositing, transport and export of sediment, total phosphorus and *Escherichia coli* from non-point sources into receiving water bodies. However, these routines are a relatively recent addition to the model and have not yet been subjected to extensive verification.

Limitations:

- The model only uses daily time steps, thus sub-hourly simulations is not possible (Görgens *et al.*, 2002: 22). Therefore, it is not suitable for simulating certain water quantity and quality studies in small or complex catchments with sub-daily responses.
- ACRU makes no provision for simulating the implementation of water allocation or ownership categories. This will be an important requirement of the NWA.
- ACRU can normally only be used in catchments with an urban land-use less than 20% (Schmitz & De Villiers, 1997: 2).

- This model is not able to simulate the water quality of the base flow accurately and it does not make any provision for the chemical influence of sediments on the quality (Schmitz & De Villiers, 1997: 3).
- The model uses a relatively simple but primitive sequential file format for managing the large numbers of time series, which are required as input or produced as output (Smithers & Schulze, 1995: AM 4-1). This impacts negatively on the efficient execution of the model on computer.
- The model is not very flexible in terms of setting up connections of flows between operating modules.

2.3.2 HSPF Model

The modules of the HSPF model are arranged in a hierarchical structure for the continuous simulation of hydrological- and water quality processes in urban- and rural catchments (Bicknell *et al.,* 1996: iv). Detailed descriptions of the modules, which are important in the hydrological simulation are given in Chapter 3.

Extensive and flexible data management and statistical routines are available for analysing simulated or observed time series data. The HSPF software is linked to several important utilities developed under contract to the Environmental Protection Agency (EPA) and available in the public domain. These include the Generalised Scenario Generator Software (GENSCN) (EPA, 1997), Better Assessment Science Integrating Point & Non-point Sources (BASINS) (Lahlou, Shoemaker, Choudhury, Elmer, Hu *et al.*, 1998) software which links ArcView 3.2 and Arc Explorer GIS to the model user control input, and the Watershed Data Management (WDM) system for managing time series

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Important applications:

- Continuous hydrological simulation and water budgeting.
- Simulation of sediment production and removal.
- Simulation of nitrogen-phosphorous behaviour.
- Simulation of water temperature and numerous other water quality constituents using a generalised approach.
- Simulation of pesticide behaviour and movement of tracer elements.
- Analyses both point- and non-point sources of pollution.
- Simulation of separate categories of water allocation or ownership.
- Performs risk analysis due to the exposure of aquatic organisms to the toxic chemicals present in receiving waters (Bicknell *et al.*, 1996 & Aqua Terra Consultants, 2002).

Limitations:

- Requires extensive meteorological- and hydrological data.
- It is a complex model and it takes time to become fully conversant with its input files, its utilities and with the calibration of the model.
- Cost associated with different best-management practices is not linked to pollutant delivery (Donigian *et al.*, 1984).

Despite these limitations, HSPF has an excellent time series management system based on random access files and optimisation of data movement in memory, which results in fats execution when compared to other hydrological models.

2.3.3 Mike-SHE Model

The Mike-SHE model is a continuous water budgeting modelling system. It simulates all major hydrological processes in the land phase of the hydrological cycle. Therefore, this integrated model includes the dynamic exchange of water between all major hydrological components, e.g. surface water, interflow and groundwater. It is also physically based and distributed; the basic equations governing the major flow processes are solved and the spatial and temporal variation of meteorological-, hydrological- and geological data is described in a gridded form for the input as well as the output from the model. The modular structure of the model allows the expanding of water quantity simulations to deal with solute transport, particle tracking and geochemical reactions (Refsgaard & Storm, 1995).

Mike-SHE is computationally efficient and easily links regional- and local scale models. The following processes are included in the model:

- Evapotranspiration (ET);
- Two-dimensional overland flow;
- One-dimensional channel flow in river reaches;
- One-dimensional unsaturated flow;
- Saturated groundwater flow and;
- Infiltration, recharge, crop growth and nitrogen cycle analysis (SSG, 2003).

Important applications:

The model has been applied in a large number of studies worldwide focusing on the conjunctive use of surface water and groundwater for domestic and industrial consumption, as well as irrigation, wetland dynamics and water quality studies (Gupta, Das, Raghuwanshi, Singh, Dutta *et al.*, n.d.). Typical applications are as follows:

- Surface water impact from groundwater withdrawal.
- Conjunctive use of groundwater and surface water.
- Wetland management and restoration.
- Catchment management and planning.
- Environmental impact assessment studies.
- Aquifer vulnerability mapping with dynamic recharge and surface water boundaries.
- Floodplain studies.
- Impact studies for changes in land-use, climate and agricultural practices (SSG, 2003).

Limitations:

- Numerical simulation results are overly dependent on grid cell sizes larger than one square kilometre due to the tight linkage of surface- and groundwater in this code.

- The lack of published examples of applying the model to pesticides.
- Aquifer geometry data are required to apply the three-dimensional groundwater sub-model.
- Numerical methods to solve the solute transport equations are under construction, thus problems concerning the conservation of mass, can be experienced (DeGloria, Pacenka, Porter, Anderson, Smith *et al.*, 1999).
- The source code is not available, and the model is expensive to purchase.

2.3.4 SWAT Model

The acronym SWAT is derived from Soil and Water Assessment Tool. SWAT is a continuous water budgeting model used to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex catchments over long periods of time (Arnold, Williams, Nicks & Sammons, 1990).

SWAT incorporates features of several Agriculture Research Service (ARS) models and is a direct outgrowth of SWRRB model (Simulator for Water Resources in Rural Basins) (Williams, Nicks & Arnold, 1985; Arnold, *et al.*, 1990). Specific models that contributed significantly to the development of SWAT were CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems) (Knisel, 1980), GLEAMS (Groundwater Loading Effects on Agricultural Management Systems) (Leonard, Knisel & Still, 1987), and EPIC (Erosion-Productivity Impact Calculator) (Williams, Jones & Dyke, 1984).

The model includes the incorporation of the urban build-up and/ or wash-off equations from Stormwater Management Model (SWMM), instream water quality based on the Enhanced Stream Water Quality Model (QUAL2E) kinetics, pond simulation and creation of interfaces with Windows, ArcView and BASINS (Neitsch, Arnold, Kiniry & Williams, 2001).

Important features:

The model is physically based. It requires specific information about meteorological data, catchment data and land management practices occurring in the catchment, rather than incorporating regression equations to describe the relationship between input and output variables. The physical processes associated with water movement, sediment transport, crop growth and nutrient cycling are directly simulated by SWAT using this input data (Arnold, *et al.*, 1990). The model is freely downloadable from the Internet.

Important applications:

- Unregulated catchments with no observed streamflow data can be modelled.
- The modelling of sediment transport, crop growth and nutrient cycling.
- The relative impact of alternative input data (changes in management practices, climate and land-use) on water quality or other variables of interest can be quantified.
- It is computationally efficient, thus the simulation of very large catchments can be performed without excessive investment of time or money.

- It enables users to study long-term impacts. Some of the problems currently addressed by users involve the gradual build-up of pollutants and the impact on downstream water bodies. Results from runs with output of several decades are needed to study these types of problems (Arnold, *et al.*, 1990).

Limitations:

- The model is not designed to simulate detailed, single-event flood routing.
- The model only uses daily time steps, thus sub-hourly simulations is not possible (Neitsch *et al.*, 2001).
- It has not been widely applied and verified as other models such as HSPF, and its application to studies in South Africa is still very limited.

2.2.5 SWMM Model

The acronym SWMM is derived from Stormwater Management Model. This model of the EPA is a comprehensive deterministic model for analysis of quantity and quality problems associated with urban runoff. The model can perform both single-event and continuous storm simulations on catchments (Huber, Heany, Nisi, Dickenson & Poleman, 1982 & Green & Stephenson, 1986: 16). Continuous simulation has not yet been extensively used in South Africa, chiefly due to problems encountered with inputting historical precipitation data (Green & Stephenson, 1986: 17).

Important applications:

- The modeller can simulate all aspects of the urban hydrological and quality cycles, including precipitation, snowmelt, surface and subsurface runoff, flow routing through a drainage network, storage and treatment (Brach, 2000: 8.40-18).

Limitations:

- Cannot simulate the effect of agricultural land-use.
- The lack of subsurface quality routing (a constant concentration is used).
- No interaction of quality processes (apart from adsorption).
- Difficulty in simulation of wetland quality processes.
- A weak scour-deposition routine in the Transport Block

(Brach, 2000: 8.40-18)

CHAPTER

3

LITERATURE REVIEW:
HSPF DEVELOPMENT & STRUCTURE

HSPF MODELLING OF THE MSUNDUZI RIVER CATCHMENT

3. LITERATURE REVIEW: HSPF DEVELOPMENT AND STRUCTURE

3.1 INTRODUCTION

The Hydrological Simulation Program-Fortran (HSPF) is a mathematical model developed under USEPA sponsorship to simulate hydrological and water quality processes in natural and man-made water systems. It is an analytical tool, which has application in the planning, design and operation of water resource systems. The model enables the use of probabilistic analysis in the fields of hydrology and water quality management (Aqua Terra Consultants, 2002).

HSPF uses historical information such as precipitation, temperature, evaporation and parameters related to land-use patterns, soil characteristics and agricultural practices to simulate the processes that occur in a catchment. The initial result of an HSPF simulation is a time history of the quantity and quality of water transported over the land surface and through various soil zones down to the groundwater aquifers (Aqua Terra Consultants, 2002). HSPF simulates for extended periods of time the hydrological- and associated water quality processes on pervious and impervious land surfaces, streams and well-mixed impoundments. HSPF uses continuous precipitation- and other meteorological data to compute streamflow hydrographs and pollutographs (Bicknell *et al.*, 1996: iv).

HSPF can simulate interception, soil moisture, interflow, groundwater recharge, base flow, surface runoff, evapotranspiration (ET), temperature, snowpack depth and water content and snowmelt. It can also simulate the processes of sediment detachment and transport, sediment routing by particle size, channel-, reservoir- and constituent routing. Furthermore HSPF can simulate the effects of dissolved oxygen (DO), biochemical oxygen demand (BOD), pesticides, conservatives, faecal coliforms, pH, ammonia, nitrite-nitrate, organic nitrogen, orthophosphate and organic phosphorous (Donigian *et al.*, 1984: 171-177).

There is no limitation on the period that may be simulated (USGS, 2002).

3.2 HSPF: DEVELOPMENT

The Environmental Research Laboratory in Athens, Georgia sponsored the original development of HSPF. The USGS Water Resources Division in Reston, Virginia has sponsored recent development of HSPF. Hydrocomp Incorporated performed the initial HSPF and user's manual development work. Anderson-Nichols & Company and Aqua Terra Consultants performed subsequent revisions and extensions to the HSPF code and user's manual (Bicknell *et al.*, 1996: 6).

Taking the above-mentioned into consideration, it is clear that HSPF is not the product of one person or organisation. It has been developed, expanded and crafted over the last 25 years.

3.3 MODEL STRUCTURE AND DESIGN

HSPF consists of a set of modules arranged in a hierarchical structure. These modules permit the continuous simulation of hydrological- and water quality processes. In the application of complex models much of the human effort is associated with data management. Sound data management is an important component in successful comprehensive models, because the user may become so entangled in data manipulation that his progress on the simulation work itself is badly influenced. The HSPF software is planned around a time series management system operating on direct access principles.

Simulation modules can draw input from time series storage files and therefore it can write output to them. Thus, these transfers require very few instructions from the user. The above-mentioned problems are then also minimised (Bicknell *et al.,* 1996: 2).

Various simulation- and utility modules can be invoked conveniently into the system, either in tandem or individually. The emphasis is on structured design and therefore a “top down” approach has been followed (Bicknell *et al.,* 1996: 2).

The first step was to design the overall framework and the time series management system. Thereafter, the work progressed down the structure from the highest, most general level to the lowest, most detailed one. Structured design has made the system easy to extend. Therefore users can add their own modules with little disruption of the existing code (Bicknell *et al.,* 1996: 2).

The “real world” is a continuum of constituents and processes, which are subdivided into "elements". These elements consist of "nodes" and "zones”. Nodes correspond to a point in space and a particular value of a spatially variable function can be associated with it. Zones correspond to a finite portion of the “real world” and it is associated with the integral of spatially variable quantities.

Zones are the smallest units into which the world is subdivided. The relationship between zonal and nodal values is comparable with that between the definite integral of a function and its values at the limits of integration. When the response of land phases of the hydrological cycle are simulated, these elements are known as "segments." A segment is a portion of land, which is assumed to have uniform properties (Bicknell *et al.,* 1996: 9).

The model builder decides what grouping of these “segments” is reasonable and meaningful when the “real world” is being simulated. This is based on his view of the “real world” processes. Nodes are used to define the boundaries of zones and elements. “Fluxes” are a zone, characterised by storage that receives inflows and disperses outflows (Bicknell *et al.,* 1996: 11).

3.3.1 PERLND Module (including section PWATER)

Water, sediment and water quality constituents leaving the catchment are assumed to move laterally to a downslope segment, reach or reservoir during the modelling process. Pervious Land Segments (PLS) have the capacity to allow enough infiltration to influence the water budget. PERLND is the module that simulates the hydrological- and water quality processes, which occur on a pervious land segment (Bicknell *et al.,* 1996: 37).

The primary module sections and their functions in PERLND are the following:

- SNOW (Simulates snow accumulation and melt);
- PWATER (Water budget, total runoff from pervious areas);
- SEDMNT (Sediment produced by land surface erosion) and;

- PQUAL (Water quality constituents by various methods).

PERLND models the movement of water along three paths: overland flow, interflow and groundwater flow to simulate the above-mentioned processes. The time delay and interactions between water and its various dissolved constituents are different (Bicknell *et al.*, 1996: 37).

PWATER is the key hydrological component of module section PERLND. This module section predicts the total runoff from a pervious area by calculating the components of the water budget. When snow accumulation and -melt are not considered, the module section PWATER requires only potential evapotranspiration (ET) and precipitation as input time series data (Bicknell *et al.*, 1996: 54).

Figure 3.1 represents the water movement and storages simulated in module section PWATER. All these parameters, which play an important role in the complex series of pathways and storages in module section PWATER are discussed in detail in section 3.5 of this chapter, as well as in Chapter 4.

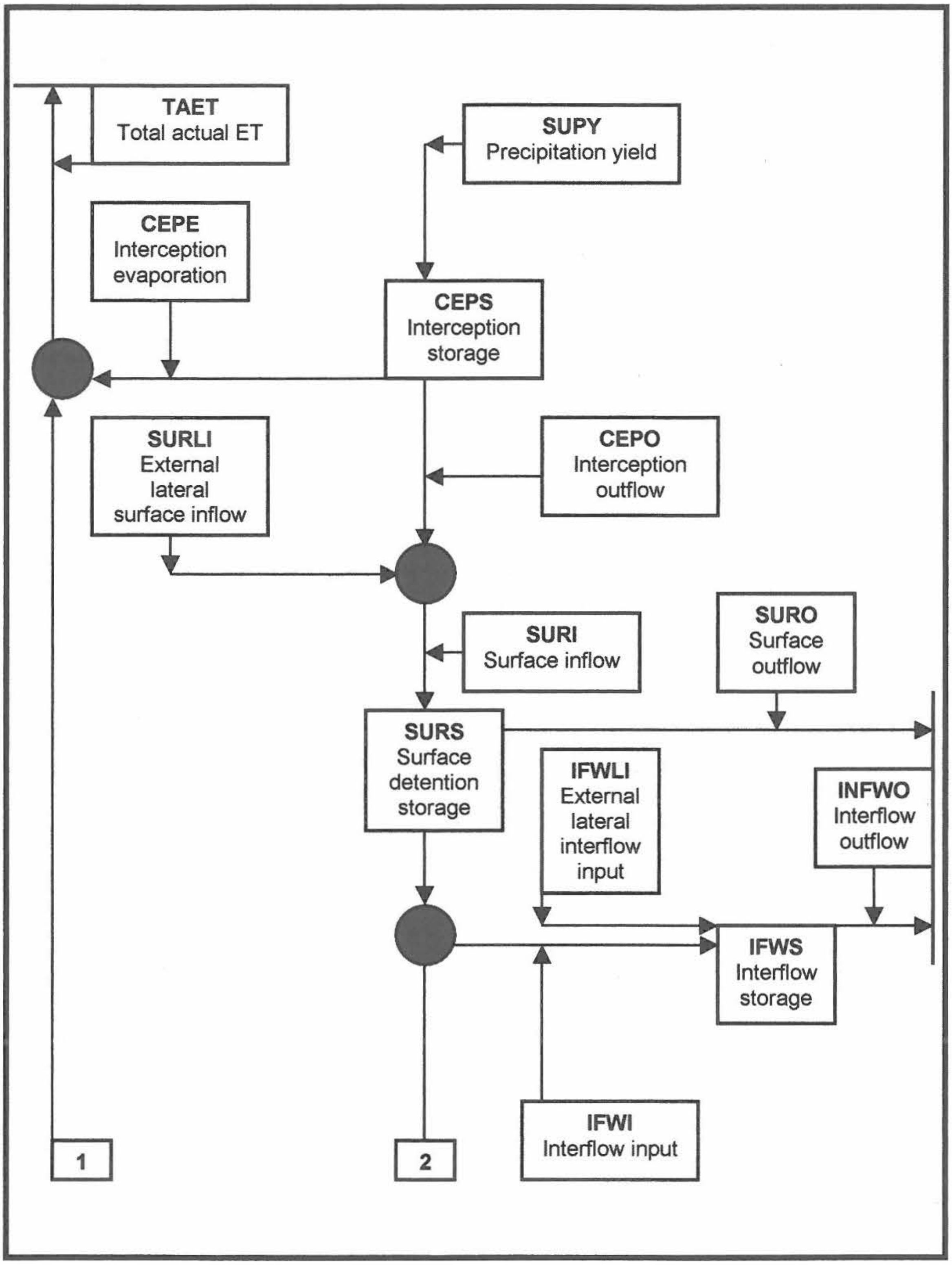

Figure 3.1: Flow diagram of water movement and storages simulated in the PWATER section (PERLND module) (Bicknell *et al.*, 1996: 57)

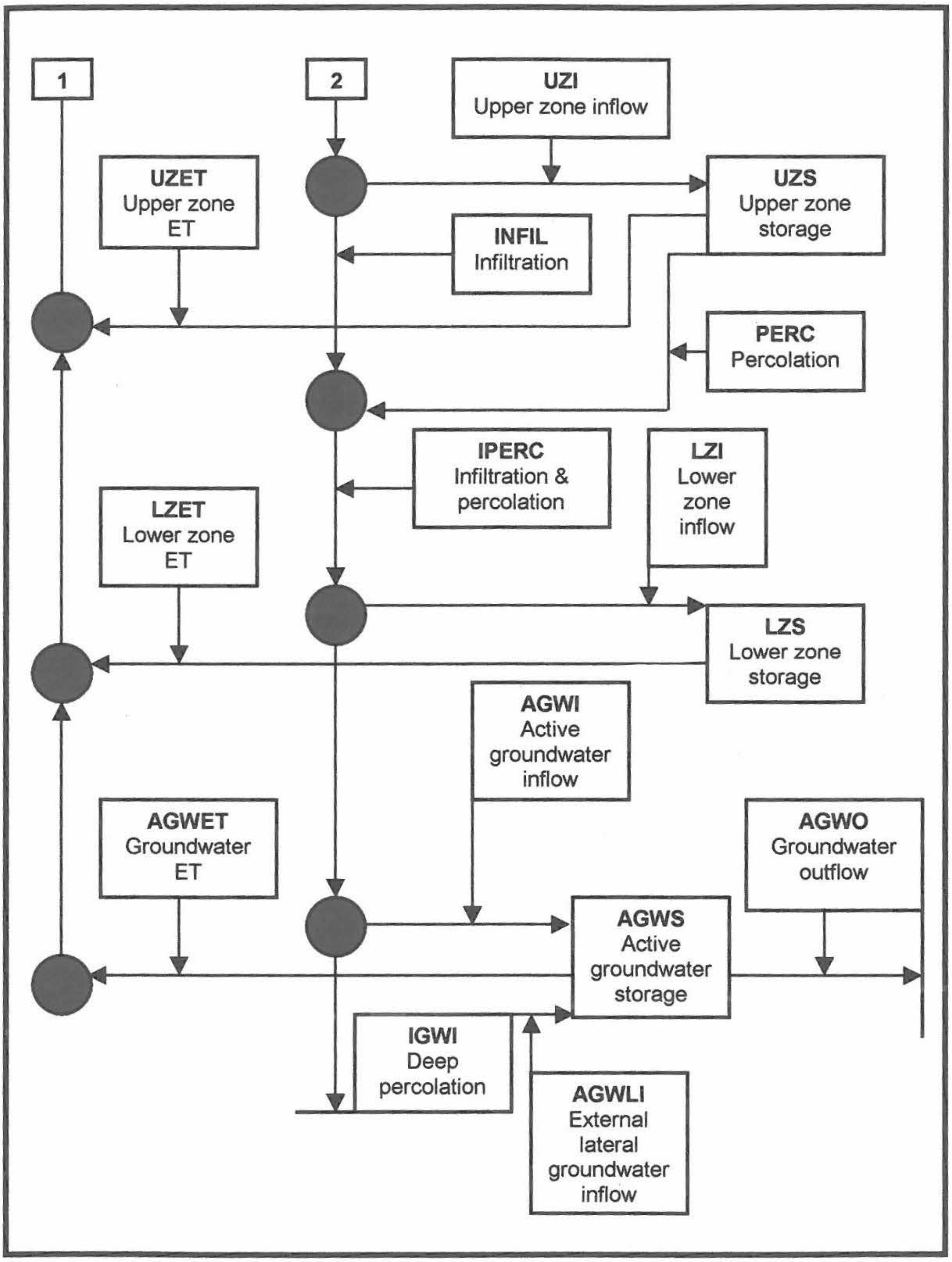

Figure 3.1 (continued): Flow diagram of water movement and storages simulated in the PWATER section (PERLND module) (Bicknell *et al.*, 1996: 58)

3.3.2 IMPLND Module (including section IWATER)

Impervious Land Segment (IMPLND) is the module that simulates the water quality and quantity processes, which occur on an impervious land segment, where little or no infiltration occurs. IWATER (Water budget for impervious land segments) simulates the retention, routing and evaporation of water from an impervious land segment. Section IWATER is similar to section PWATER of the PERLND module. In IWATER there is no infiltration and consequently no subsurface processes. IWATER has the same time series requirements as section PWATER (Bicknell *et al.,* 1996: 114). Figure 3.2 represents the fluxes and storages simulated in module section IWATER.

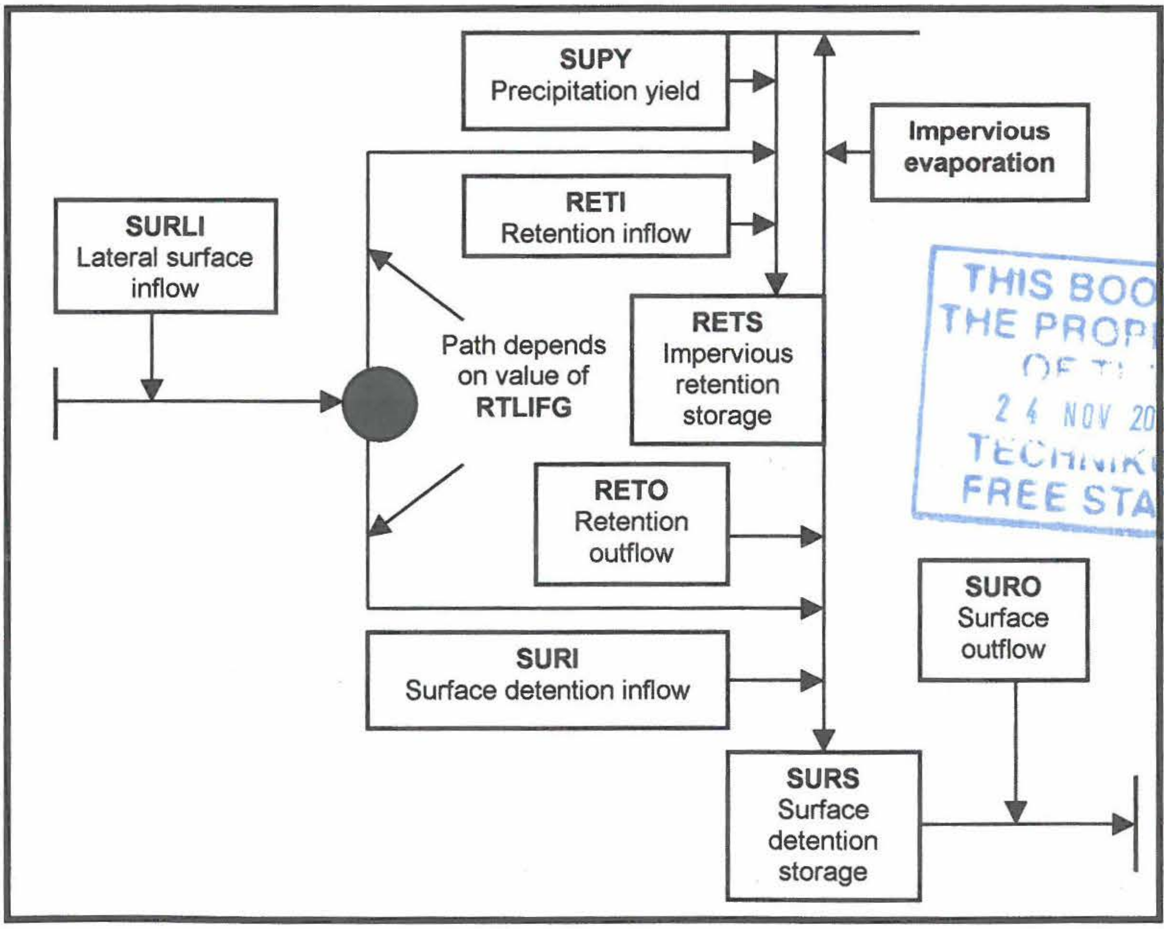

Figure 3.2: Flow diagram of water movement and storages simulated in the IWATER section (IMPLND module) (Bicknell *et al.*, 1996: 117)

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3.3.3 RCHRES Module (including section HYDR)

RCHRES (Runoff Simulator in a Single Reach) routes the movement of runoff water and its associated water quality constituents simulated by PERLND and IMPLND, through river networks and reservoirs. These processes occur in a single reach of an open or closed channel or a completely mixed lake. Due to the assumption of complete mixing, the RCHRES module consists of a single zone situated between two nodes. These nodes are the extremities of the RCHRES (Bicknell *et al.*, 1996: 128).

The flow through a RCHRES is uni-directional. Water and other constituents from other reaches and local sources enter the RCHRES through a single gate (INFLO). The outflow (OFLO) leaves the RCHRES through one of several gates or exits. A RCHRES can have up to five exits. Precipitation, evaporation and other fluxes also influence the processes, which occur in the RCHRES. These processes do not pass through the exits (Bicknell *et al.*, 1996: 128).

The HYDR section simulates the hydraulic processes occurring in a reach or a mixed reservoir. The final goals of the HYDR section is flood routing, study of reservoir behaviour and analysis of dissolved constituents. The input of water from precipitation and the loss of water by evaporation from the surface can also be considered (Bicknell *et al.*, 1996: 132). A flow diagram that illustrates the principal state variable (stored volume) and fluxes of the HYDR section is shown in Figure 3.3.

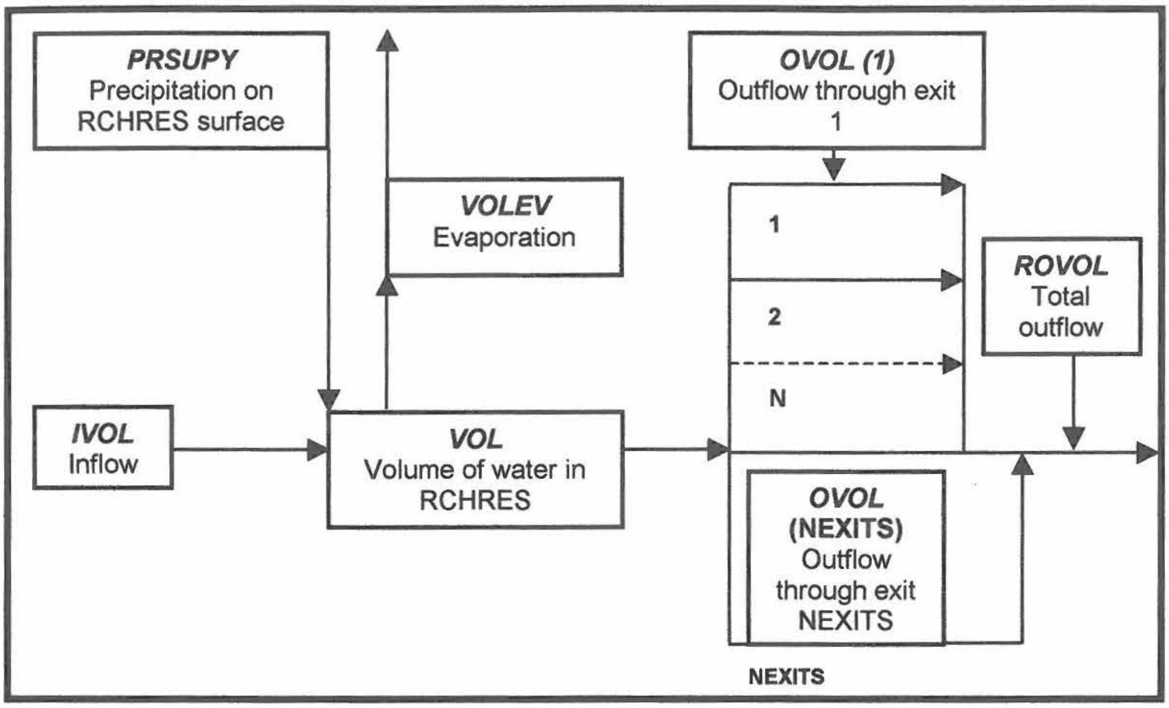

Figure 3.3: Flow diagram for the HYDR section of the RCHRES module (Bicknell *et al.*, 1996: 133)

3.4 MODEL CAPABILITIES AND STRATEGY

Some of the many capabilities available in the PERLND module include the simulation of:

- Water budget;
- Snow accumulation and melt;
- Sediment production and removal;
- Nitrogen and phosphorous behaviour;
- Pesticide behaviour and;
- Movement of tracer chemicals (Aqua Terra Consultants, 2002).

In this study, only the water budget capability was used.

Some of the many processes that can be modelled in the RCHRES module, includes the following:

- Hydraulic behaviour and water temperature;
- Inorganic sediment deposition and transport by particle size;
- Chemical partitioning, hydrolysis, volatilisation, oxidation and biodegradation;
- DO and BOD balances;
- Inorganic nitrogen and phosphorous balances;
- Plankton populations and;
- Ph, CO_2, total inorganic carbon and alkalinity (Aqua Terra Consultants, 2002).

In this study, only the hydraulic behaviour capability was used.

The development of a strategy or simulation plan implies the following steps, namely:

- Identifying all the relevant meteorological data;
- Developing a catchment discretisation scheme, referring to discretisation of all the homogeneous hydrological responses, soil characteristics and land-uses;
- Identifying the hydraulic and geometric characteristics of the river network;
- Examining of all available streamflow- and water quality data and;
- Devising a modelling strategy, which make use of all the data (Donigian *et al.,* 1984: 17).

3.5 HSPF'S CONCEPTUALISATION OF THE HYDROLOGICAL CYCLE

In the HSPF model the hydrological cycle is simulated by a complex series of storages and pathways. HSPF's conceptualisation of the hydrological cycle and how the model depicts soil water budgeting is shown in Figure 3.4. The cycle is simulated as follows:

- Vegetation intercepts the precipitation. Only a part of the precipitation reaches the land surface, while the vegetation retains the other part. This interception storage (CEPS) is simulated as a reservoir, which must be filled before any precipitation can reach the land surface. The capacity of this CEPS reservoir varies, as the seasonal vegetation cover differs. The water in storage evaporates back into the atmosphere (Bicknell *et al.,* 1996: 56, 59).

- The other percentage of water, which reaches the land surface, is available as surface detention storage (SURS). This SURS is a temporary reservoir.

  The water can either enter the upper zone as potential runoff or it can infiltrate to the subsurface. The distribution of potential runoff and infiltration is a function of the infiltration rate and antecedent soil moisture content. A high soil moisture content and low infiltration rate normally results in a higher percentage of runoff (Bicknell *et al.,* 1996: 56, 60).

- Potential direct runoff is the water available in the upper zone. This potential direct runoff can be sub-divided into direct surface-, interflow- and upper zone storage. The quantity of runoff for a specific time interval is a function of the catchment slope, roughness and distance to the main stream (Munson, 1998: 84).

- Interflow runoff is also stored in a reservoir. This reservoir empties according to an active groundwater recession rate parameter (AGWRC) (1/day). The upper zone nominal storage (UZSN) represents depressions such as ditches on the catchment surface. Water in this storage can either evaporate or percolate to the subsurface or it may become runoff or interflow during the next time interval (Munson, 1998: 84).

- The water is either routed to the lower zone storage (LZS), active groundwater storage (AGWS) or deep, inactive groundwater (IGWI) after infiltration. Firstly, the water is trapped in the LZS and it is based on the ratio water currently in storage to the nominal storage capacity. All the water in the lower zone nominal storage (LZSN) evaporates back to the atmosphere. After the LZS is satisfied, the remaining water is then divided between inactive and active groundwater. The groundwater specified as inactive is then lost from the cycle. AGWS is stored in a reservoir and then released to the baseflow (Bicknell *et al.*, 1996: 69-71).

- In the HSPF model pan evaporation is normally multiplied by a factor ranging between 0.8 and 0.85 to convert it to daily total potential ET, since the pan evaporation data are normally too high (Wilson, 1990: 55). In order to meet the specific amount of ET in HSPF, the sequence of evaporation from the five possible storages is as follows: Baseflow, CEPS, upper zone storage (UZS), AGWRC and LZS. ET processes occur until all reservoirs are empty or the measured ET is satisfied (Munson, 1998: 84).

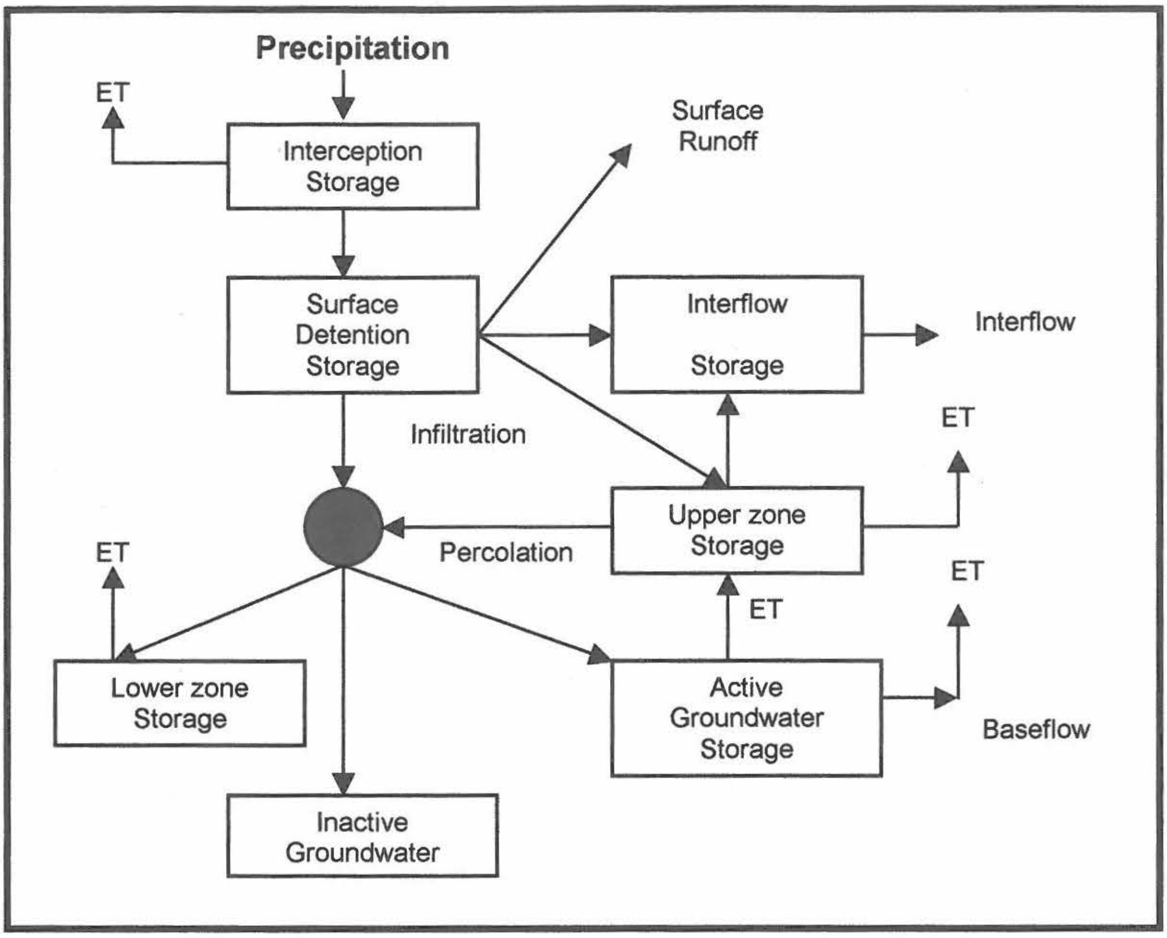

Figure 3.4: HSPF hydrological cycle (Munson, 1998: 83)

3.6 DATA REQUIREMENTS

HSPF requires extensive data to accurately simulate hydrological processes in a catchment. The amount and type of data required depends on what is to be simulated. Some input variables can be assumed to be constant, which will reduce the data requirements, but also the functionality of the simulation. The quality of a HSPF simulation will strongly depend on the quality of the input data.

Data requirements are grouped into three broad categories:

- Catchment-specific information is necessary to accurately represent the catchment. These data include altitudes, average slopes and channel geometry, soil types, vegetation types and land-use (Munson, 1998: 35).

  For the Msunduzi River Catchment, the impact of human water use must also be considered. Such information can be collected from topographical maps, field observations, GIS databases and historical records.

- HSPF requires meteorological data to drive the hydrological cycle during a simulation (Munson, 1998: 35). Data are collected from weather stations maintained by the South African Weather Service in and near the Msunduzi River Catchment. Meteorological records of precipitation and estimates of potential ET are required for catchment simulation. Surrogates of these meteorological data can be used (Dent, 2002). The monthly mean evaporation used in the Msunduzi River Catchment is a typical example.

- Physical measurements and related parameters are required to describe the land-use, rivers and reservoirs within a catchment (USGS, 2002). The successful application of HSPF in a catchment is influenced by the representation of the catchment's physical characteristics. The larger and more heterogeneous the catchment, the more difficult it becomes to collect a complete data set (Munson, 1998: 36).

4. LITERATURE REVIEW: PARAMETERS, CALIBRATION AND MODEL PERFORMANCE

4.1 PARAMETER ESTIMATION

The overarching principle in parameter estimation should be that the estimated values must be realistic; therefore make hydrological sense and reflect the conditions on the catchment.

In the process of hydrological simulation there are two types of parameters, namely control-oriented and process-oriented parameters. Control-oriented parameters specify the period of simulation, the type of constituents to be modelled and the presenting of the simulation results. Process-oriented parameters are used to provide a mechanism to adjust the simulation for specific topographical-, hydrological-, land-use- and hydraulic conditions in a specific catchment (Donigian *et al.,* 1984: 77).

The values of physical parameters vary on a seasonal basis; therefore it is recommended that parameters such as precipitation interception, upper zone storage capacity, land surface roughness and ET be estimated on a monthly basis (Donigian *et al.,* 1984: 83).

4.1.1 PWATER Parameters

Only the most important PWATER parameters are discussed in detail. All the other parameters that form a less important role in this hydrological modelling attempt or are used as default values are summarised in Table 4.5.

LZSN is the lower zone nominal soil moisture storage (mm). It is related to both precipitation patterns and soil characteristics in a catchment. LZSN is firstly an estimated value (normally between 130 and 380 mm) and then calibrated (USEPA, 2000: 9). According to Viessman, Lewis and Knapp (1989) initial estimates for LZSN as used in the Stanford Watershed Model is one-quarter of the mean annual precipitation plus 100 mm for arid and semi-arid regions or one-eighth of the mean annual precipitation plus 100 mm for coastal, humid or sub-humid climates. These formulae tend to give values somewhat higher than the typically final calibrated values. LZSN will be adjusted through an iterative calibration procedure.

INFILT is the index to mean soil infiltration rate (mm/hr). This parameter effectively controls the overall division of the available moisture from precipitation into surface-, subsurface flow and storage components. High values of INFILT will produce more water in the LZS and AGWS. This will result in higher baseflow to the stream. Low values of INFILT will produce more water in the UZS and interflow storage. This will result in greater direct overland flow and interflow. INFILT is firstly estimated, and then followed by an iterative calibration process. INFILT is primarily a function of soil characteristics (USEPA, 2000: 9-10). The value ranges have been related to SCS hydrological soil groups as depicted in Table 4.1.

Table 4.1: SCS hydrological INFILT estimations (Donigian & Davis, 1978: 61)

Soil group	Infiltration (mm/hr)	Runoff potential
A	10 - 25	Low
B	2.5 - 10	Moderate
C	1.25 - 2.5	Moderate to high
D	0.25 - 1.25	High

LSUR is the length of the assumed overland flow plane (m). It is an approximation of the average length of travel for water to reach a stream reach or any drainage path that quickly deliver the water to the stream or waterbody. LSUR can be estimated or measured from topographical data by dividing the catchment area by twice the length of all streams, gullies and ditches that move the water to the stream. That is, a representative straight-line reach with length L, bisecting a representative square areal segment of the catchment. This will produce two overland flow planes of width 0.5 L. LSUR values derived from topographical data are often over-estimated when the data are of insufficient resolution to display the many small streams (USEPA, 2000: 11).

SLSUR is the average slope of assumed overland flow path (m/m). GIS capabilities can be used to estimate average SLSUR values for each land-use being simulated. Graphical techniques whereby a grid pattern is imposed on the catchment and then the slope values for each grid point for each land-use are calculated, can also be implemented (USEPA, 2000: 11).

KVARY is the groundwater recession flow parameter used to describe the non-linear groundwater recession rate (/mm). It is usually one of the last PWATER parameters to be adjusted. It is normally used when the observed groundwater recession demonstrates a seasonal variability with a faster recession during wet periods (USEPA, 2000: 11).

AGWRC is the ratio of current groundwater discharge to that from 24 hours earlier, when KVARY (groundwater recession rate) (1/day) is zero (USEPA, 2000: 12).

In other words, it is the ratio of today's flow divided by yesterday's flow. HSPF assumes the groundwater reservoir is "linear". This ratio should be constant and a semi-logarithmic plot of groundwater flow should be a straight line, because the flow is decreasing exponentially (Johanson, 1989). AGWRC is first estimated and then calibrated (USEPA, 2000: 12).

DEEPFR is the fraction of infiltrating water, which is lost to deep aquifers (inactive groundwater). The remaining fraction (1-DEEPFR) is assigned to active groundwater storage that contributes baseflow to a stream. It also represents any other losses that may not be measured at the hydrological gauging station used for calibration. Flow around or under the gauge site, or underlying dolomitic geology are typical examples. This accounts for one of only three major losses from the PWATER balance. The other two losses are ET and lateral stream outflows. Initially DEEPFR is set to zero or estimated based on groundwater studies. It is then calibrated in conjunction with adjustments to ET parameters to achieve a reasonable annual water balance (USEPA, 2000: 13).

CEPSC is the amount of precipitation (mm), which is retained by vegetation and never reaches the land surface and is eventually evaporated (USEPA, 2000: 14). Typical values for CEPSC for selected land-uses are shown in Table 4.2.

Table 4.2: Maximum interception versus land-use (Donigian & Davis, 1978: 54)

Land-use	Maximum interception (mm)/day
Grassland	2.54
Cropland	2.54-6.35
Forest cover, light	3.81
Forest cover, heavy	5.08

As part of an annual water balance, it must be noted that 10-20% of precipitation during the growing season is intercepted. As much as 25% of total annual precipitation is intercepted under dense closed forests. Crops and grassland exhibit a wide range of interception rates, between 7% and 60% of the total precipitation (USEPA, 2000: 15).

UZSN is the nominal upper zone soil moisture storage (mm). It is related to land-use characteristics, topography and LZSN. UZSN may change due to variations in agricultural conditions, tillage and other practices over the course of the growing season. Increasing UZSN values increase the amount of water retained in the upper zone and that available for ET. It thereby decreases the dynamic behaviour of the surface and reduces direct overland flow. Decreasing UZSN has the opposite effect (USEPA, 2000: 15).

Initial estimates for UZSN of 0.06 LZSN (steep slopes, limited vegetation and low depression storage), 0.08 LZSN (moderate slopes, moderate vegetation and moderate depression storage) and 0.14 LZSN (heavy forest cover, soils subject to cracking, high depression storage and very mild slopes) can be used (Donigian & Davis, 1978: 54).

NSUR is Manning's *n* for an overland flow plane. Manning's *n* values for overland flow are considerably higher than the more common published values (USEPA, 2000: 15). According to Hwang and Hita (1987) *n* values for flow through a channel range from a low of about 0.011 for smooth concrete, to as high as 0.050-0.10 for flow through unmaintained channels.

The tabulated values for the following different land-use conditions are shown in Table 4.3.

Table 4.3: Manning's *n* value versus land-use (Donigian & Davis, 1978: 61)

Land-use	Manning's *(n)*
Smooth packed surface	0.05
Normal roads and parking lots	0.10
Disturbed land surfaces	0.15-0.25
Moderate turf/pasture	0.20-0.30
Heavy turf, forest litter	0.30-0.45
Conventional tillage	0.15-0.25
Smooth fallow	0.15-0.20
Rough fallow, cultivated	0.20-0.30
Crop residues	0.25-0.35
Meadow, heavy turf	0.30-0.40

INTFW is the coefficient that determines the amount of water that enters the ground from surface detention storage and becomes interflow, in contrast to direct overland flow and upper zone storage. Interflow can have an important influence on storm hydrographs, particularly when shallow, less permeable soils delay vertical percolation. The timing of runoff is affected by INTFW, due to the division of water between interflow and surface processes (USEPA, 2000: 15). Increasing INTFW increases the amount of interflow and decreases direct overland flow. Therefore peak flows are reduced, while the same volume is maintained. The shape of the hydrograph is then affected, by shifting and delaying the flow to later in time (USEPA, 2000: 16).

IRC is the interflow recession coefficient. It is analogous to the groundwater recession parameter, AGWRC. IRC affects the rate at which interflow is discharged from storage. It also affects the hydrograph shape in the recession limb of the curve. The maximum value range is from 0.3 to 0.85, with lower values on steeper slopes. High values of IRC will make interflow behave more like baseflow. Low values will make interflow behave more like overland flow (USEPA, 2000: 16). Typical values are between 0.2 and 0.4 (Johanson, 1989).

LZETP is the index to lower zone evapotranspiration. It is a coefficient used to define the ET opportunity. It affects ET from the lower zone, which represents the primary soil moisture storage and root zone of the soil profile. LZETP behaves much like a "crop coefficient" with values mostly in the range of 0.2 to 0.7. It is primarily a function of the different land-uses and vegetation (USEPA, 2000: 17). Typical LZETP values for the different land-uses are listed in Table 4.4.

Table 4.4: Typical LZETP values versus land-use

Land-use	LZETP
Forest	0.6-0.8
Grassland	0.4-0.6
Row crops	0.5-0.7
Barren	0.1-0.4
Wetlands	0.6-0.9

Table 4.5: HSPF pervious hydrology parameters and value ranges (USEPA, 2000: 30)

Parameter	Unit	Range of values		Comment (Function of)
		Typical	Possible	
PWAT-PARM 2				
LZSN	mm	76-200	50-380	Calibration (Soil and climate)
INFILT	mm/h	0.25-6.4	0.025-2.7	Calibration, divides surface and sub-surface flow (Soil and land-use)
LSUR	m	60-150	30-215	Estimate from high resolution topographical maps or GIS (Topography)
SLSUR	m/m	0.01-0.15	0.001-0.3	Estimate from high resolution topographical maps or GIS (Topography)
KVARY	1/mm	0.0-76	0.0-127	Used when recession rate varies with groundwater levels (Baseflow recession variation)
AGWRC	none	0.92-0.99	0.85-0.99	Calibration (Baseflow recession)
PWAT-PARM 3				
INFEXP	none	2	1-3	Exponent in infiltration equation Usually default of 2.0 (Soil variability)
INFILD	none	2	1-3	Ratios of max/ mean infiltration capacities. Default of 2.0 (Soil variability)
DEEPFR	none	0-0.2	0-0.5	Accounts for subsurface losses (Geology and groundwater recharge)
BASETP	none	0-0.05	0-0.2	Fraction of remaining ET from baseflow, thus direct ET from vegetation (Riparian vegetation)
AGWETP	none	0-0.05	0-0.2	Fraction of remaining ET from groundwater, thus direct ET from shallow groundwater (Marsh or wetland extent)
CEPSC	mm	0.76-5	0.25-10	Monthly values usually used (Vegetation and land-use)

Table 4.5 (continued): HSPF pervious hydrology parameters and value ranges (USEPA, 2000: 30)

Parameter	Unit	Range of values		Comment (Function of)
		Typical	Possible	
PWAT-PARM 4				
UZSN	mm	2.5-25	1.3-50	Accounts for near surface retention (Surface soil conditions and land-use)
NSUR	none	0.15-0.35	0.05-0.5	Monthly values often used for croplands (Surface conditions and residue)
INTFW	none	1-3	1-10	Calibration, based on hydrograph separation (Soil, topography and land-use)
IRC	none	0.5-0.7	0.3-0.85	Often start with a value of 0.7 and then adjust (Soil, topography and land-use)
LZETP	none	0.2-0.7	0.1-0.9	Calibration (Vegetation type, density and root depth)

4.1.2 IWATER Parameters

LSUR is the length of the assumed overland flow plane (m). LSUR reflects the overland flow length on directly connected or effective impervious area. It is usually in the range of 15 – 76 m, although longer lengths may apply in commercial or industrial areas (USEPA, 2000: 20).

RETSC is the retention/ interception storage (mm) of the impervious surface, thus the depth of water that collects on the impervious surface before any runoff occurs. It is the impervious equivalent of the interception storage variable (CEPSC) used for pervious land segments. According to Dinicola (1990) an initial value of 2.5 mm for RETSC is appropriate. During detention storage design of parking lots and rooftops, larger values of up to 13 mm may be reasonable (USEPA, 2000: 21).

Table 4.6: HSPF impervious hydrology parameters and value ranges (USEPA, 2000: 31)

Parameter	Unit	Range of values		Comment (Function of)
		Typical	Possible	
IWAT-PARM 2				
LSUR	m	15-46	15-76	Estimate from maps, GIS or field survey (Topography and drainage)
SLSUR	m/m	0.01-0.05	0.001-0.15	Estimate from maps, GIS or field survey (Topography and drainage)
NSUR	none	0.03-0.1	0.01-0.15	Typical range is 0.05-0.10 for roads or parking lots (Impervious surface conditions)
RETSC	mm	0.8-2.5	0.25-8	Typical range is 0.76-2.54 for roads or parking lots (Impervious surface conditions)

4.1.3 HYDR Parameters (Flow routing)

Only the most important HYDR parameters are discussed in detail. All the other parameters and functions are summarised in Table 4.7.

HSPF computes streamflow through a stream reach or reservoir based on two assumptions:

- A fixed relationship exists between depth, volume and discharge and;
- Discharge is a function of volume (USEPA, 2000: 23).

Flow reversals and backwater effects in an upstream reach are therefore not simulated. Routing is computed using the techniques of storage routing or kinematic wave routing. Momentum is not considered in the routing computations (USEPA, 2000: 23).

LEN is the length of the stream reach (km). It is used in the computation of parameter values (USEPA, 2000: 24).

DELTH is the change in elevation from the upstream end of the river reach to the downstream end (m) (USEPA, 2000: 24).

KS is a weighting factor applied in the computation of the river reach outflow. A KS value of 0.5 is recommended (USEPA, 2000: 24).

CRRAT is the ratio of the maximum velocity to the mean velocity in the stream channel cross-section under typical flow conditions. It must be 1.0 or greater. A value of 1.0 corresponds to completely uniform velocity across the stream channel. It is used to determine the relative volumes of water stored in the stream reach versus that leaving the reach in a given time interval. The outflow is assumed to be in part, made up of water that entered the reach in that same interval, when CRRAT is greater than the volume: outflow ratio. The inflow constituent concentration then alters and influences the outflow constituent concentration (USEPA, 2000: 26).

Table 4.7: HSPF hydraulic parameters and value ranges (USEPA, 2000: 32)

Parameter	Unit	Range of values		Comment (Function of)
		Typical	Possible	
HYDR-PARM 2				
FTBDSN	none	none	1-999	Used only if FTABLE is in WDM file (WDM file)
FTABNO	none	none	1-999	Used only if FTABLE is in UCI file (RCHRES block or reach numbering)
LEN	km	0.161-1.61	0.016-161	Used only in computing auxiliary parameters (Topography and river morphology)
DELTH	m	3.05-30.48	0.031-305	Used only for water quality and sediment (Topography and river morphology)
STCOR	m	0-none	0-none	Stage correction factor. Dependent on elevation datum used (Topography)
KS	none	0-0.5	0-0.99	Use KS = 0.5 (River slope and flow obstructions)
DB50	mm	0.25-0.51	0.025-25.4	Bed sediment diameter. Used only in sediment calculations (River bed properties)
ADCALC-DATA				
CRRAT	none	1.5-2	1-3.5	Only used with water quality (Climate and vegetation)
VOL	M.m³	0-none	0-none	Initial volume in river reach (Season, river geometry and climate)

4.2 HSPF: CALIBRATION

Calibration is a process whereby the parameters in a simulation model are adjusted in a certain range until the differences between the model simulated values and observed data are within selected criteria for performance. The period of simulation must not only be based on the availability of meteorological data, but also on the availability of instream quantity- and quality data (Donigian *et al.*, 1984: 3, 51).

Calibration is an iterative procedure. Parameter evaluation and refinement is part of the comparison between simulated values and observed data. Calibration is applicable to non-deterministic parameters, which are parameters that cannot be evaluated from topographical-, climatic-, physical- and chemical characteristics. Calibration should be based on several years of simulation, preferably three to five years as a minimum. The longer the period of simulation, the better, because then all the changes in climate, soil moisture and water quality conditions can be evaluated. The areal variability of precipitation and ET can cause additional uncertainty in the process of simulation. Calibration must be successful for dry- and wet periods (Donigian *et al.,* 1984: 84).

In the case of hydraulic calibration, particular attention should be given to items such as approximations of river geometry, river roughness coefficients and the interpretation and extrapolation of stage versus discharge data (Donigian *et al.,* 1984: 94).

In general, calibration results for hydrology and hydraulics, must have a percent variation of between 0 – 25%. Percentage variations less than 10% are above good, between 10 – 15% good and between 15 – 25% fair. Verification complements calibration and is an independent test of how well a model represents the important processes occurring in a catchment (Donigian *et al.,* 1984: 3, 51, 114).

4.2.1 Hydrological Calibration (Streamflow)

A large number of factors control the hydrological cycle. During the process of calibration it is difficult to alter the correct factor in order to improve the simulation, especially when taken into consideration that these factors are non-linear (Donigian *et al.*, 1984: 89).

The starting conditions for an HSPF simulation are determined as follows: The surface related storages of PERLND (CEPS, SURS and IFWS) and IMPLND (RETS and SURS) are initially set to zero, because individual storms are not being simulated (Donigian *et al.*, 1984: 92). The soil storages, LZS and UZS are the initial moisture storages in PERLND and are set equal to LZSN and UZSN, except when the simulation starts in a very dry- or wet period. In very wet periods, the actual quantities stored in LZS and UZS can go higher than the nominal storage capacities of LZSN and UZSN. In dry periods between storms, these storages can drop well below the nominal storages due to ET (Johanson, 1997). The factors describing the physical characteristics of the catchment, which are considered constant, are identified and suitable parameter values chosen.

After determining the starting conditions, HSPF calibration proceeds in the following sequence:

- An overall water balance over several simulation years is obtained by adjusting the parameters, which affect evaporation and runoff, mainly LZSN and LZETP. The latter is largely determined by land-use, and is set to a constant value at the start of calibration, and only minor adjustments are made to it. LZSN is then adjusted so that simulated runoff, over a long period of time, is approximately equal to the observed runoff.
- The wet versus the dry seasonal water balance is calibrated to ensure the correct distribution of seasonal streamflow. The most important parameter

influencing seasonal distribution of runoff is INFILT. If wet season runoff is too high and dry season baseflow too low, INFILT is increased to allow more precipitation to infiltrate to the groundwater zone. Baseflow recession rates are adjusted with AGWRC.

- Finally, hydrographs for individual storm events are calibrated. Simulated streamflow peaks and slopes of the hydrograph limbs are adjusted to match the observed data. The most important parameters influencing hydrograph shape are AGWRC, INTFW, UZSN and IRC (Donigian *et al.*, 1984: 89-93 & Johanson, 1997).

During the process of HSPF calibration the main aim is to minimise the root-mean-square-errors (*RMSE*) and maximise the coefficient of determination (r^2 values). r^2 Values are the most widely published; therefore the daily, monthly and annual streamflow r^2 values can be compared with those of other catchments or other models. According to several publications on HSPF calibration a good calibration has an r^2 value of 0.9, at the annual level, 0.8 seasonally and 0.6 daily (Munson, 1998: 86).

4.2.1.1 Water Balance (Annual and Seasonal)

The establishment of a water balance on an annual basis is the first step of hydrological calibration. The water balance can be defined as follows:

$$\text{Runoff} = \text{Precipitation} - \text{Actual ET} - \text{Deep percolation} - \Delta\ \text{Soil moisture storage} \qquad (1)$$

The annual water balance is determined by four parameters, namely INFILT, LZSN, LZETP and to a lesser extent, UZSN.

The input meteorological data series, as well as the parameters such as LZSN, INFILT and LZETP control the water balance. Actual ET must be adjusted to produce a change in the long-term runoff component of the water balance when precipitation is high and percolation to groundwater is low. LZSN and INFILT have a significant impact on percolation and therefore also on the annual water balance (Donigian *et al.,* 1984: 90).

LZSN represents water, which is stored in the subsurface zone and evaporates to the atmosphere. LZSN is the primary parameter when the annual water balance is adjusted. It is also mainly responsible for most of the evaporation from the catchment (Donigian *et al.,* 1984: 90).

Hydrocomp Incorporated recommends an initial value of:

$$LZSN = 0.25*P+100 \tag{2}$$

where: P = Total annual precipitation (mm) (Munson, 1998: 95).

LZETP controls the rate of evaporation from the lower zone, which is influenced by the fraction of the catchment area covered by deep-rooted vegetation.

UZSN is the water trapped on the catchment's surface and therefore it is a function of the topography. The type of vegetation, slope and soil types influences the amount of surface storage (Donigian *et al.,* 1984: 90).

4.2.1.2 Hydrograph Calibration

Adjusting the shape of individual storm hydrographs is the final stage of hydrological calibration. HSPF parameters can be used to adjust the rising- and descending limb, as well as the streamflow peak. INTFW and IRC are the most important parameters for adjusting the shape of storm hydrographs. UZSN has significant influence on the magnitude of streamflow peaks, especially on small catchments, as well as on the timing of the ascending limb. Increasing INTFW will reduce peak flows and prolong recession of the hydrograph (Donigian *et al.*, 1984: 92-93).

Munson (1998) found that HSPF simulated the timing of hydrographs correctly, but in some cases it under-estimated the volume, thus the runoff. Streamflow peaks of baseflow were also sometimes under-estimated. The recession rate of large hydrographs was frequently simulated incorrectly. Under-simulation of winter storms, where applicable, lead to the under-estimation of spring recharge and summer baseflow. Human induced hydrological changes may also effect the correlation between simulated- and observed hydrographs.

4.2.2 Non-Calibration Model Parameters

Non-calibration parameters are the physical parameters, which are constant according to the land-use and do not change during hydrological calibration. Typical parameters are latitude, elevation and vegetation type. The parameters NSUR, SLSUR and LSUR are used by the HSPF model to route surface runoff. However, studies have shown that HSPF is largely insensitive to these parameters (Munson, 1998: 90).

Impervious land influences the response time of the catchment. In urban areas where the runoff contributes a significant amount of stormwater and pollutants, impervious land plays an important role. High percentages of impervious land are associated with higher amounts of runoff and increased pollutants (Munson, 1998: 91).

4.3 MODEL PERFORMANCE

The visual comparison of simulation results against observed data can be highly subjective. Statistical model performance measures are therefore used to evaluate a hydrological model's "performance" against certain predetermined statistical criteria of goodness-of-fit in the reproduction of observed data (Schulze, 1995: AT 21.1). According to Roberts (1987) this goodness-of-fit criteria are objective mathematical functions, which express the most desirable characteristics between a model's simulated output and the real world observations.

According to Willmott (1982) and Schulze (1995) the range of goodness-of-fit statistics applicable to hydrological modelling, falls into two major categories, namely:

- Conservation statistics (Conservation of the mean, standard deviation and *RMSE*) and;
- Regression statistics (Slope, *y*-intercept and the coefficient's of determination and efficiency).

The HSPF model's simulated results are evaluated by making use of the above-mentioned conservation- and regression statistics. These results, as well as the scatter plots of the linear regression analyses are discussed in Chapter 6.

In the various examples of statistics of model performance, the following symbols are applicable:

x_i = Observed time series.

$\overline{x}$ = Mean value of the observed time series.

$\overline{\overline{y}}$ = Estimated value from the regression line of y on x.

$\overline{\overline{y_i}}$ = $a + bx_i$

y_i = Simulated time series.

s = Standard deviation.

n = Sample size of the time series (For i from 1 to n, depending on the time step of output selected).

4.3.1 Conservation Statistics

Conservation of the mean: This is a measure of central tendency of the data.

$$\overline{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \tag{3}$$

The objective is to minimise the percentage difference between the means of observed data (x) and simulated values (y).

$$100.\frac{(\overline{x} - \overline{y})}{\overline{x}} \tag{4}$$

Standard deviation: This is a measure of dispersion about the mean in original units. The observed data (x) and simulated values (y) are defined by the following equations:

$$s_x = \sqrt{V_x} \tag{5}$$

$$s_y = \sqrt{V_y} \tag{6}$$

The objective is to minimise the percentage difference between the standard deviations of observed data (x) and simulated values (y):

$$100.\frac{(s_x - s_y)}{s_x} \tag{7}$$

Root-Mean-Square-Error: This statistic defines the actual size of error produced by the model. It does not indicate the source and type of error. The objective is to minimise the *RMSE*. It is defined by the following equation:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(x_i - y_i)^2}{n}} \tag{8}$$

4.3.2 Regression Statistics

Slope: It is the slope (b) of the least-squares regression line. This line denotes the relative change of simulated (y)- to observed (x) trends.

$$b = \frac{n\sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{n\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2} \tag{9}$$

The objective is to attain a slope as closely as possible to unity (1.0). Slope values greater than unity (>1.0) indicates over-simulation at the upper end of the simulated values. Slope values less than unity (<1.0) indicates under-simulation.

Base Constant (y-intercept): This is the point where the line crosses the *y*-axis. A positive *y*-intercept indicates over-simulation of low values, while a negative *y*-intercept indicates under-simulation of low values.

$$a = \frac{\sum_{i=1}^{n} y_i - b\sum_{i=1}^{n} x_i}{n} \tag{10}$$

The objective is to minimise the base constant (*y*-intercept) to zero.

Coefficient of determination: It measures the degree of association between the simulated values (*y*) and the estimated values as predicted by the regression model.

$$r^2 = \frac{\sum_{i=1}^{n}\left(y_i - \bar{y}\right)^2 - \sum_{i=1}^{n}\left(y_i - \bar{\bar{y}}\right)^2}{\sum_{i=1}^{n}\left(y_i - \bar{y}\right)^2} \tag{11}$$

The objective is to maximise the coefficient of determination to unity (1.0). High r^2 values indicate a good degree of association.

Coefficient of efficiency: This coefficient measures the degree of association between observed data (*x*) and simulated values (*y*). It can be used to quantify or indicate model bias by determining the difference between the coefficients of determination and efficiency. It is identical to the coefficient of determination; except that the estimated simulated values replace the observed data.

$$E_c = \frac{\sum_{i=1}^{n}\left(y_i - \overline{y}\right)^2 - \sum_{i=1}^{n}\left(y_i - x_i\right)^2}{\sum_{i=1}^{n}\left(y_i - \overline{y}\right)^2} \tag{12}$$

The objective is to maximise the coefficient of efficiency to the value of the coefficient of determination.

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CHAPTER

5

STUDY AREA & DATA DEVELOPMENT

HSPF MODELLING OF THE MSUNDUZI RIVER CATCHMENT

5. STUDY AREA AND DATA DEVELOPMENT

5.1 CATCHMENT DATA

5.1.1 Location

The Msunduzi River Catchment covers an area of 901 km². It is located between the latitudes 29°32' and 29°47' south, and longitudes 30°05' and 30°41' east, in the province of Kwa-Zulu Natal near the east coast of the Republic of South Africa (Figure 5.1).

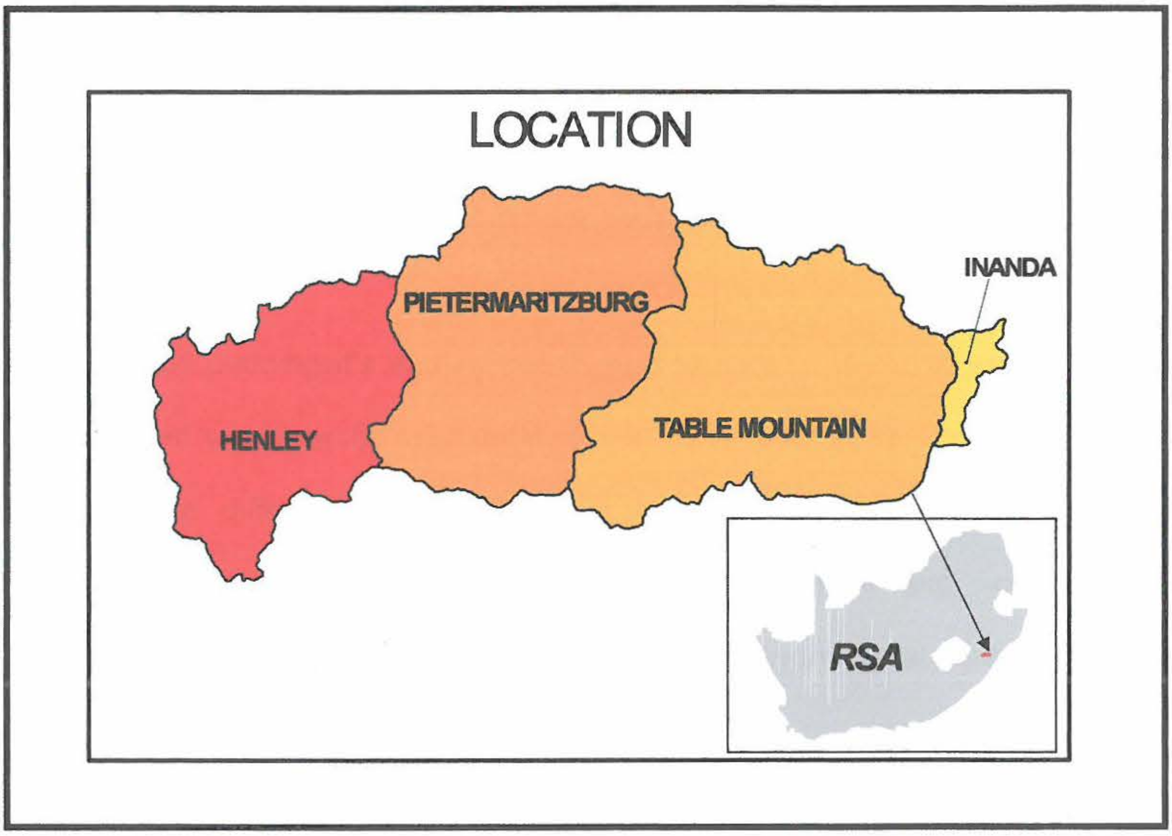

Figure 5.1: Location of the Msunduzi River Catchment

5.1.2 Topography

Soil surveys provide a general overview of the catchment's topography. The topography of the Msunduzi River Catchment is mountainous and undulating with numerous hills, as well as lowlands, wetlands, marshes and relatively flatter areas. The mean altitude above sea level in the catchment varies from 285 m to 1520 m. The average slope of the catchment varies from 2.5 to 33%.

5.1.3 Geological Data

Soil maps are extremely useful. However, soil types can be highly variable, especially in the rapidly developing urban areas of the Msunduzi River Catchment where soils may be removed or otherwise disturbed by human activity. The disturbed urban areas have highly variably runoff rates in most soil types, even after vegetation has been re-established.

Inspection by pedologist's and infiltration studies may be useful to verify the soil types related to a specific catchment (Brach, 2000: 8.20-3, 4). Pedologists view soils from a different perspective than hydrologists. They are specifically interested in the soil classification, agricultural potential and –constraints. Hydrologists on the other hand, are interested in the hydrological attributes of the soils (Tarboton & Schulze, 1992: 59).

The soil surveys of the Msunduzi River Catchment contain detailed aerial maps with the boundaries of the geological soil groups delineated on them. At least six distinct geological soil groups, which include Adelaide (mud- and sandstone), Dwyka (dyamictite, tillite, shale, mud- and sandstone), Ecca (sandstone, ecca-, coal- and carbonaceous shale), Natal (quartzitic sandstone, arkose and shale) and Tugela and Mapumulo (amphibolite, gneiss, schist and granulite) soils were identified in the catchment (Tarboton & Schulze, 1992: 61). The distribution of these geological soil groups is listed in Table 5.1.

Table 5.1: Distribution of geological soil groups

Geological soil group	Area (km²)	Percentage-distribution (%)
Adelaide	31	3
Ecca	545	60
Dwyka	169	19
Natal	6	1
Tugela and Mapumulo	150	17
Total:	**901**	**100**

West of Pietermaritzburg the shales of the Ecca- and Beaufort groups predominate. Further inland soils are weakly developed, with lithocutanic subsoil horizons. It consists of either red- and black clays or duplex and plinthic soils. At the higher altitudes of Pietermaritzburg well-drained yellow and red dystrophic or mesotrophic soils prevail. These soils vary widely in texture, drainage and depth (Tarboton & Schulze, 1992: 1).

The composition of the diagnostic sub-soil horizons and descriptive soil forms are summarised in Table 5.2.

Table 5.2: Composition of diagnostic sub-soil horizons (Tarboton & Schulze, 1992: 61)

Geological soil group	Diagnostic sub-soil horizon	Soil form composition / description	
Adelaide	Red-yellow apedal, freely drained soils.	**Ac**	Red and yellow dystrophic and/ or mesotrophic.
Ecca	Red-yellow apedal, freely drained soils.	**Ab**	Red, dystrophic and/ or mesotrophic.
		Ah	Red and yellow, high base status, usually <15% clay.
	Plinthic Catena: Upland duplex and Margalitic soils, rare.	**Bb**	Dystrophic and/ or mesotrophic, red soils not widely spread.
	Glenrosa and/or Mispah forms.	**Fa/ b**	Lime rare or absent in landscape or upland soils, but generally present in low-lying soils.
Dwyka	Red-yellow apedal, freely drained soils.	**Ab**	Red, dystrophic and/ or mesotrophic.
		Ah	Red and yellow, high base status, usually <15% clay.
	Glenrosa and/or Mispah forms.	**Fa**	Lime rare or absent in entire landscape.
Natal	Glenrosa and/or Mispah forms.	**Fa**	Lime rare or absent in entire landscape.
Tugela and Mapumulo	Red-yellow apedal, freely drained soils.	**Ab**	Red, dystrophic and/ or mesotrophic.
	Glenrosa and/or Mispah forms.	**Fa**	Lime rare or absent in entire landscape.

Soil type is the most important determinant of the infiltration rate. Different soil types have different infiltration characteristics. Fine-textured soils, such as clay, generally produce a higher rate of runoff than coarse-textured soils, such as sand. The higher the infiltration rates; the lower is the quantity of surface runoff.

The infiltration rate, which is controlled by surface conditions, is the rate at which water enters the soil at the soil surface. The transmission rate is the rate at which the water moves within the soil. This rate is controlled by the soil profile.

It is thus important to have a good understanding of the soils present in the Msunduzi River Catchment, as well as their association with the different hydrological groups. Each soil type is assigned to one of the four hydrological groups:

- **Group A:** These soils have a low runoff potential and high infiltration rates even when completely wetted. They consist mainly of deep, well to excessively drained sands or gravel and have a high rate of water transmission (>7.6 mm per hour).
- **Group B:** These soils have moderate infiltration rates when completely wetted. They consist mainly of moderately deep to deep, moderately well to well-drained soils with reasonably fine to reasonably coarse textures. These soils have an average rate of water transmission (3.8-7.6 mm per hour).
- **Group C:** These soils have low infiltration rates when completely wetted. They consist mainly of soils with a layer that impedes downward movement of water and soils with reasonably fine to fine texture. These soils have a low rate of water transmission (1.3-3.8 mm per hour).
- **Group D:** These soils have a high runoff potential. They have very low infiltration rates when completely wetted and consist mainly of clay soils with a high swelling potential, permanent high water table and claypan or clay layer at or near the surface. These soils have a very low rate of water transmission (0-1.3 mm per hour) (Brach, 2000: 8.20-3).

5.1.4 Land-use and Vegetation

The land-use within the Msunduzi River Catchment has different hydrological characteristics and therefore it can also be associated with different meteorological data.

Land-use can be determined by satellite images, aerial photographs, topographical maps and field visits. The hydrological properties of each land-use can be determined by a number of variables such as crop coefficients, canopy interception and root system activities in the topsoil. These variables can be calculated for each catchment by superimposing the land-use with maps and area-weighting the relevant values (Kienzle *et al.*, 1997: 15).

The type of land-use and its condition affects runoff volume through its influence on the infiltration rate of the soil. Vegetation maintains the soil's infiltration potential by preventing the sealing of the soil surface by the impact of the precipitation. Some of the raindrops are also retained on the surface of the vegetation. This would then increase the chance of the raindrops being evaporated back to the atmosphere. Some of the intercepted moisture takes so long to drain down to the soil that it is withheld from the initial period of runoff. Foliage also transpires moisture into the atmosphere, thereby creating a moisture deficiency in the soil. This deficiency must be replaced by precipitation before runoff can occur (Brach, 2000: 8.20-4).

The natural vegetation in the Msunduzi River Catchment consists of Valley bushveld and thornveld in the lowlands and Ngongoni veld (Zululand) in the hinterland (Acocks, 1988).

The bioclimate in both these regions can be described as humid to sub-humid (Tarboton & Schulze, 1992: 1). Further inland temperate and transitional forest and scrub of the highland and Dohne sourveld, Southern tall grassveld and Ngongoni veld (Natal mist belt) types are found in a region with a sub-humid to mild sub-arid bioclimate (Acocks, 1988). Natural vegetation has been replaced in many areas by afforestation and agricultural cropping (Tarboton & Schulze, 1992: 1).

Although many people consider the Msunduzi as an urban river, this is only true in the greater Pietermaritzburg area. Overall, the amount of residential land (± 189 km²) is smaller than the amount of grassland (± 276 km²), reflecting the rural nature of the upper catchment.

The Msunduzi River Catchment is divided into eight main land-use groups. It can be categorised as follows:

- **Forest (1):** This includes Eucalyptus-, indigenous-, mixed or undefined-, other- and pine forest, as well as woodlands and wattles.
- **Open spaces (2):** This includes cropland (irrigated pastures, low-density smallholdings, maize, sugar cane, and undefined cropping), participation recreation (Parks: sport and fields), urban open space, savannah veld and Valley of Thousand Hills.
- **Grassland (3):** This includes undefined open spaces and normal grassland.
- **Central Business District (CBD) and industrial (4):** This includes the CBD's of the main cities or towns and all the industrial areas.

- **Medium-density residential (5):** This includes the transfer between rural and urban areas and residential areas with few trees.
- **Low-density residential (6):** This includes residential areas, especially gardens and mining.
- **High-density residential (7):** This includes small residential areas, spectator recreation and multi-family residential areas.
- **Wetland/Riparian (8):** This includes wetland, water-based recreation, water and waste disposal.

The percentage-distributions of these main land-use groups are shown and listed in Figure 5.2 and Table 5.3. The percentage-distribution (where applicable) of each individual land-use is summarised in Tables 5.4 to 5.8.

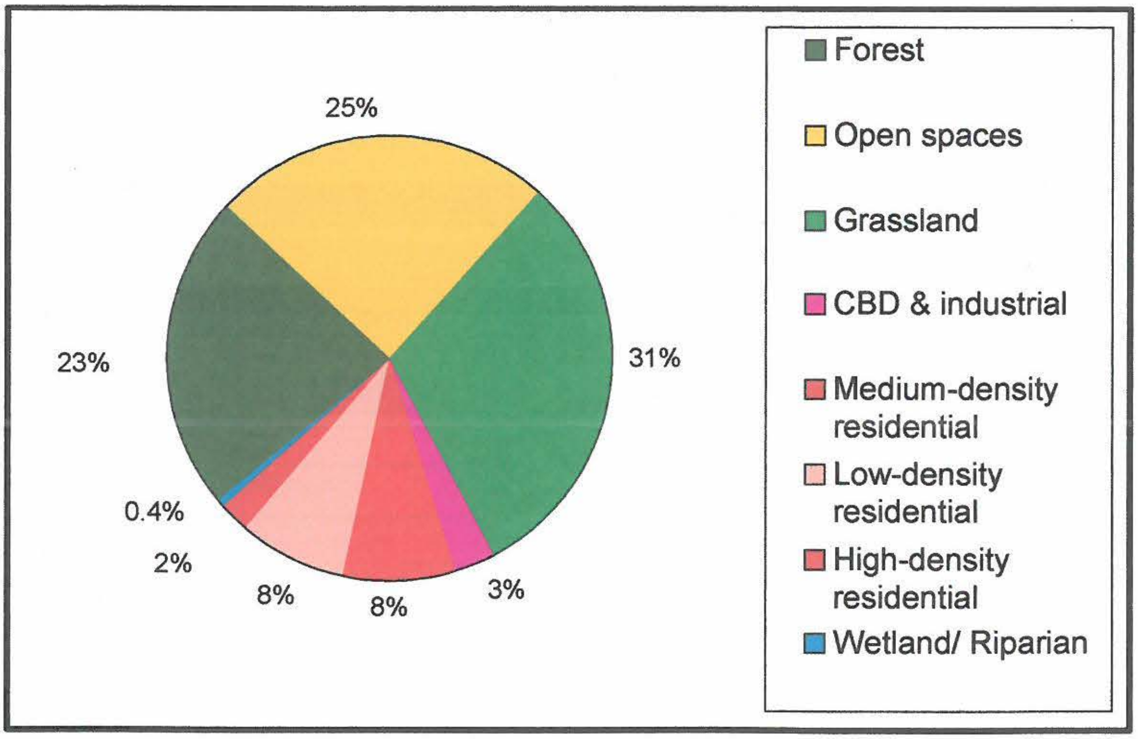

Figure. 5.2: Distribution of main land-use groups

Table 5.3: Main land-use groups

Main land-use group	Area (km²)	Percentage-distribution (%)
Forest	208	23
Open spaces	223	25
Grassland	276	31
CBD and industrial	26	3
Medium-density residential	73	8
Low-density residential	70	8
High-density residential	21	2
Wetland/ Riparian	4	0.4
Total:	**901**	**100**

Table 5.4: Land-use: Forest

Land-use	Area (km²)	Percentage-distribution (%)
Eucalyptus	21	10
Indigenous forest	41	20
Mixed- or undefined forest	23	11
Other forest	0.3	0
Pines	8	4
Woodland	109	53
Wattles	5	2
Total:	**207**	**100**

Table 5.5: Land-use: Open spaces

Land-use	Area (km²)	Percentage-distribution (%)
Irrigated pastures	1	0.5
Low-density smallholdings	15	7
Maize	33	15
Sugar cane	35	16
Undefined cropping	78	35
Parks: sport and fields	9	4
Savannah veld	51	23
Valley of Thousand Hills	1	0.5
Total:	**223**	**100**

Table 5.6: Land-use: Grassland

Land-use	Area (km²)	Percentage-distribution (%)
Undefined open spaces	39	14
Normal grassland	237	86
Total:	**276**	**100**

Table 5.7: Land-use: Medium-density residential

Land-use	Area (km²)	Percentage-distribution (%)
Medium-density residential (few trees)	11	15
Medium-density residential (trees)	27	37
Rural-urban transition	35	48
Total:	**73**	**100**

Table 5.8: Land-use: Wetland/ Riparian

Land-use	Area (km²)	Percentage-distribution (%)
Wetlands	4	80
Dams	1	20
Total:	**5**	**100**

These eight main land-use groups are assigned to pervious and impervious land segments in HSPF. As discussed in Chapter 3, pervious land allows water to infiltrate, while impervious land does not. However, there is an important distinction between the common understanding and HSPF's use of impervious land.

Generally, impervious land refers to any surface, which does not allow water to penetrate. This includes man-made structures such as driveways, sidewalks and rooftops. Impervious land can also include natural features such as rock outcrops of dense clay soil.

Water falling on an impervious surface cannot directly infiltrate and therefore it may travel to a pervious surface where it can infiltrate. Even though a surface is considered impervious, water falling on it still has the opportunity to infiltrate (Munson, 1998: 42).

This is the point at which HSPF's use of impervious land differs. In HSPF the impervious land segment is considered to be directly connected to a river, thus all the precipitation falling on it runs off. There is no infiltration or evaporation (Munson, 1998: 42-43).

In HSPF true impervious land is only likely to occur in urbanised areas in the proximity of a river. An urban driveway that drains to a storm sewer in the street and the sewer, in turn, drains to the nearest river is a typical example. The HSPF Application Guide (Donigian *et al.*, 1984) states that: "if urban runoff does not contribute significant water or pollutants to the study area, it is appropriate to represent the entire watershed with pervious land segments."

5.1.5 Discretisation of Catchment and River Network

Any discretisation method employed must take all the elements of a catchment, as well as the variation in the catchment parameters like land-use, soil types, vegetation, pollutant sources and topography into consideration (Coleman & Simpson, 1996: 3.3).

- **Grid Method:**

  A uniform grid is superimposed over the surfaces of the catchment regardless of any internal boundaries or drainage systems. Two-dimensional modelling is

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- **Grid Method:**

  A uniform grid is superimposed over the surfaces of the catchment regardless of any internal boundaries or drainage systems. Two-dimensional modelling is normally used in this method. These grids play an important role in the solution of the overland flow equations. Even if the grid is very fine, the topography and rivers are normally poorly detailed. This method is normally used to model rural catchments (Coleman & Simpson, 1996: 3.4).

- **Element Method:**

  This method involves the subdivision of the catchment into sub-catchments with the boundaries chosen along flow lines or water divides. These segments are further divided into elements parallel to the contours and to the stream at the end of a hillslope. Only one-dimensional modelling is possible. This method requires effort and a lot of data (Coleman & Simpson, 1996: 3.5).

- **Sub-catchment Method:**

  This is one of the more common methods in use. The catchment is also divided into sub-catchments on the basis of topography, vegetation, soil types and land-use. Each catchment is considered to be homogeneous with only one set of parameters. As in the case of kinematic routing where the flow length has to be specified, the catchment is handled as a rectangular plane with a length and a width. This one-dimensional sheet flow from the rectangular plane will produce the same runoff as the actual catchment. This method is effective and can be used as an urban planning model for stormwater (Coleman & Simpson, 1996: 3.6-3.7).

- **Modular Method:**

  This method is an improvement and extension of the sub-catchment method. The sub-catchment method is used for the overall discretisation of the catchment. The catchment is then further divided into modules, which are linked in such a way to represent the catchment and the stormwater drainage system. This method is frequently used in urban planning (Coleman & Simpson, 1996: 3.7).

The discretisation used in this HSPF study of the Msunduzi River Catchment is in accordance with the original ACRU model discretisation of the study area into hydrologically homogeneous sub-catchments (Sub-catchment method). These sub-catchments were further subdivided according to the land-use type, which constituted the HSPF pervious (PERLND) and impervious (IMPLND) land segments.

The sub-catchment layout of the Msunduzi River Catchment was numbered from one to 42. To this numbering scheme was appended a number from one to eight to indicate one of eight possible land-use groups. For instance, sub-catchment 1, land-use 8 was numbered 18, sub-catchment 10, land-use 5 was numbered 105, etc. Since all eight land-use groups do not occur in each sub-catchment, not all possible combinations of sub-catchment number or land-use group are represented in the HSPF input. HSPF performs the simulation in the order that land segment operations are specified in the OPN SEQUENCE (Operation Sequence) block of the HSPF user control input file.

Kienzle *et al.* (1997) stated that the discretisation standards, which were applied in the Msunduzi River Catchment, could be summarised as follows:

- The size of sub-catchments is normally determined by the level of homogeneity and the distribution of precipitation gauging networks; normally not greater than 50 km^2;

- Sub-catchments must be homogeneous in terms of the land-use, climate and soil and;
- It's preferable that, if possible, there must be operational gauging weirs and water quality sampling stations with lengthy records at the outlet of the particular sub-catchment.

The river network in a catchment is also segmented into reaches, each of which is considered to be a perfectly mixed tank. Flow constraints and transport considerations normally determine the length of river reaches. Reach boundaries should also coincide with physical structures in the river, such as dams, tributaries and farm dams.

River hydrogeometry is a primary consideration in the process of river segmentation. Associated with each reach is a sub-catchment, which may then be divided into pervious and impervious land segments (Munson, 1998: 29).

The sub-catchments are defined so that precipitation falling anywhere in one of the 42 sub-catchments eventually drains to a single river reach. A total of 42 reaches were delineated. The drainage area for each reach was determined by using topographical maps and GIS data. Sub-catchments range in area from approximately 0 to 65 km².

Unfortunately, there are few stage-discharge measurements in the Msunduzi River and little is known about channel geometry. The stage-discharge relationships of the river network can be determined making use of Manning's open channel flow equations (Munson, 1998: 38).

Multiplying the area of each land segment with the unit area runoff, the runoff to each reach can be determined and in conjunction the instream hydraulics and water quality processes can be simulated for the entire catchment (Donigian *et al.*, 1984: 39, 48).

The discretisation and relevant details of the Msunduzi River Catchment are summarised in Table 5.9.

Table 5.9: Summary of catchment discretisation

Reach-/ sub-catchment number	Area (km^2)	Average sub-catchment slope (%)	River (tributaries where applicable)	Length (km)
1	39	12	Msunduzi	13
2	54	15	Msunduzi	14
3	1.4	9	Msunduzi	2
4	39	15	Msunduzi/ Inkobongwana	5
5	45	19	Msunduzi	13
6	0.4	15	Msunduzi	1
7	30	22	Nqabeni	10
8	7	33	Nqabeni	5
9	4	17	Nqabeni	2
10	30	28	Msunduzi	10
11	36	31	Sinathingi	9
12	19	20	Msunduzi	6
13	15	18	Kwapata	9
14	9	12	Msunduzi	5
15	27	13	Wilgerfontein River	10
16	18	13	Slang Spruit	8
17	4	5	Slang Spruit	2
18	4	9	Slang Spruit / Camp's Drift	2

Table 5.9 (continued): Summary of catchment discretisation

Reach-/ sub-catchment number	Area (km²)	Average sub-catchment slope (%)	River (tributaries where applicable)	Length (km)
19	3	4	Camp's Drift / Msunduzi	1
20	2	4	Msunduzi	1
21	13	5	Msunduzi	3
22	19	22	Dorpspruit	6
23	31	23	Town Bush Stream	5
24	24	11	Town Bush Stream/ Dorpspruit	11
25	6	2	Msunduzi	3
26	15	2	Blackborough Spruit	6
27	4	6	Msunduzi	3
28	1	1	Msunduzi	2
29	28	11	Baynes Spruit	6
30	11	10	Msunduzi	6
31	15	8	Mkhondeni	8
32	56	8	Mpushini	12
33	13	4	Mpushini	4
34	65	9	Msunduzi	18
35	41	16	Msunduzi	8
36	7	16	Msunduzi	4
37	46	27	Msunduzi	12
38	22	12	Mnambiti	12
39	33	12	Mshwati	12
40	36	19	Mshwati	11
41	9	10	Msunduzi	6
42	19	13	Msunduzi	15
Total:	**901**		**Total:**	**301**

5.1.6 Data Collection

Due to the lack of stage-discharge measurements and channel geometry information, data were collected from topographical maps, orthographical photographs, GIS data and limited field visits. River hydrogeometry data, which were estimated, include characteristics such as the length, geometry (depth at mean flow, top- and bottom width), average slope of the channel, slope of the flood plane and the estimated values of Manning's *n* for both the channel and the floodplain.

The river cross-sections used to compute the stage-discharge relationships in HSPF were also based on limited topographical- and section surveys. The surveys were obtained from DWAF (Figures 5.3 to 5.15).

The stage-discharge relationship of each reach is specified in the HSPF user control input file with an FTABLE (Function Table) entry. Each FTABLE was generated with a small stand-alone Fortran program, XSECT, which was obtained from the USGS. The XSECT program assumes a uniform channel with trapezoidal cross-section and a shallow V-notch bottom. It uses the above-mentioned data as input data to compute the FTABLE for each reach. The FTABLE for Henley Dam was determined using data obtained from Umgeni Water. These data related dam water depth to area and capacity, as well as spillway discharge.

The average slope of each river reach was determined with the 10-85-equation as discussed in Chapter 6. Reach numbers were chosen to correspond with their associated sub-catchment number.

Typical river cross-sections representative of reaches six, 14, 18, 19, 20, 30 and 41 are shown in Figures 5.3 to 5.15. The dashed lines (- - - - -) represent the natural ground level of each river cross-section, while the solid lines (——), where applicable, represent the reduced levels of the hydrological gauging weirs' overflows (Sharp-crested, Crump- and V-crump weirs). The reduced levels of each cross-section are not related to each other and are at a local datum, except for sections for Camp's Drift, where mean sea level is used as datum.

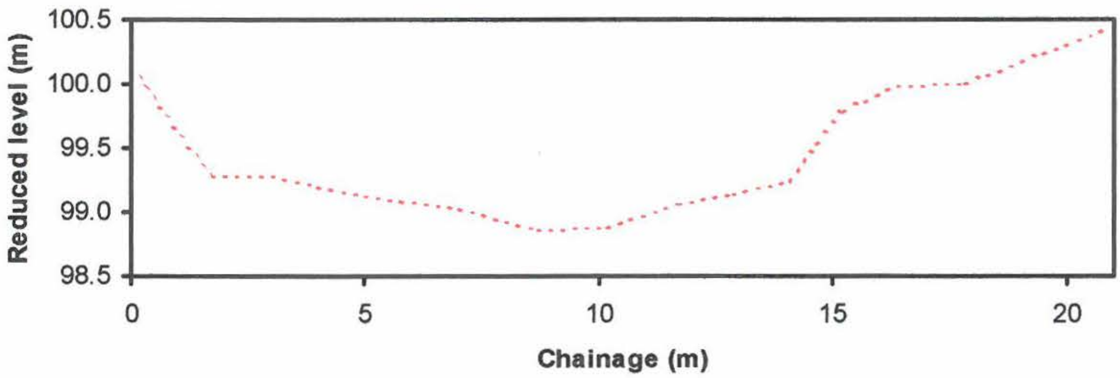

Figure 5.3: Sub-catchment 6: U2H011 Msunduzi River at Henley Dam: Inlet section

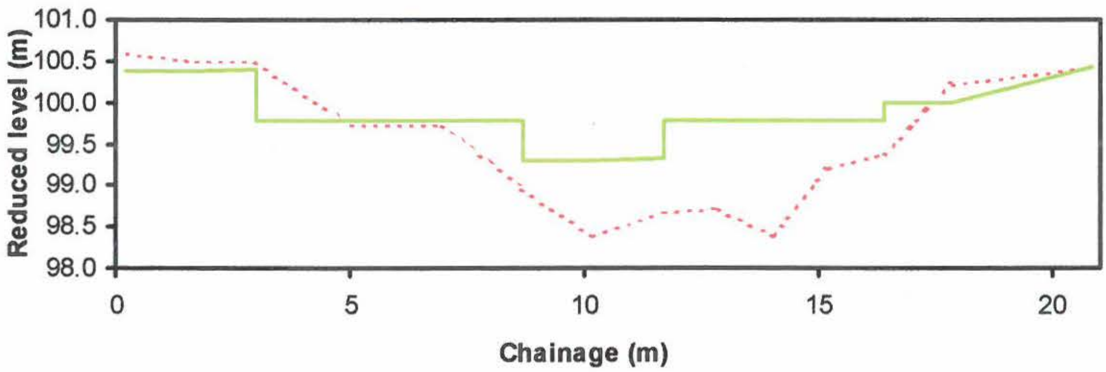

Figure 5.4: Sub-catchment 6: U2H011 Msunduzi River at Henley Dam: Upstream section

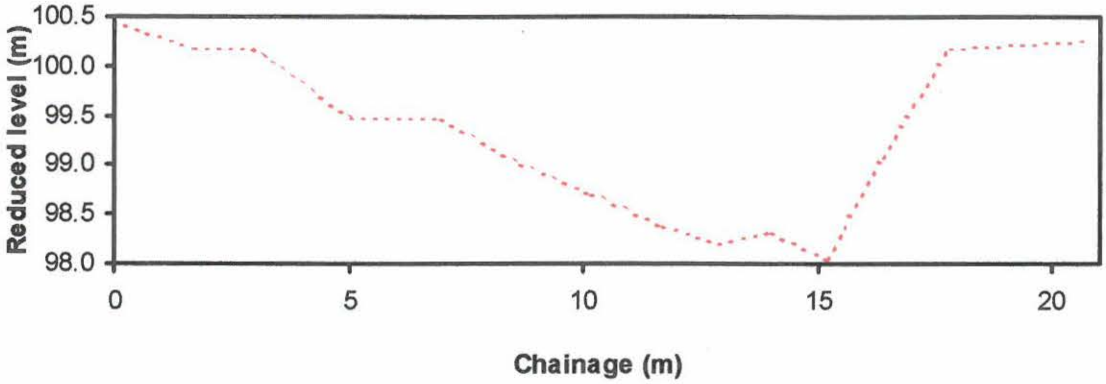

Figure 5.5: Sub-catchment 6: U2H011 Msunduzi River at Henley Dam: Downstream section

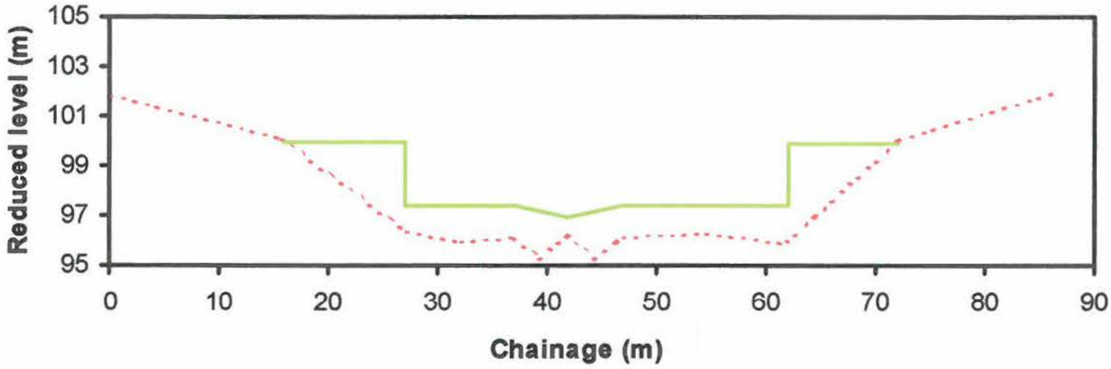

Figure 5.6: Sub-catchment 14: U2H058 Msunduzi River at Mason's Mill: Upstream section

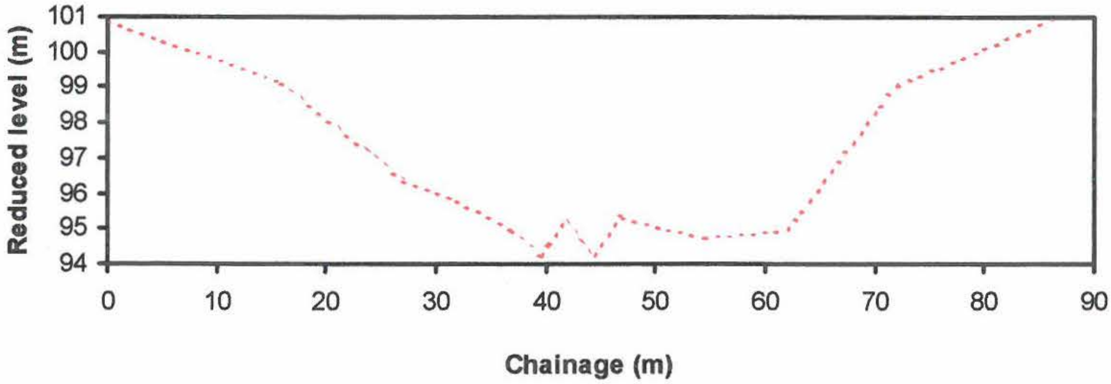

Figure 5.7: Sub-catchment 14: U2H058 Msunduzi River at Mason's Mill: Downstream section

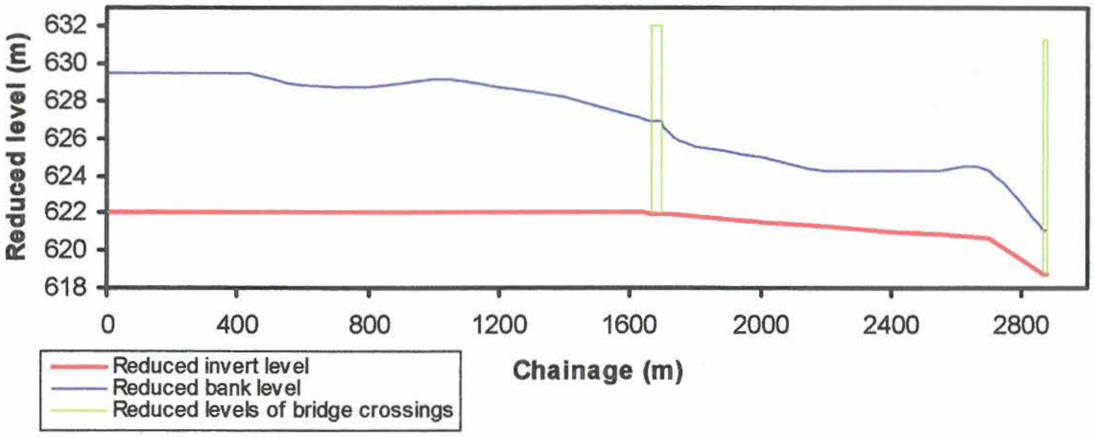

Figure 5.8: Sub-catchments 18-20: Camp's Drift: Longitudinal section

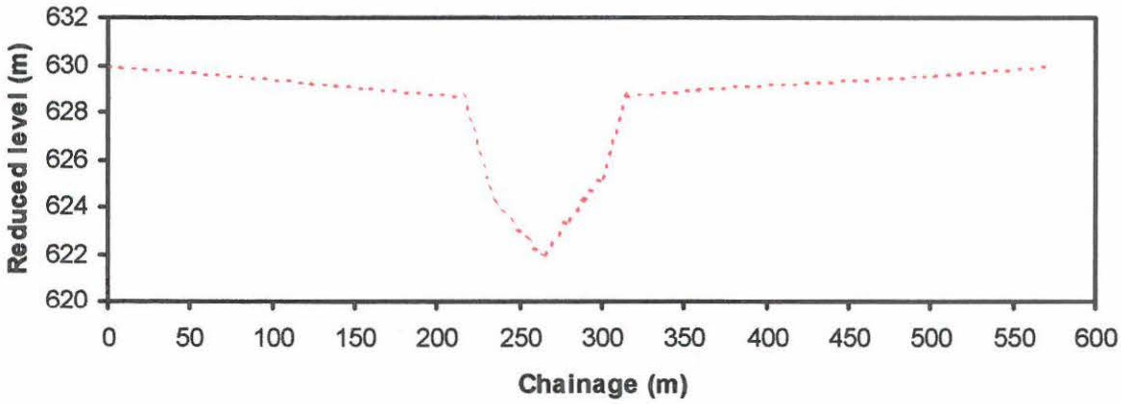

Figure 5.9: Sub-catchments 18-20: Camp's Drift: Cross-section at 1.2 km chainage

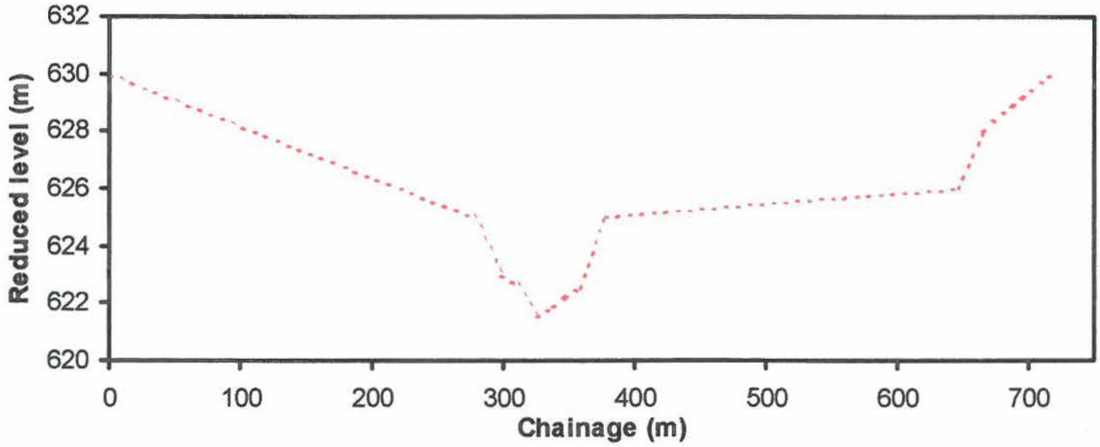

Figure 5.10: Sub-catchments 18-20: Camp's Drift: Cross-section at 2 km chainage

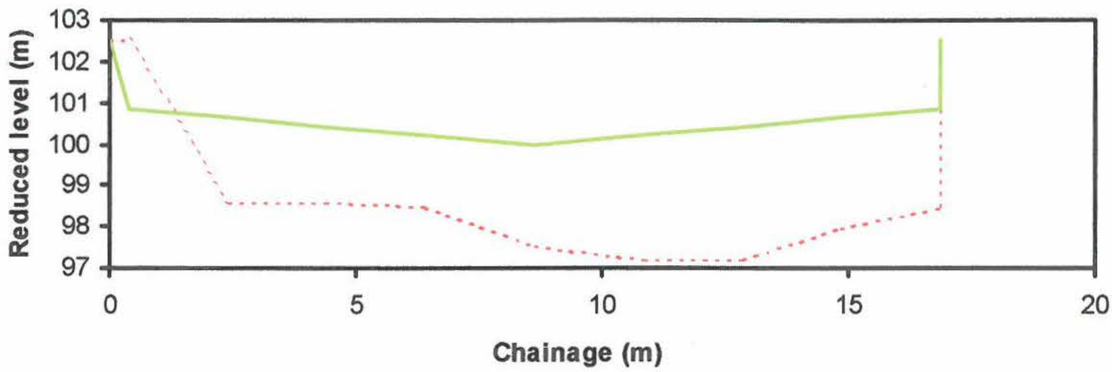

Figure 5.11: Sub-catchment 30: U2H041 Msunduzi River at Hampstead Park, Moto-X: Upstream section

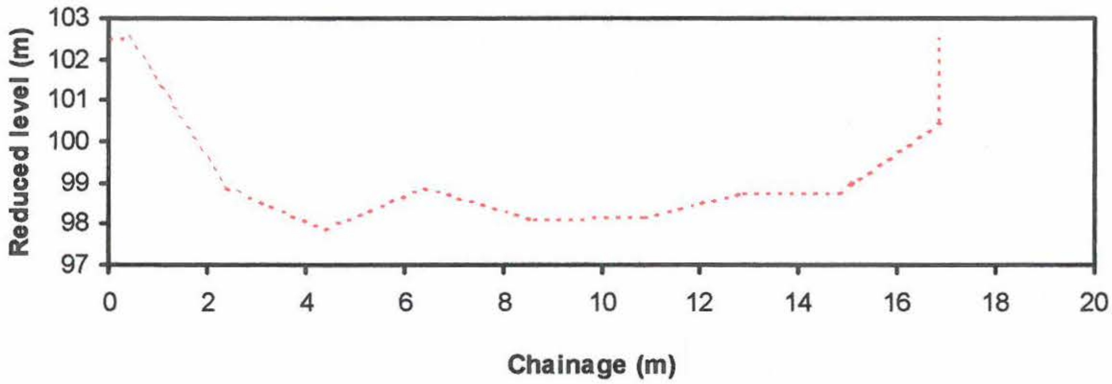

Figure 5.12: Sub-catchment 30: U2H041 Msunduzi River at Hampstead Park, Moto-X: Downstream section

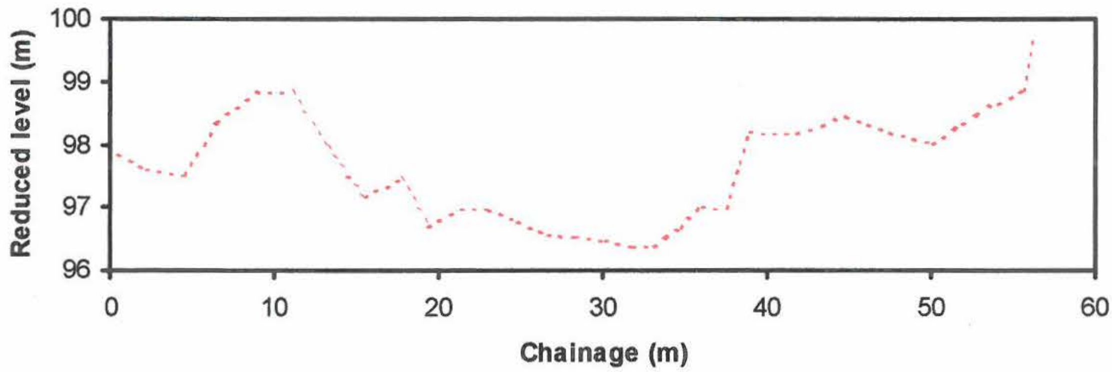

Figure 5.13: Sub-catchment 41: U2H022 Msunduzi River at Nomfihlelo: Inlet section

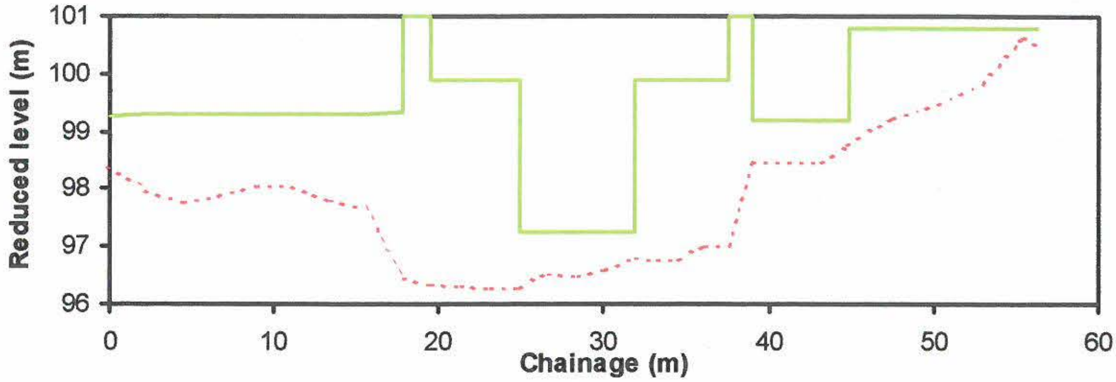

Figure 5.14: Sub-catchment 41: U2H022 Msunduzi River at Nomfihlelo: Upstream section

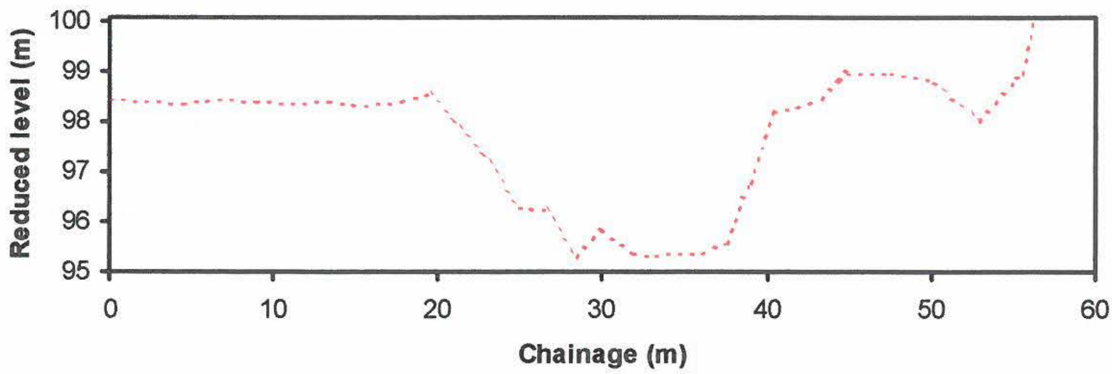

Figure 5.15: Sub-catchment 41: U2H022 Msunduzi River at Nomfihlelo: Downstream section

5.2 HYDROLOGICAL DATA

This section describes the most significant anthropogenic hydrological alterations of the Msunduzi River Catchment.

5.2.1 Human Water use

The primary water supply to Pietermaritzburg comes from the Midmar Dam, which is situated outside the Msunduzi River Catchment. Henley Dam (U2R005) also contributed until mid-1995, when all supply from Henley Dam ceased with the closure of the H.D. Hill water purification plant (Simpson, 2002).

5.2.2 Wastewater Treatment Plants

The Darvill wastewater treatment plant contributes water to the Msunduzi River. Much of the outflow represents an inter-basin transfer from Midmar Dam. The inflow data (*Mℓ*/day) at the plant for the period of record (1990 to 2001) are shown graphically in Figure 5.16. Outflow is not separately recorded.

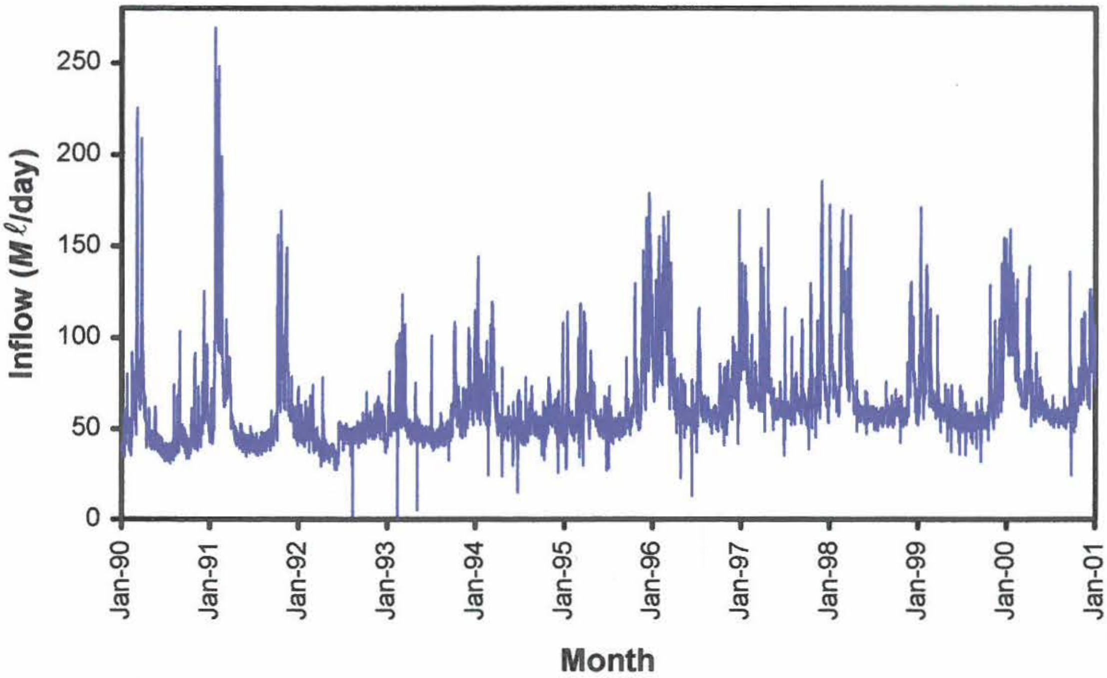

Figure 5.16: Inflow to Darvill wastewater treatment plant: January 1990-January 2001 (Umgeni Water, 2002)

The assumption has been made that the total inflow equals the total outflow, thus ignoring any losses. Discharge is the lowest in late autumn and winter and the highest during late summer and early autumn. These discharges include not only municipal sewage, but also infiltrated groundwater in the pipes. The amount of infiltration is a function of the water table height. The water table is generally highest in late summer and lowest in winter, which correlates with the seasonal variation of total wastewater discharge (Simpson, 2002).

5.2.3 Hydrological Gauging Stations

The spatial locations of hydrological gauging-, precipitation- and water quality stations are illustrated in Chapter 9, Annexure A, Plates 6 and 7 and are listed in Table 5.10.

Table 5.10: Summary of hydrological gauging stations (DWAF, 1990)

Station description (DWAF number & name)	Data set	Period of record	Location (Lat./ Long.)
U2H011 Msunduzi River at Henley Dam	Stage-discharge Water quality	1993 - 1996 1977 - 2001	Sub-catchment 6 Lat: 29°38'44" Long: 30°15'34"
U2R005 Henley Dam	Stage-discharge Water quality	1989 - 2001 1985 - 2001	Sub-catchment 9 Lat: 29°37'23" Long: 30°14'50"
U2H058 Msunduzi River at Mason's Mill	Stage-discharge Water quality	1995 - 2000 1995 - 2000	Sub-catchment 14 Lat: 29°37'51" Long: 30°21'12"
U2H041 Msunduzi River at Hampstead Park, Moto-X	Stage-discharge Water quality	1996 - 2000 1985 - 2000	Sub-catchment 30 Lat: 29°36'27" Long: 30°27'00"
U2H022 Msunduzi River at Nomfihlelo	Stage-discharge Water quality	1987 - 2000 1984 - 2001	Sub-catchment 41 Lat: 29°39'39" Long: 30°38'13"

5.2.4 Data Quality

All the processed daily streamflow- and precipitation data for the Msunduzi River Catchment for the relevant period of record have been extracted from the DWAF files through the Computing Centre for Water Research (CCWR). Although there are many sites at which water quality grab samples are taken, there is paucity of measured streamflow data and even at sites with streamflow measurements; the data were often unreliable or missing.

All the missing streamflow data are summarised in Table 5.11.

Table 5.11: Summary of missing streamflow data

Station description (DWAF number & name)	Data set	Period of missing data
U2H011 Msunduzi River at Henley Dam	Stage-discharge (1993 - 1996)	1995/01/15 - 1995/02/15; 1995/06/30 - 1995/08/01; 1995/08/11 - 1995/11/21; 1995/12/21 - 1996/01/04; 1996/01/07 - 1996/02/01.
U2H058 Msunduzi River at Mason's Mill	Stage-discharge (1995 - 2000)	1996/09/17 - 1996/09/25; 1997/03/18 - 1997/03/25; 1997/11/25 - 1997/12/02; 1998/01/13 - 1998/01/20; 1998/04/28 - 1998/06/11; 2000/04/04 - 2000/04/14.
U2H041 Msunduzi River at Hampstead Park, Moto-X	Stage-discharge (1996 - 2000)	1996/11/26 - 1997/11/03; 1999/08/13 - 1999/09/28; 1999/12/28 - 2000/01/04.
U2H022 Msunduzi River at Nomfihlelo	Stage-discharge (1987 - 2000)	1987/08/24 - 1987/08/31; 1987/09/21 - 1987/10/10; 1988/01/25 - 1989/07/20; 1991/06/27 - 1991/11/10; 1991/11/23 - 1992/01/10; 1994/06/01 - 1994/12/09; 1995/01/25 - 1995/02/01; 1996/04/03 - 1996/04/23; 1996/10/09 - 1996/10/16; 1997/12/09 - 1997/12/31; 1998/07/08 - 1998/07/24.

The HSPF model was therefore verified with the hydrological gauging stations with the best streamflow data, *viz.* at U2H022, U2H041 and U2H058.

5.2.5 Conclusions regarding Flow Data

The human-induced hydrological alterations (human water use and treatment plants) can have a substantial impact on the hydrological response of the Msunduzi River Catchment. Therefore, it is important to take all these parameters and factors into consideration during the process of initial data development for the period of simulation, as well as during the actual simulation process. Streamflow data records are vital to verify the ability of the HSPF modelling system to simulate the observed flows accurately, before any impact scenarios can be simulated. This fact also emphasises the importance that the data quality obtained from hydrological gauging stations must be good and a true reflection of the real world. Data collection is a continuous process, as new data are compiled it can be incorporated into the HSPF model with the goal of improving hydrological simulations.

5.3 METEOROLOGICAL DATA

The HSPF simulation is driven by meteorological data measured in or near the Msunduzi River Catchment. The data must be representative of the catchment. A good hydrological simulation is unlikely to be achieved without accurate and representative meteorological data. Precipitation and evaporation are the most important meteorological variables for hydrological simulation.

5.3.1 Precipitation

Precipitation data are one of the most important variables in hydrological modelling; therefore it is important to obtain the best daily precipitation data for each catchment. In practice it is normally applicable to make use of one "driver" precipitation station to forecast the hydrological response of a sub-catchment (Kienzle *et al.*, 1997: 14).

Target precipitation stations were selected based on their position in the Msunduzi River Catchment and number of years of record. A set of nearby stations with similar Mean Annual Precipitation (MAP) to the target station was selected to fill in missing data at the target stations.

Only six of the 13 precipitation stations within the catchment were identified as suitable target stations, mainly based on the quality and period of record. The set of nearby stations consists of a further six precipitation stations.

The precipitation stations were numbered by the CCWR according to a numbering scheme devised by the South African Weather Bureau (SAWB). In addition to the SAWB number for each station, the source organisation of the data was indicated by a suffix: 'A' for Department of Agriculture, 'P' for private individual, 'S' for South African Sugar Experiment Station and 'W' for SAWB. The details and relevant data of these precipitation stations are listed in Tables 5.12 and 5.13. The location of each station in relation to the catchment boundary is shown in Chapter 9, Annexure A, Plate 6.

precipitation station to forecast the hydrological response of a sub-catchment (Kienzle *et al.*, 1997: 14).

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Table 5.12: Summary of target precipitation data within the Msunduzi River Catchment

Station description (Name & number)	Location (Lat./ Long.)	Altitude above MSL (m)	Period of record	MAP (mm)
Allerton, 0239604W	Sub-catchment 23 Lat: 29°35' Long: 30°21'	703	1912 - 2000	957
Camperdown, 0240073W	Sub-catchment 39 Lat: 29°43'00" Long: 30°33'00"	762	1914 - 2000	685
Edendale, 0239518W	Sub-catchment 12 Lat: 29°38' Long: 30°18'	765	1946 - 1997	946
Pietermaritzburg purification works, 0239756W	Sub-catchment 24 Lat: 29°36' Long: 30°26'	609	1969 - 2000	826
Pietermaritzburg purification works, 0239577W	Sub-catchment 24 Lat: 29°37' Long: 30°20'	765	1949 - 1997	927
Ukulinga-AGR, 0239700W	Sub-catchment 21 Lat: 29°40' Long: 30°24'	775	1959 - 1991	706

Table 5.13: Summary of target precipitation data near the Msunduzi River Catchment

Station description (Name & number)	Location (Lat./ Long.)	Altitude above MSL (m)	Period of record	MAP (mm)
Baynesfield Estates, 0239585W	Lat: 29°46' Long: 30°20'	808	1927 - 2000	771
Cedara College, 0239482W	Lat: 29°32' Long: 30°17'	1066	1959 - 2000	842
Elandshoek, Boston, 0239097A	Lat: 29°37' Long: 30°04'	1540	1905 - 2000	1007
Inchanga, 0240284W	Lat: 29°44' Long: 30°40'	620	1928 - 1998	790

Table 5.13 (continued): Summary of target precipitation data near the Msunduzi River Catchment

Station description (Name & number)	Location (Lat./ Long.)	Altitude above MSL (m)	Period of record	MAP (mm)
Nagle, 0240185W	Lat: 29°35' Long: 30°37'	442	1941 - 2000	749
Vaucluse, 0239133W	Lat: 29°43' Long: 30°05'	1430	1933 - 1997	1005

The MAP varies from 684 mm to 1186 mm throughout the entire catchment. The detail and relevant data of the additional precipitation stations used to fill in any missing data are listed in Table 5.14.

Table 5.14: Summary of additional precipitation data in and near the Msunduzi River Catchment

Station description (Name & number)	Location (Lat./ Long.)	Period of record	MAP (mm)
Allerton, 0239184A	Lat: 29°34' Long: 30°21'	1959 - 1960	1069
Ashley Grange, Merrivale, 0239184A	Lat: 29°34' Long: 30°07'	1903 - 1989	732
Baynesfield Estates, 0239585A	Lat: 29°45' Long: 30°20'	1927 - 1991	767
Bloemendal, Bishopstown, 0239812A	Lat: 29°32' Long: 30°28'	1952 - 1989	884
Botha's Hill, 0240404W	Lat: 29°44' Long: 30°44'	1951 - 2000	823
Bruyns Hill, 0270329S	Lat: 29°29' Long: 30°41'	1976 - 1998	981
Cedara Agricultural Station, 0239482A	Lat: 29°32' Long: 30°17'	1914 - 1991	875
Cosmoore, Cato Ridge, 0239855A	Lat: 29°45' Long: 30°29'	1956 - 1988	763

Table 5.14 (continued): Summary of additional precipitation data in and near the Msunduzi River Catchment

Station description (Name & number)	Location (Lat./ Long.)	Period of record	MAP (mm)
Dargle, 0239002W	Lat: 29°32' Long: 30°01'	1953 - 2000	976
Edmonds, J.P., 0240033A	Lat: 29°33' Long: 30°32'	1949 - 1989	734
Hilly Prospect, 0239196A	Lat: 29°46' Long: 30°07'	1947 - 1983	1035
Intake, 0240564W	Lat: 29°47' Long: 30°46'	1923 - 1991	867
Kensington, 0239784W	Lat: 29°34' Long: 30°27'	1965 - 1987	932
Kloof purification works, 0240586W	Lat: 29°46' Long: 30°50'	1932 - 2000	1064
Merrivale, 0239421W	Lat: 29°31' Long: 30°14'	1914 - 1978	805
Natal Est., Mount Edgecombe, 0240883A	Lat: 29°43' Long: 31°00'	1929 - 1989	1043
Natal Est., Thornville, 0239705A	Lat: 29°45' Long: 30°24'	1981 - 1989	737
Phipson, Merrivale, 0239483A	Lat: 29°33' Long: 30°17'	1983 - 1989	925
Pietermaritzburg Botanic Gardens, 0239605P	Lat: 29°35' Long: 30°21'	1907 - 1989	1026
Pietermaritzburg Country Club, 0239574W	Lat: 29°35' Long: 30°20'	1932 - 1964	1161
Pietermaritzburg Municipality, 0239666W	Lat: 29°36' Long: 30°23'	1959 - 1968	822
Sevontein, Elandskop, 0239225A	Lat: 29°45' Long: 30°08'	1983 - 1989	861
St. John's Cottage, 0239633A	Lat: 29°33' Long: 30°22'	1975 - 1984	1186

Table 5.14 (continued): Summary of additional precipitation data in and near the Msunduzi River Catchment

Station description (Name & number)	Location (Lat./ Long.)	Period of record	MAP (mm)
Symonds Lane, Howick, 0269388A	Lat: 29°28' Long: 30°13'	1970 - 1989	961
Thornville, 0239705S	Lat: 29°45' Long: 30°24'	1983 - 2000	758
Ukulinga- AGR. Res., 0239730W	Lat: 29°40' Long: 30°25'	1959 - 1966	793
Umlaas Road, 0240014W	Lat: 29°44' Long: 30°31'	1931 - 1976	749
Wahroonga, 0239216W	Lat: 29°36' Long: 30°08'	1925 - 1944	875
Windy Hill, 0270119S	Lat: 29°29' Long: 30°34'	1966 - 1996	984
Windy Hill No. 2, 0270119W	Lat: 29°30' Long: 30°34'	1932 - 1999	994

The daily precipitation data were obtained from the CCWR precipitation database and in-filled with the Time Series Extraction and Manipulation (TEAMS) program available on the CCWR. The technique used by TEAMS for in-filling precipitation data is as follows:

The set of selected nearby stations used to fill in missing data at the target station was ordered according to preference. The order of preference was based on the similarity of MAP and geographic proximity to the target station. Each of the infilling stations, starting with the most preferred station and ending with the least preferred station, was selected in turn, and their data used for filling in the target until all missing values were filled, or the set of infilling stations was exhausted.

The data from an infilling station were adjusted before filling in the target by multiplying by the ratio of the MAPs of the target- and infilling stations. The details of the target- and infilling stations are listed in Table 5.15.

Table 5.15: Summary of the infilling procedure of precipitation data

Target precipitation station (Name & number)	List of infilling precipitation stations used (in order of preference)
Allerton, 0239604W	0239604A, 0239574W, 0239605P, 0239216W, 0239576W, 0239666W, 0239756W, 0239756AW, 0239633A and 0239482W
Baynesfield Estates, 0239585A	239585A, 239705A, 0239705S, 0239700A, 0239730W, 0239855A, 0240014W, 0239518W and 0239577W
Camperdown, 0240073W	240014W, 0239855A, 0240284W, 0240404W, 0239705A, 0239730W, 0239700A, 0239818A and 0240586W
Cedara College, 0239482W	0239482A, 0239483A, 0239421W, 0269388A, 0239184A, 0239574W, 0239518W, 0239216W, 0239604W and 0239604A
Edendale, 0239518W	0239577W, 0239574W, 0239604W, 0239605P, 0239576W, 0239666W, 0239604A, 0239585A and 0239585W
Elandshoek, Boston, 0239097A	0239216W, 0239002W, 0239184A, 0239133W, 0239225A, 0239196A, 0239421W, 0239483A and 0239482W
Inchanga, 0240284W	0240564W, 0240404W, 0240073W, 0240185W, 0240014W, 0239855A and 0240586W
Nagle, 0240185W	0270329S, 0270119S, 0270119W, 0240033A, 0239818A, 0239756W, 0239784W, 0240073W, 0240284W and 0240586W

Table 5.15 (continued): Summary of the infilling procedure of precipitation data

Target precipitation station (Name & number)	List of infilling precipitation stations used (in order of preference)
Pietermaritzburg, purification works 0239577W	0239518W, 0239574W, 0239756AW, 0239756W, 0239604W, 0239604A, 0239576W, 0240185W and 0239700A
Pietermaritzburg, purification works 0239756W	0239577W, 0239518W, 0239574W, 0239756AW, 0239604W, 0239604A, 0239576W, 0240185W and 0239700A
Ukulinga- AGR, 0239700W	239730W, 0239518W, 0239756AW, 0239756W, 0239666W, 0240883A, 0239585A, 0239585W and 0239855A
Vaucluse, 0239133W	0239196A, 0239225A, 0239097A, 0239216W, 0239184A, 0239518W, 0239002W, 0239421W, 0239482W and 0239482A

There are two main sources of precipitation error relevant to the Msunduzi River Catchment HSPF model: Poor areal representation and possible instrumentation error. Each is discussed below:

- It is difficult to accurately represent precipitation falling on a catchment as large as the Msunduzi. Precipitation is highly variable in time and space. Precipitation gauges only measure precipitation at a single point. Modellers must therefore be satisfied to apply data collected at one point over a large area of the catchment, unless a catchment is peppered with precipitation stations. The total amount of precipitation, areal- and time distributions of a storm throughout the duration of the storm are three major factors that affect the peak rate of runoff (Brach, 2000: 8.20-2).

The HSPF Application Guide (Donigian *et al.*, 1984) states that: "the assumption of uniform areal precipitation is a major source of error with direct effects on the simulation, since precipitation is the driving force of HSPF. Precipitation is rarely uniform and is highly non-uniform in thunderstorm prone regions of the country. Catchments greater than approximately 100 km^2 require at least three different precipitation records, perhaps more if precipitation patterns are highly variable."

- Instrumentation error might be a second source of inaccuracy in precipitation measurements. First, gauges must be designed so they do not deflect precipitation away from the collector.

The area influenced by each target precipitation station was determined using Thiessen polygons (Wilson, 1990: 21-25). These polygons are also representative of a specific sub-catchment (-s). The borders of the sub-catchments and polygons did not coincide. Thus, the area of each sub-catchment was divided into sub-areas according to its coincidence with a Thiessen polygon using GIS. These sub-areas were expressed as a percentage-distribution of the relevant polygon of each target precipitation station. These percentage-distributions were then used in the External Sources Table (EXT SOURCES) in the HSPF user control input file and linked to the specific target precipitation stations stored in WDM data sets using an appropriate multiplier.

Assumptions made to distribute the measured precipitation over the catchment and throughout the time distribution of the precipitation event may have a great impact on the simulation results, especially in the processes of calibration and verification. The farther the precipitation station is from a specific part of the catchment, the less likely the data from the station will adequately represent the depth or time distribution that actually occurred there (Brach, 2000: 8.20–2).

5.3.2 Evaporation

Mean monthly A- or S-pan potential evaporation values can be superimposed on the boundaries of a sub-catchment in order to produce mean monthly A-pan equivalent values for each sub-catchment (Kienzle *et al.*, 1997: 15). Gridded images of mean monthly A-pan equivalent evaporation have been developed and are available at a resolution of one minute by one minute of a degree latitude and longitude covering Southern Africa (Schulze, 1995: AT 4.10). These gridded images of the monthly A-pan equivalent evaporation of the Msunduzi River Catchment are illustrated in Chapter 9 (Annexure A, Plate 9).

The only weather stations near the catchment for which any evaporation data were available were Cedara College (0239482W) and the South African Sugar Experiment Station at Mount Edgecombe. Neither of these is representative of the catchment and according to Donigian *et al.* (1984) the model is not sensitive to evaporation inputs. Therefore the mean monthly A-pan equivalent evaporation values, as developed by Schulze and Maharaj (1991), were obtained from the CCWR.

The catchment was divided into three evaporation regions in two steps. First, the mean monthly evaporation within each sub-catchment was determined. Secondly, similar monthly evaporation values were assigned to an evaporation region. This resulted in a total of three evaporation regions. Representative grid points were chosen for the upper, mid and lower regions and the 12 monthly grid values were used to generate a monthly time series, which was disaggregated to three daily total evaporation time series in HSPF.

The monthly A-pan evaporation is converted to Potential Evapotranspiration (PET) in HSPF by multiplying each value by a factor ranging between 0.8 and 0.85 (Munson, 1998: 75). The percentage-distribution of the mean annual evaporation of the Msunduzi River Catchment is listed in Table 5.16.

Table 5.16: Mean annual evaporation

Mean annual evaporation range (mm)	Area (km^2)	Percentage-distribution (%)
1572-1630	79	9
1631-1663	197	22
1664-1693	256	28
1694-1720	256	28
1721-1779	113	13
Total:	**901**	**100**

CHAPTER

6

RESULTS & DISCUSSIONS

HSPF MODELLING OF THE MSUNDUZI RIVER CATCHMENT

6. RESULTS AND DISCUSSIONS

6.1 DATA COLLECTION RESULTS

This section discusses the results obtained from the collection of river hydrogeometry data, stage-discharge measurements and development of Thiessen polygons for precipitation distribution in the Msunduzi River Catchment.

One of the important river hydrogeometry characteristics, the average slope of a river reach was determined by making use of the "10-85" method as prescribed by the USGS (Rooseboom, Basson, Loots & Wiggett, 1993: 2.29). The 10-85-equation is as follows:

$$S_{AVG.} = \frac{(H_{0.85L} - H_{0.10L})}{(1000 * 0.75L)} \tag{13}$$

where:

L	= Length of river reach (km)
$S_{AVG.}$	= Average slope (m/m)
$H_{0.85L}$	= Height of river reach at length 0.85 L
$H_{0.10L}$	= Height of river reach at length 0.10 L

However, during the determination of the stage-discharge relationships 100% of the river reach length is used and not 75% as in the 10-85-equation. The results of the stage-discharge relationship computations are listed in the FTABLEs (Annexure C: 236 & 270).

The results are listed in Table 6.1.

Table 6.1: Summary of the average slope of the river reaches

Reach- or sub-catchment number	Length (km)	$H_{0.85L}$ (m)	$H_{0.10L}$ (m)	Average slope ($S_{AVG.}$) (m/m)
1	12.9	1462	1169	0.030
2	13.5	1351	1156	0.019
3	1.7	1128	1117	0.008
4	5.4	1397	1108	0.072
5	12.5	1050	949	0.011
6	0.6	936	935	0.001
7	9.5	1305	979	0.046
8	5.2	1275	975	0.076
9	2.4	934	930	0.002
10	9.5	896	723	0.024
11	9.2	1159	754	0.059
12	5.7	694	665	0.007
13	9.2	1140	718	0.061
14	4.8	655	626	0.008
15	10.2	936	693	0.032
16	7.9	902	689	0.036
17	1.8	658	647	0.008
18	1.8	622	621.9	0.0001
19	1.1	622	621.8	0.0001
20	0.9	622	621	0.002
21	2.9	620	619	0.001
22	5.7	993	758	0.055
23	4.6	933	698	0.068
24	10.7	710	629	0.010
25	3.4	618	611	0.003
26	6.4	746	623	0.025
27	2.6	609	603	0.003
28	1.8	602	600	0.001
29	6.1	798	648	0.033
30	5.8	621	591	0.007
31	8.2	794	666	0.021
32	11.9	856	660	0.022

Table 6.1 (continued): Summary of the average slope of the river reaches

Reach- or sub-catchment number	Length (km)	$H_{0.85L}$ (m)	$H_{0.10L}$ (m)	Average slope ($S_{AVG.}$) (m/m)
33	4.2	628	598	0.010
34	18.1	574	509	0.005
35	7.5	492	449	0.008
36	4.2	441	432	0.003
37	12.4	423	383	0.004
38	11.6	679	495	0.021
39	11.5	709	498	0.025
40	11	456	385	0.009
41	6.1	375	362	0.003
42	15.1	349	292	0.005

As discussed in Chapter 5, the sub-areas of each sub-catchment influenced by the different target precipitation stations were determined by making use of Thiessen polygons. The average precipitation calculated with the arithmetic mean had a value of 850 mm, which correlates well with the result of the Thiessen polygons (844 mm). The summary of Thiessen polygons are shown in Table 6.2.

Table 6.2: Summary of Thiessen polygons

Sub-catchment	Station description (Name & number)	MAP (mm)	Sub-area (km^2)	Precipitation.area ($mm.km^2$)
1	Elandshoek, Boston (0239097A)	1007	12.2	12304
	Vaucluse, Elandskop (0239133W)	993	26.8	26561
2	Vaucluse, Elandskop (0239133W)	993	53.7	53280
3	Vaucluse, Elandskop (0239133W)	993	1.4	1387
4	Elandshoek, Boston (0239097A)	1007	11.8	11829
	Vaucluse, Elandskop (0239133W)	993	24.3	24166
	Edendale (0239518W)	946	3	2844

Table 6.2 (continued): Summary of Thiessen polygons

Sub-catchment	Station description (Name & number)	MAP (mm)	Sub-area (km^2)	Precipitation.area ($mm.km^2$)
5	Elandshoek, Boston (0239097A)	1007	0.9	903
	Vaucluse, Elandskop (0239133W)	993	2.6	2598
	Edendale (0239518W)	946	40.4	38206
	Baynesfield Estates (0239585A)	767	0.7	504
6	Edendale (0239518W)	946	0.4	348
7	Elandshoek, Boston (0239097A)	1007	9.9	10002
	Edendale (0239518W)	946	20.4	19329
8	Cedara College (0239482W)	842	0.2	173
	Edendale (0239518W)	946	7.2	6845
9	Edendale (0239518W)	946	4.1	3914
10	Cedara College (0239482W)	842	1.7	1397
	Edendale (0239518W)	946	28.2	26695
11	Edendale (0239518W)	946	31.8	30095
	Baynesfield Estates (0239585A)	767	3.9	3017
12	Edendale (0239518W)	946	18.4	17355
	Pietermaritzburg purification works (0239577W)	927	1	933
13	Edendale (0239518W)	946	10.8	10195
	Pietermaritzburg purification works (0239577W)	927	0.8	748
	Baynesfield Estates (0239585A)	767	3.4	2636
14	Edendale (0239518W)	946	0.1	80
	Pietermaritzburg purification works (0239577W)	927	8.7	8096
15	Edendale (0239518W)	946	3.6	3362
	Pietermaritzburg purification works (0239577W)	927	0.8	708

Table 6.2 (continued): Summary of Thiessen polygons

Sub-catchment	Station description (Name & number)	MAP (mm)	Sub-area (km^2)	Precipitation.area ($mm.km^2$)
15	Baynesfield Estates (0239585A)	767	14.5	11109
	Ukulinga-AGR (0239700A)	706	7.8	5495
16	Baynesfield Estates (0239585A)	767	1.4	1053
	Ukulinga-AGR (0239700A)	706	16.5	11672
17	Pietermaritzburg purification works (0239577W)	927	0.6	569
	Ukulinga-AGR (0239700A)	706	3.6	2537
18	Pietermaritzburg purification works (0239577W)	927	3.0	2773
	Ukulinga-AGR (0239700A)	706	0.6	438
19	Pietermaritzburg purification works (0239577W)	927	1.7	1524
	Ukulinga-AGR (0239700A)	706	1.0	709
20	Pietermaritzburg purification works (0239577W)	927	1.8	1648
	Ukulinga-AGR (0239700A)	706	0.2	168
	Pietermaritzburg purification works (0239756AW)	826	0.1	15
21	Pietermaritzburg purification works (0239577W)	927	0.2	197
	Allerton (0239604W)	957	1.9	1792
	Ukulinga-AGR (0239700A)	706	9.1	6426
	Pietermaritzburg purification works (0239756AW)	826	2.0	1662
22	Cedara College (0239482W)	842	3.2	2704
	Edendale (0239518W)	946	1.6	1477
	Pietermaritzburg purification works (0239577W)	927	8.3	7677
	Allerton (0239604W)	957	6.1	5829

Table 6.2 (continued): Summary of Thiessen polygons

Sub-catchment	Station description (Name & number)	MAP (mm)	Sub-area (km^2)	Precipitation.area ($mm.km^2$)
23	Cedara College (0239482W)	842	5.5	4610
	Allerton (0239604W)	957	25.1	23996
24	Edendale (0239518W)	946	0.1	65
	Pietermaritzburg purification works (0239577W)	927	8.9	8203
	Allerton (0239604W)	957	14.6	13933
	Pietermaritzburg purification works (0239756AW)	826	0.8	660
25	Allerton (0239604W)	957	0.5	425
	Pietermaritzburg purification works (0239756AW)	826	5.5	4514
26	Ukulinga-AGR (0239700A)	706	10.3	7266
	Pietermaritzburg purification works (0239756AW)	826	4.4	3619
27	Pietermaritzburg purification works (0239756AW)	826	4.4	3595
28	Pietermaritzburg purification works (0239756AW)	826	1.4	1124
29	Allerton (0239604W)	957	9.1	8727
	Pietermaritzburg purification works (0239756AW)	826	19.1	15751
30	Pietermaritzburg purification works (0239756AW)	826	11.1	9158
31	Ukulinga-AGR (0239700A)	706	14.9	10527
32	Baynesfield Estates (0239585A)	767	4.9	3748
	Ukulinga-AGR (0239700A)	706	42.3	29861
	Camperdown (0240073W)	685	8.6	5861
33	Ukulinga-AGR (0239700A)	706	9.6	6785
	Pietermaritzburg purification works (0239756AW)	826	0.7	570
	Camperdown (0240073W)	685	3.0	2035

Table 6.2 (continued): Summary of Thiessen polygons

Sub-catchment	Station description (Name & number)	MAP (mm)	Sub-area (km^2)	Precipitation.area (mm.km^2)
34	Ukulinga-AGR (0239700A)	706	9.5	6672
	Pietermaritzburg purification works (0239756AW)	826	47.7	39376
	Camperdown (0240073W)	685	7.9	5398
35	Pietermaritzburg purification works (0239756AW)	826	22.8	18861
	Camperdown (0240073W)	685	9.7	6607
	Nagle (0240185W)	749	8.0	6010
36	Nagle (0240185W)	749	6.7	4995
37	Camperdown (0240073W)	685	8.1	5571
	Nagle (0240185W)	749	38.3	28689
38	Camperdown (0240073W)	685	22.3	15250
39	Camperdown (0240073W)	685	33.1	22687
40	Camperdown (0240073W)	685	28.3	19358
	Nagle (0240185W)	749	0.6	479
	Inchanga (0240284W)	790	7.4	5869
41	Nagle (0240185W)	749	7.3	5454
	Inchanga (0240284W)	790	1.3	996
42	Nagle (0240185W)	749	10.7	7978
	Inchanga (0240284W)	790	8.0	6330

6.2 STREAMFLOW SIMULATIONS

Following the data preparation discussed in Chapter 5, model parameters are entered into the HSPF User Control Input (UCI) file and meteorological time-series data are entered into the Watershed Data Management (WDM) file. All the model parameters and related information of these simulation- and utility modules are listed in Annexure C. The various parameters in the UCI were determined according to the possible value ranges and guidelines as stipulated in Chapter 4 and Basins Technical Note 6 (USEPA, 2000).

The modules and their order of execution was set out in the Operational-Sequence (OPN SEQUENCE) Table (Annexure C: 216 & 251), according to the numbering scheme mentioned in Chapter 5. The ACTIVITY Block of each module section is a row of switches, which determine which simulation routines are to be executed. Since only hydrology, and no water quality was simulated in this study, only PWATER section of module PERLND, the IWATER section of module IMPLND and the HYDR section of module RCHRES was activated for each operation.

General descriptions of the pervious- and impervious land segments and reaches or reservoirs were entered in the General Information (GEN-INFO) Tables of PERLND-, IMPLND- and RCHRES modules (Annexure C: 220, 232, 234 & 255, 266, 269).

The PWAT-PARM 1 Table (Annexure C: 222 & 258) consists of a set of flags or switches, and is used to specify whether certain parameters vary monthly or are assumed constant throughout a simulation run. In the land-use categories Crops (2) and Grassland (3), the parameters LZETP and CEPSC were assumed to vary monthly. The monthly values for these land-use categories were entered in tables MON-LZETPARM and MON-INTERCEP (Annexure C: 230, 231 & 264, 265).

In the PWAT-PARM 2 Table (Annexure C: 223 & 258) the different parameters (LZSN, KVARY and AGWRC) were determined according to the possible value ranges and guidelines as stipulated in Chapter 4.

The parameter FOREST applies only to the northern hemisphere coniferous forest, and was set to zero. The average slope of the overland flow plane (SLSUR), which is a function of topography and estimated from GIS-data, indirectly influences the length of LSUR. Therefore lower LSUR values are associated with higher SLSUR values within the range of 0.01 to 0.30 m/m. The LSUR values were initially associated with these SLSUR values of each sub-catchment and then interpolated within the range of 30 to 215 m with the corresponding SLSUR range of 0.01 to 0.30 m/m (USEPA, 2000: 30).

LZSN and INFILT are some of the parameters that determine the annual water balance and were determined by calibration, as discussed in Chapter 4. LSUR and SLSUR are non-calibration model parameters. KVARY is used to represent season variability in groundwater recession rates, and was defaulted to zero.

In the IWAT-PARM 2 Table (Annexure C: 233 & 267) the different parameters (NSUR and RETSC) were determined according to the possible value ranges and guidelines as stipulated in Chapter 4. SLSUR also indirectly influences LSUR as in the case of PWAT-PARM 2. NSUR is a non-calibration model parameter. The criteria for determining LSUR- and SLSUR values are the same as for pervious land segments, except that the LSUR- and SLSUR values are within the range of 15 to 76 m and 0.01 to 0.15 m/m respectively (USEPA, 2000: 31).

In the PWAT-PARM 3 Table (Annexure C: 225 & 261) the different parameters (INFEXP and INFILD) were set according to the possible value ranges and guidelines as stipulated in Chapter 4. DEEPFR was set to zero, since there were no significant dolomitic regions in the study area, and seepage below streamflow gauges was considered negligible. BASETP and AGWETP, which represent ET losses from riparian vegetation and groundwater, were assumed non-significant and set to zero.

In IWAT-PARM 3 (Annexure C: 234 & 268) default values were used.

In the PWAT-PARM 4 Table (Annexure C: 228 & 262) the parameters (CEPSC, UZSN, NSUR, INTFW, IRC and LZETP) were initially set to default values according to the possible value ranges and guidelines as stipulated in Chapter 4. UZSN has a minor, and LZETP a major influence on the annual water balance. UZSN, INTFW and IRC were subsequently adjusted by calibration.

PWAT-PARM 5 Table (Annexure C: 230 & 264) was omitted, since defaults were used for all its parameters.

In the MON-INTERCEP Table (Annexure C: 230 & 264) the monthly values of CEPSC are developed according to the results as obtained in PWAT-PARM 4. In the MON-LZETPARM Table (Annexure C: 231 & 265) the monthly values of LZETP are developed using an expected maximum value from the PWAT-PARM 4 Table. These values reflect seasonal changes in ET due to the changes in the density of the vegetation, depth of root zone and the stage of growth.

The PWAT-STATE 1 Table (Annexure C: 232 & 266) is used to set starting conditions at the beginning of a simulation run. The surface related storages (CEPS, SURS and IFWS) were set to zero and allowed to equilibrate during simulation. UZS and LZS were set equal to UZSN and LZSN. Seasonal recession was not represented, therefore, GWVS is not calculated and was set to zero. Setting AGWS too high or too low will lead to baseflow that is either too high or skewed low. AGWS was therefore initially set to 25 mm (USEPA, 2000: 18-19).

Similarly, the IWAT-STATE 1 Table (Annexure C: 234 & 268) is used to set starting conditions for impervious land segments. The storage of water in retention (RETS) and surface detention storage (SURS) were initially assumed to be zero and allowed to equilibrate during simulation.

In the HYDR-PARM 1 Table (Annexure C: 235 & 269) flags are selected in order to indicate which auxiliary variables must be computed and to specify volume and time-dependent outflow demands for each reach or reservoir. Since most of the auxiliary variables are only used in water quality simulations, the flags selecting their computation were turned off, with the exception of the first flag (AUX1FG), which allowed for the computation of depth, stage, surface area, average depth and top width.

With the exception of Henley Dam, all reaches were assumed to have one volume-dependent outflow. For Henley Dam, three outflows were specified: two volume-dependent outflows, to represent the spillway and downstream releases, and one time-dependent outflow, representing abstractions to the H.D. Hill water purification plant. These abstractions ceased mid-1995. The downstream dam releases were simulated as a volume-dependent outflow, since separate time-series of these releases and the spillway overflows were unobtainable.

The HYDR-PARM 2 Table (Annexure C: 235 & 269) is used to set the parameters LEN (reach length), DELTH (drop in reach elevation) and KS (weighting factor for hydraulic routing). The values determined with GIS were entered for LEN and DELTH. The EPA recommended value of 0.5 was used for KS.

In the HYDR-INIT Table (Annexure C: 235 & 270) the initial conditions for the HYDR section are described. VOL is the initial volume of water in the RCHRES. In this modelling attempt all the reaches, except for Henley Dam, were assumed initially empty and allowed to equilibrate during simulation. An initial storage of 1.4 million m^3 was used for Henley Dam. This corresponds with the dam capacity information as provided by DWAF.

The values calculated from river geometry data with the XSECT program were entered in the FTABLES (Annexure C: 236 & 270).

The External Sources (EXT SOURCES) Table (Annexure C: 244 & 279) is used to specify connections of time series stored in the WDM file and internal simulation modules. The meteorological time series (precipitation and evaporation) used by the PERLND and IMPLND modules, as well as time series representing abstractions or point sources for the RCHRES module are specified in this table.

The WDM data sets are summarised in Table 6.3.

Table 6.3: Summary of time series in the Watershed Data Management file

Data set number	Description
1	Elandshoek, Boston (0239097A)
2	Vaucluse (0239133W)
3	Cedara College (0239482W)
4	Edendale (0239518W)
5	Pietermaritzburg purification works (0239577W)
6	Baynesfield Estates (0239585A)
7	Allerton (0239604W)
8	Ukulinga- AGR (0239700W)
9	Pietermaritzburg purification works (0239756W)
10	Camperdown (0240073W)
11	Nagle (0240185W)
12	Inchanga (0240284W)
13	Evaporation region No. 1 (Annual mean of 1664 mm)
14	Evaporation region No. 2 (Annual mean of 1708 mm)
15	Evaporation region No. 3 (Annual mean of 1679 mm)
600	Darvill wastewater treatment plant (inflow)
611	U2H011 Msunduzi River at Henley Dam
622	U2H022 Msunduzi River at Nomfihlelo
641	U2H041 Msunduzi River at Hampstead Park, Moto-X
658	U2H058 Msunduzi River at Mason's Mill
692	Henley Dam abstractions
800-841	Hydrological simulation output, Sub-catchments 1-42

The multiplication-factor column in the EXT SOURCES Table (Annexure C: 244 & 279) is the factor by which the precipitation- and evaporation data will be multiplied before being sent to the target operation. In the case of precipitation these factors correspond with the percentage distribution of the area influenced by each precipitation station relative to the area of the sub-catchments of concern (see Table 6.2). The multiplication factors of the A-pan evaporation data were set to correct to open water equivalent evaporation.

Effective impervious area (EIA) as a function of land-use is also an important aspect worth mentioning, because the effect of development and impervious area on increased runoff and loss of recharge are well known. Therefore the main land-use groups were divided into effective impervious areas as follows (Beyerlein, 2000):

- CBD and industrial: 86%
- Medium-density residential: 10%
- High-density residential: 26%

These residential EIA values assume that not all roof runoff is tight-lipped to a stormwater drainage system (Beyerlein, 2000).

The SCHEMATIC Block (Annexure C: 246 & 281) is used to specify connections of flow between operating modules. For example, connections between PERLND-, IMPLND- and RCHRES modules to represent runoff into streams, and RCHRES-to-RCHRES connections to specify the stream network, are specified in this table, with a multiplication factor where necessary.

The MASS-LINK Table (Annexure C: 249 & 285) is used in combination with the SCHEMATIC Block to specify flows of individual constituents between operating modules. Since only hydrological simulations were performed, the entries in this table reflect only the connections of water flows from land segments into reaches, and from upstream to downstream reaches.

The NETWORK Block (Annexure C: 250) can be used to specify individual time series connections, which cannot be easily done with the MASS-LINK- and SCHEMATIC Blocks. Output of simulated flows into the WDM file is specified in the External Targets (EXT TARGETS) Block.

6.3 RESULTS OF STREAMFLOW CALIBRATION

The model was calibrated at a daily level against streamflow measured at the four hydrological gauging stations described in Chapter 5. Hydrological calibration proceeded along the lines described in Chapter 4.

6.3.1 Observed Streamflow Data

According to the various rating curves of each hydrological gauging station provided by DWAF (Hydrology), streamflow measurements are only accurate below the upper limit of accurately measured data of each station. Thus, any part of the hydrographs above this limit should be discounted.

U2H011, Msunduzi River at Henley Dam:

This hydrological gauging station (sharp-crested gauging weir) represents the upper sub-catchments one to five with a three-year period of available data, 1993 to 1996. Henley Dam is upstream of U2H011. Streamflow measurements mainly represent dam releases and occasional spillway overflow and are accurate to flows of approximately 16 m^3/second.

These sub-catchments encompass 19.7% of the entire catchment and only 0.3% is impervious land. Grassland, undefined open spaces and low-density residential areas dominate. The average slopes (0.138 m/m) contribute to moderate runoff, but the land-use, pervious land, routing of more water through the subsurface as interflow and high interception storage capacities retain much of the runoff. Henley Dam attenuates any natural factors, which could affect the hydrograph shape. The observed daily hydrograph of U2H011 and the corresponding precipitation data of Vaucluse (0239133W) are shown respectively in Figure 6.1 and 6.2.

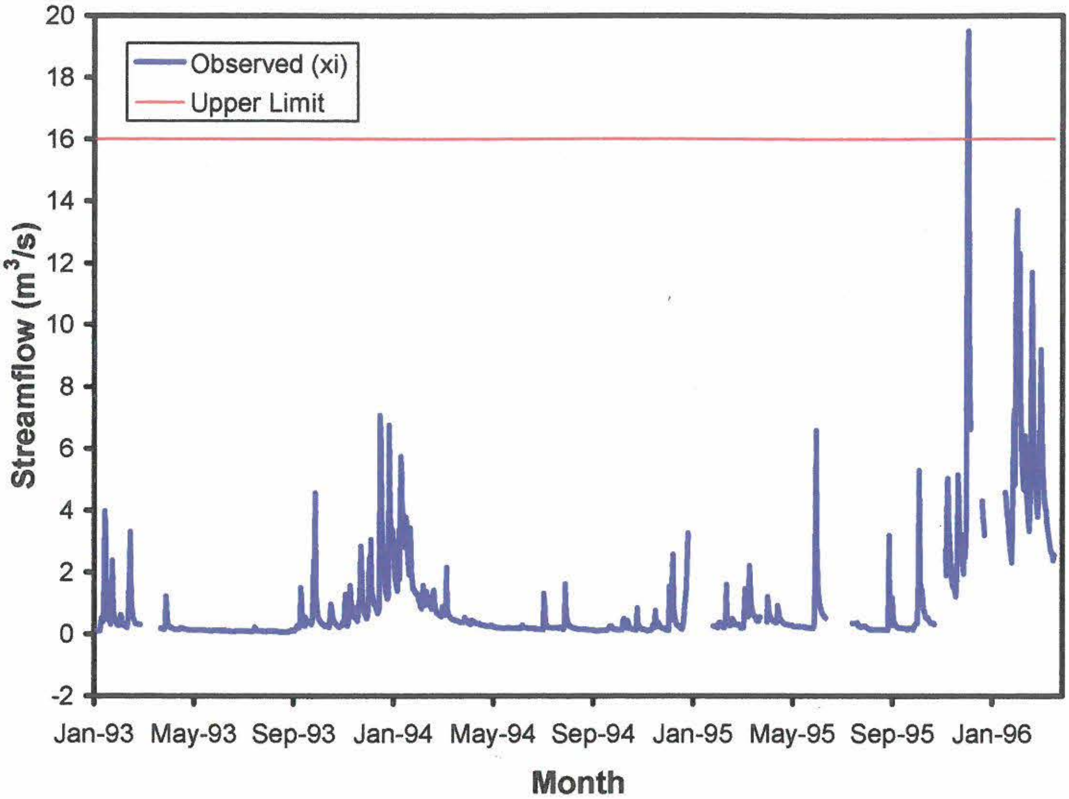

Figure 6.1: Observed daily hydrograph: U2H011: Msunduzi River at Henley Dam. Hydrological years: 1993-1996

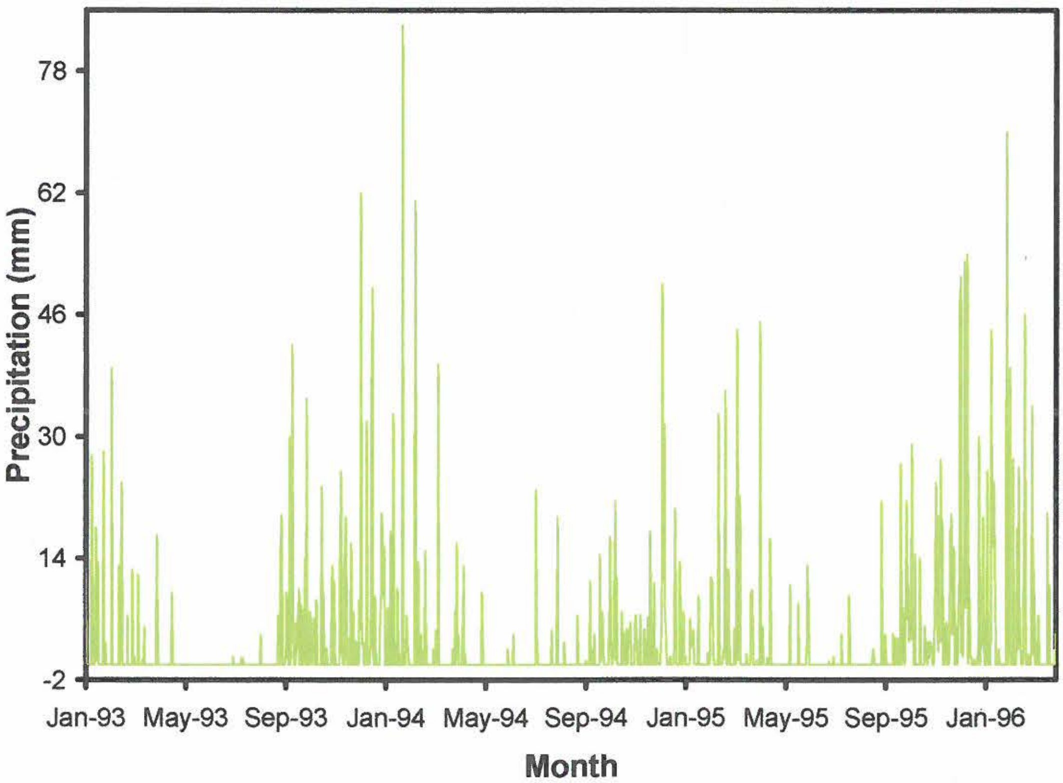

Figure 6.2: Observed precipitation data: Vaucluse (0239133W). Period of record: 1993-1996

U2H058, Msunduzi River at Mason's Mill:

Sub-catchments six to 14 contribute the streamflow to this hydrological gauging station. Data are available for a five-year period, 1995 to 2000. Streamflow measurements at this V-crump/ horizontal-crump gauging weir are accurate to flows of 336.6 m^3/second.

These sub-catchments cover 16.8% of the entire catchment. The percentage impervious land, namely 5.9% is higher than at U2H011. The average slopes are also steeper (0.217 m/m) and grassland, undefined open spaces, rural-urban transitions, medium-density residential areas and forest dominate.

All these factors help to explain the nature of U2H058's hydrograph. The steeper average slopes and higher percentage of impervious land contribute to quick runoff, resulting in the sharper rising- and descending limbs of the daily storm hydrographs.

The observed daily hydrograph of U2H058 is shown in Figure 6.3. The precipitation data of Edendale (0239518W) has the largest influence on the precipitation-distribution and are shown in Figure 6.4 for the corresponding period. The contributions of the other four precipitation stations (0239097A, 0239482W, 0239577W and 0239585A) are insignificant.

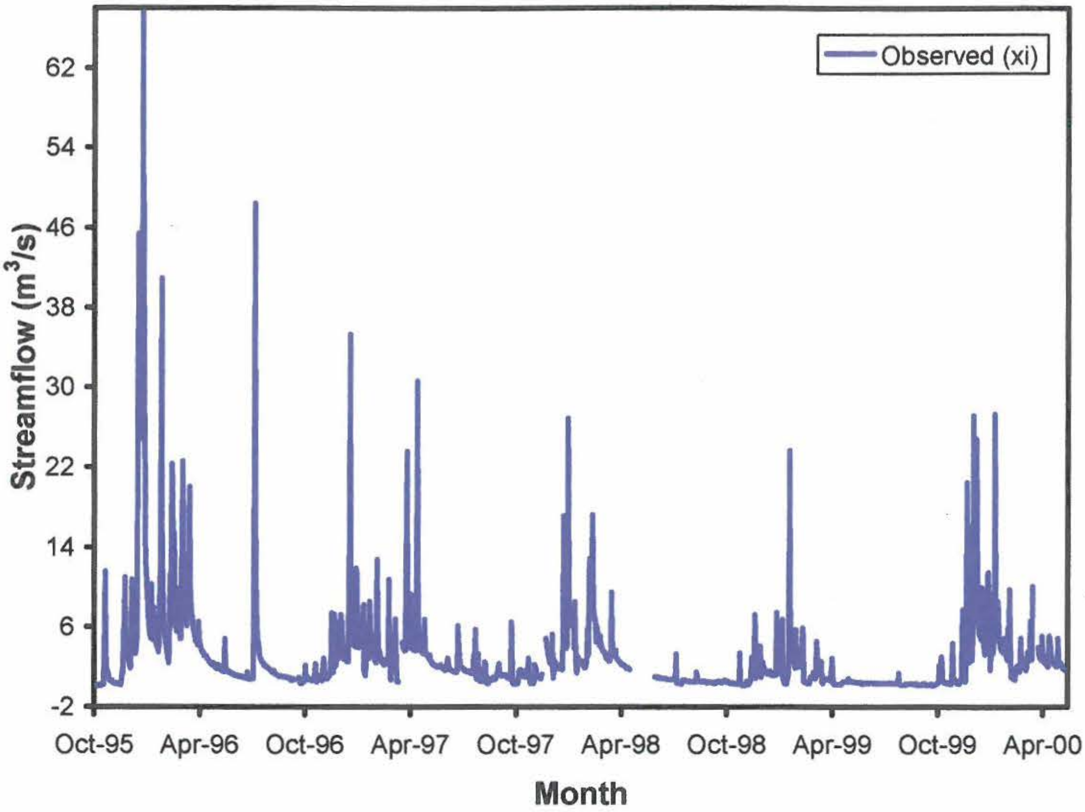

Figure 6.3: Observed daily hydrograph: U2H058: Msunduzi River at Mason's Mill. Hydrological years: 1995-2000

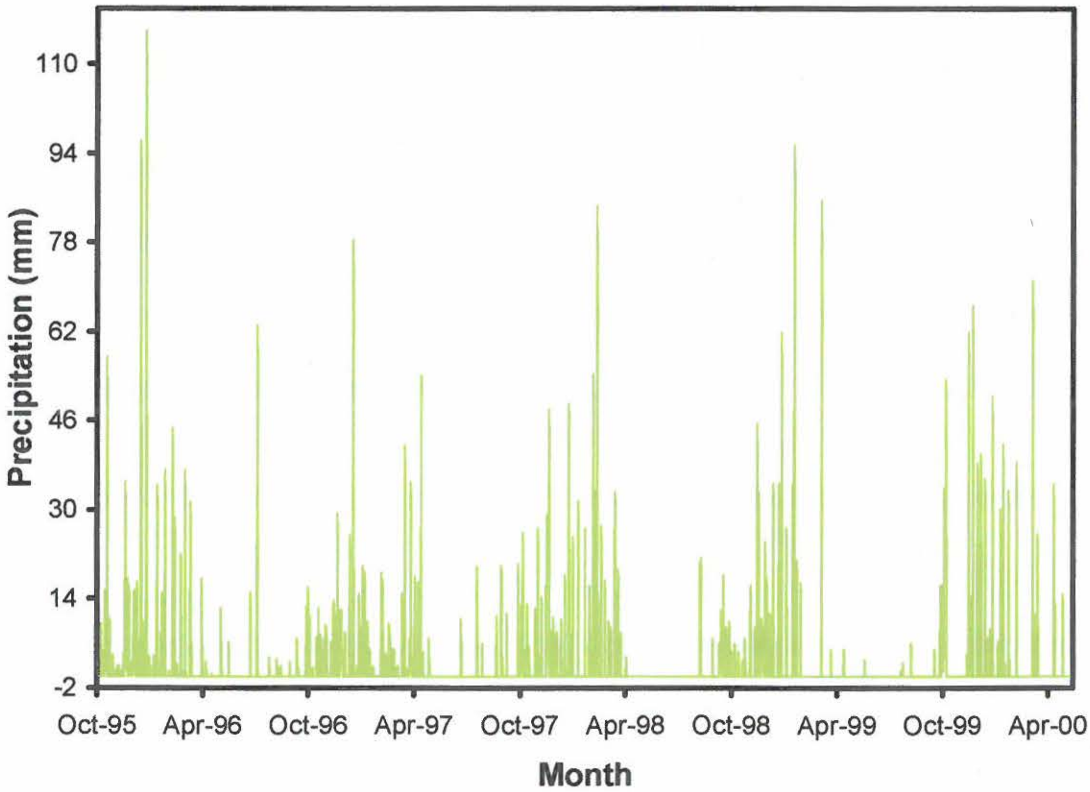

Figure 6.4: Observed precipitation data: Edendale (0239518W). Period of record: 1995-2000

U2H041, Msunduzi River at Hampstead Park, Moto-X:

The single notch V-crump gauging weir at this hydrological gauging station can measure the streamflow, contributed by sub-catchments 15 to 30 accurately up to 106.9 m^3/second. Data are only available for a three-year period, 1997 to 2000.

These sub-catchments encompass 23.3% of the entire catchment and the percentage of impervious land is also the highest, namely 11.2%. The sub-catchments above U2H041 have shallow slopes with an average of 0.088 m/m. Grassland, rural-urban transitions, medium-density residential areas, CBD and industrial areas and forest dominate.

The shallow slopes, larger catchment area and longer travel time to the river ensure that the hydrograph varies smoothly over time. On the other hand, the higher percentage of impervious land contributes to quick runoff response with sharper rising- and descending limbs of the daily storm hydrographs during single-event storms. Furthermore the seasonal variation of total wastewater discharge from the Darvill wastewater treatment plant in sub-catchment 30 can affect the natural conditions in this sub-catchment and thus the hydrographs. Although insignificant, it was taken into consideration.

The observed daily hydrograph of U2H041 is shown in Figure 6.5. The precipitation stations, Ukulinga-AGR (0239700W) and Pietermaritzburg purification works (0239756W) have the biggest influence on the precipitation-distribution in sub-catchments 15 to 30. The precipitation data for the corresponding period are shown in Figures 6.6 and 6.7.

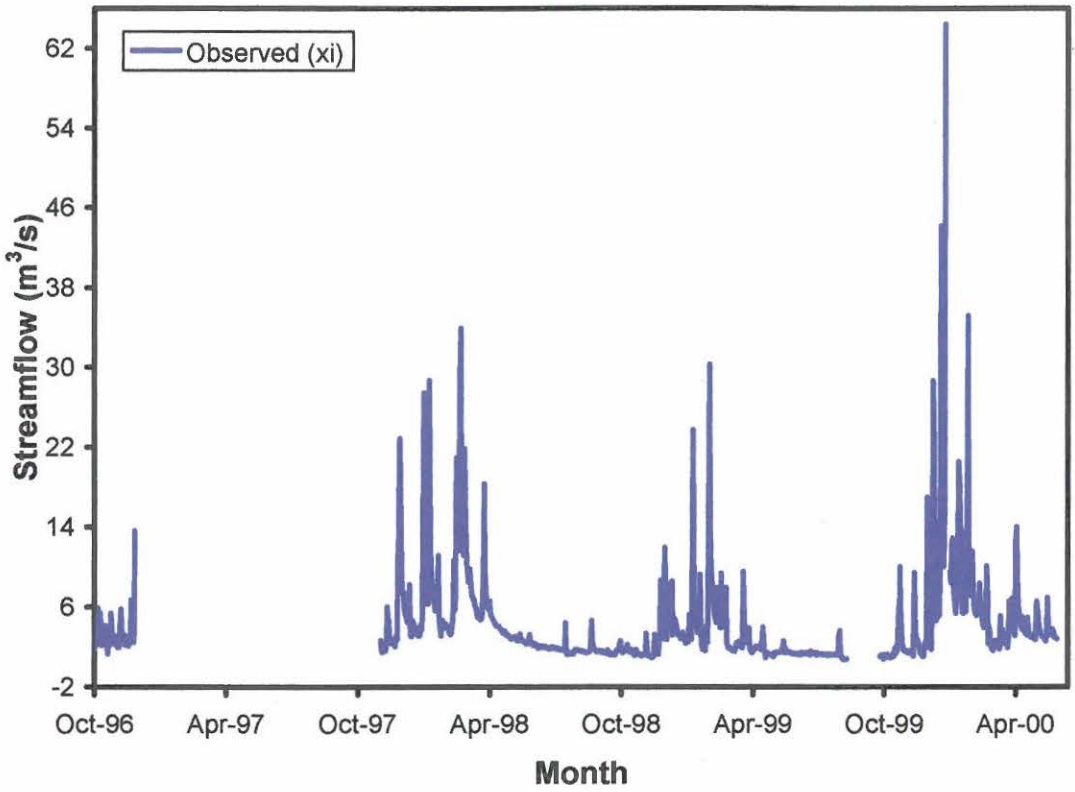

Figure 6.5: Observed daily hydrograph: U2H041: Msunduzi River at Hampstead Park, Moto-X. Hydrological years: 1997-2000

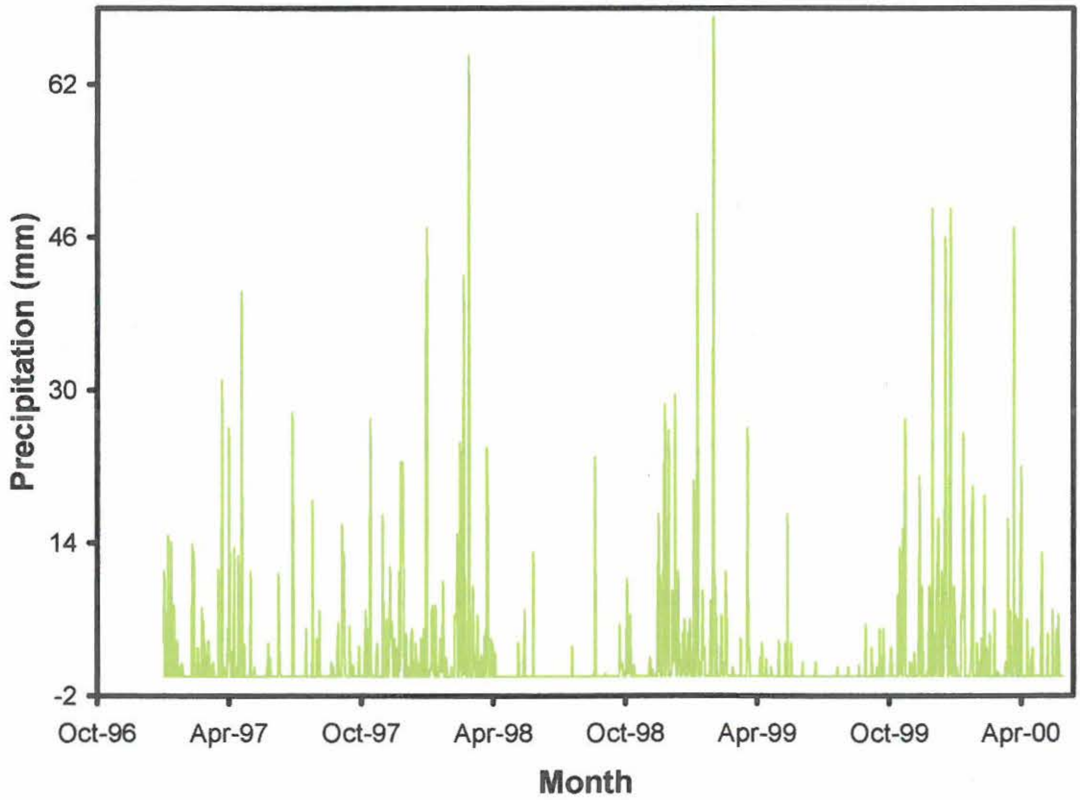

Figure 6.6: Observed precipitation data: Ukulinga-AGR (0239700W). Period of record: 1997-2000

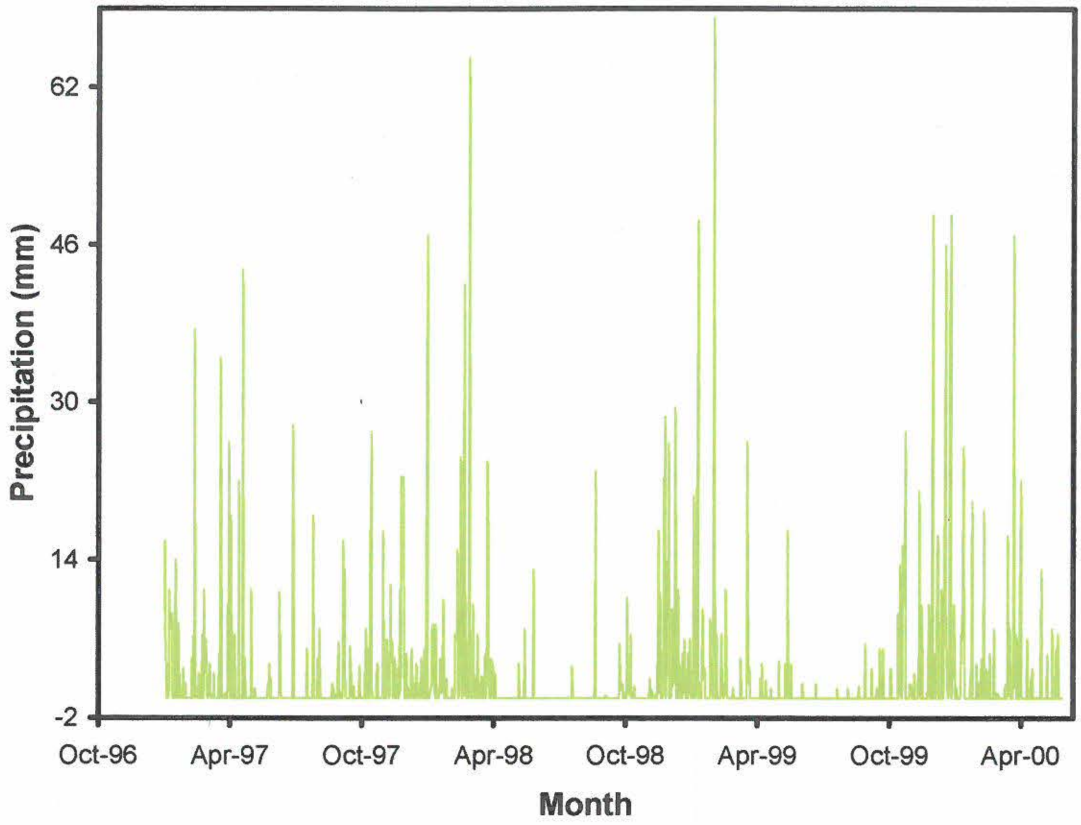

Figure 6.7: Observed precipitation data: Pietermaritzburg purification works (0239756W). Period of record: 1997-2000

U2H022, Msunduzi River at Nomfihlelo:

Sub-catchments 31 to 42 contribute the runoff and therefore streamflow to this hydrological gauging station. Compared to the other hydrological gauging stations, the best observed data set (1992 to 2000) was available at this station. This multiple gauging weir consists of a hydro flume and three broad crest notches. Streamflow measurements are characterised by the absence of submergence data and therefore the structure can only be calibrated to flows of approximately 36.5 m^3/second. Even at this streamflow, inaccuracies are obvious as the effects of submergence would no doubt already be evident. Any part of the hydrograph above the upper limit of measured data should be discounted.

These sub-catchments cover 40.2% of the lower Msunduzi River Catchment. The amount of impervious land is 0.5%. Shallow to steep slopes (0.129 m/m), forest, open spaces, cropping and grassland are typical sub-catchment characteristics. All above-mentioned factors, as in the case of U2H041, ensure that the hydrograph varies smoothly over time.

Among all the stations, it can be argued that U2H022 is most representative of the natural conditions in the entire Msunduzi River Catchment, because there are no significant human-induced hydrological alterations present in these sub-catchments. The hydrograph at U2H022 closely mimics the hydrograph at U2H041, with sharp rising- and descending limbs of the daily storm hydrographs. The observed daily hydrograph of U2H022 is shown in Figure 6.8. The precipitation data of Camperdown (0240073W) and Nagle (0240185W) are shown in Figures 6.9 and 6.10.

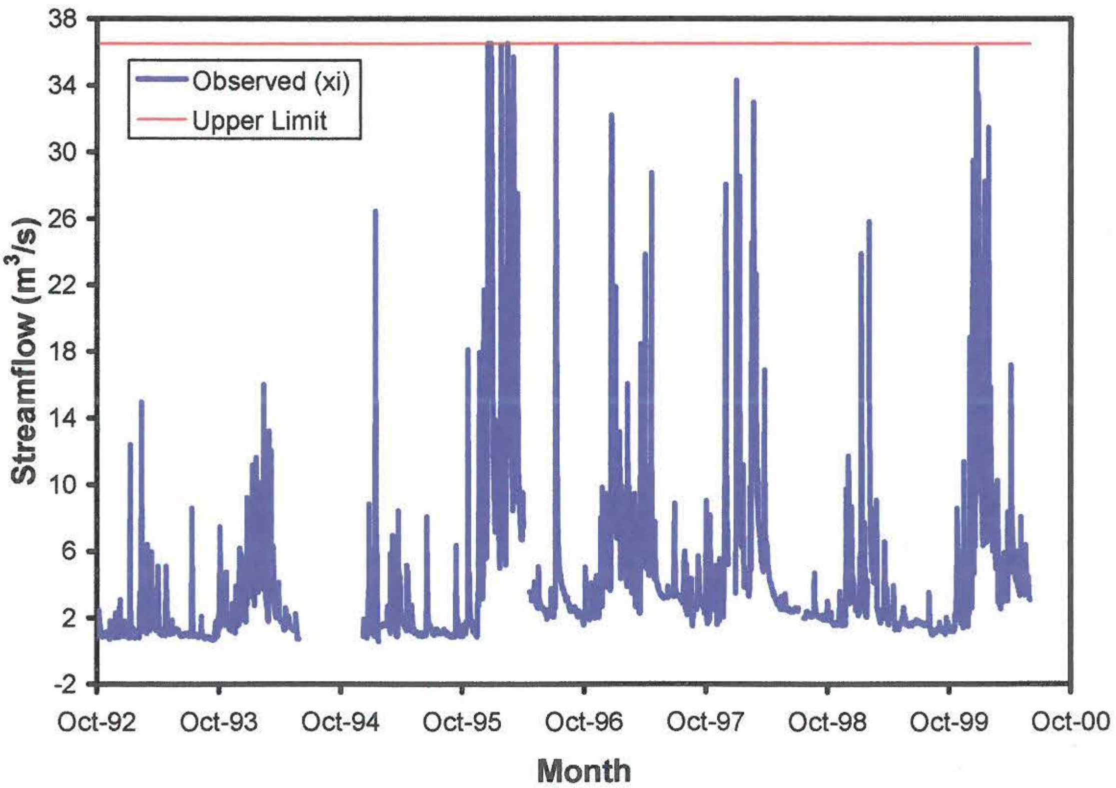

Figure 6.8: Observed daily hydrograph: U2H022: Msunduzi River at Nomfihlelo. Hydrological years: 1992-2000

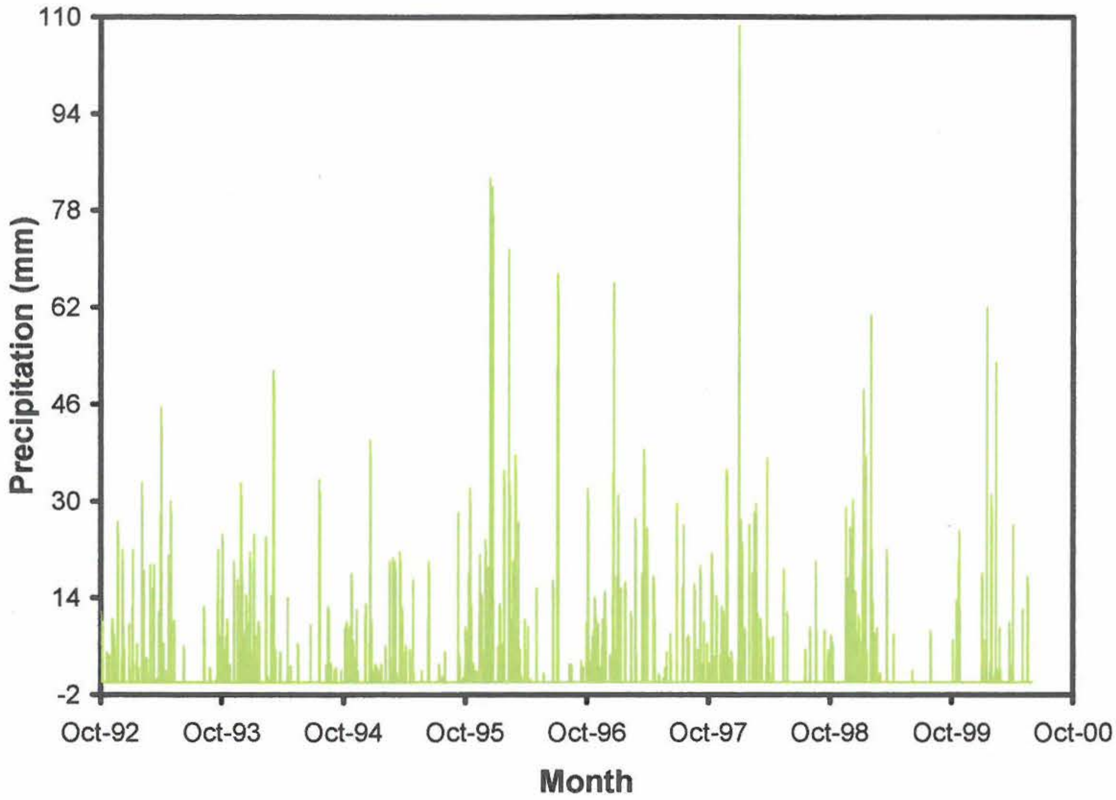

Figure 6.9: Observed precipitation data: Camperdown (0240073W). Period of record: 1992-2000

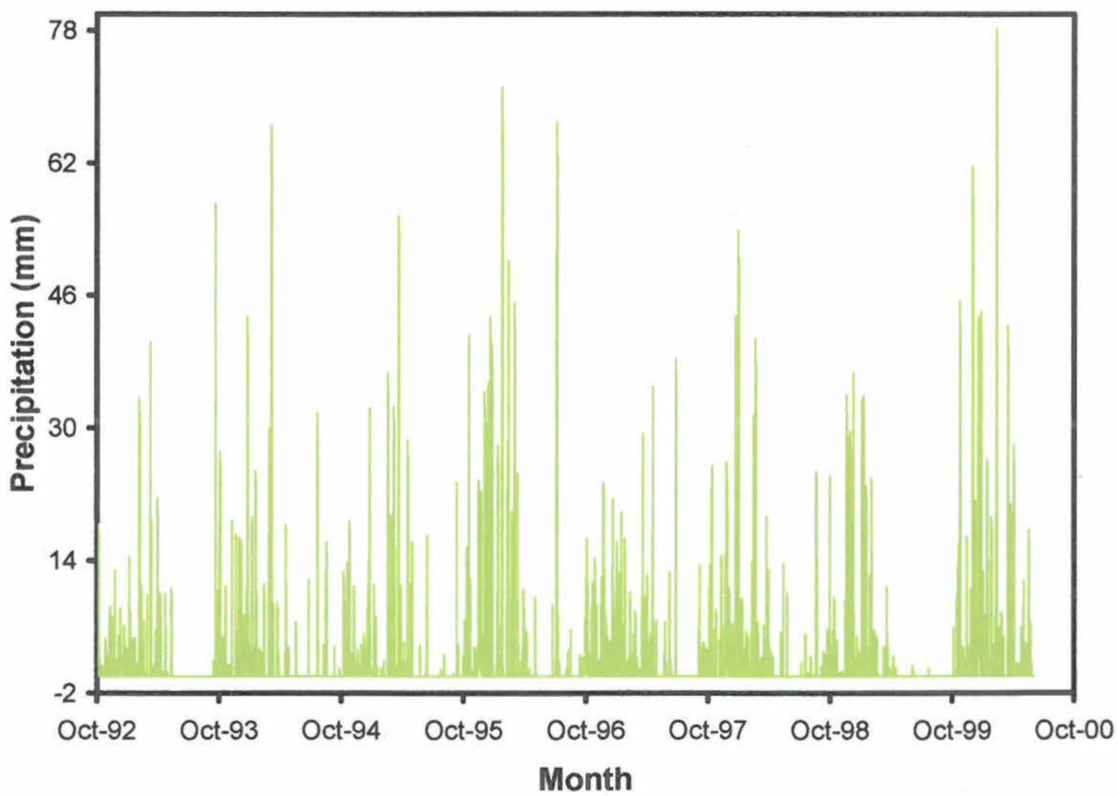

Figure 6.10: Observed precipitation data: Nagle (0240185W). Period of record: 1992-2000

6.3.2 Comparison of Observed Data and Simulated Streamflow Values

The period of calibration corresponded with the period of availability of catchment- (topography, geology and land-use), hydrological- (streamflow, human water use and wastewater treatment plants) and meteorological data (precipitation and evaporation). The periods used for the calibration of the four hydrological gauging stations are summarised in Table 6.4.

Table 6.4: Summary of calibration data

Station description (DWAF number & name)	Period of calibration
U2H011 Msunduzi River at Henley Dam	1993/02/01-1996/03/31
U2H058 Msunduzi River at Mason's Mill	1995/10/01-1998/09/31
U2H041 Msunduzi River at Hampstead Park, Moto-X	1996/10/01-1999/09/31
U2H022 Msunduzi River at Nomfihlelo	1992/10/01-1998/09/31

In the Msunduzi River Catchment, only three of the main land-use groups are thought to contribute runoff directly to the river. The CBD and industrial, medium-density residential and high-density residential land-use groups are therefore simulated as EIA as discussed earlier. The percentage-distribution of these EIA as a percentage of the total area of impervious land is summarised in Table 6.5.

Table 6.5: Summary of Effective Impervious Areas (EIA)

Main land-use group	EIA (km^2)	Percentage-distribution (%)
CBD and industrial	22	63
Medium-density residential	7	20
High-density residential	6	17
Total:	35	100

The AGWRC parameters varied between 0.93 and 0.99 throughout the catchment. Values for the AGWRC parameters were determined by comparing the slopes of semi-logarithmic plots of the observed streamflow data and simulated streamflow values during the baseflow period (winter months) at the different hydrological gauging stations. According to Johanson (1997) HSPF assumes the groundwater reservoir is "linear" and since AGWRC represents the ratio of today's flow divided by yesterday's flow, semi-logarithmic plots will result in a straight line, because the flow is decreasing exponentially.

The INFILT parameter varied between 0.6 and 1.0 throughout sub-catchments one to 42. The higher values used on sub-catchments six to 42 could account for the over-simulation of the baseflow period. Since INFILT also has an influence on the seasonal runoff distribution, it is possible that, together with IRC and AGWRC it might be responsible for the high autumn baseflow in these sub-catchments.

The LZSN parameter varied throughout the catchment. Lower values were used in sub-catchments six to 14 in order to increase the annual runoff. In the other sub-catchments, higher values were used to increase the actual ET, thus decreasing the annual water balance.

Lower values of UZSN at the dominant land-use groups (forest and grassland) were used in sub-catchments one to five in order to increase the peak flows of the rising limb of the hydrograph at U2H011. In the rest of the catchment, higher UZSN values were used at the dominant land-use groups in order to retain more water in the upper zone and increase the amount available for ET.

The AGWRC parameters varied between 0.93 and 0.99 throughout the catchment. Values for the AGWRC parameters were determined by comparing the slopes of semi-logarithmic plots of the observed streamflow data and simulated streamflow values during the baseflow period (winter months) at the different hydrological gauging stations. According to Johanson (1997) HSPF assumes the groundwater reservoir is “linear” and since AGWRC represents the ratio of today’s flow divided by yesterday’s flow, semi-logarithmic plots will result in a straight line, because the flow is decreasing exponentially.

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Lower values of UZSN at the dominant land-use groups (forest and grassland) were used in sub-catchments one to five in order to increase the peak flows of the rising limb of the hydrograph at U2H011. In the rest of the catchment, higher UZSN values were used at the dominant land-use groups in order to retain more water in the upper zone and increase the amount available for ET.

LZETP values were selected in accordance with the land-use groups, as discussed in Chapters 4 and 5.

During the final stage of streamflow calibration at a daily level, the individual hydrographs are calibrated to best match response time, maximum peakflows and recession rate. The most important adjustments were made to the parameters INTFW and IRC.

The final calibrated values of INTFW in the catchment range from 1.0 to 3.0 for the various main land-use groups. These relatively high INTFW values help to better match the hydrograph peaks, while maintaining a reasonable amount of runoff volume. INTFW is also responsible for the division of water between interflow and surface processes, thus influencing the timing of the simulated hydrographs.

Various IRC values, recommended in the literature, were used with little or no effect, especially with respect to the autumn baseflow. The simulation results varied; simulated interflow recession was either too slow or accurate. A constant IRC value of 0.7 gave the best results overall.

The over-simulation of single storm events (higher streamflow peaks) was the most consistent error that occurred during the period of calibration. This is likely due to the poor representation and areal distribution of precipitation data, which did not account accurately for the spatial variation in precipitation and storm distributions.

U2H011, Msunduzi River at Henley Dam:

The daily calibration at U2H011 was better than the calibration at U2H058. The variations in the simulation results were indicative that there is no model bias.

The wet period was under-simulated by 7%, thus reflecting an overall under-simulation of streamflow peaks, especially during the hydrological year 1994 to 1995. High streamflow peaks were simulated for the period of 1995/12/21 to 1996/02/01, but there were no observed data available for this period. The dry period was over-simulated by 35%.

The observed data at U2H011 are also questionable, especially considering all the missing data during the period of calibration. Another factor complicating the accurate simulation of U2H011 was the simplifying assumptions made about downstream dam releases from Henley Dam. The final calibrated values of the five parameters, which determine the seasonal and annual water balance in sub-catchments one to five are listed in Table 6.6.

Table 6.6: Summary of seasonal and annual water balance parameters in sub-catchments one to five

Main land-use group	LZETP	UZSN (mm)	LZSN (mm)	AGWRC	INFILT (mm/h)
Forest	0.80	19	380	0.99	0.60
Open spaces	0.60	17			
Grassland	0.50	6			
CBD and industrial	0.10	3			
Medium-density residential	0.20	7			
Low-density residential	0.35	10			
High-density residential	0.15	4			
Wetland	0.75	10			

In the hydrological year 1993 to 1994 the timing of the hydrograph was incorrectly shifted to a later date, but the overall period of calibration at U2H011 must be taken into consideration. Overall, interflow recession was correctly simulated throughout the period of calibration.

The final calibrated values for INTFW and IRC are listed in Table 6.7.

Table 6.7: Summary of hydrograph shape parameters in sub-catchments one to five

Main land-use group	INTFW	IRC
Forest	2.5	0.7
Open spaces	3.0	
Grassland	3.0	
CBD and industrial	1.5	
Medium-density residential	1.5	
Low-density residential	1.8	
High-density residential	1.0	
Wetland	2.0	

The comparison of observed- and simulated daily streamflow at U2H011 for each hydrological year is shown in Figures 6.11 to 6.13.

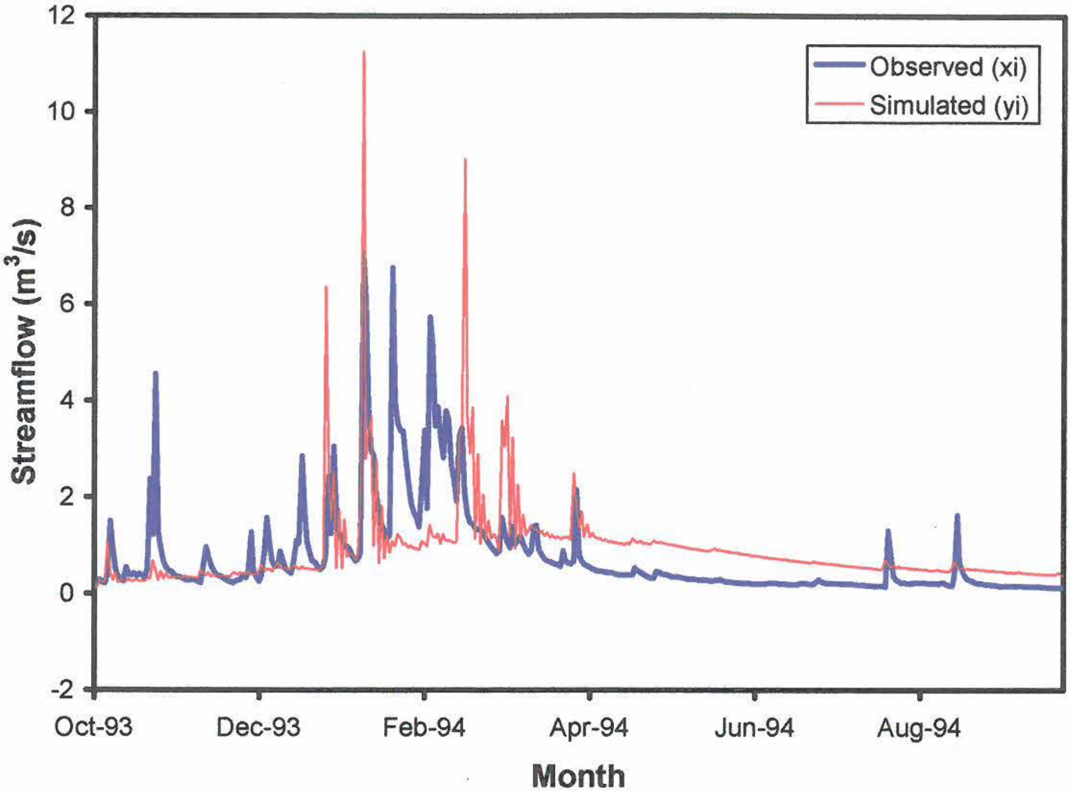

Figure 6.11: Comparison of observed and simulated daily streamflow: U2H011: Msunduzi River at Henley Dam. Hydrological year: 1993-1994

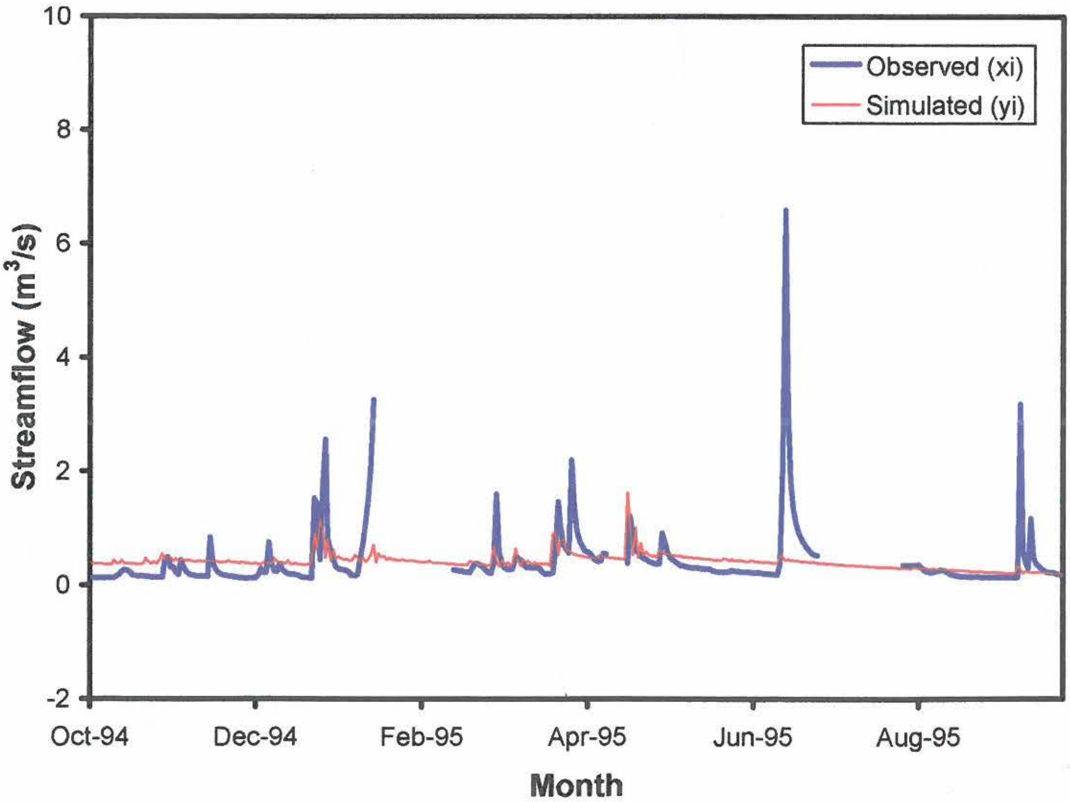

Figure 6.12: Comparison of observed and simulated daily streamflow: U2H011: Msunduzi River at Henley Dam. Hydrological year: 1994-1995

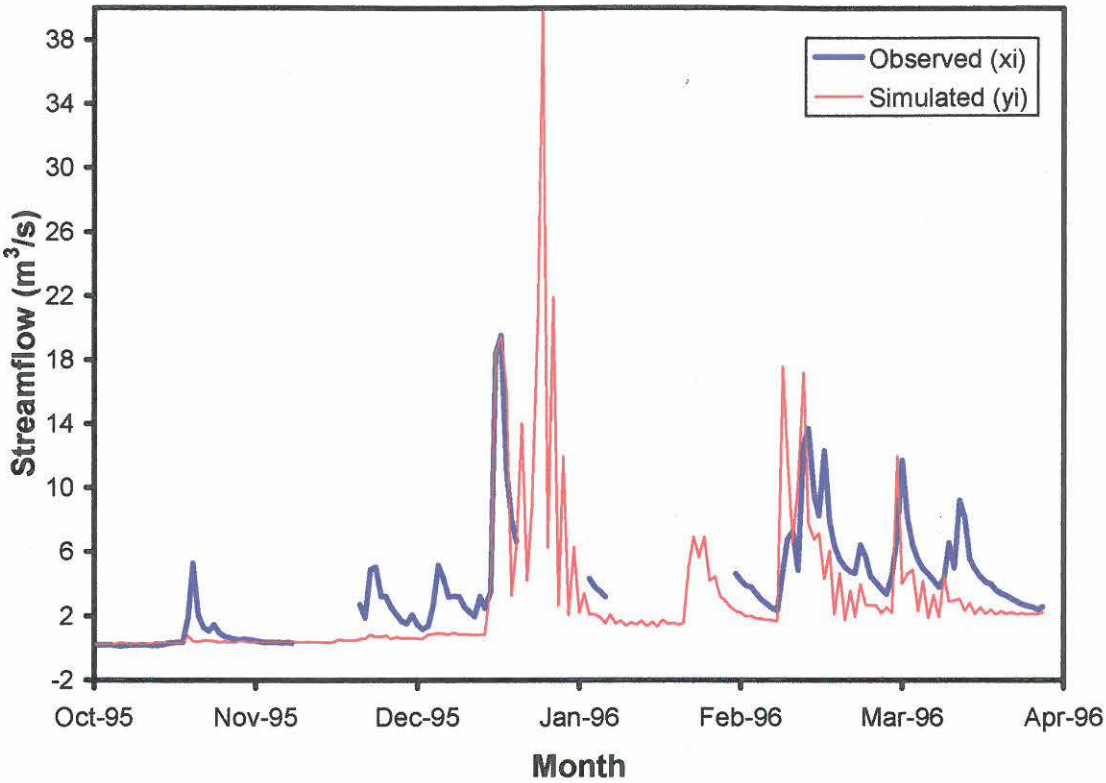

Figure 6.13: Comparison of observed and simulated daily streamflow: U2H011: Msunduzi River at Henley Dam. Hydrological year: 1995-1996

U2H058, Msunduzi River at Mason's Mill:

The daily calibration at U2H058 was the poorest among the four hydrological gauging stations. The wet period was under-simulated by 13%. Only on single occasions, the streamflow peaks were over-simulated during the hydrological years 1995 to 1996 (1995/12/26; 1996/07/08) and 1997 to 1998 (1998/02/22 - 1998/02/24).

The dry period was over-simulated by 9%. The baseflow was generally correctly simulated, but at some single events it was either over- or under-simulated. Overall, the annual water balance at U2H058 was slightly under-simulated.

The representation and areal distribution of the precipitation stations used in the hydrological simulation of sub-catchments six to 14 is better than at U2H011, however the assumption of uniform precipitation has an influence on the simulation results.

The final calibrated values of the five parameters, which determine the seasonal and annual water balance in sub-catchments six to 14 are listed in Table 6.8.

Table 6.8: Summary of seasonal and annual water balance parameters in sub-catchments six to14

Main land-use group	LZETP	UZSN (mm)	LZSN (mm)	AGWRC	INFILT (mm/h)
Forest	0.80	29	280	0.95	1.00
Open spaces	0.60	17	280		
Grassland	0.50	17	280		
CBD and industrial	0.10	3	280		
Medium-density residential	0.20	7	280		
Low-density residential	0.40	10	280		
High-density residential	0.15	4	280		
Wetland	0.75	10	280		

Table 6.9: Summary of hydrograph shape parameters in sub-catchments six to 14

Main land-use group	INTFW	IRC
Forest	2.5	0.7
Open spaces	3.0	
Grassland	3.0	
CBD and industrial	1.5	
Medium-density residential	1.5	
Low-density residential	1.8	
High-density residential	1.0	
Wetland	2.0	

The timing of the simulated hydrographs was correctly simulated throughout the period of calibration. Overall, the simulated interflow recession corresponds with the observed data.

The comparison of observed- and simulated daily streamflow at U2H058 for each hydrological year is shown in Figures 6.14 to 6.16.

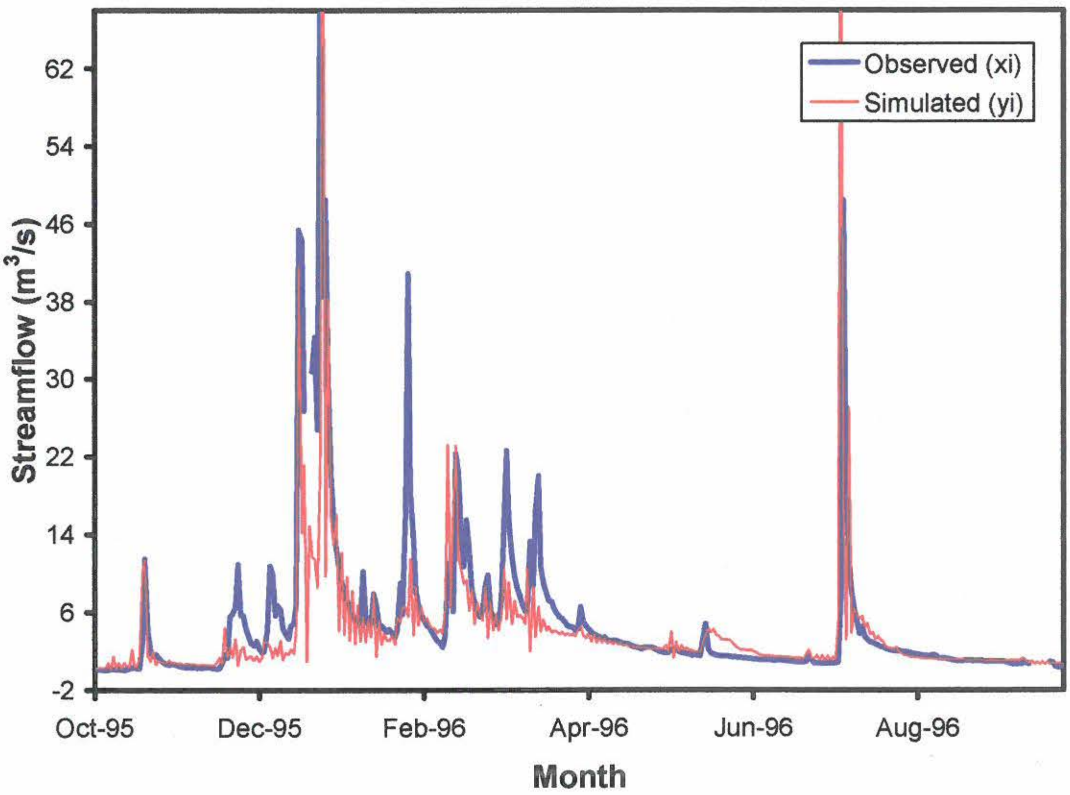

Figure 6.14: Comparison of observed and simulated daily streamflow: U2H058: Msunduzi River at Mason's Mill. Hydrological year: 1995-1996

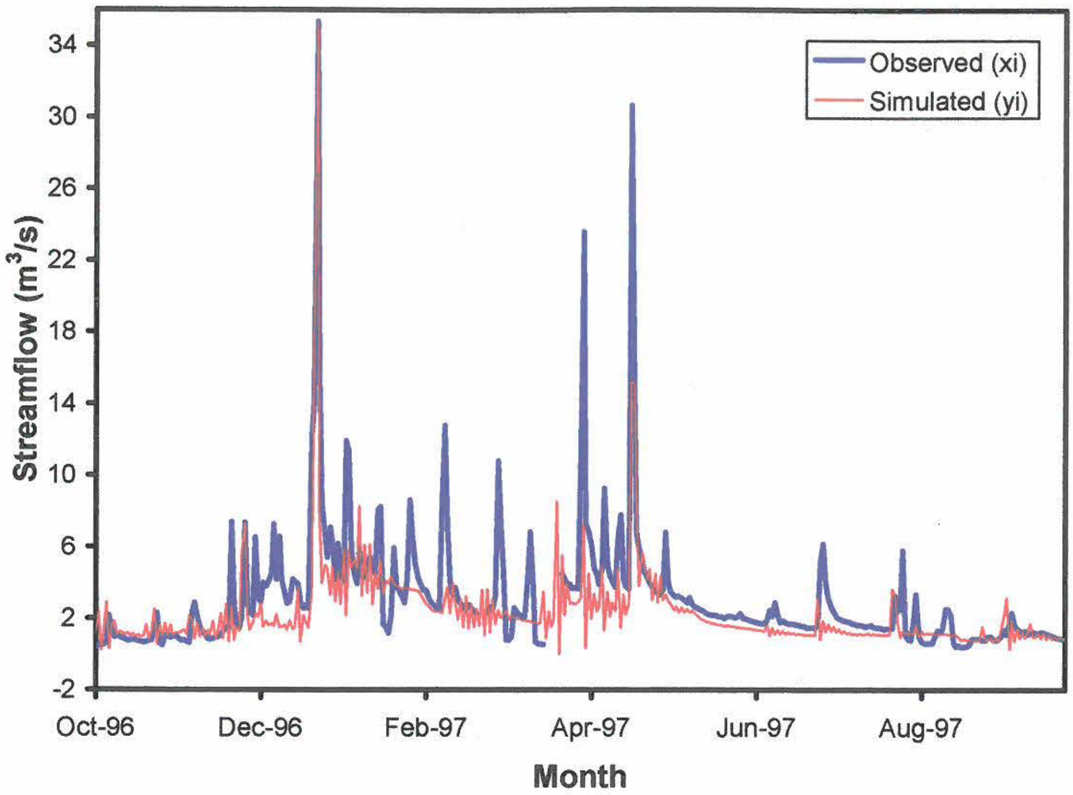

Figure 6.15: Comparison of observed and simulated daily streamflow: U2H058: Msunduzi River at Mason's Mill. Hydrological year: 1996-1997

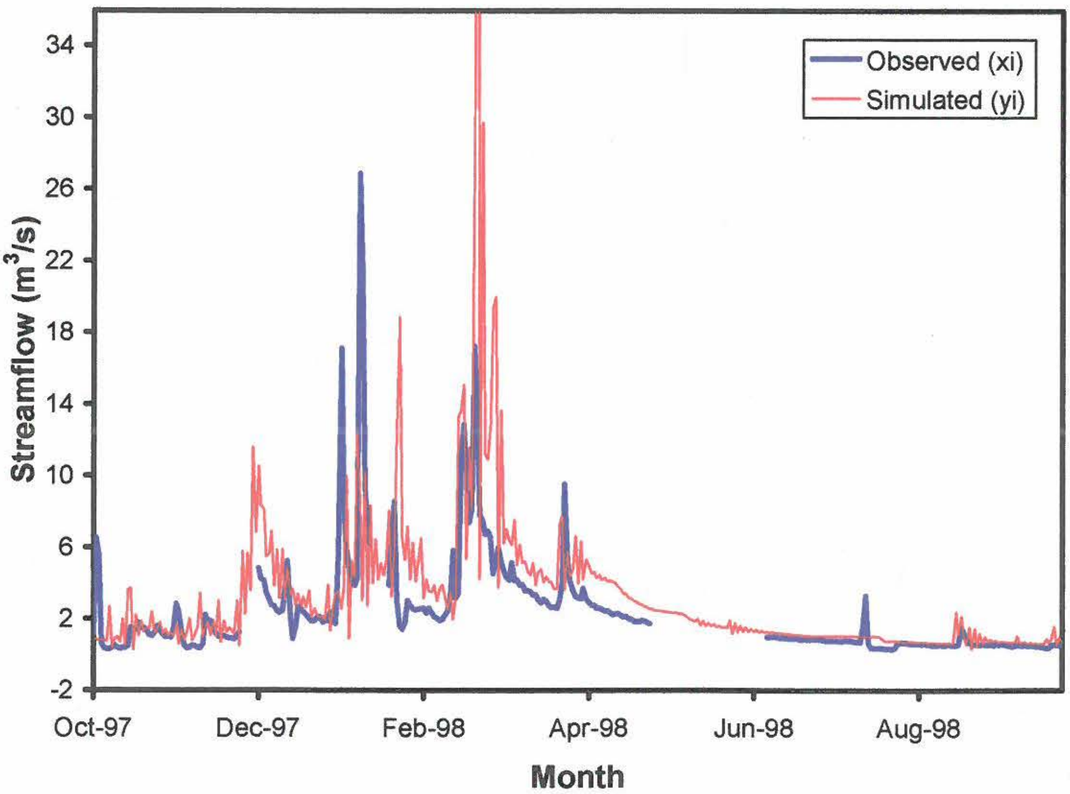

Figure 6.16: Comparison of observed and simulated daily streamflow: U2H058: Msunduzi River at Mason's Mill. Hydrological year: 1997-1998

U2H041, Msunduzi River at Hampstead Park, Moto-X:

The wet period was over-simulated by 24%, characterised by the over-simulation of single storm events. The dry period was over-simulated by 5%. The baseflow agreed well with the observed data, except during the first part of the hydrological year 1998 to 1999.

The timing of the simulated hydrographs was accurately simulated throughout the period of calibration; thus the final INTFW values were well calibrated. The hydrographs at U2H041 and U2H058 mimic each other, although the simulated streamflow values at U2H041 are higher overall, and the annual water balance at U2H041 is over-simulated. The final calibrated values of the five parameters, which determines the seasonal and annual water balance in sub-catchments 15 to 30 are listed in Table 6.10.

Table 6.10: Summary of seasonal and annual water balance parameters in sub-catchments 15 to 30

Main land-use group	LZETP	UZSN (mm)	LZSN (mm)	AGWRC	INFILT (mm/h)
Forest	0.80	29	300	0.93	1.00
Open spaces	0.60	17	300		
Grassland	0.50	17	300		
CBD and industrial	0.10	3	300		
Medium-density residential	0.20	7	300		
Low-density residential	0.40	10	300		
High-density residential	0.15	4	300		
Wetland	0.75	10	300		

The final calibrated values of INTFW and IRC are listed in Table 6.11.

Table 6.11: Summary of hydrograph shape parameters in sub-catchments 15 to 30

Main land-use group	INTFW	IRC
Forest	2.5	0.70
Open spaces	3.0	
Grassland	2.0	
CBD and industrial	1.0	
Medium-density residential	1.5	
Low-density residential	1.8	
High-density residential	1.0	
Wetland	2.0	

The comparison of observed and simulated daily streamflow at U2H041 for each hydrological year is shown in Figures 6.17 to 6.19.

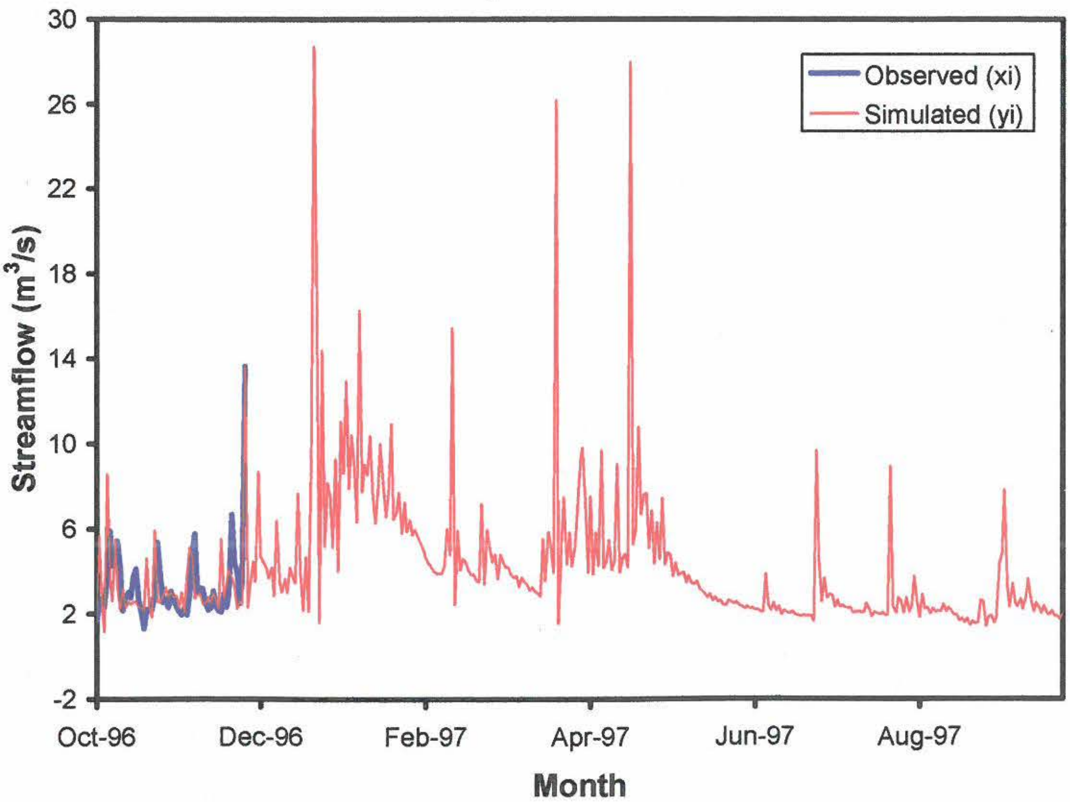

Figure 6.17: Comparison of observed and simulated daily streamflow: U2H041: Msunduzi River at Hampstead Park, Moto-X. Hydrological year: 1996-1997

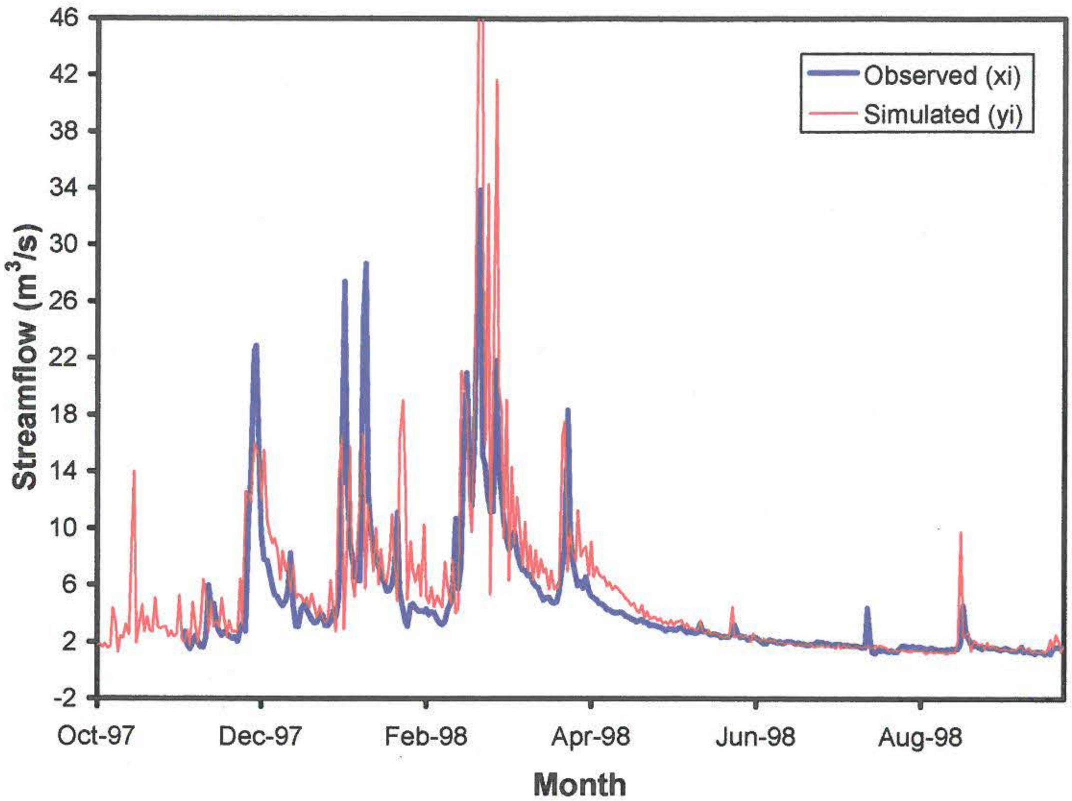

Figure 6.18: Comparison of observed and simulated daily streamflow: U2H041: Msunduzi River at Hampstead Park, Moto-X. Hydrological year: 1997-1998

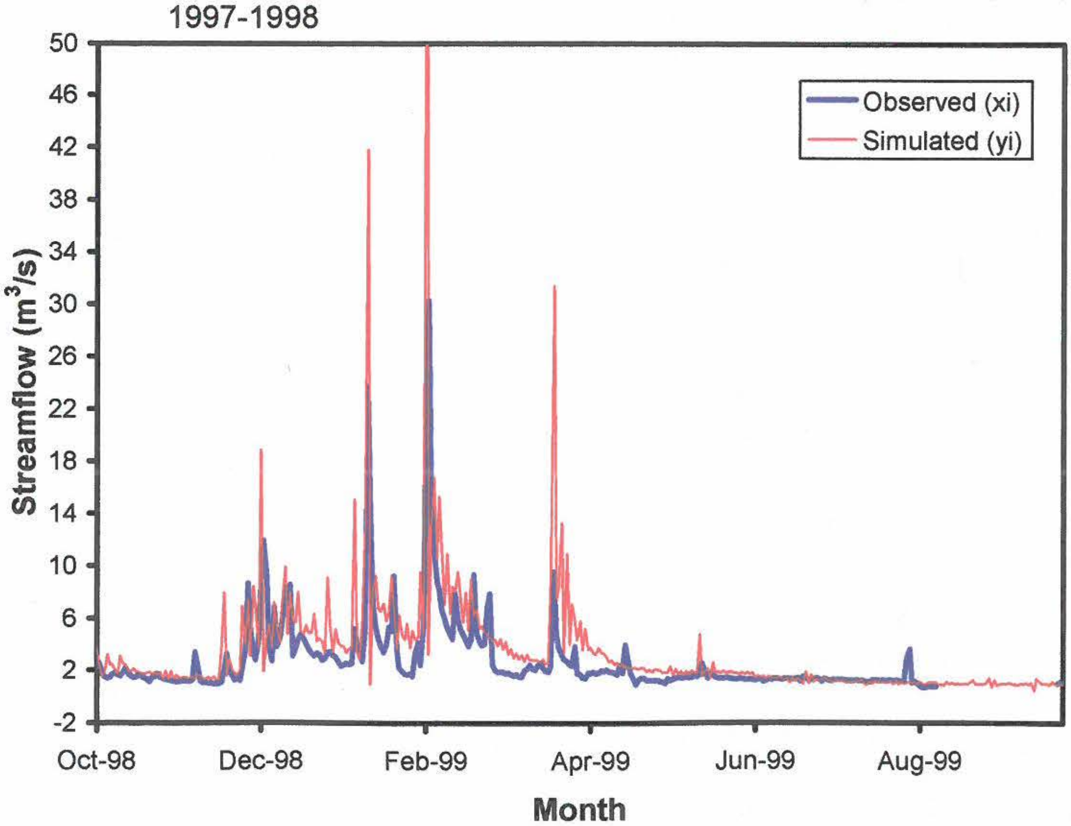

Figure 6.19: Comparison of observed and simulated daily streamflow: U2H041: Msunduzi River at Hampstead Park, Moto-X. Hydrological year: 1998-1999

U2H022, Msunduzi River at Nomfihlelo:

The period of calibration at this hydrological gauging station is for the hydrological years of 1992 to 1998. The wet- and dry period were over-simulated by 14% and 2% respectively. Overall, the annual water balance at U2H022 was over-simulated.

The higher streamflow peaks were over-simulated on various events, especially on 1993/10/06, 1993/12/27,1994/02/15, 1994/12/27, 1995/12/26-27, 1996/07/09, 1998/02/22 and 1998/02/23.

The baseflow was correctly simulated throughout the period of calibration, except during the hydrological years of 1992 to 1994 and 1997 to 1998. In both instances, the autumn baseflow at the recession limbs of the hydrographs was over-simulated.

The observed data of 1995/12/25 to 1995/12/28 are questionable, because a constant streamflow of 36.49 m^3/second was recorded. This constant streamflow could possibly be ascribed to faulty electronic data-logger readings or to the entanglement of the Type-X mechanical recorder cable system in the recorder well. Taking the hydrological responsiveness of these sub-catchments, which are prone to a spatial variation in precipitation data due to thunderstorm activities into consideration, a constant hydrograph limb in the descending phase is quite irregular. Furthermore it is important to note that the upper limit of accurately measured data at this hydrological gauging station is 36.50 m^3/second.

The final calibrated values of the five parameters, which determine the seasonal and annual water balance in sub-catchments 31 to 42 are listed in Table 6.12.

Table 6.12: Summary of seasonal and annual water balance parameters in sub-catchments 31 to 42

Main land-use group	LZETP	UZSN (mm)	LZSN (mm)	AGWRC	INFILT (mm/h)
Forest	0.80	29	320	0.93	1.00
Open spaces	0.60	17	320		
Grassland	0.50	17	320		
CBD and industrial	0.10	3	320		
Medium-density residential	0.20	7	320		
Low-density residential	0.40	10	320		
High-density residential	0.15	4	320		
Wetland	0.75	10	320		

In the final stage of the hydrological calibration of U2H022, the shape of the individual hydrographs was adjusted by the parameters INTFW and IRC. The final calibrated values of these two parameters are listed in Table 6.13.

Table 6.13: Summary of hydrograph shape parameters in sub-catchments 31 to 42

Main land-use Group	INTFW	IRC
Forest	2.5	0.7
Open spaces	3.0	
Grassland	2.0	
CBD and industrial	1.0	
Medium-density residential	1.5	
Low-density residential	1.8	
High-density residential	1.0	
Wetland	2.0	

The final INTFW values of the simulated hydrographs were accurately simulated. Simulated interflow recession was incorrectly simulated at the end of the wet period of the hydrological year 1992 to 1993, as well as the next hydrological year. Thereafter, it was correctly simulated during the period of October 1994 to May 1997. The dry period up to June 1997 was incorrectly simulated, resulting in a lower baseflow up to the end of September 1997. Over-simulation of autumn baseflow at the descending limb of the hydrograph was the most consistent error during the last hydrological year.

The daily calibration at U2H022 is the best among the four hydrological gauging stations. This could be ascribed to the fact that the available precipitation data's areal distribution was much more representative and reasonably accounted for the spatial variation in precipitation and storm distributions. The hydrographs at U2H022 and U2H041 mimic each other, especially the timing of the hydrographs, not so specifically the magnitudes of the higher streamflow peaks.

The comparison of observed- and simulated daily streamflow at U2H022 for each hydrological year is shown in Figures 6.20 to 6.26. A summary of the annual water balance at the four hydrological gauging stations is listed in Table 6.14.

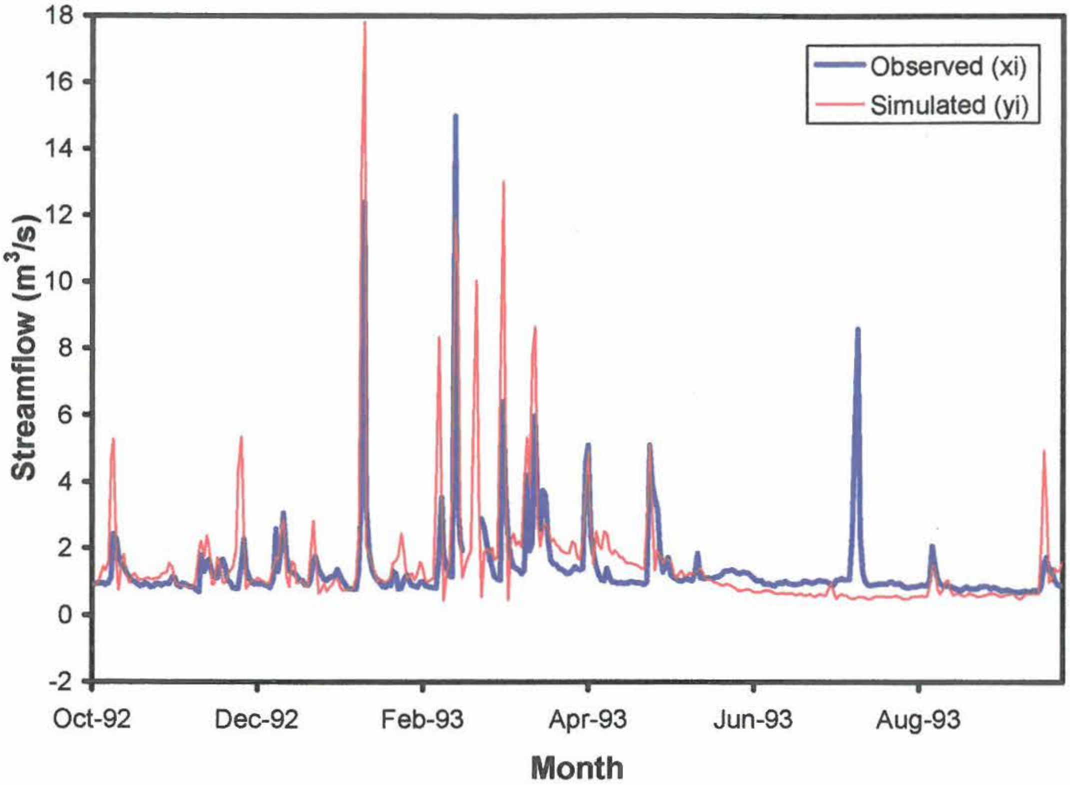

Figure 6.20: Comparison of observed and simulated daily streamflow: U2H022: Msunduzi River at Nomfihlelo. Hydrological year: 1992-1993

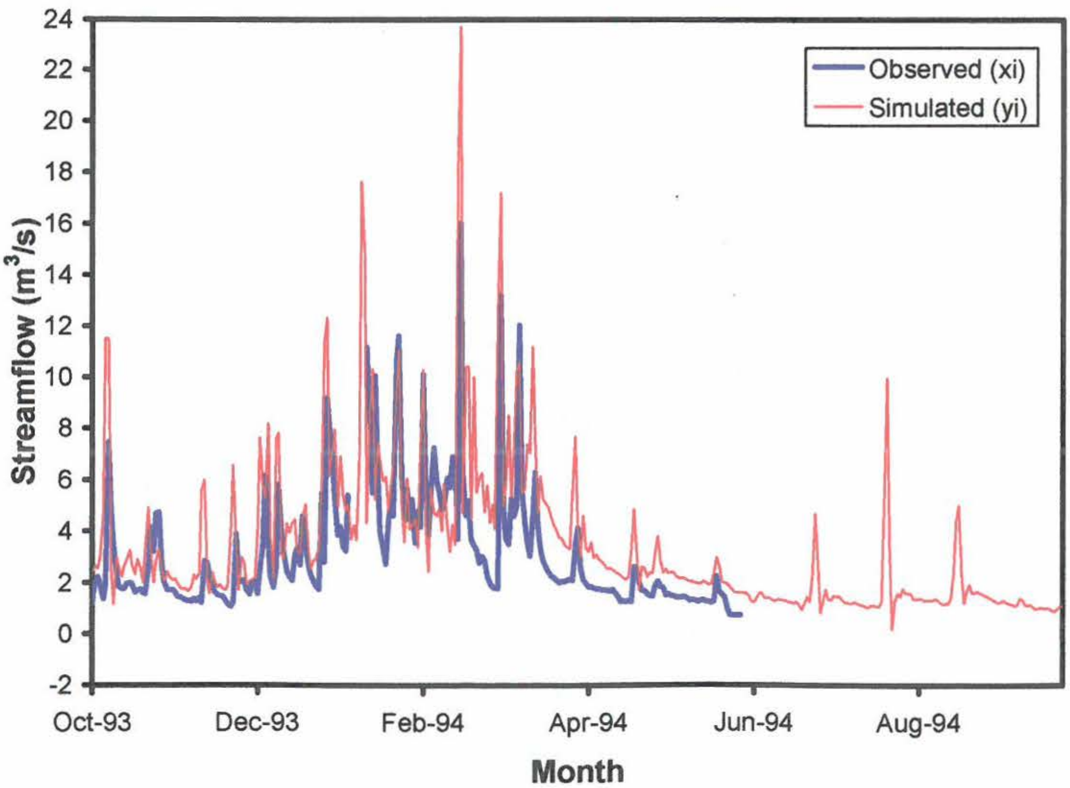

Figure 6.21: Comparison of observed and simulated daily streamflow: U2H022: Msunduzi River at Nomfihlelo. Hydrological year: 1993-1994

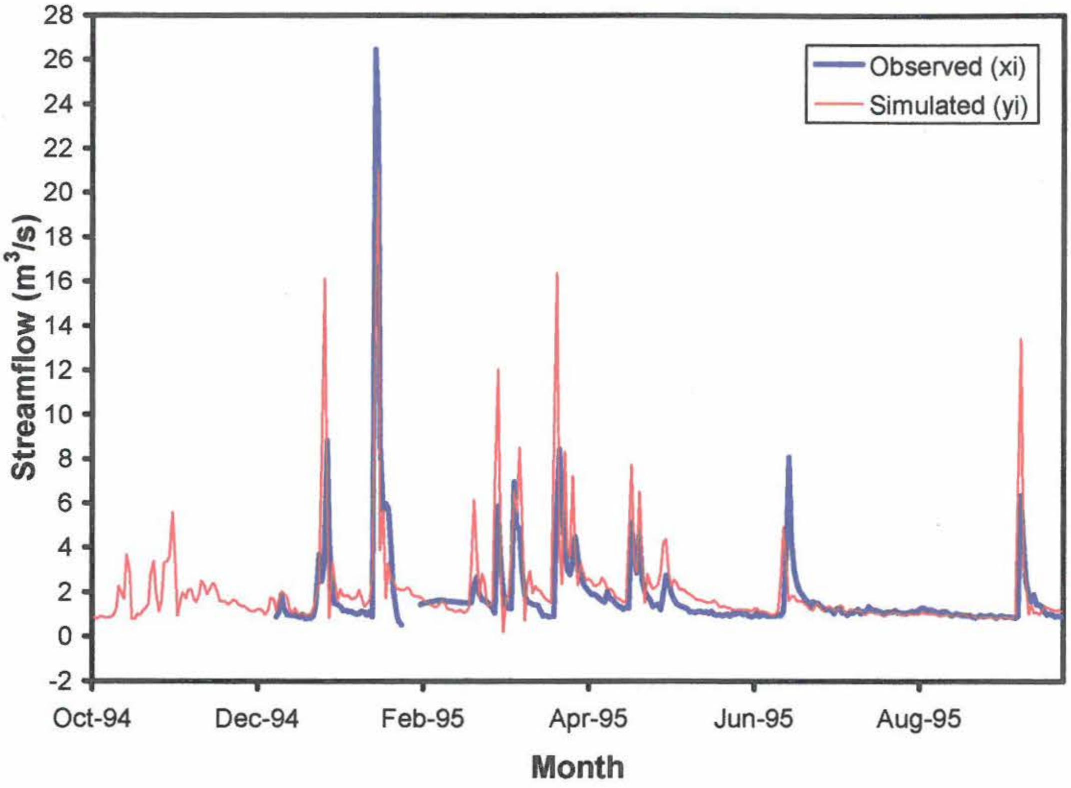

Figure 6.22: Comparison of observed and simulated daily streamflow: U2H022: Msunduzi River at Nomfihlelo. Hydrological year: 1994-1995

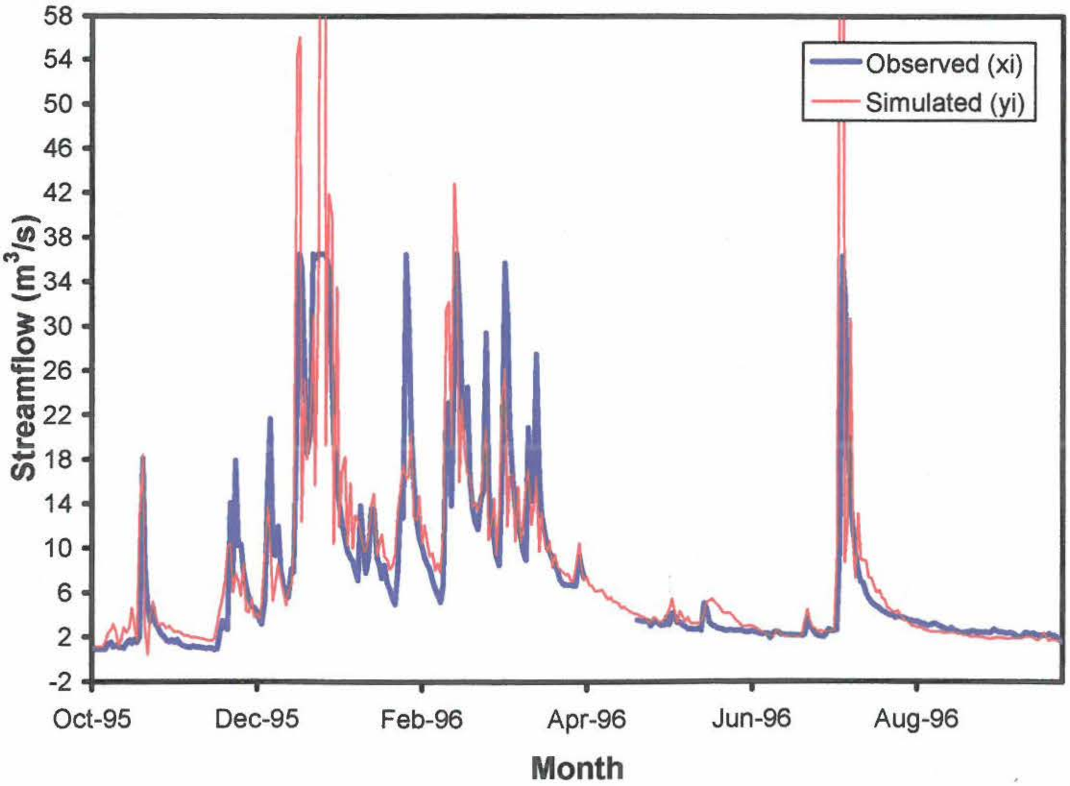

Figure 6.23: Comparison of observed and simulated daily streamflow: U2H022: Msunduzi River at Nomfihlelo. Hydrological year: 1995-1996

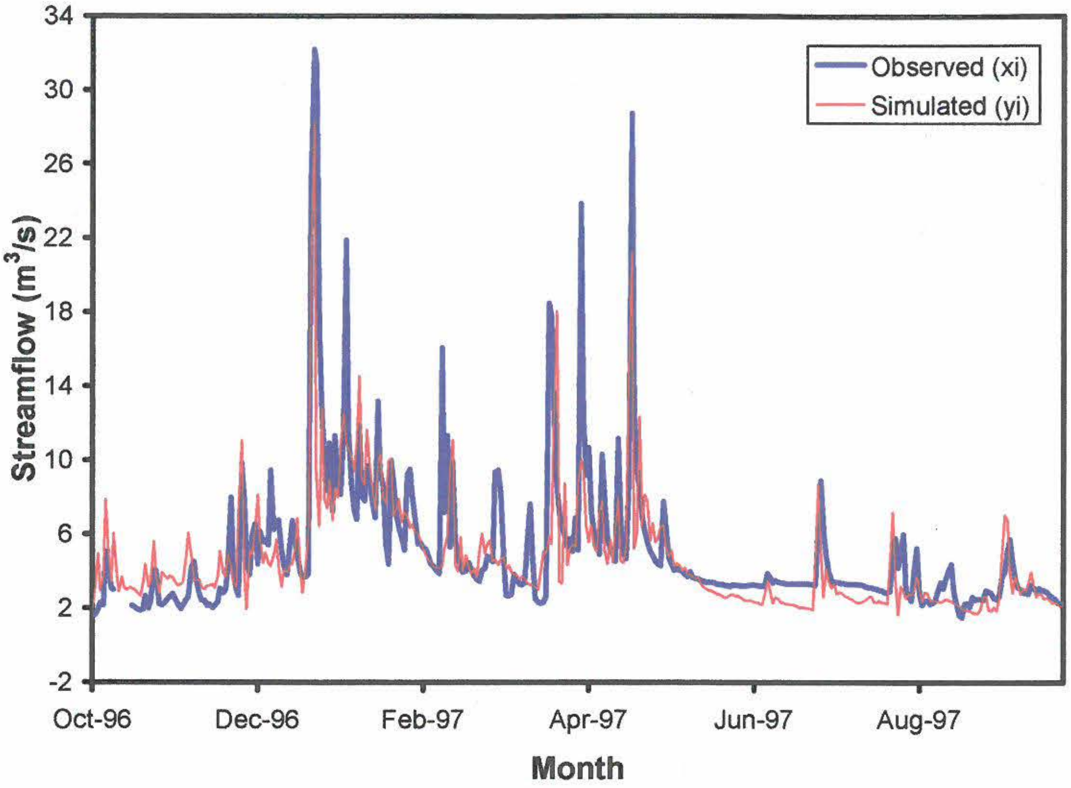

Figure 6.24: Comparison of observed and simulated daily streamflow: U2H022: Msunduzi River at Nomfihlelo. Hydrological year: 1996-1997

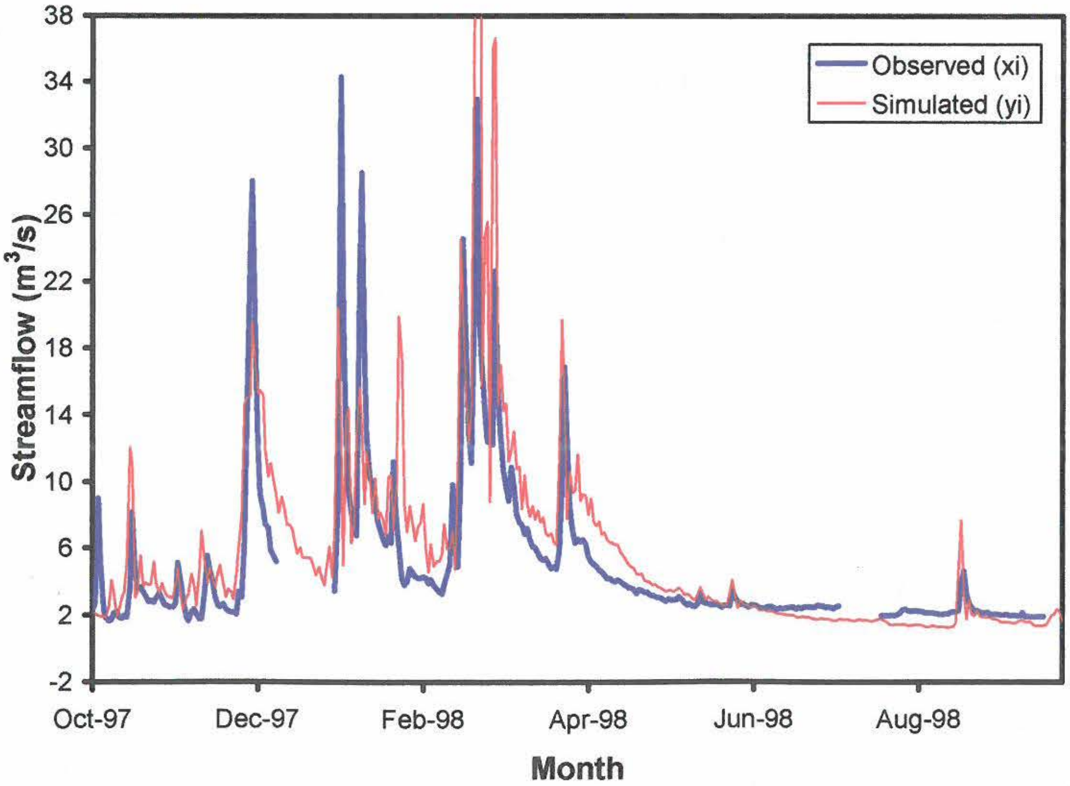

Figure 6.25: Comparison of observed and simulated daily streamflow: U2H022: Msunduzi River at Nomfihlelo. Hydrological year: 1997-1998

Table 6.14: Summary of the annual water balance at the hydrological gauging stations during calibration. (± Indicates either over- or under-simulation)

Station number	Period of calibration	Annual water balance (Observed x_i, x10^{6}m^3)	Annual water balance (Simulated y_i, x10^{6}m^3)	Percentage difference (%)
U2H011	1993-1996	49	50	+2
U2H058	1995-1998	313	285	-9
U2H041	1996-1999	226	286	+21
U2H022	1992-1998	682	769	+11

6.3.3 Verification of Streamflow Simulations

The verification of the hydrological simulations at a daily level was an extension of the calibration process. The verification assures that the calibrated data used in the HSPF model properly assesses all the variables and conditions, which can affect the final modelling results. Therefore only a portion of the record of observed data was used for finalising the parameters during calibration. The remaining records of observed data were then used for verification.

However, due to a lack of good observed data at U2H011, the entire observed record was used for calibration. The periods used for the verification of the four hydrological gauging stations are summarised in Table 6.15.

Table 6.15: Summary of verification data

Station description (DWAF number and name)	Period of verification
U2H011 Msunduzi River at Henley Dam	None
U2H058 Msunduzi River at Mason's Mill	1998/10/01-2000/06/01
U2H041 Msunduzi River at Hampstead Park, Moto-X	1999/10/01-2000/06/01
U2H022 Msunduzi River at Nomfihlelo	1998/10/01-2000/06/01

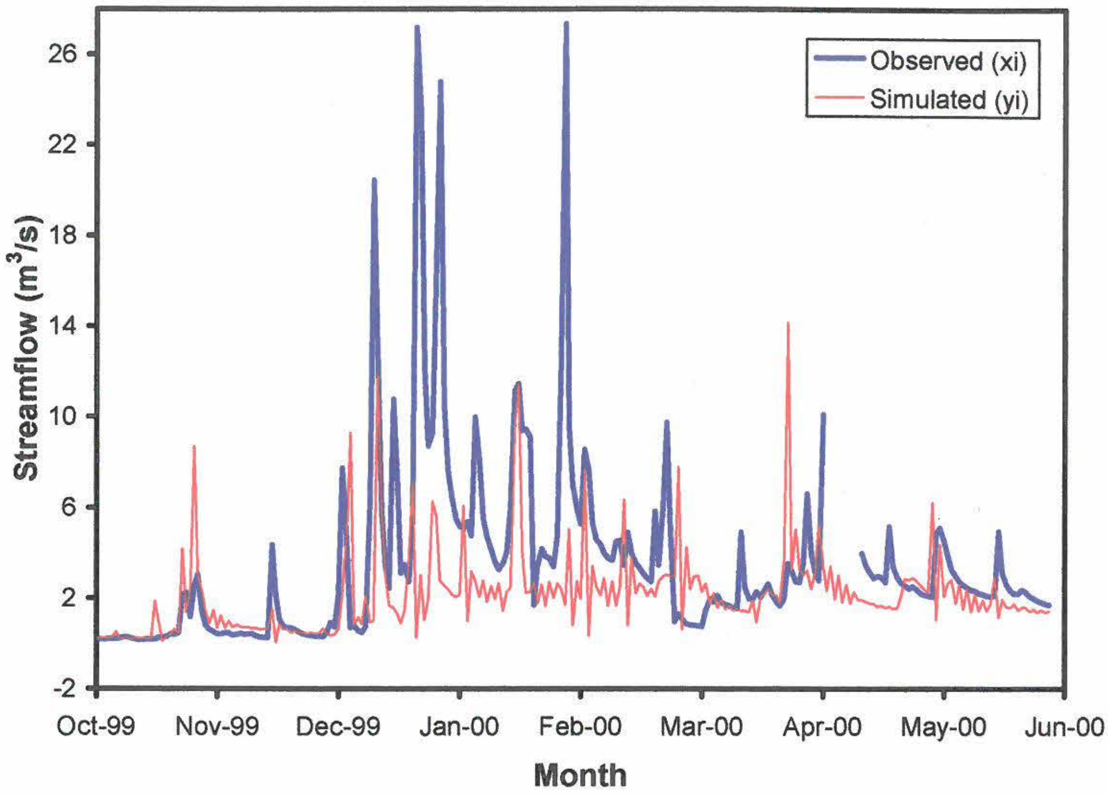

Figure 6.27: Comparison of observed and simulated daily streamflow: U2H058: Msunduzi River at Mason's Mill. Verification year: 1999-2000

U2H041, Msunduzi River at Hampstead Park, Moto-X:

The verification period was only for one year. The results were average to poor. The wet period was under-simulated by 17%, while the dry period was over-simulated by 2%, resulting in under-simulation of the annual water balance.

In the verification year 1999 to 2000, low streamflow peaks in the order of 12 to 14 m^3/second were over-simulated, while the higher streamflow peaks were under-simulated. This could be indicative that the model was not responding rapidly to the precipitation input in order to contribute streamflow of this magnitude.

The timing of the hydrograph peaks was incorrectly simulated during certain months; suggesting possible improvements to the INTFW parameter. Overall, the interflow recession of the largest hydrographs was correctly simulated. The comparison of observed and simulated daily streamflow at U2H041 is shown in Figure 6.28.

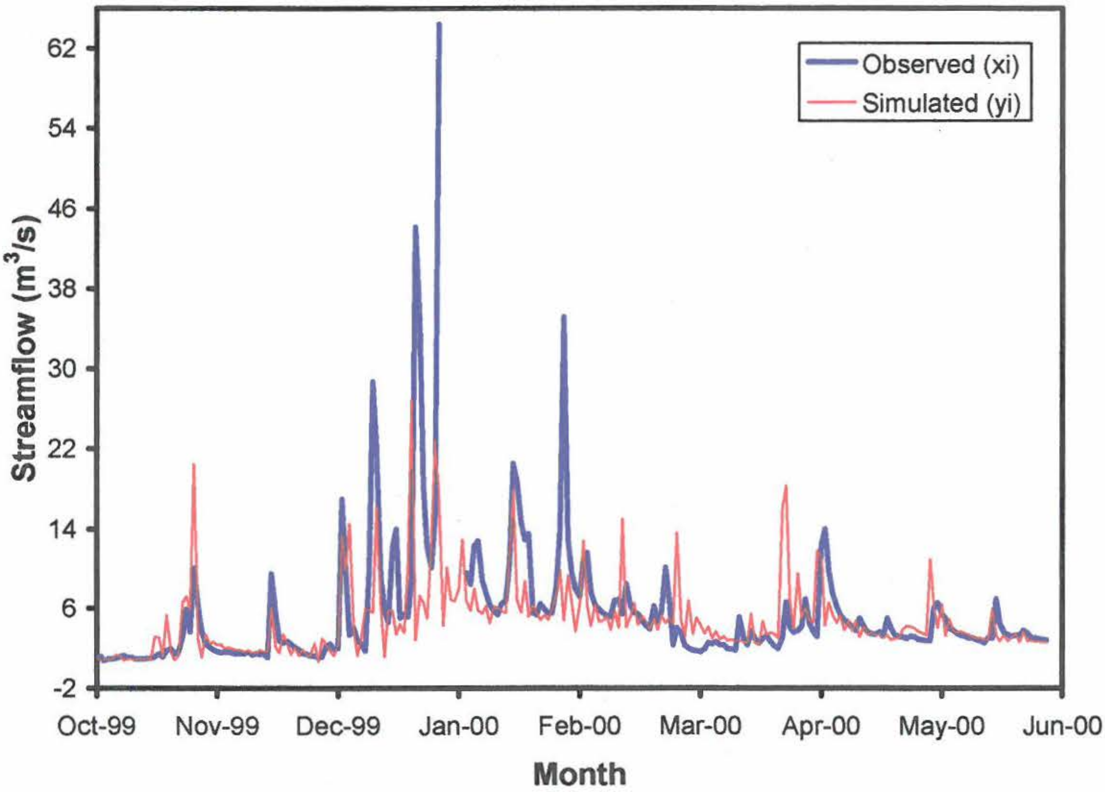

Figure 6.28: Comparison of observed and simulated daily streamflow: U2H041: Msunduzi River at Hampstead Park, Moto-X. Verification year: 1999-2000

U2H022, Msunduzi River at Nomfihlelo:

The verification at U2H022 was the best among the three hydrological gauging stations. This could be ascribed to the fact that the available precipitation data's areal distribution was much more representative. The wet period was over-simulated by 7% and the dry period was under-simulated by 10%. The annual water balance was over-simulated.

The hydrograph shape of the simulated hydrographs was accurately simulated throughout the period of verification. Interflow recession was inaccurately simulated for the first year of verification, thereafter it was satisfactorily simulated. A summary of the annual water balance at the three hydrological gauging stations is listed in Table 6.16. The comparison of observed and simulated daily streamflow at U2H022 for each verification year is shown in Figures 6.29 to 6.30.

Table 6.16: Summary of the annual water balance at the hydrological gauging stations during verification (± Indicates either over- or under-simulation)

Station number	Period of verification	Annual water balance (Observed x_i, $x10^6m^3$)	Annual water balance (Simulated y_i, $x10^6m^3$)	Percentage difference (%)
U2H058	1998-2000	107	101	-6
U2H041	1999-2000	114	96	-16
U2H022	1998-2000	221	233	+5

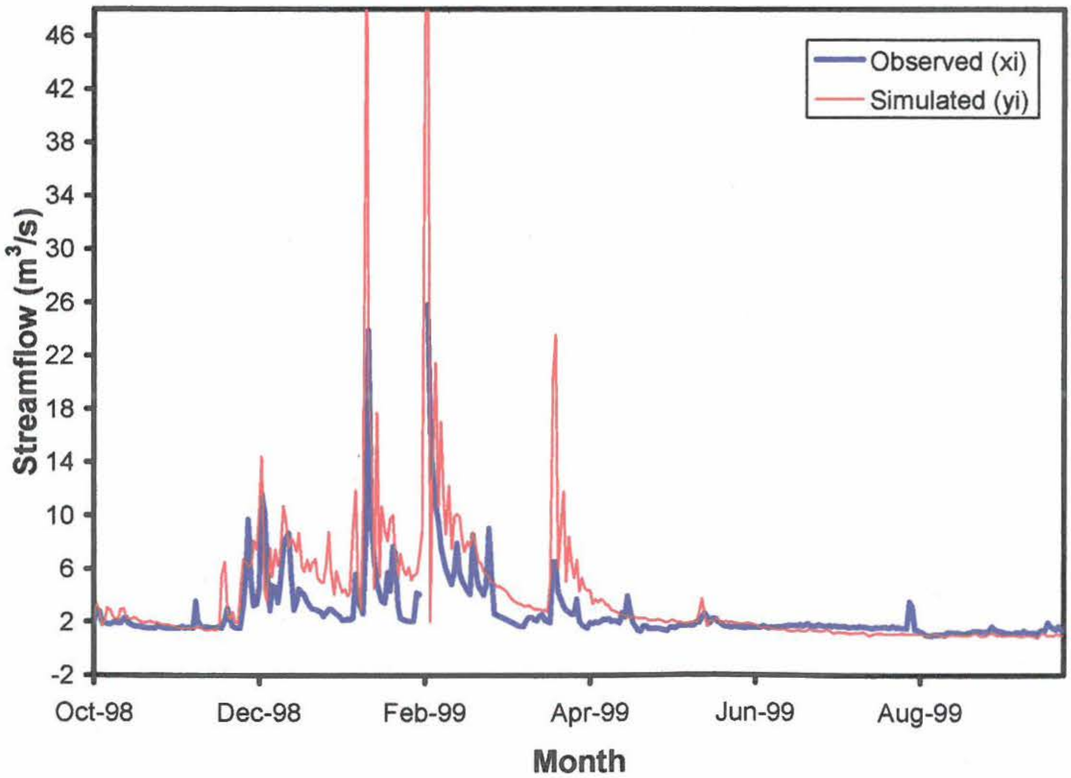

Figure 6.29: Comparison of observed and simulated daily streamflow: U2H022: Msunduzi River at Nomfihlelo. Verification year: 1998-1999

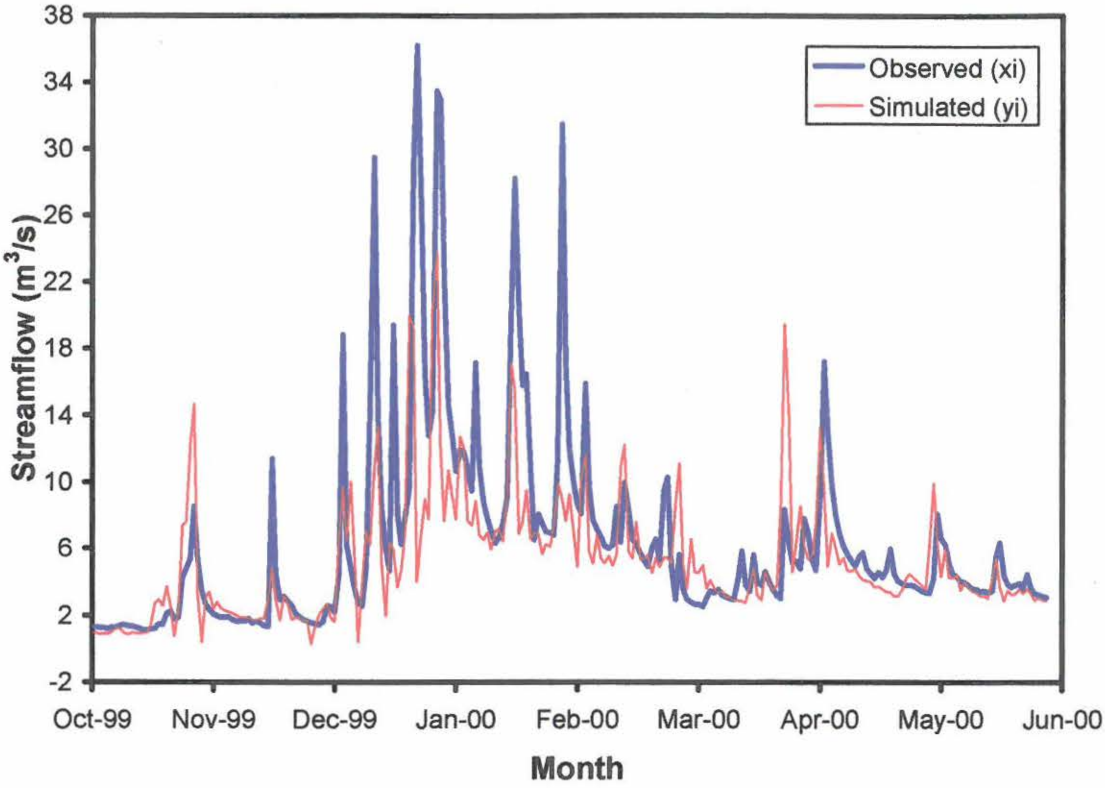

Figure 6.30: Comparison of observed and simulated daily streamflow: U2H022: Msunduzi River at Nomfihlelo. Verification year: 1999-2000

6.4 ANALYSIS OF MODEL PERFORMANCE

The visual comparison of simulation results against observed data can be highly subjective. Therefore, the pairs of observed data and simulated values of the HSPF model were compared and evaluated using the array of conservation- and regression statistics discussed in Chapter 4.

According to Donigian *et al.* (1984: 114) the performance of hydrology and hydraulic models at an annual- or monthly level with percentage variations of less than 10% are considered very good, between 10 – 15% are good and between 15 – 25% are fair. Munson (1998) stated that several publications on HSPF model performance indicated that a “good” calibration has an r^2 value of 0.9, at the annual level, 0.8 seasonally and 0.6 daily.

The extent and reliability of the meteorological data, especially precipitation, was the biggest limitation in achieving this kind of results. On the other hand, it is a common mistake to accept all observed data as being absolutely accurate. In fact, any measurement obtained under field conditions will usually contain at least a five to 10% variation from the actual value (Donigian *et al.*, 1984: 112).

6.4.1 Graphical Analysis and Scatter Plots

In addition to the model performance measures, scatter plots of the model-simulated values against observed data of the four hydrological gauging stations used to calibrate the model, were obtained to provide a visual measure of model performance.

The scatter plots and model performance measures for the four hydrological gauging stations are shown in Figures 6.32 to 6.46 and Table 6.17, respectively. Results for both calibration- and verification periods are presented, except where a lack of observed data precluded this, such as at U2H011. Values of the *y*-intercept (*a*), slope (*b*), coefficients of determination (r^2) and efficiency (E_C) for the complete simulation periods are reported in Table 6.17, but values for individual hydrological years are indicated on the scatter plots, where appropriate. These results provide quantitative amplification of the results discussed in Section 6.3.

The best overall results were obtained for U2H022 (r^2=0.65 and E_C =0.59) and the worst overall results at U2H058 (r^2=0.37 and E_C =0.05), with U2H041 only marginally better.

Table 6.17: Summary of goodness-of-fit-statistics at the four hydrological gauging stations

Conservation statistics	U2H011	U2H058	U2H041	U2H022
Observed mean (x)	0.97	2.89	4.20	4.14
Simulated mean (y)	0.86	2.79	4.62	4.41
Percentage-difference (%)	11.15	3.55	-9.89	-6.57
Observed standard deviation (S_x)	1.84	4.95	5.04	5.07
Simulated standard deviation (S_y)	1.67	4.24	4.80	4.91
Percentage-difference (%)	9.19	14.23	4.81	3.26
Regression statistics	**U2H011**	**U2H058**	**U2H041**	**U2H022**
Base constant / y-intercept (a)	0.18	1.29	2.15	1.19
Slope (b)	0.70	0.52	0.59	0.78
Coefficient of determination (r^2)	0.59	0.37	0.38	0.65
Coefficient of efficiency (E_C)	0.48	0.05	0.18	0.59

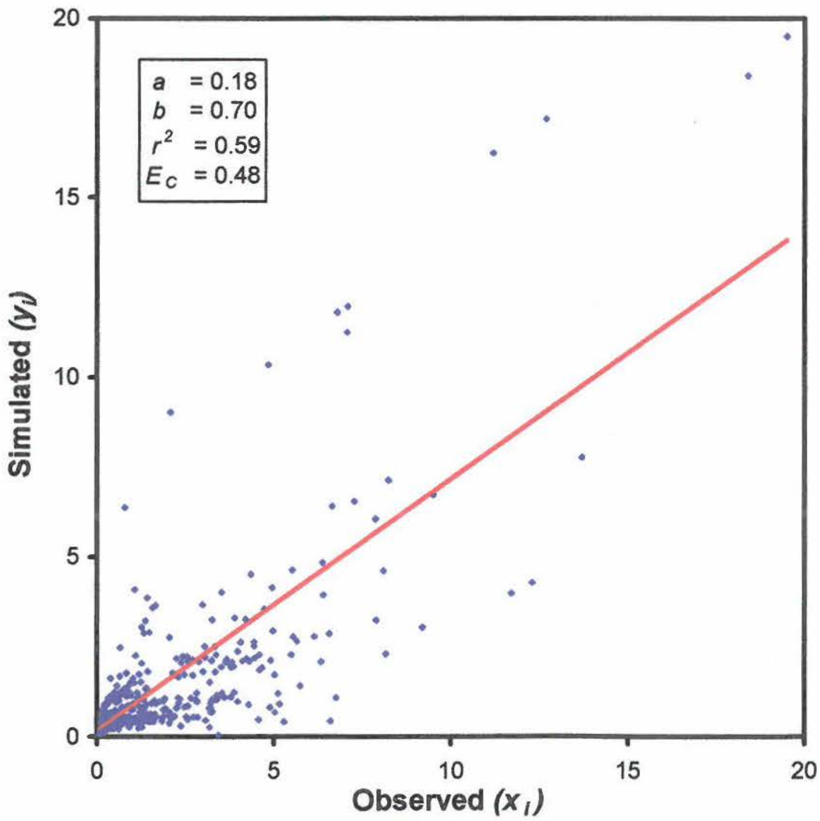

Figure 6.31: Scatter plot: U2H011: Msunduzi River at Henley Dam. Hydrological years: 1993-1996

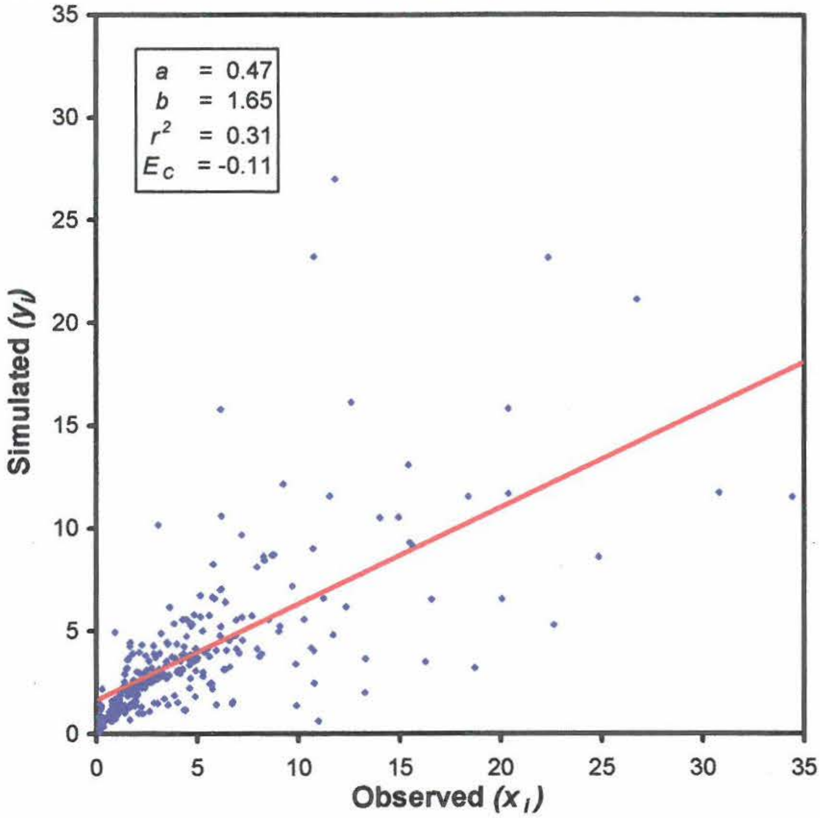

Figure 6.32: Scatter plot: U2H058: Msunduzi River at Mason's Mill. Hydrological year: 1995-1996

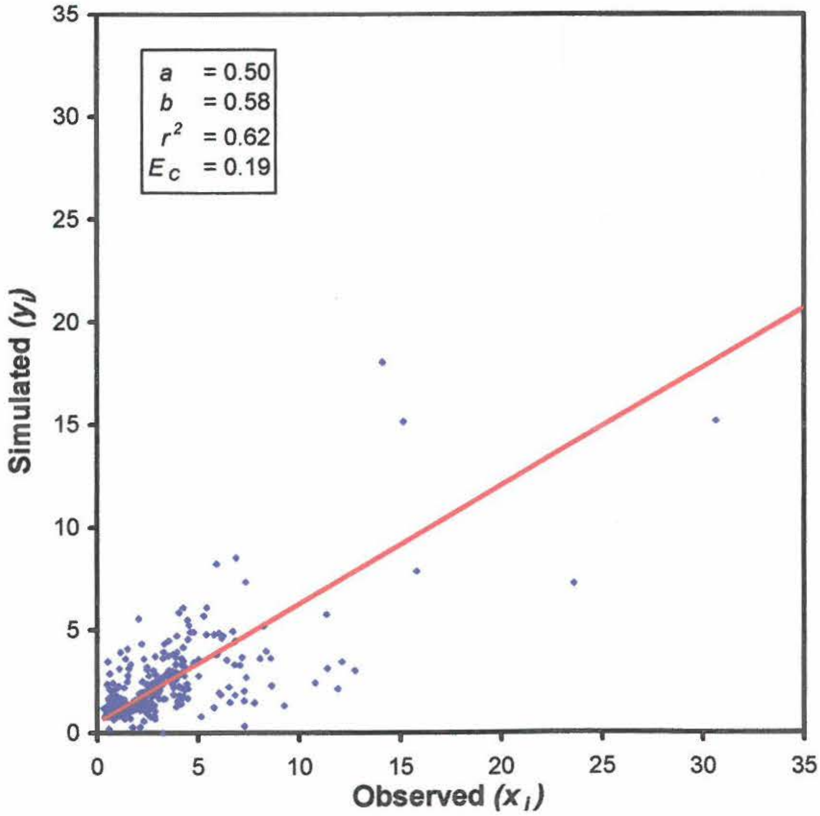

Figure 6.33: Scatter plot: U2H058: Msunduzi River at Mason's Mill. Hydrological year: 1996-1997

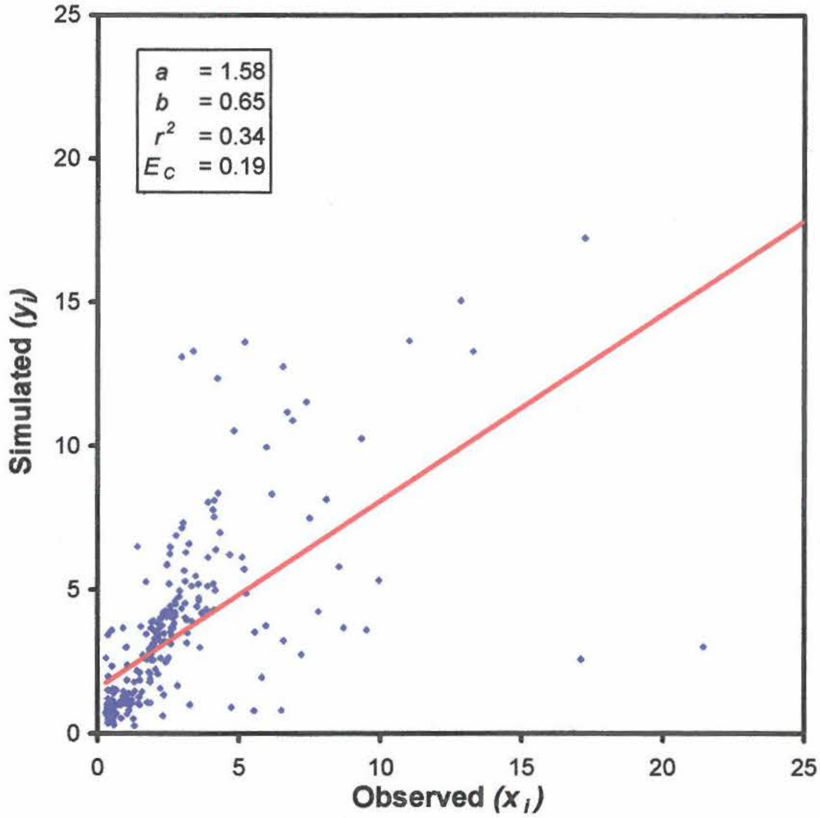

Figure 6.34: Scatter plot: U2H058: Msunduzi River at Mason's Mill. Hydrological year: 1997-1998

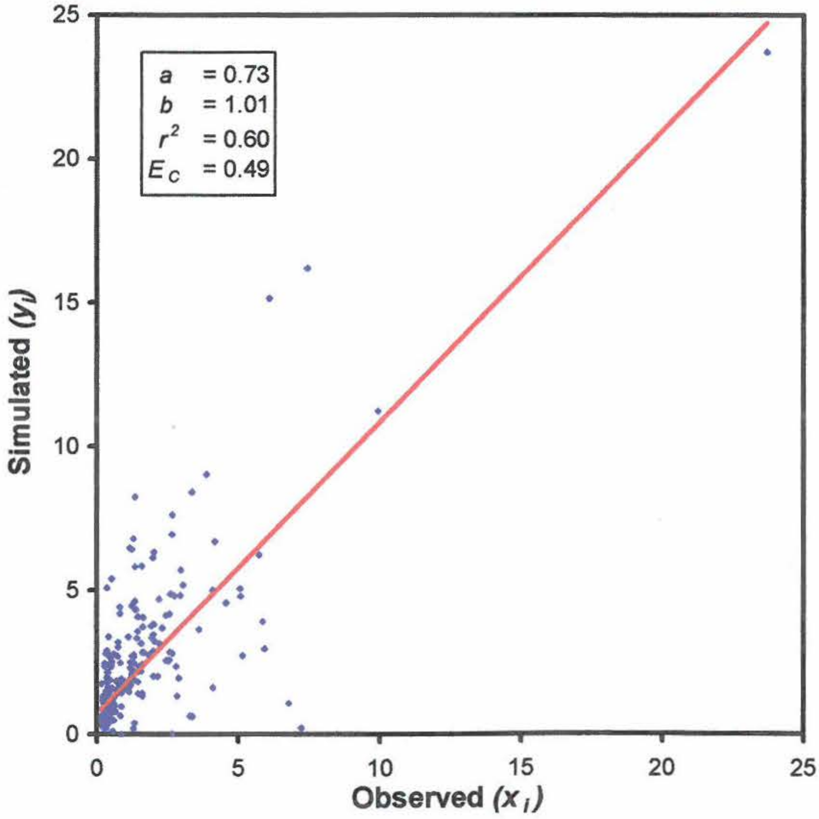

Figure 6.35: Scatter plot: U2H058: Msunduzi River at Mason's Mill. Verification year: 1998-1999

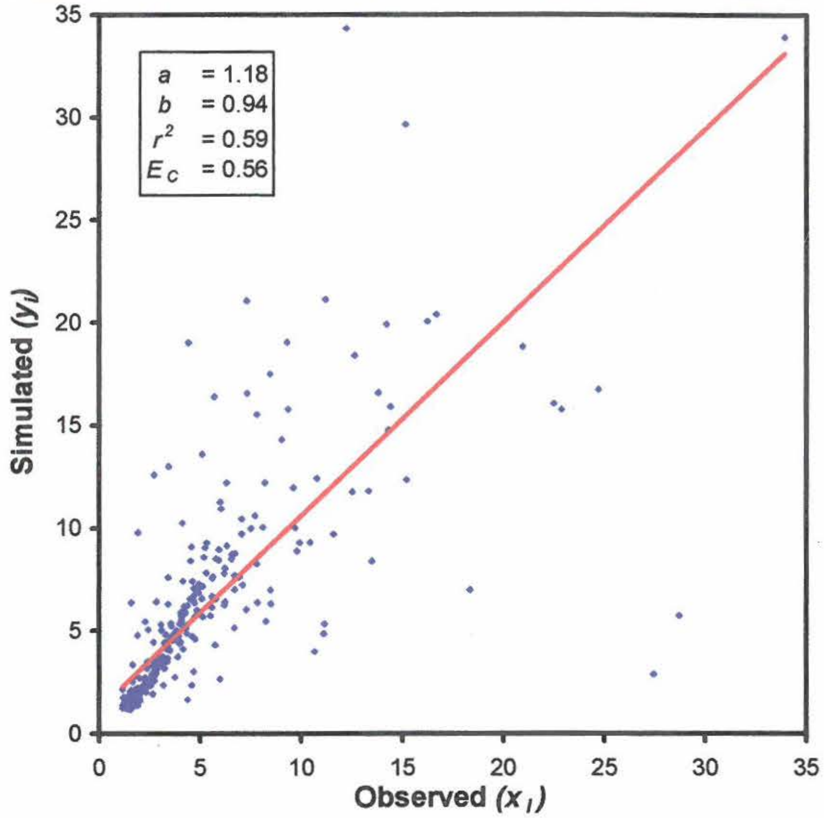

Figure 6.36: Scatter plot: U2H041: Msunduzi River at Hampstead Park, Moto-X. Hydrological year: 1997-1998

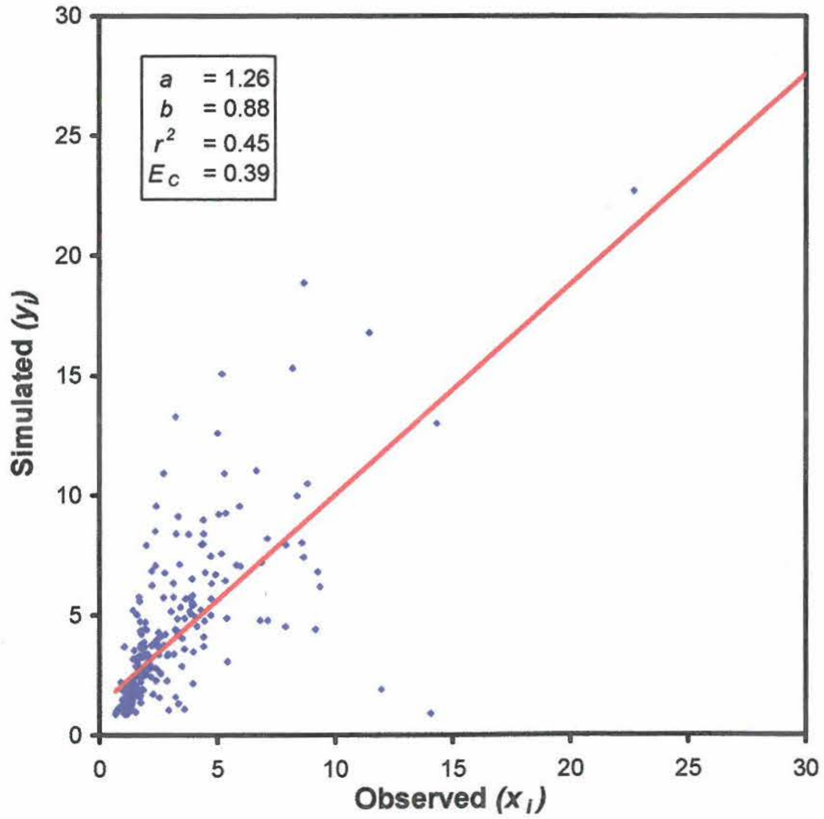

Figure 6.37: Scatter plot: U2H041: Msunduzi River at Hampstead Park, Moto-X. Hydrological year: 1998-1999

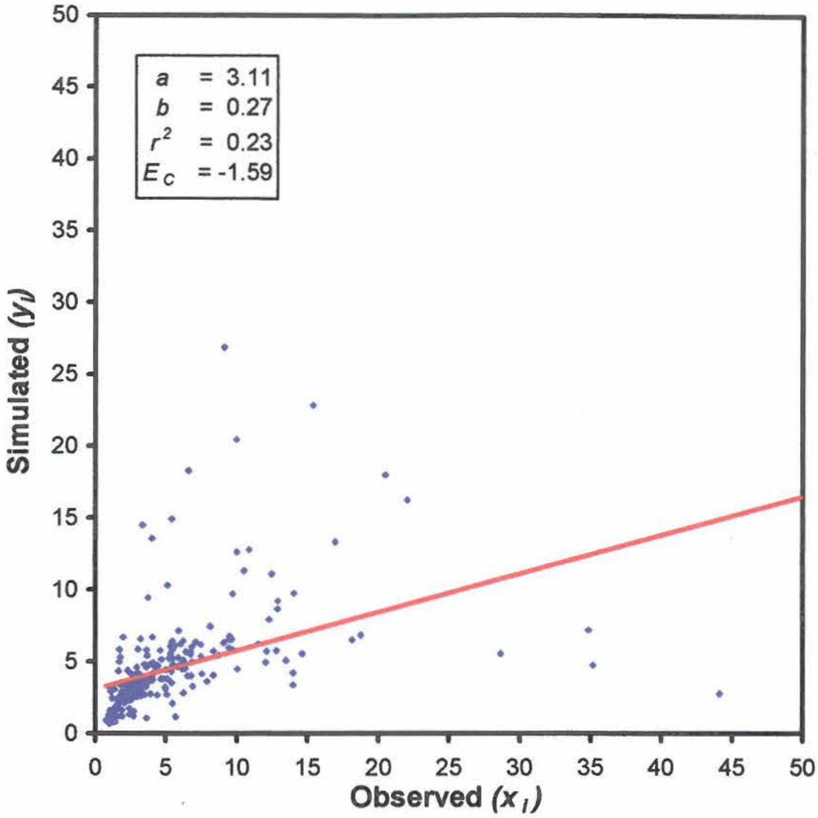

Figure 6.38: Scatter plot: U2H041: Msunduzi River at Hampstead Park, Moto-X. Verification year: 1999-2000

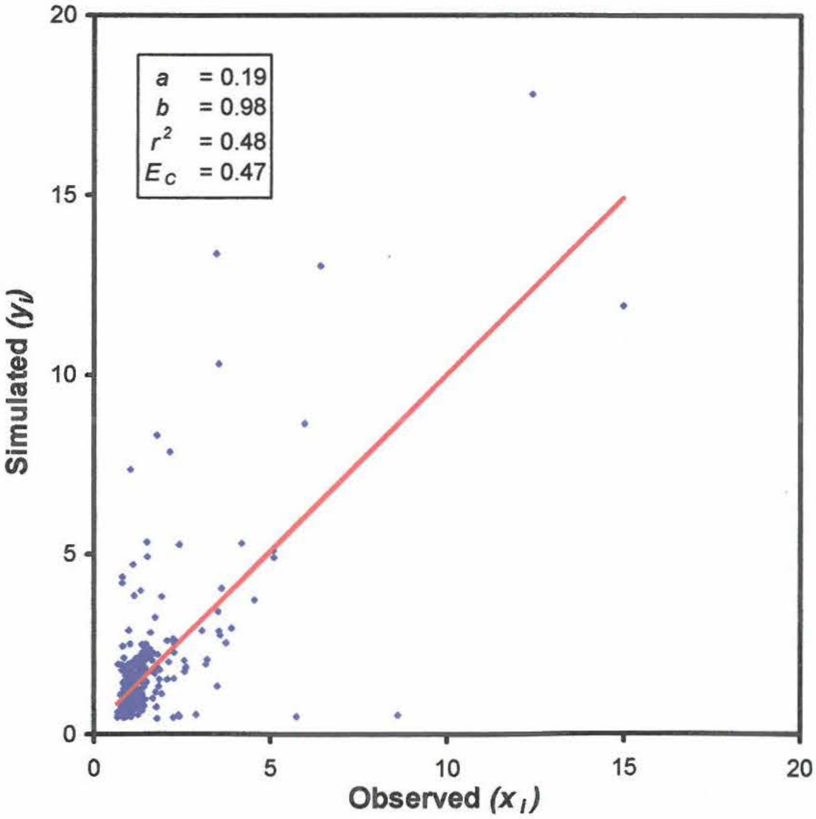

Figure 6.39: Scatter plot: U2H022: Msunduzi River at Nomfihlelo. Hydrological year: 1992-1993

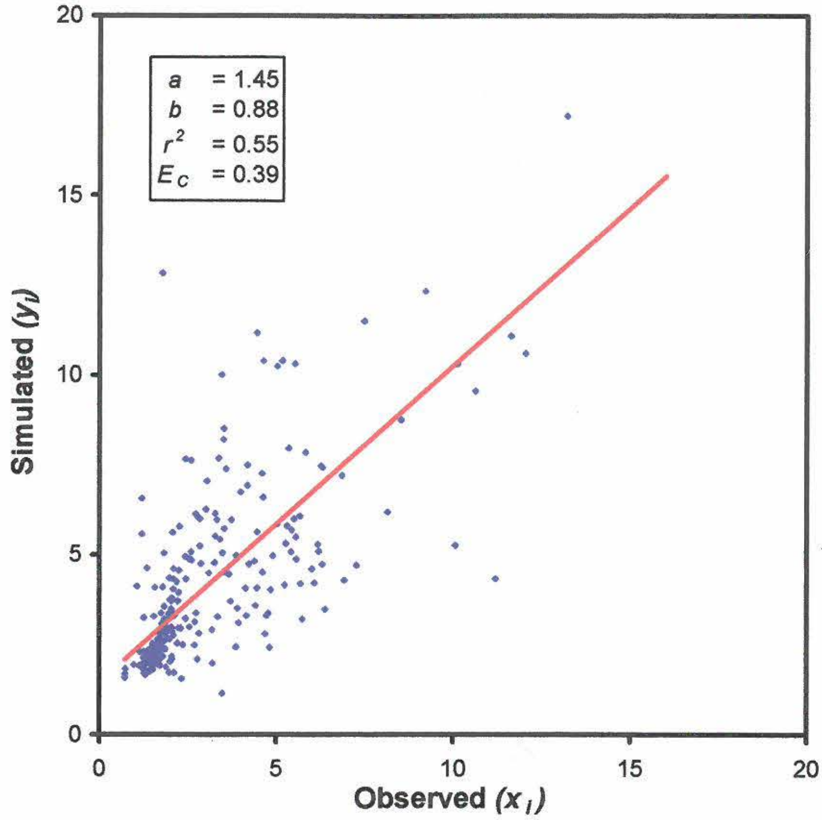

Figure 6.40: Scatter plot: U2H022: Msunduzi River at Nomfihlelo. Hydrological year: 1993-1994

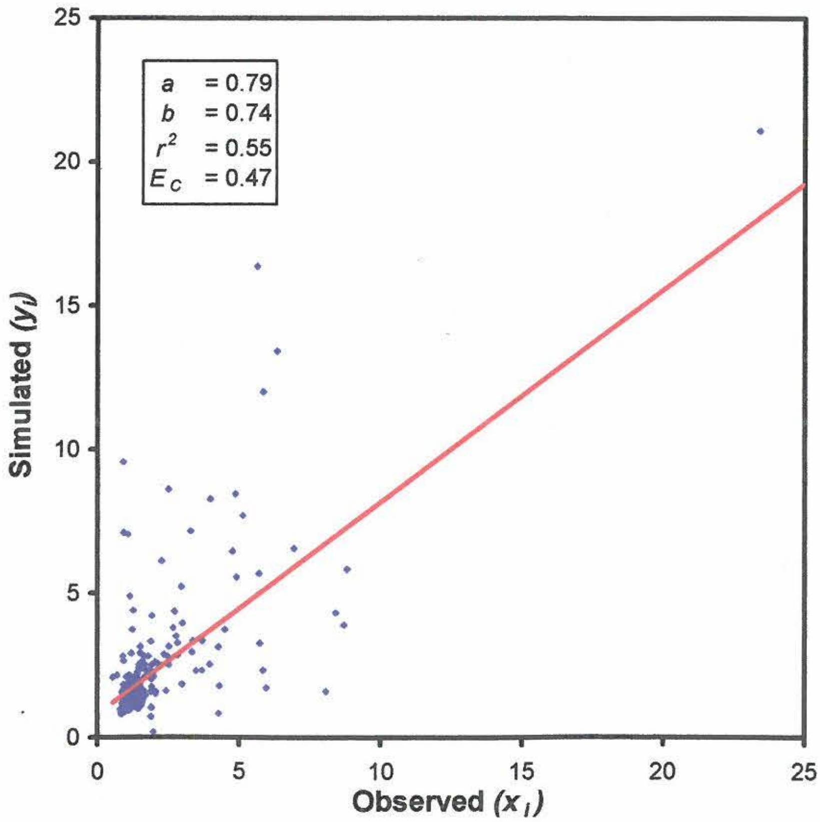

Figure 6.41: Scatter plot: U2H022: Msunduzi River at Nomfihlelo. Hydrological year: 1994-1995

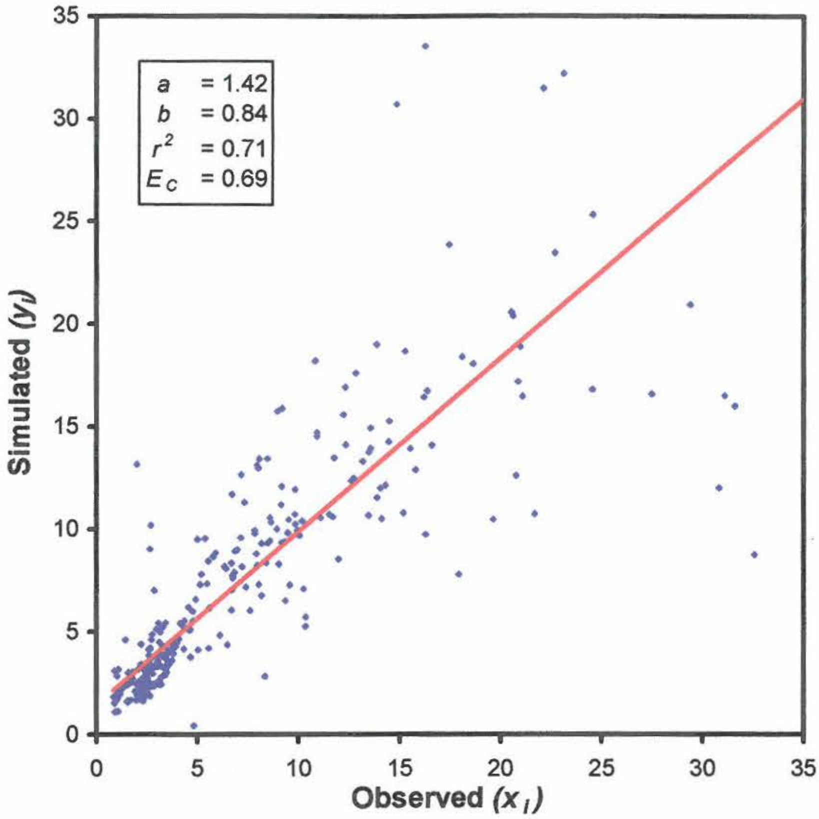

Figure 6.42: Scatter plot: U2H022: Msunduzi River at Nomfihlelo. Hydrological year: 1995-1996

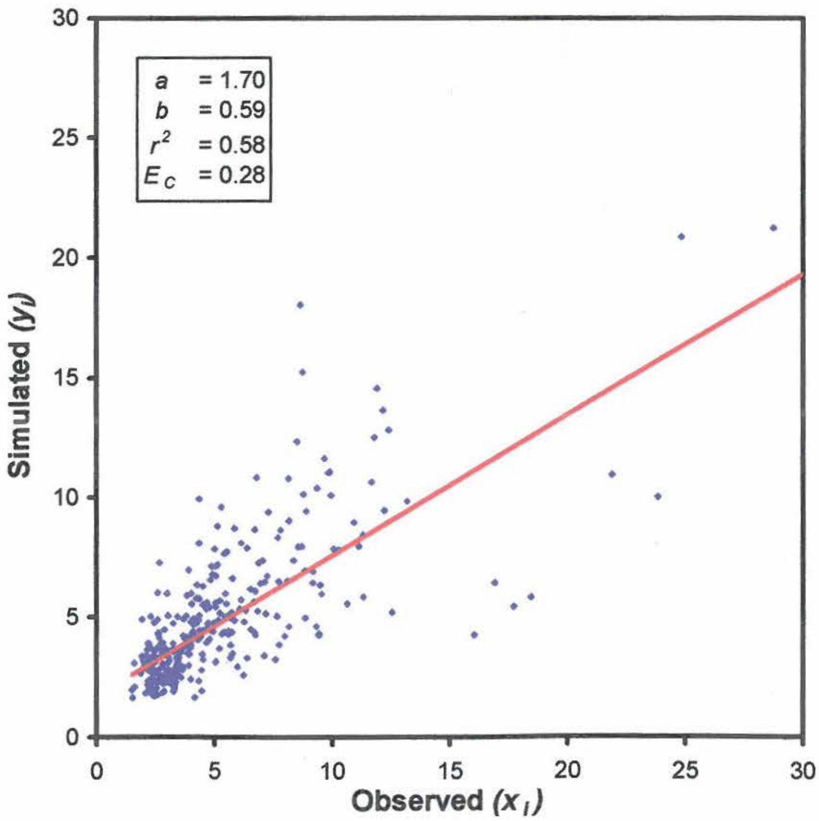

Figure 6.43: Scatter plot: U2H022: Msunduzi River at Nomfihlelo. Hydrological year: 1996-1997

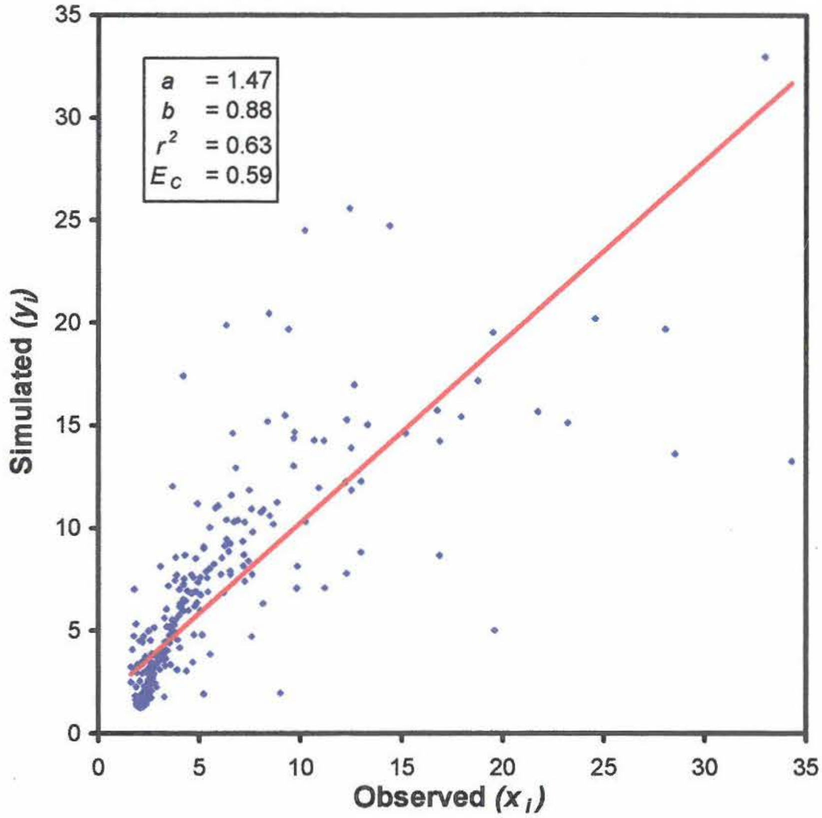

Figure 6.44: Scatter plot: U2H022: Msunduzi River at Nomfihlelo. Hydrological year: 1997-1998

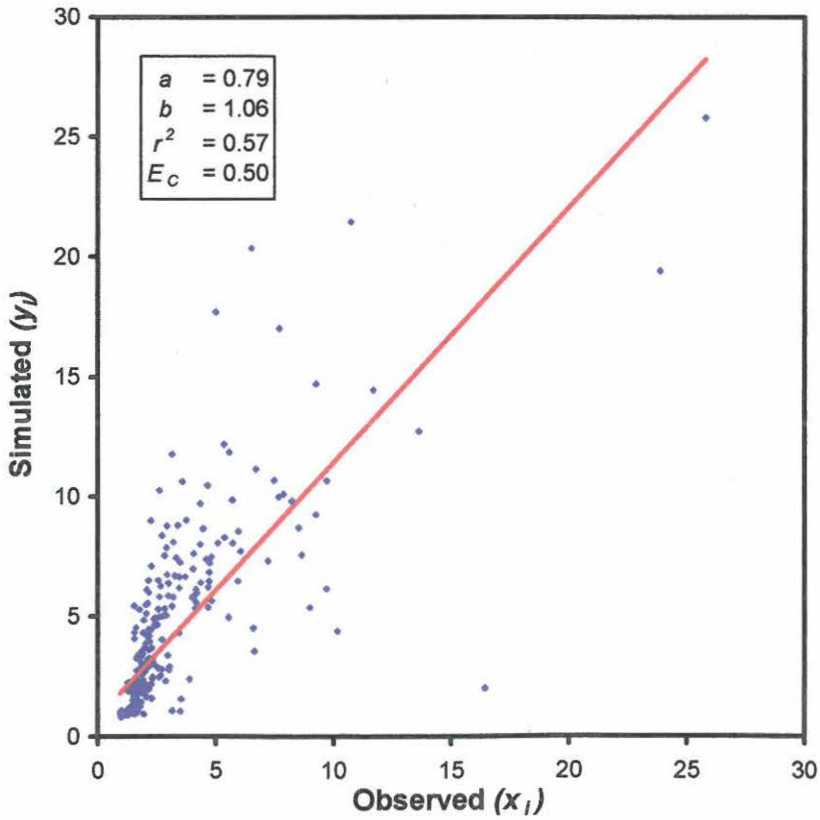

Figure 6.45: Scatter plot: U2H022: Msunduzi River at Nomfihlelo. Verification year: 1998-1999

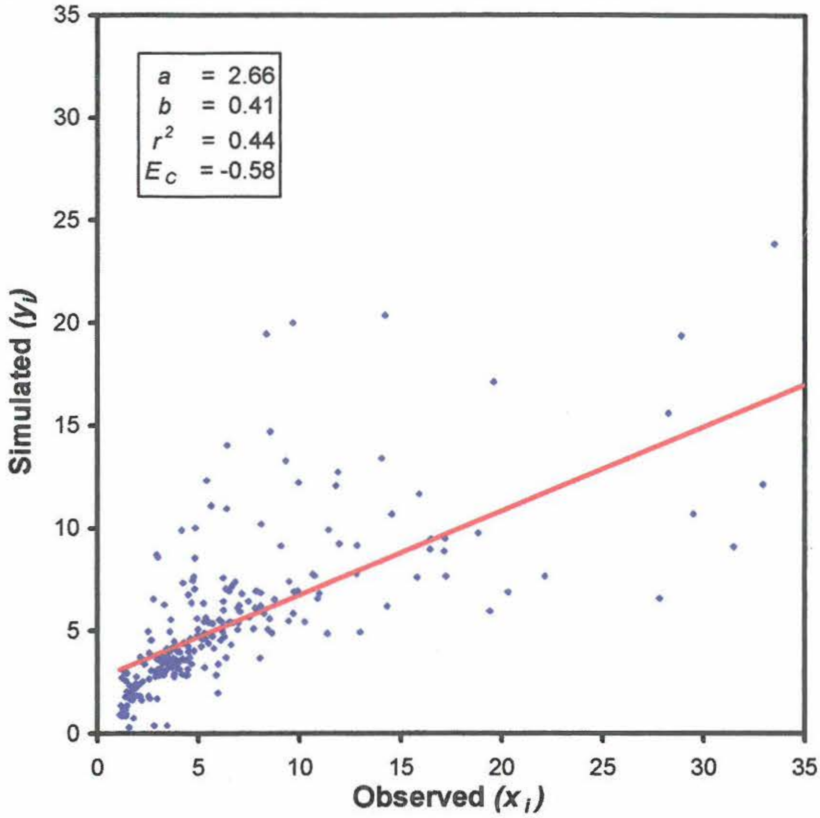

Figure 6.46: Scatter plot: U2H022: Msunduzi River at Nomfihlelo. Verification year: 1999-2000

6.5 ANALYSIS OF PRECIPITATION DATA

The reliability, along with the poor representation and assumption of uniform areal distribution of precipitation data were the key factors, which influenced the calibration and model performance at a daily level. In order to substantiate this statement, the coefficient of determination (r^2) and scatter plots were used to evaluate the correlation between two or more of the precipitation stations used at each hydrological gauging station. Only the original precipitation records, without the infilling as discussed in Chapter 5 were used. The duration of the period of evaluation was therefore in most instances shorter than the period of calibration and verification. The scatter plots and r^2-values at each of the precipitation stations used for the various sub-catchments are shown in Figures 6.47 to 6.50.

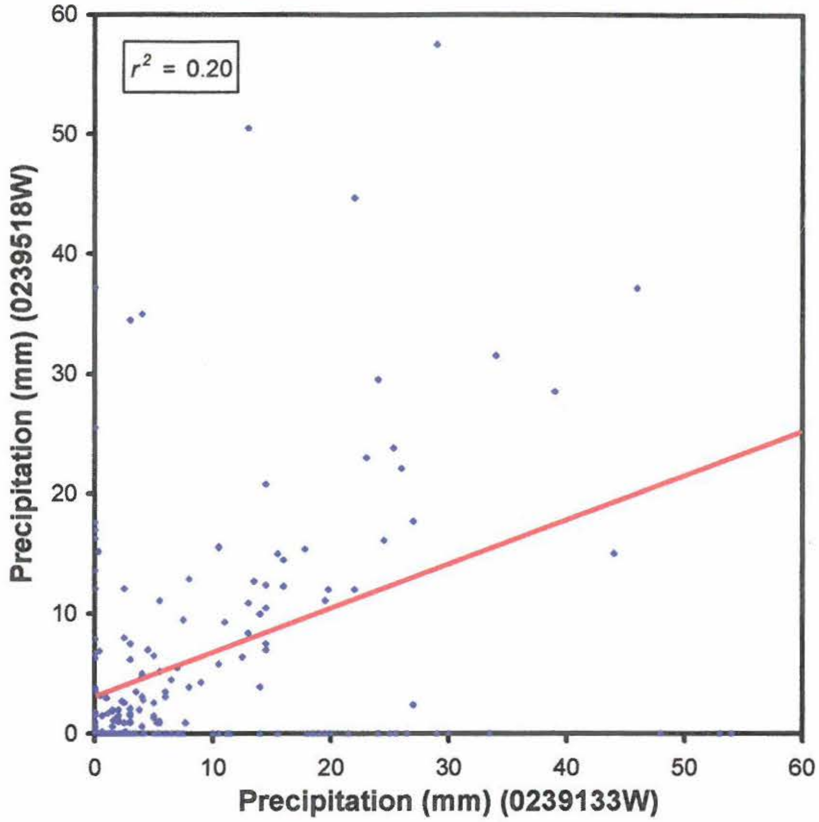

Figure 6.47: Scatter plot: Vaucluse (0239133W) versus Edendale (0239518W) used for sub-catchments one to five (upstream of U2H011)

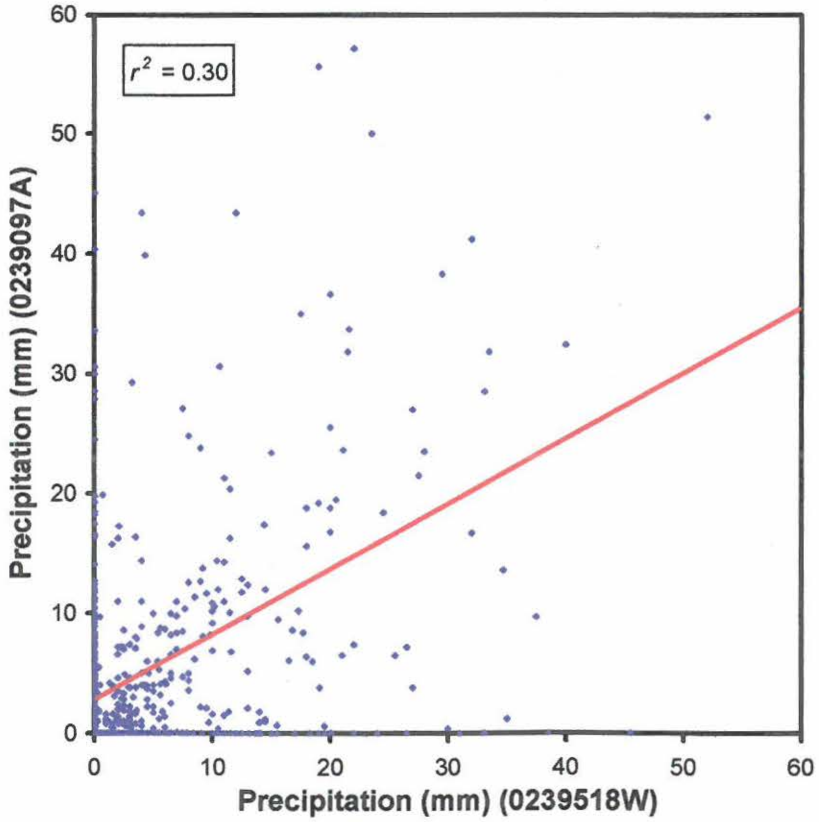

Figure 6.48: Scatter plot: Edendale (0239518W) versus Elandshoek (0239097A) used for sub-catchments six to 14 (upstream of U2H058)

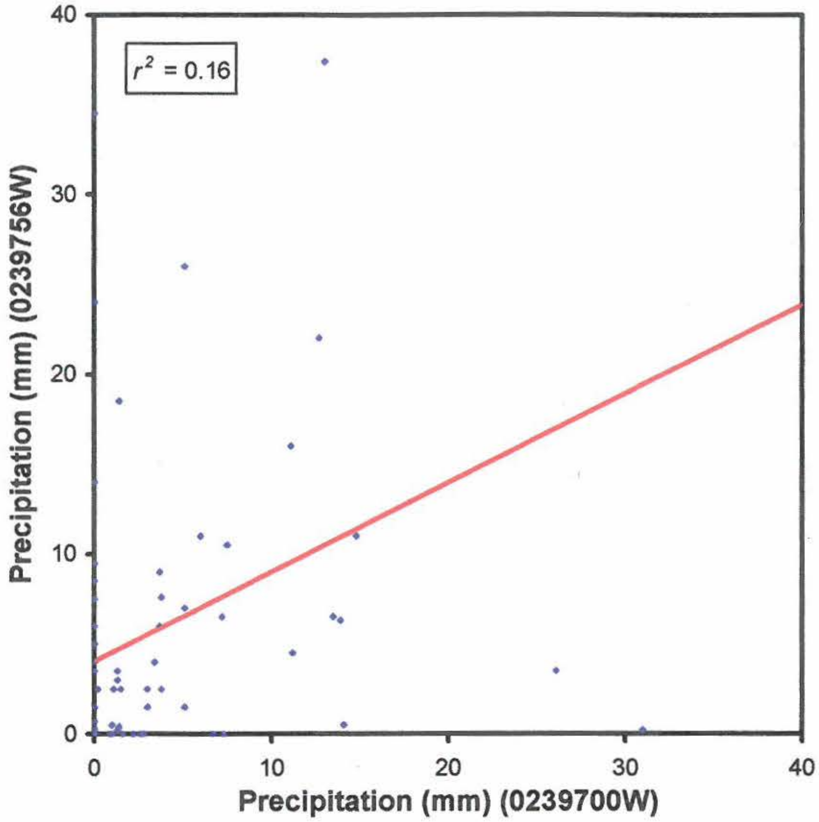

Figure 6.49: Scatter plot: Ukulinga (0239700W) versus Pietermaritzburg purification works (0239756W) used for sub-catchments 15 to 30 (upstream of U2H041)

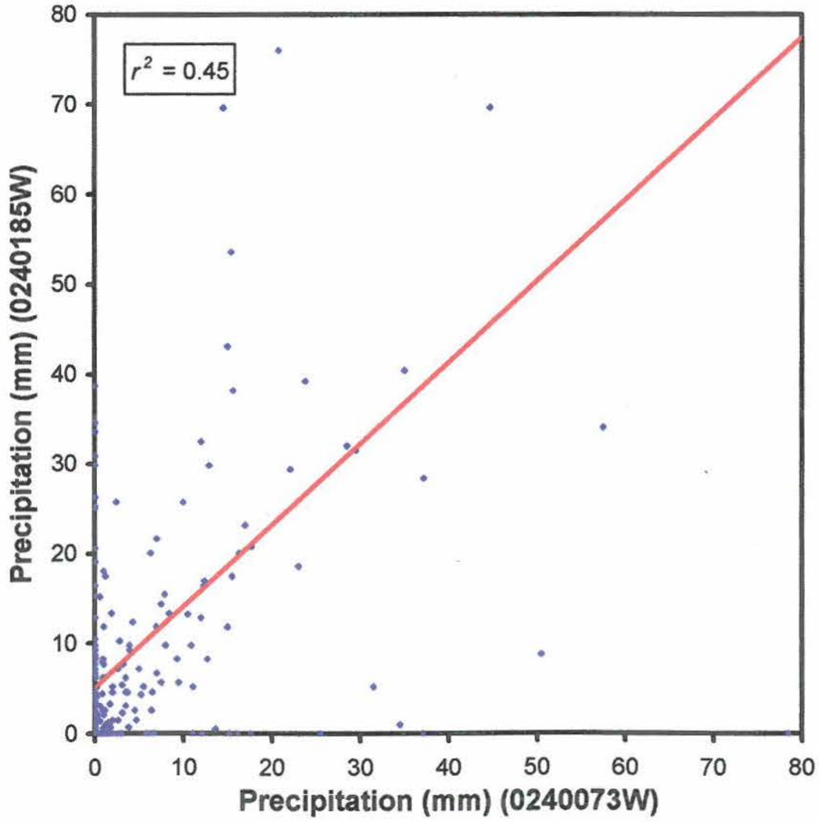

Figure 6.50: Scatter plot: Camperdown (0240073W) versus Nagle (0240185W) used for sub-catchments 31 to 42 (upstream of U2H022)

The results of the scatter plots indicate a low correlation between the different precipitation data sets, thus emphasising the spatial variation in precipitation- and storm distributions. Individual hydrographs were best simulated at U2H022 possibly because of more representative precipitation data (highest r^2- values) within those sub-catchments.

Even when the precipitation stations have a low degree of correlation, they are still representative of the parts of the catchment for which they provide precipitation distribution as determined by the Thiessen polygons. The question is really whether the precipitation stations are representative of the precipitation distribution suggested by the Thiessen polygons. Since there is bound to be variation in areal distribution in precipitation within a given polygon, given the small number of precipitation stations, a single station is considered to be a poor representative of the entire polygon. The only solution to this problem is a more representative distribution of precipitation stations, or using an alternative method to represent precipitation distribution.

Central University of Technology, Free State

CHAPTER

7

CONCLUSIONS & RECOMMENDATIONS

HSPF MODELLING OF THE MSUNDUZI RIVER CATCHMENT

7. CONCLUSIONS AND RECOMMENDATIONS

The *primary objective* of this modelling process was the application of the streamflow generation component of the HSPF model in order to provide hydrological information essential to those responsible for planning, development and management of the Msunduzi River Catchment. The *focus* of this modelling process was on the development and implementation of all input data and the testing of HSPF's continuous modelling system to correctly represent the hydrological components of the hydrological cycle.

The specific objectives were to:

- Collect and process input data and information for the modelling system.
- Develop and establish a Geographical Information System (GIS) containing the relevant spatial information for the Msunduzi River Catchment.
- Develop the hydrological modelling system to simulate all hydrological processes of the catchment successfully in terms of water quantity. This effort included discretisation of the entire catchment, extensive preparation of hydrological- and meteorological data and development of the stage-discharge relationships of the rivers.
- Verify the streamflow simulations against observed data at a daily level where available and evaluate the performance of the modelling system by making use of an array of goodness-of-fit-statistics.

7.1 DATA COLLECTION AND PREPARATION

HSPF demands a vast amount of data, especially when water quality simulations are being considered. Data collection was considerably simplified by having access to the CCWR computer system and software developed at the CCWR.

The stand-alone programs ANNIE (Interactive Hydrological Analyses and Data Management) and IOWDM (Input and Output for Watershed Data Management File), which were developed by the USGS for loading and manipulating data in the WDM file can be tedious to use. This is especially true when dealing with large numbers of time series. A great deal of automation can be achieved by automating the processes with general purpose tools such as Unix "awk" and "sed" commands and shell scripts, which were used extensively during the data preparation phase. Fortunately, both ANNIE and IOWDM lend themselves toward this kind of automation.

7.2 STREAMFLOW SIMULATION AND CALIBRATION

The areal distribution of the main land-use groups contributing to the different hydrological gauging stations within each of the sub-catchments played an important role in distributing the runoff.

Model parameters should not account for major errors in input and output time series. Streamflow measurements are only accurate below the upper limit of accurately measured data of hydrological gauging stations. Any part of the hydrographs above these limits should therefore be discounted. Observed data measured during prevailing conditions of submergence must be verified with conventional current gaugings.

The greatest difficulty in obtaining accurate streamflow simulations was due to the lack of good streamflow records, especially for U2H011. The lack of data on water releases from Henley Dam also made good simulation at this hydrological gauging station difficult.

The margin of error in the simulated annual water balance varied between two and 11% during calibration, while it varied between five and 16% during the period of verification. There is a slight bias in the seasonal calibration for under-estimating the streamflow in the upper sub-catchments during the wet period and over-estimating the baseflow during autumn and follow-on dry periods. In the lower sub-catchments, the wet periods were over-simulated and the baseflow was correctly simulated during the dry period.

The over-simulation of the various single storm events (higher streamflow peaks) was the most consistent error that occurred during the period of calibration. This can probably be ascribed to the poor representation and areal distribution of precipitation data, which did not account accurately for the spatial variation in precipitation- and storm distributions. The results of the scatter plots indicated that there is a low correlation between the different precipitation data sets, thus emphasising the spatial variation in precipitation- and storm distributions. Individual hydrographs were best simulated at U2H022 and this might be linked to the more representative precipitation data (highest r^2- values) within those sub-catchments.

Even when the precipitation stations have a low degree of correlation, they are still representative of the parts of the catchment for which they provide precipitation distribution as determined by the Thiessen polygons. The question is really whether the precipitation stations are representative of the precipitation distribution suggested by the Thiessen polygons. Since there is bound to be variation in areal distribution in precipitation within a given polygon, given the small number of precipitation stations, a single station is considered to be a poor representative of the entire polygon. The only solution to this problem is a more representative distribution of precipitation stations, or using an alternative method to represent precipitation distribution.

The over-estimation of baseflows could be due to inadequate representation of the effects of riparian vegetation in the model. The parameter, which is used to account for riparian vegetation is BASETP. Alternatively, the KVARY parameter, which was considered to be constant in this study, could play a role.

The response time and interflow recession rates of the hydrographs were accurately simulated, except for some cases during autumn where the interflow recession rate was incorrectly simulated. Therefore, AGWRC and IRC must be decreased in order to accomplish faster recession in the recession tails of the simulated storm hydrographs in autumn- or follow-on winter baseflow. Decreasing the IRC value should "steepen" the recession and increase peak flows.

7.3 ANALYSIS OF MODEL PERFORMANCE

The reported value ranges of the coefficient of determination (r^2) for other HSPF applications in the literature were used as a guideline of model performance analysis. The objective was to maximise the coefficient of determination (r^2) to unity, or at least to the proposed value of 0.6 at a daily level.

As in the case of calibration and verification, the best model performance was associated with the best hydrological- and meteorological data. The model performance at U2H022 is a typical example, because the best input data, compared to the other hydrological gauging stations, were available at U2H022. The final r^2 values of U2H022 were within the acceptable range of 0.6 at a daily level.

7.4 RECOMMENDATIONS

Recommendations for future refinements of the Msunduzi River Catchment HSPF model are as follows:

- Collect more representative river geometry data in order to improve the stage-discharge relationships, especially when in-depth water quality studies are to be performed in future. Many water quality processes depend on river depth. The river cross-sections used to compute the stage-discharge relationships in HSPF were based on very limited data, *viz.* GIS data, topographical maps, orthographical photographs and topographical- and section surveys. Although the hydrological calibration is not very sensitive to river geometry.

- Further streamflow calibration by adjusting the BASETP parameters and extended examination of areal photographs, GIS data and field visits to determine the areas most likely to be affected by riparian vegetation.
- Collect hourly meteorological data throughout the catchment. New precipitation estimation techniques such as spatial radar precipitation estimation and improved real-time precipitation data can be incorporated to improve the precipitation data. This would also permit simulation of processes, which are sensitive to diurnal changes, such as water temperature and other quality constituents. It would also allow for more accurate simulation of precipitation events in smaller catchments, such as the Slang Spruit.
- The finer discretisation of sub-catchments based on the resolution of accurate precipitation estimation and the hydrological response of the different land-uses.
- The use of PEST, a model-independent, non-linear parameter estimator to improve the final calibrated values (Doherty, Brebber & Whyte, 1994). PEST also allows confidence limits to be set on parameter estimates, allowing for a more reliable application of the model as a predictive tool.
- The simulation of water quality constituents to assess the impact of point source- and diffuse sources of pollution.
- Human water use. This model incorporates the effects of water abstractions from Henley Dam and the discharge of Darvill wastewater treatment plant. However, if the model is used to simulate the effects of increased pumping or wastewater discharge, water consumption of all the urban- and informal areas of Pietermaritzburg, Cato Ridge, Vulindlela and other townships will need to be incorporated.

- The automation and improvement of integration between the GIS and HSPF by incorporating stand alone processes in the GIS or modelling system, utilising the GIS for the display of simulation results and further development to enable interactive scenario assessment. Many of these goals can be achieved by the implementation of BASINS, a multipurpose environmental analysis system, which provides an integrated catchment framework, to support and standardise all the processes of hydrological- and water quality modelling. The GENSCN tool can also be used for integration of GIS information and HSPF (Kittle, Lumb, Hummel, Duda, & Gray, 1998).

CHAPTER

8

REFERENCES

HSPF MODELLING OF THE MSUNDUZI RIVER CATCHMENT

8. REFERENCES

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CHAPTER

9

ANNEXURES

HSPF MODELLING OF THE MSUNDUZI RIVER CATCHMENT

9. ANNEXURES

ANNEXURE A: **PLATES 1 to 9: SPATIAL GIS DATA OF THE MSUNDUZI RIVER CATCHMENT**

ANNEXURE B: **PLATES 10 to 24 b: PHOTOGRAPHS OF THE MSUNDUZI RIVER CATCHMENT**

ANNEXURE C: **LIST OF USER'S CONTROL INPUT FILES AND INPUT DATA OF THE MSUNDUZI RIVER CATCHMENT**

This annexure lists the final User's Control Input files developed for the Msunduzi River Catchment. Two separate files were used to simulate the upper- and lower catchments.

ANNEXURE

A

SPATIAL GIS DATA OF THE MSUNDUZI RIVER CATCHMENT

HSPF MODELLING OF THE MSUNDUZI RIVER CATCHMENT

MSUNDUZI RIVER CATCHMENT
Management Sub-Catchments

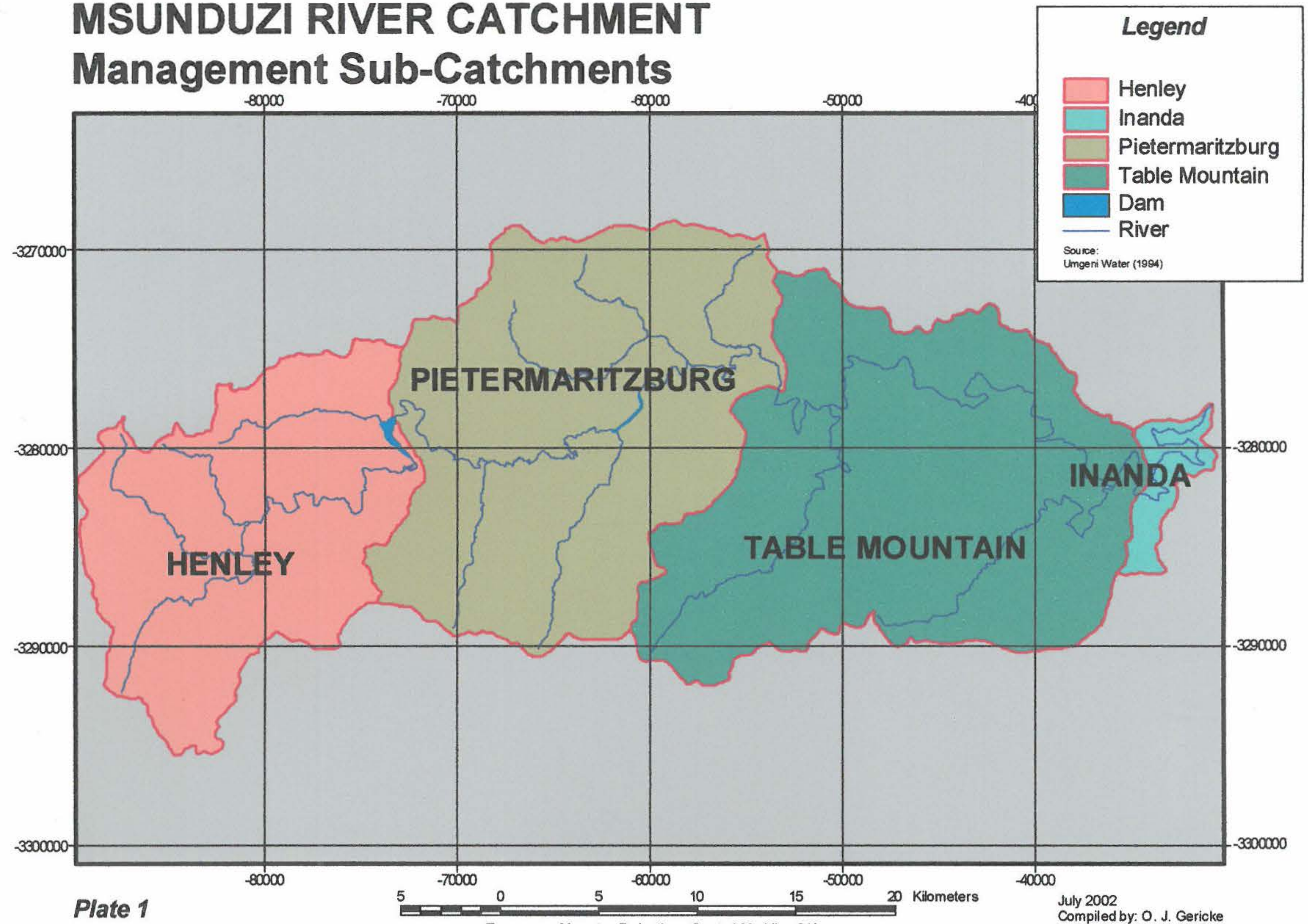


Plate 1

July 2002
Compiled by: O. J. Gericke

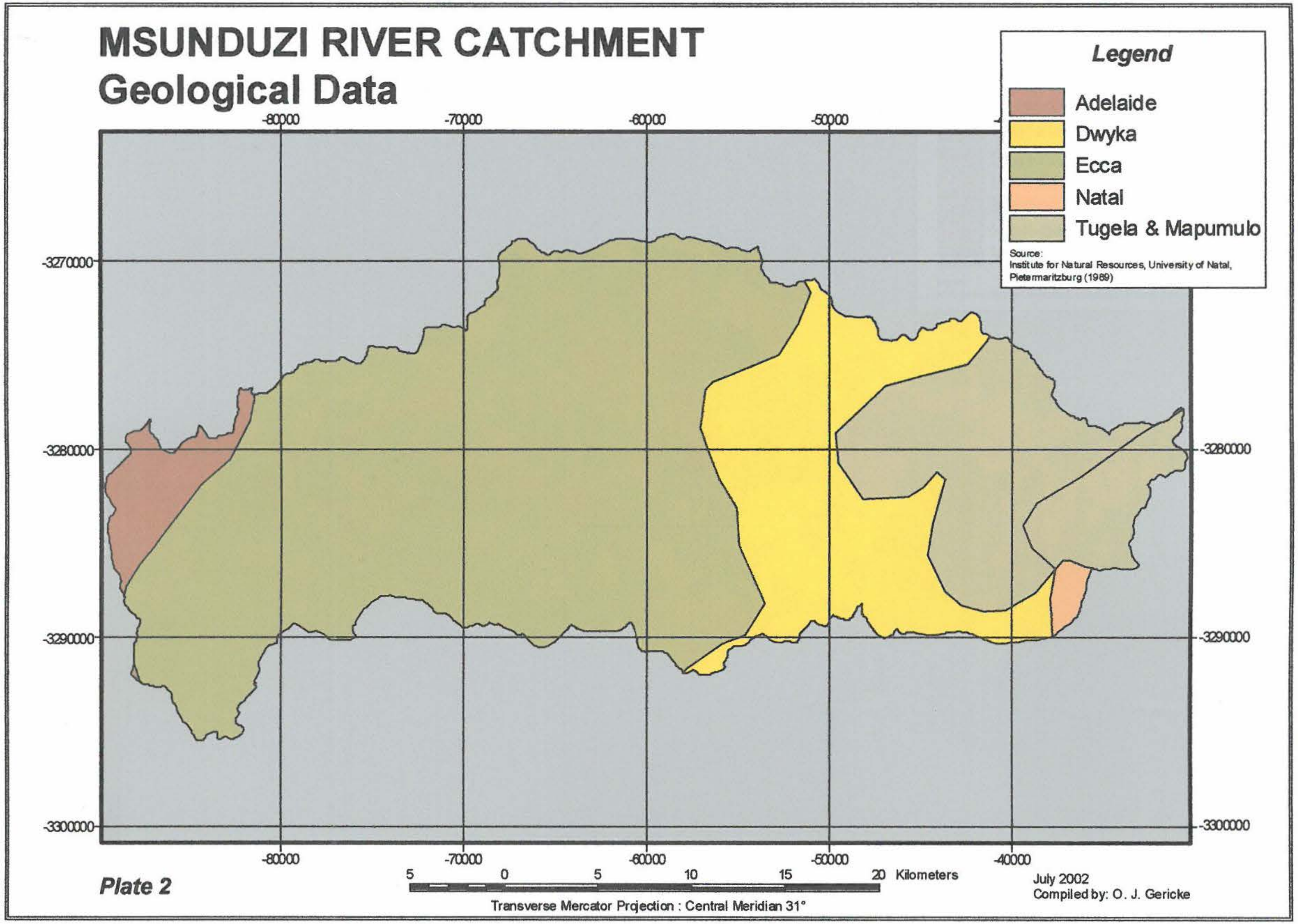
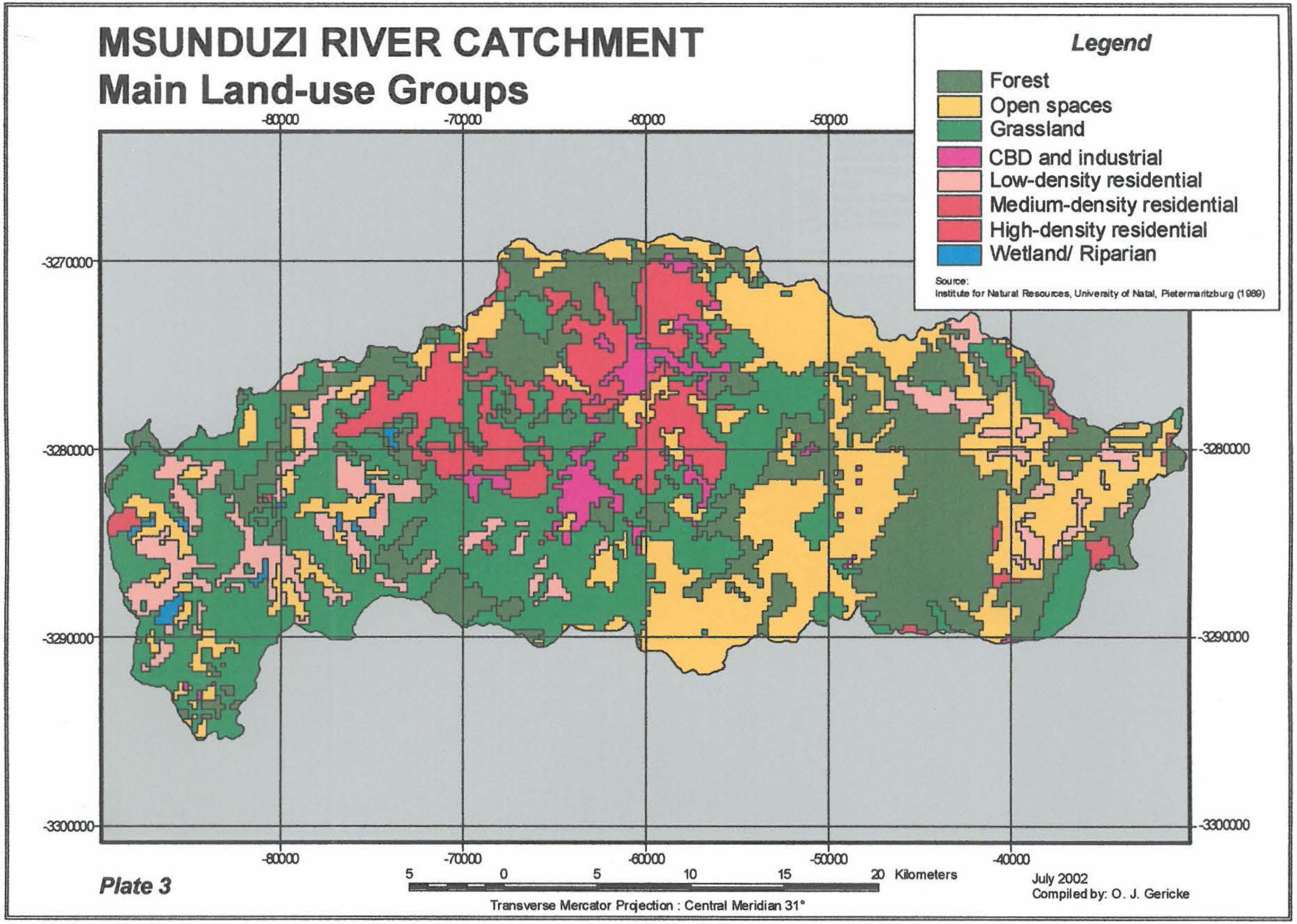
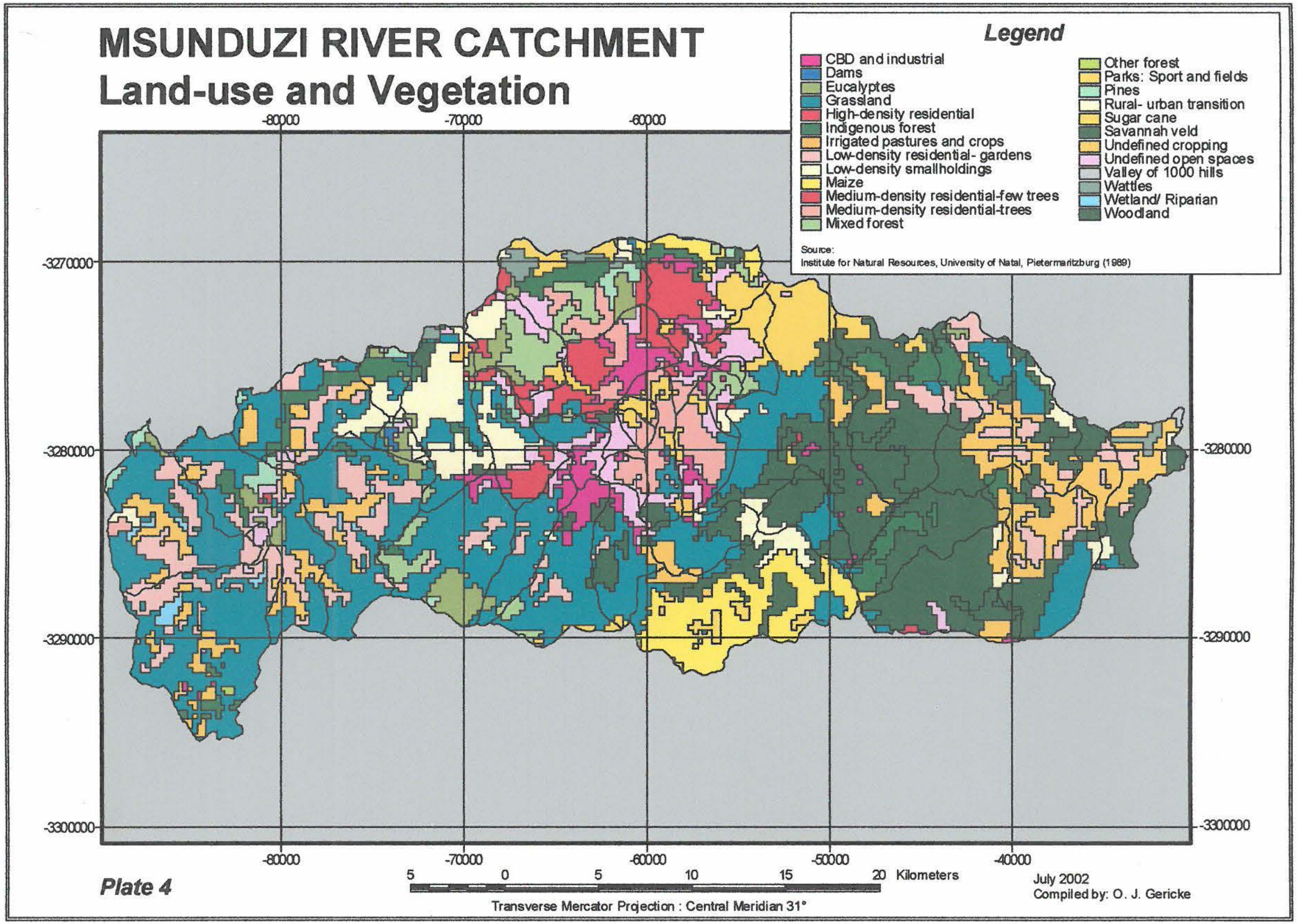

MSUNDUZI RIVER CATCHMENT
Geological Data
Legend
Adelaide
Dwyka
Ecca
Natal
Tugela & Mapumulo
Source:
Institute for Natural Resources, University of Natal, Pietermaritzburg (1989)
-80000
-70000
-60000
-50000
-40000
-3270000
-3280000
-3290000
-3300000
5 0 5 10 15 20 Kilometers
Transverse Mercator Projection : Central Meridian 31°
July 2002
Compiled by: O. J. Gericke

Plate 2


MSUNDUZI RIVER CATCHMENT
Main Land-use Groups
Legend
Forest
Open spaces
Grassland
CBD and industrial
Low-density residential
Medium-density residential
High-density residential
Wetland/ Riparian
Source:
Institute for Natural Resources, University of Natal, Pietermaritzburg (1989)
-80000
-70000
-60000
-50000
-40000
-3270000
-3280000
-3290000
-3300000
Plate 3
5 0 5 10 15 20 Kilometers
Transverse Mercator Projection : Central Meridian 31°
July 2002
Compiled by: O. J. Gericke

ANNEXURE A


MSUNDUZI RIVER CATCHMENT
Land-use and Vegetation
Legend
CBD and industrial
Dams
Eucalyptes
Grassland
High-density residential
Indigenous forest
Irrigated pastures and crops
Low-density residential- gardens
Low-density smallholdings
Maize
Medium-density residential-few trees
Medium-density residential-trees
Mixed forest
Other forest
Parks: Sport and fields
Pines
Rural- urban transition
Sugar cane
Savannah veld
Undefined cropping
Undefined open spaces
Valley of 1000 hills
Wattles
Wetland/ Riparian
Woodland
Source:
Institute for Natural Resources, University of Natal, Pietermaritzburg (1989)
-80000
-70000
-60000
-50000
-40000
-3270000
-3280000
-3290000
-3300000
5 0 5 10 15 20 Kilometers
Plate 4
Transverse Mercator Projection : Central Meridian 31°
July 2002
Compiled by: O. J. Gericke

ANNEXURE A

MSUNDUZI RIVER CATCHMENT
Discretisation of Catchment and River Network

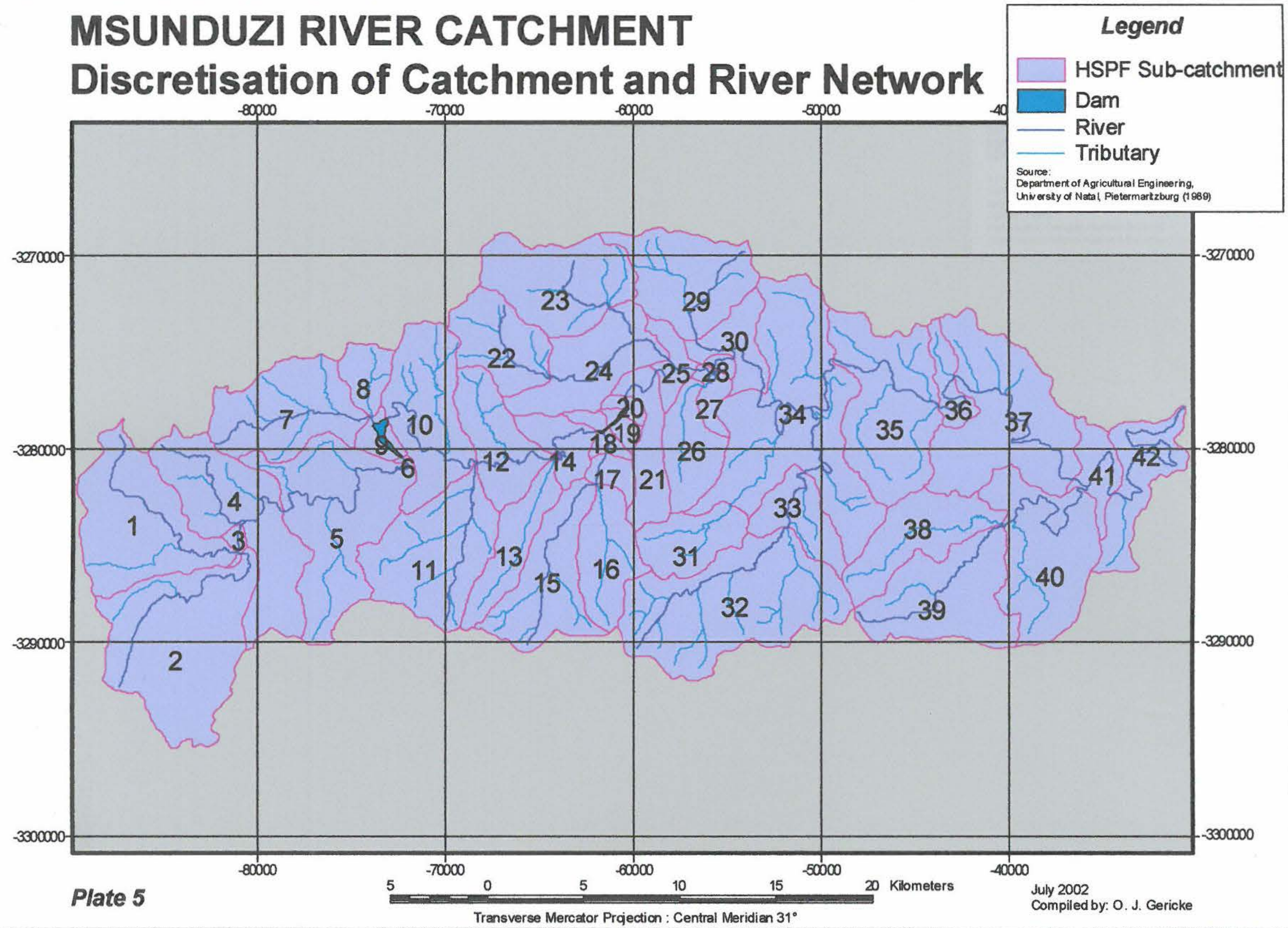
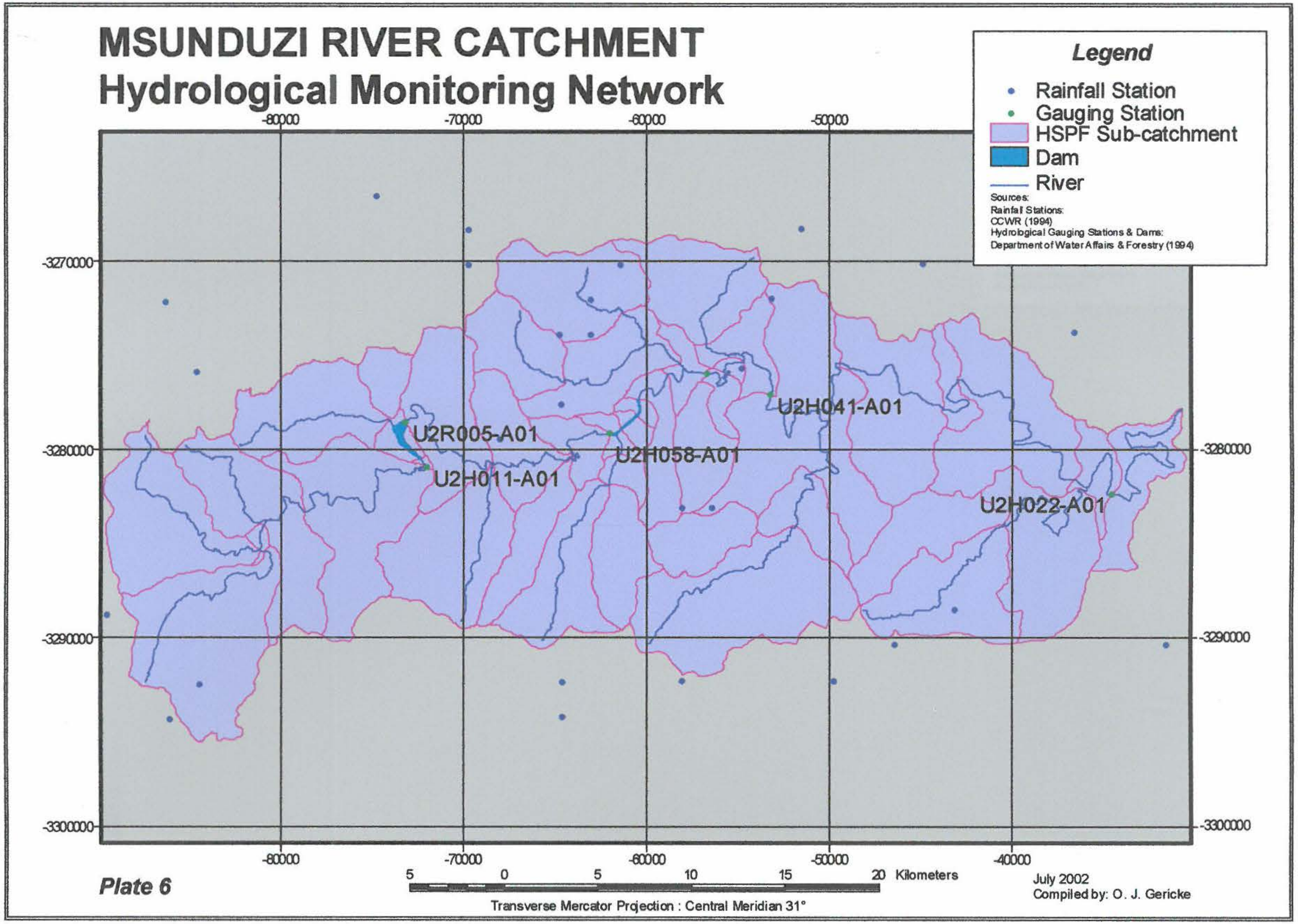


Plate 5

July 2002
Compiled by: O. J. Gericke

ANNEXURE A


MSUNDUZI RIVER CATCHMENT
Hydrological Monitoring Network
Legend
Rainfall Station
Gauging Station
HSPF Sub-catchment
Dam
River
Sources:
Rainfall Stations:
CCWR (1994)
Hydrological Gauging Stations & Dams:
Department of Water Affairs & Forestry (1994)
U2R005-A01
U2H011-A01
U2H058-A01
U2H041-A01
U2H022-A01
-80000
-70000
-60000
-50000
-40000
-3270000
-3280000
-3290000
-3300000
5
0
5
10
15
20
Kilometers
Transverse Mercator Projection : Central Meridian 31°
July 2002
Compiled by: O. J. Gericke
Plate 6

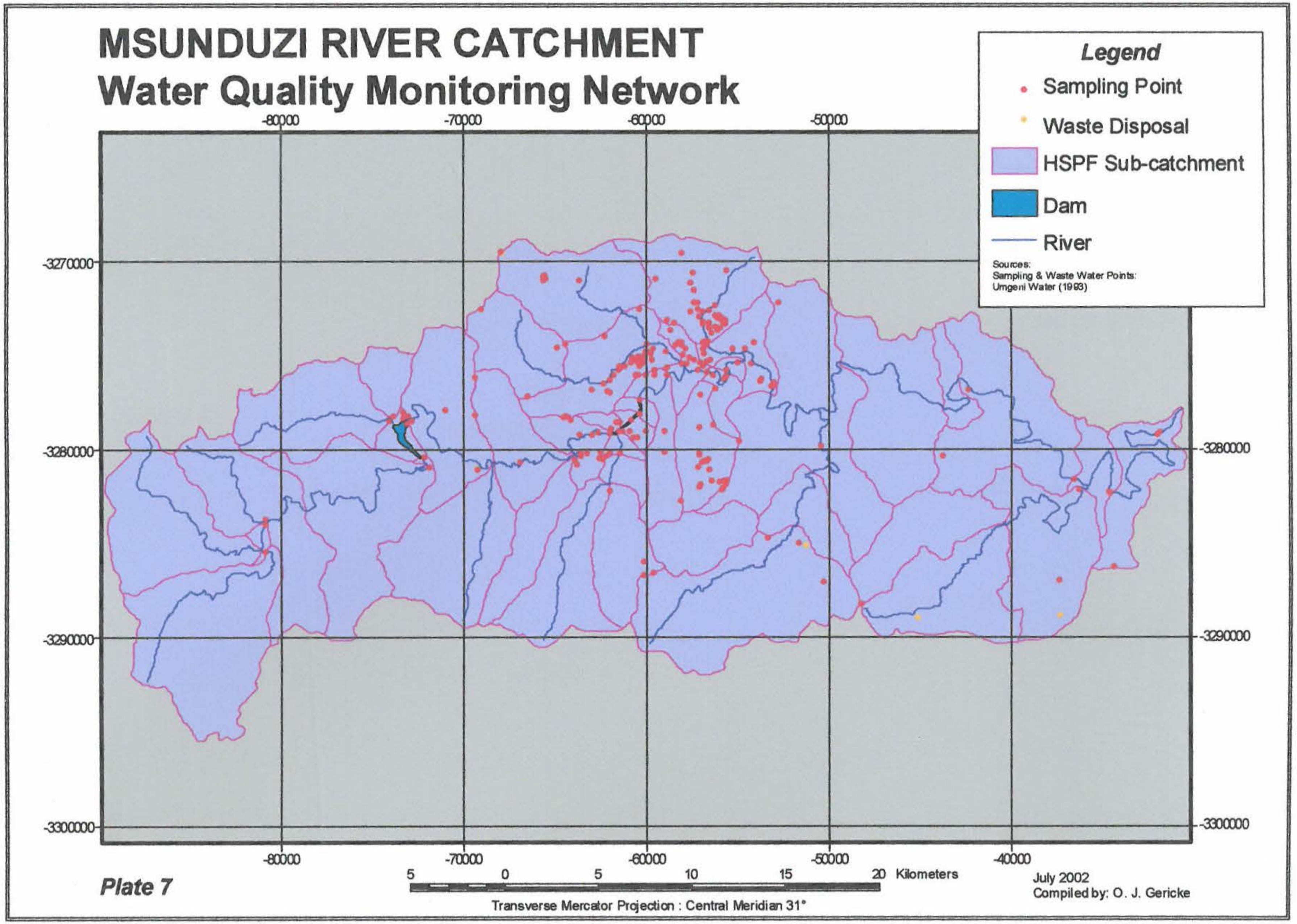

MSUNDUZI RIVER CATCHMENT
Water Quality Monitoring Network
Legend
Sampling Point
Waste Disposal
HSPF Sub-catchment
Dam
River
Sources:
Sampling & Waste Water Points:
Umgeni Water (1993)
-80000
-70000
-60000
-50000
-40000
-3270000
-3280000
-3290000
-3300000
5 0 5 10 15 20 Kilometers
Transverse Mercator Projection : Central Meridian 31°
July 2002
Compiled by: O. J. Gericke

Plate 7

MSUNDUZI RIVER CATCHMENT
Thiessen Polygons

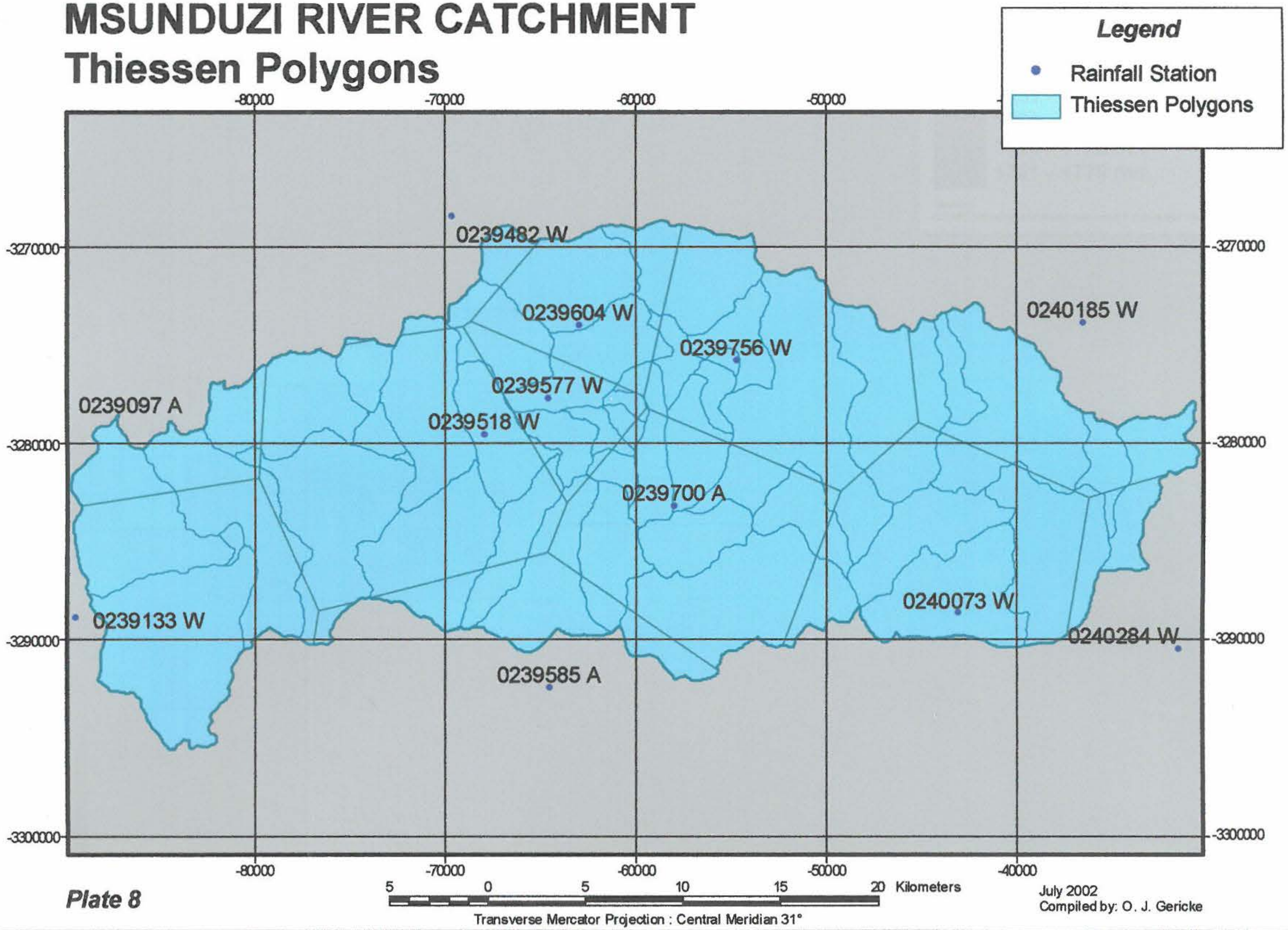


Plate 8

© Central University of Technology, Free State

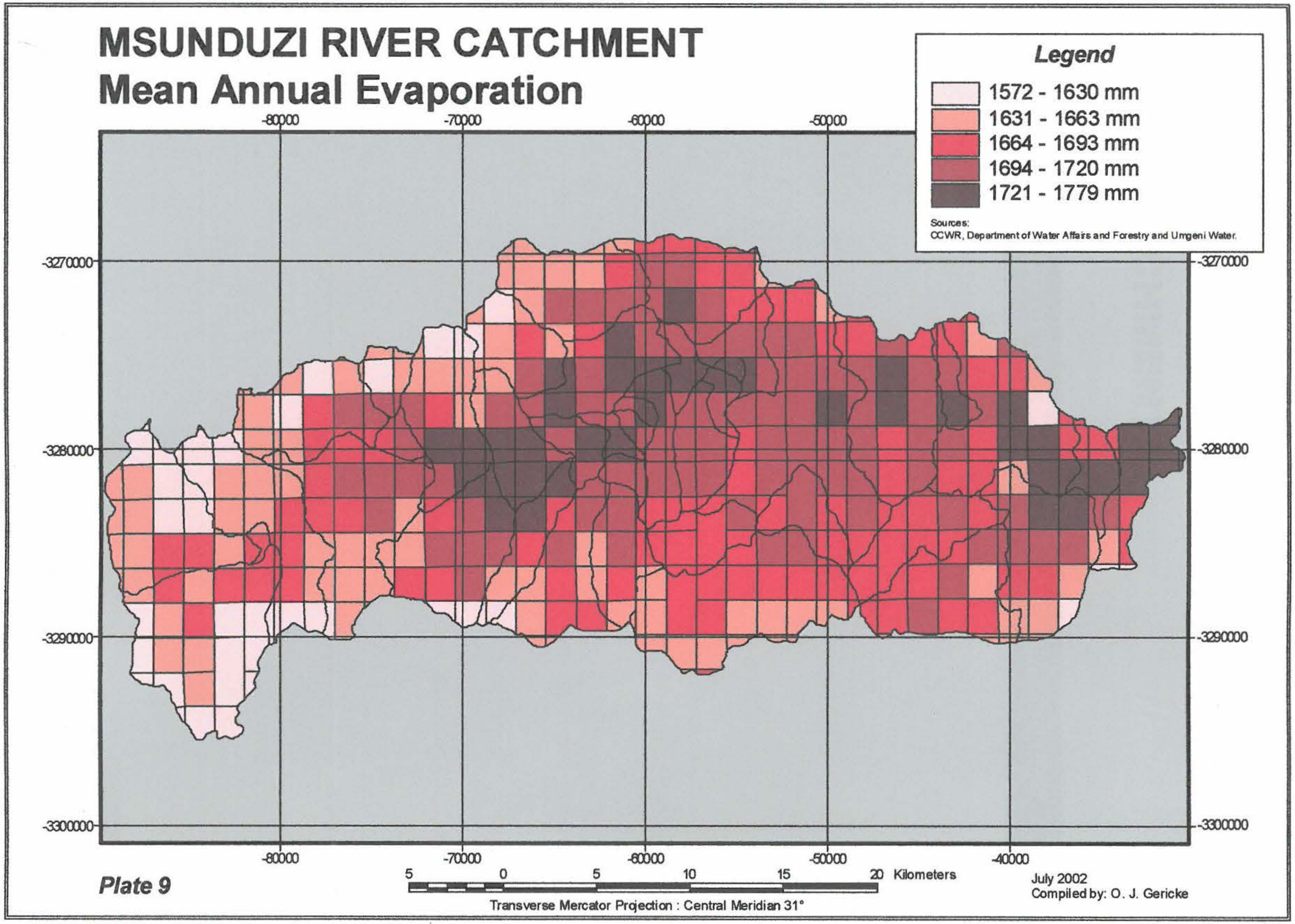

MSUNDUZI RIVER CATCHMENT
Mean Annual Evaporation
Legend
1572 - 1630 mm
1631 - 1663 mm
1664 - 1693 mm
1694 - 1720 mm
1721 - 1779 mm
Sources:
CCWR, Department of Water Affairs and Forestry and Umgeni Water.
-80000
-70000
-60000
-50000
-40000
-3270000
-3280000
-3290000
-3300000
5
0
5
10
15
20 Kilometers
Transverse Mercator Projection : Central Meridian 31°
July 2002
Compiled by: O. J. Gericke

Plate 9

ANNEXURE

B

PHOTOGRAPHS OF THE MSUNDUZI RIVER CATCHMENT

Plate 10: U2H011 Msunduzi River at Henley Dam: Sub-catchment 5

Plate 11: U2H058 Msunduzi River at Mason's Mill: Sub-catchment 14

Plate 12: **U2H041 Msunduzi River at Hampstead Park, Moto-X:** Sub-catchment 30

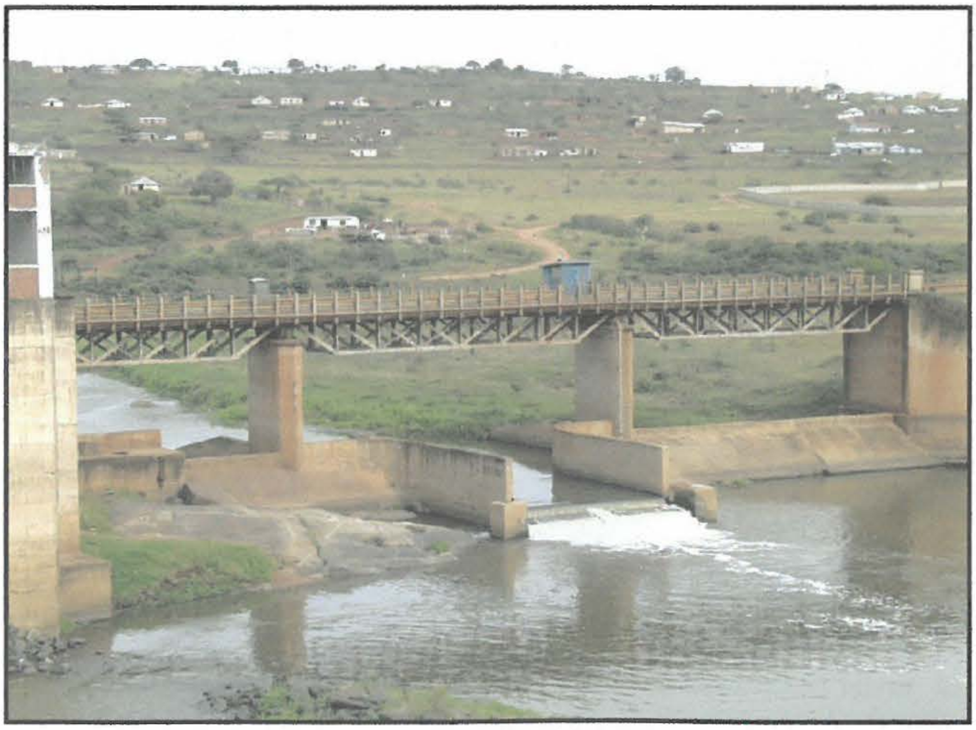


Plate 13: **U2H022 Msunduzi River at Nomfihlelo:** Sub-catchment 42

Plate 14: **Silt trapping weir upstream of Camp's Drift bridge:** Sub-catchment 18. Msunduzi River

Plate 15: **Camp's Drift Road:** Sub-catchment 19. Msunduzi River. Upstream view of canalised recreational area above Camp's Drift weir towards silt trapping weir

Plate 16 a: Camp's Drift weir at College Road: Sub-catchment 20. Msunduzi River. Multiple notches. Ogee structure with an overflow of approximately 65 to 70 m

Plate 16 b: Camp's Drift weir at College Road: Sub-catchment 20. Msunduzi River. Typical downstream conditions are a defined river section of approximately 57 m

Plate 17: **Railway bridge at Ritchie Road:** Sub-catchment 21. Reaches of the Foxhill Spruit. Uniform channel, defined flow path covered with grass and reeds. Approximate width of 20.6 m

Plate 18 a: **Alexandra Park pedestrian bridge, near Gutridge- and Prince Alfred Streets:** Sub-catchment 21. Msunduzi River. Upstream view. Uniform channel with trapezoidal section. Approximate top width of 30 m and bottom width of 14 m. Rocky bed conditions with contractions upstream

Plate 18 b: Alexandra Park pedestrian bridge, near Gutridge- and Prince Alfred Streets: Sub-catchment 21. Msunduzi River. Downstream view. Uniform channel with trapezoidal section. Approximate top width of 30 m and bottom width of 14 m

Plate 19 a: Durban Road bridge at Durban Road near Kershaw Park: Sub-catchment 21. Msunduzi River. Uniform channel with trapezoidal section. Approximate top width of 39.5 m and bottom width of 29 m. Upstream section

Plate 19 b: Durban Road bridge at Durban Road near Kershaw Park: Sub-catchment 21. Msunduzi River. Downstream section

Plate 20 a: Daniel Lindley bridge: Boshoff Street: Sub-catchment 21. Msunduzi River. Downstream of Durban Road bridge. Upstream section

Plate 20 b: Daniel Lindley bridge: Boshoff Street: Sub-catchment 21. Msunduzi River. Upstream section

Plate 21: Upstream of Howick Road bridge, near Royal Show grounds: Sub-catchment 24. Lower reaches of the Dorp Spruit. Uniform channel with trapezoidal section. Approximate top width of 10 m and bottom width of 7 m

Plate 22: **Upstream view from Connor Road bridge:** Sub-catchment 24. Reaches of the Chase Valley Stream. Uniform channel with trapezoidal section. Approximate top width of 17 m and bottom width of 8 m

Plate 23 a: **Low-water bridge between Woodhouse- and Promed Roads:** Sub-catchment 27. Reaches of the Msunduzi River. Uniform channel with trapezoidal section. Approximate top width of 35 m and bottom width of 25 m. Upstream section

Plate 23 b: Low-water bridge between Woodhouse- and Promed Roads: Sub-catchment 27. Downstream section

Plate 24 a: Low-water bridge at Grimthorpe Avenue near Hampstead Park: Sub-catchment 34. Reaches of the Msunduzi River. Uniform channel with trapezoidal section. Approximate top width of 25 m and bottom width of 14 m. Upstream section

Plate 24 b: Low-water bridge at Grimthorpe Avenue near Hampstead Park: Sub-catchment 34. Reaches of the Msunduzi River. Downstream section

ANNEXURE

C

USER'S CONTROL INPUT FILES AND INPUT DATA OF THE MSUNDUZI RIVER CATCHMENT

HSPF MODELLING OF THE MSUNDUZI RIVER CATCHMENT

USER'S CONTROL INPUT FILES

UPPER SUB-CATCHMENTS (1-20)

```
RUN

GLOBAL
  HSPF DEMONSTRATION RUN UPSTREAM OF MGENI CONFLUENCE
  START       1992/01/01          END     2000/06/01
  RUN INTERP OUTPUT LEVEL    4
  RESUME     0 RUN     1 TSSFL     0 WDMSFL     0 UNITS     2
END GLOBAL

FILES
<FILE>  <UN#>***<----FILE NAME------------------------------------------------->
WDM        21   msunduzi.wdm
MESSU      22   msunduzi.ech
           61   msunduzi.p61
           62   msunduzi.p62
           63   msunduzi.p63
           64   msunduzi.p64
           92   msunduzi.plt
END FILES

OPN SEQUENCE
    INGRP              INDELT 24:00
      Catchment     1 ******
      PERLND       11
      PERLND       12
      PERLND       13
      PERLND       14***
      IMPLND       14***
      PERLND       15
      IMPLND       15
      PERLND       16
      PERLND       17***
      IMPLND       17***
      PERLND       18
      RCHRES        1
      Catchment     2 ******
      PERLND       21
      PERLND       22
      PERLND       23
      PERLND       24
      IMPLND       24
      PERLND       25***
      PERLND       26
      PERLND       27***
      PERLND       28
      RCHRES        2
      Catchment     3 ******
      PERLND       31
      PERLND       32***
      PERLND       33
      PERLND       34***
      PERLND       35***
      PERLND       36
      PERLND       37***
      PERLND       38***
      RCHRES        3
      Catchment     4 ******
      PERLND       41
      PERLND       42
      PERLND       43
      PERLND       44***
```

```
PERLND     45***
PERLND     46
PERLND     47
IMPLND     47
PERLND     48
RCHRES      4
Catchment   5 ******
PERLND     51
PERLND     52
PERLND     53
PERLND     54***
PERLND     55
IMPLND     55
PERLND     56
PERLND     57***
PERLND     58
RCHRES      5
Catchment   6 ******
PERLND     61
PERLND     62***
PERLND     63
PERLND     64***
PERLND     65
IMPLND     65
PERLND     66***
PERLND     67***
PERLND     68***
RCHRES      6
Catchment   7 ******
PERLND     71
PERLND     72
PERLND     73
PERLND     74***
PERLND     75
IMPLND     75
PERLND     76
PERLND     77***
PERLND     78***
RCHRES      7
Catchment   8 ******
PERLND     81
PERLND     82
PERLND     83
PERLND     84***
PERLND     85
IMPLND     85
PERLND     86***
PERLND     87***
PERLND     88***
RCHRES      8
Catchment   9 ******
PERLND     91
PERLND     92***
PERLND     93
PERLND     94***
PERLND     95
IMPLND     95
PERLND     96***
PERLND     97***
PERLND     98***
RCHRES      9
COPY        1
Catchment  10 ******
PERLND    101
PERLND    102
PERLND    103
PERLND    104
IMPLND    104
```

```
PERLND      105
IMPLND      105
PERLND      106
PERLND      107
IMPLND      107
PERLND      108***
RCHRES       10
Catchment    11 ******
PERLND      111
PERLND      112***
PERLND      113
PERLND      114
IMPLND      114
PERLND      115
IMPLND      115
PERLND      116
PERLND      117
IMPLND      117
PERLND      118***
RCHRES       11
Catchment    12 ******
PERLND      121
PERLND      122***
PERLND      123
PERLND      124
IMPLND      124
PERLND      125
IMPLND      125
PERLND      126***
PERLND      127
IMPLND      127
PERLND      128***
RCHRES       12
Catchment    13 ******
PERLND      131
PERLND      132***
PERLND      133
PERLND      134
IMPLND      134
PERLND      135
IMPLND      135
PERLND      136
PERLND      137
IMPLND      137
PERLND      138***
RCHRES       13
Catchment    14 ******
PERLND      141
PERLND      142***
PERLND      143
PERLND      144
IMPLND      144
PERLND      145
PERLND      146***
PERLND      147***
PERLND      148***
RCHRES       14
Catchment    15 ******
PERLND      151
PERLND      152
PERLND      153
PERLND      154
IMPLND      154
PERLND      155
IMPLND      155
PERLND      156
PERLND      157***
PERLND      158***
```

```
        RCHRES        15
        Catchment     16 ******
        PERLND       161
        PERLND       162
        PERLND       163
        PERLND       164
        IMPLND       164
        PERLND       165***
        PERLND       166
        PERLND       167***
        PERLND       168***
        RCHRES        16
        Catchment     17 ******
        PERLND       171***
        PERLND       172***
        PERLND       173
        PERLND       174
        IMPLND       174
        PERLND       175
        IMPLND       175
        PERLND       176***
        PERLND       177***
        PERLND       178***
        RCHRES        17
        Catchment     18 ******
        PERLND       181
        PERLND       182***
        PERLND       183
        PERLND       184
        IMPLND       184
        PERLND       185
        IMPLND       185
        PERLND       186***
        PERLND       187
        IMPLND       187
        PERLND       188***
        RCHRES        18***
        Catchment     19 ******
        PERLND       191***
        PERLND       192
        PERLND       193
        PERLND       194***
        PERLND       195
        IMPLND       195
        PERLND       196***
        PERLND       197***
        PERLND       198***
        RCHRES        19***
        Catchment     20 ******
        PERLND       201
        PERLND       202
        PERLND       203
        PERLND       204***
        PERLND       205
        IMPLND       205
        PERLND       206***
        PERLND       207
        IMPLND       207
        PERLND       208***
        RCHRES        20
        PLTGEN         1***
    END INGRP
END OPN SEQUENCE
```

```
COPY
  TIMESERIES
    #    #  NPT  NMN ***
    1         1
  END TIMESERIES
END COPY

PERLND

  ACTIVITY
    <PLS >          Active Sections (1=Active; 0=Inactive)            ***
    # -  # ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC ***
   11  208              1
  END ACTIVITY

  PRINT-INFO
    <PLS >          Print-flags                                   *** PIVL  PYR
    # -  # ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC       ***
   11  208     5        5                                                    09
  END PRINT-INFO

  GEN-INFO
    <PLS ><-------Name------->        Unit-systems   Printer ***
    # -  #                                t-series Engl Metr ***
                                          in   out           ***
   11      Catch  1, Forest                2     2    0   61
   12      Catch  1, Crops                 2     2    0   61
   13      Catch  1, Grassland             2     2    0   61
   14      Catch  1, CBD                   2     2    0   61
   15      Catch  1, MD Res.               2     2    0   61
   16      Catch  1, LD Res.               2     2    0   61
   17      Catch  1, HD Res.               2     2    0   61
   18      Catch  1, Wetland               2     2    0   61
   21      Catch  2, Forest                2     2    0   61
   22      Catch  2, Crops                 2     2    0   61
   23      Catch  2, Grassland             2     2    0   61
   24      Catch  2, CBD                   2     2    0   61
   25      Catch  2, MD Res.               2     2    0   61
   26      Catch  2, LD Res.               2     2    0   61
   27      Catch  2, HD Res.               2     2    0   61
   28      Catch  2, Wetland               2     2    0   61
   31      Catch  3, Forest                2     2    0   61
   32      Catch  3, Crops                 2     2    0   61
   33      Catch  3, Grassland             2     2    0   61
   34      Catch  3, CBD                   2     2    0   61
   35      Catch  3, MD Res.               2     2    0   61
   36      Catch  3, LD Res.               2     2    0   61
   37      Catch  3, HD Res.               2     2    0   61
   38      Catch  3, Wetland               2     2    0   61
   41      Catch  4, Forest                2     2    0   61
   42      Catch  4, Crops                 2     2    0   61
   43      Catch  4, Grassland             2     2    0   61
   44      Catch  4, CBD                   2     2    0   61
   45      Catch  4, MD Res.               2     2    0   61
   46      Catch  4, LD Res.               2     2    0   61
   47      Catch  4, HD Res.               2     2    0   61
   48      Catch  4, Wetland               2     2    0   61
   51      Catch  5, Forest                2     2    0   61
   52      Catch  5, Crops                 2     2    0   61
   53      Catch  5, Grassland             2     2    0   61
   54      Catch  5, CBD                   2     2    0   61
   55      Catch  5, MD Res.               2     2    0   61
   56      Catch  5, LD Res.               2     2    0   61
   57      Catch  5, HD Res.               2     2    0   61
   58      Catch  5, Wetland               2     2    0   61
   61      Catch  6, Forest                2     2    0   61
   62      Catch  6, Crops                 2     2    0   61
   63      Catch  6, Grassland             2     2    0   61
```

64	Catch 6, CBD	2	2	0	61
65	Catch 6, MD Res.	2	2	0	61
66	Catch 6, LD Res.	2	2	0	61
67	Catch 6, HD Res.	2	2	0	61
68	Catch 6, Wetland	2	2	0	61
71	Catch 7, Forest	2	2	0	61
72	Catch 7, Crops	2	2	0	61
73	Catch 7, Grassland	2	2	0	61
74	Catch 7, CBD	2	2	0	61
75	Catch 7, MD Res.	2	2	0	61
76	Catch 7, LD Res.	2	2	0	61
77	Catch 7, HD Res.	2	2	0	61
78	Catch 7, Wetland	2	2	0	61
81	Catch 8, Forest	2	2	0	61
82	Catch 8, Crops	2	2	0	61
83	Catch 8, Grassland	2	2	0	61
84	Catch 8, CBD	2	2	0	61
85	Catch 8, MD Res.	2	2	0	61
86	Catch 8, LD Res.	2	2	0	61
87	Catch 8, HD Res.	2	2	0	61
88	Catch 8, Wetland	2	2	0	61
91	Catch 9, Forest	2	2	0	61
92	Catch 9, Crops	2	2	0	61
93	Catch 9, Grassland	2	2	0	61
94	Catch 9, CBD	2	2	0	61
95	Catch 9, MD Res.	2	2	0	61
96	Catch 9, LD Res.	2	2	0	61
97	Catch 9, HD Res.	2	2	0	61
98	Catch 9, Wetland	2	2	0	61
101	Catch 10, Forest	2	2	0	61
102	Catch 10, Crops	2	2	0	61
103	Catch 10, Grassland	2	2	0	61
104	Catch 10, CBD	2	2	0	61
105	Catch 10, MD Res.	2	2	0	61
106	Catch 10, LD Res.	2	2	0	61
107	Catch 10, HD Res.	2	2	0	61
108	Catch 10, Wetland	2	2	0	61
111	Catch 11, Forest	2	2	0	61
112	Catch 11, Crops	2	2	0	61
113	Catch 11, Grassland	2	2	0	61
114	Catch 11, CBD	2	2	0	61
115	Catch 11, MD Res.	2	2	0	61
116	Catch 11, LD Res.	2	2	0	61
117	Catch 11, HD Res.	2	2	0	61
118	Catch 11, Wetland	2	2	0	61
121	Catch 12, Forest	2	2	0	61
122	Catch 12, Crops	2	2	0	61
123	Catch 12, Grassland	2	2	0	61
124	Catch 12, CBD	2	2	0	61
125	Catch 12, MD Res.	2	2	0	61
126	Catch 12, LD Res.	2	2	0	61
127	Catch 12, HD Res.	2	2	0	61
128	Catch 12, Wetland	2	2	0	61
131	Catch 13, Forest	2	2	0	61
132	Catch 13, Crops	2	2	0	61
133	Catch 13, Grassland	2	2	0	61
134	Catch 13, CBD	2	2	0	61
135	Catch 13, MD Res.	2	2	0	61
136	Catch 13, LD Res.	2	2	0	61
137	Catch 13, HD Res.	2	2	0	61
138	Catch 13, Wetland	2	2	0	61
141	Catch 14, Forest	2	2	0	61
142	Catch 14, Crops	2	2	0	61
143	Catch 14, Grassland	2	2	0	61
144	Catch 14, CBD	2	2	0	61
145	Catch 14, MD Res.	2	2	0	61
146	Catch 14, LD Res.	2	2	0	61
147	Catch 14, HD Res.	2	2	0	61

```
148      Catch 14, Wetland                      2     2     0     61
151      Catch 15, Forest                       2     2     0     61
152      Catch 15, Crops                        2     2     0     61
153      Catch 15, Grassland                    2     2     0     61
154      Catch 15, CBD                          2     2     0     61
155      Catch 15, MD Res.                      2     2     0     61
156      Catch 15, LD Res.                      2     2     0     61
157      Catch 15, HD Res.                      2     2     0     61
158      Catch 15, Wetland                      2     2     0     61
161      Catch 16, Forest                       2     2     0     61
162      Catch 16, Crops                        2     2     0     61
163      Catch 16, Grassland                    2     2     0     61
164      Catch 16, CBD                          2     2     0     61
165      Catch 16, MD Res.                      2     2     0     61
166      Catch 16, LD Res.                      2     2     0     61
167      Catch 16, HD Res.                      2     2     0     61
168      Catch 16, Wetland                      2     2     0     61
171      Catch 17, Forest                       2     2     0     61
172      Catch 17, Crops                        2     2     0     61
173      Catch 17, Grassland                    2     2     0     61
174      Catch 17, CBD                          2     2     0     61
175      Catch 17, MD Res.                      2     2     0     61
176      Catch 17, LD Res.                      2     2     0     61
177      Catch 17, HD Res.                      2     2     0     61
178      Catch 17, Wetland                      2     2     0     61
181      Catch 18, Forest                       2     2     0     61
182      Catch 18, Crops                        2     2     0     61
183      Catch 18, Grassland                    2     2     0     61
184      Catch 18, CBD                          2     2     0     61
185      Catch 18, MD Res.                      2     2     0     61
186      Catch 18, LD Res.                      2     2     0     61
187      Catch 18, HD Res.                      2     2     0     61
188      Catch 18, Wetland                      2     2     0     61
191      Catch 19, Forest                       2     2     0     61
192      Catch 19, Crops                        2     2     0     61
193      Catch 19, Grassland                    2     2     0     61
194      Catch 19, CBD                          2     2     0     61
195      Catch 19, MD Res.                      2     2     0     61
196      Catch 19, LD Res.                      2     2     0     61
197      Catch 19, HD Res.                      2     2     0     61
198      Catch 19, Wetland                      2     2     0     61
201      Catch 20, Forest                       2     2     0     61
202      Catch 20, Crops                        2     2     0     61
203      Catch 20, Grassland                    2     2     0     61
204      Catch 20, CBD                          2     2     0     61
205      Catch 20, MD Res.                      2     2     0     61
206      Catch 20, LD Res.                      2     2     0     61
207      Catch 20, HD Res.                      2     2     0     61
208      Catch 20, Wetland                      2     2     0     61
END GEN-INFO

PWAT-PARM1
  <PLS >  PWATER variable monthly parameter value flags    ***
  # -   # CSNO RTOP UZFG  VCS  VUZ  VNN VIFW VIRC  VLE IFFC ***
 12          0    0    0    1    0    0    0    0    1
 13          0    0    0    1    0    0    0    0    1
 22          0    0    0    1    0    0    0    0    1
 23          0    0    0    1    0    0    0    0    1
 32          0    0    0    1    0    0    0    0    1
 33          0    0    0    1    0    0    0    0    1
 42          0    0    0    1    0    0    0    0    1
 43          0    0    0    1    0    0    0    0    1
 52          0    0    0    1    0    0    0    0    1
 53          0    0    0    1    0    0    0    0    1
 62          0    0    0    1    0    0    0    0    1
 63          0    0    0    1    0    0    0    0    1
 72          0    0    0    1    0    0    0    0    1
 73          0    0    0    1    0    0    0    0    1
```

```
  82          0     0     0     1     0     0     0     0     1
  83          0     0     0     1     0     0     0     0     1
  92          0     0     0     1     0     0     0     0     1
  93          0     0     0     1     0     0     0     0     1
 102          0     0     0     1     0     0     0     0     1
 103          0     0     0     1     0     0     0     0     1
 112          0     0     0     1     0     0     0     0     1
 113          0     0     0     1     0     0     0     0     1
 122          0     0     0     1     0     0     0     0     1
 123          0     0     0     1     0     0     0     0     1
 132          0     0     0     1     0     0     0     0     1
 133          0     0     0     1     0     0     0     0     1
 142          0     0     0     1     0     0     0     0     1
 143          0     0     0     1     0     0     0     0     1
 152          0     0     0     1     0     0     0     0     1
 153          0     0     0     1     0     0     0     0     1
 162          0     0     0     1     0     0     0     0     1
 163          0     0     0     1     0     0     0     0     1
 172          0     0     0     1     0     0     0     0     1
 173          0     0     0     1     0     0     0     0     1
 182          0     0     0     1     0     0     0     0     1
 183          0     0     0     1     0     0     0     0     1
 192          0     0     0     1     0     0     0     0     1
 193          0     0     0     1     0     0     0     0     1
 202          0     0     0     1     0     0     0     0     1
 203          0     0     0     1     0     0     0     0     1
END PWAT-PARM1

PWAT-PARM2
  <PLS > ***  PWATER input info: Part 2
   # -  # ***FOREST      LZSN    INFILT      LSUR     SLSUR     KVARY     AGWRC
  11          0.000     380.0      0.60      83.0     0.117       0.0      0.99
  12          0.000     380.0      0.60      83.0     0.117       0.0      0.99
  13          0.000     380.0      0.60      83.0     0.117       0.0      0.99
  14          0.000     380.0      0.60      83.0     0.117       0.0      0.99
  15          0.000     380.0      0.60      83.0     0.117       0.0      0.99
  16          0.000     380.0      0.60      83.0     0.117       0.0      0.99
  17          0.000     380.0      0.60      83.0     0.117       0.0      0.99
  18          0.000     380.0      0.60      83.0     0.117       0.0      0.99
  21          0.000     380.0      0.60      63.0     0.147       0.0      0.99
  22          0.000     380.0      0.60      63.0     0.147       0.0      0.99
  23          0.000     380.0      0.60      63.0     0.147       0.0      0.99
  24          0.000     380.0      0.60      63.0     0.147       0.0      0.99
  25          0.000     380.0      0.60      63.0     0.147       0.0      0.99
  26          0.000     380.0      0.60      63.0     0.147       0.0      0.99
  27          0.000     380.0      0.60      63.0     0.147       0.0      0.99
  28          0.000     380.0      0.60      63.0     0.147       0.0      0.99
  31          0.000     380.0      0.60      99.0     0.092       0.0      0.99
  32          0.000     380.0      0.60      99.0     0.092       0.0      0.99
  33          0.000     380.0      0.60      99.0     0.092       0.0      0.99
  34          0.000     380.0      0.60      99.0     0.092       0.0      0.99
  35          0.000     380.0      0.60      99.0     0.092       0.0      0.99
  36          0.000     380.0      0.60      99.0     0.092       0.0      0.99
  37          0.000     380.0      0.60      99.0     0.092       0.0      0.99
  38          0.000     380.0      0.60      99.0     0.092       0.0      0.99
  41          0.000     380.0      0.60      64.0     0.146       0.0      0.99
  42          0.000     380.0      0.60      64.0     0.146       0.0      0.99
  43          0.000     380.0      0.60      64.0     0.146       0.0      0.99
  44          0.000     380.0      0.60      64.0     0.146       0.0      0.99
  45          0.000     380.0      0.60      64.0     0.146       0.0      0.99
  46          0.000     380.0      0.60      64.0     0.146       0.0      0.99
  47          0.000     380.0      0.60      64.0     0.146       0.0      0.99
  48          0.000     380.0      0.60      64.0     0.146       0.0      0.99
  51          0.000     380.0      0.60      54.0     0.187       0.0      0.99
  52          0.000     380.0      0.60      54.0     0.187       0.0      0.99
  53          0.000     380.0      0.60      54.0     0.187       0.0      0.99
  54          0.000     380.0      0.60      54.0     0.187       0.0      0.99
  55          0.000     380.0      0.60      54.0     0.187       0.0      0.99
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56	0.000	380.0	0.60	54.0	0.187	0.0	0.99
57	0.000	380.0	0.60	54.0	0.187	0.0	0.99
58	0.000	380.0	0.60	54.0	0.187	0.0	0.99
61	0.000	280.0	1.00	61.0	0.149	0.0	0.95
62	0.000	280.0	1.00	61.0	0.149	0.0	0.95
63	0.000	280.0	1.00	61.0	0.149	0.0	0.95
64	0.000	280.0	1.00	61.0	0.149	0.0	0.95
65	0.000	280.0	1.00	61.0	0.149	0.0	0.95
66	0.000	280.0	1.00	61.0	0.149	0.0	0.95
67	0.000	280.0	1.00	61.0	0.149	0.0	0.95
68	0.000	280.0	1.00	61.0	0.149	0.0	0.95
71	0.000	280.0	1.00	48.0	0.217	0.0	0.95
72	0.000	280.0	1.00	48.0	0.217	0.0	0.95
73	0.000	280.0	1.00	48.0	0.217	0.0	0.95
74	0.000	280.0	1.00	48.0	0.217	0.0	0.95
75	0.000	280.0	1.00	48.0	0.217	0.0	0.95
76	0.000	280.0	1.00	48.0	0.217	0.0	0.95
77	0.000	280.0	1.00	48.0	0.217	0.0	0.95
78	0.000	280.0	1.00	48.0	0.217	0.0	0.95
81	0.000	280.0	1.00	31.0	0.300	0.0	0.95
82	0.000	280.0	1.00	31.0	0.300	0.0	0.95
83	0.000	280.0	1.00	31.0	0.300	0.0	0.95
84	0.000	280.0	1.00	31.0	0.300	0.0	0.95
85	0.000	280.0	1.00	31.0	0.300	0.0	0.95
86	0.000	280.0	1.00	31.0	0.300	0.0	0.95
87	0.000	280.0	1.00	31.0	0.300	0.0	0.95
88	0.000	280.0	1.00	31.0	0.300	0.0	0.95
91	0.000	280.0	1.00	58.0	0.165	0.0	0.95
92	0.000	280.0	1.00	58.0	0.165	0.0	0.95
93	0.000	280.0	1.00	58.0	0.165	0.0	0.95
94	0.000	280.0	1.00	58.0	0.165	0.0	0.95
95	0.000	280.0	1.00	58.0	0.165	0.0	0.95
96	0.000	280.0	1.00	58.0	0.165	0.0	0.95
97	0.000	280.0	1.00	58.0	0.165	0.0	0.95
98	0.000	280.0	1.00	58.0	0.165	0.0	0.95
101	0.000	280.0	1.00	34.0	0.284	0.0	0.95
102	0.000	280.0	1.00	34.0	0.284	0.0	0.95
103	0.000	280.0	1.00	34.0	0.284	0.0	0.95
104	0.000	280.0	1.00	34.0	0.284	0.0	0.95
105	0.000	280.0	1.00	34.0	0.284	0.0	0.95
106	0.000	280.0	1.00	34.0	0.284	0.0	0.95
107	0.000	280.0	1.00	34.0	0.284	0.0	0.95
108	0.000	280.0	1.00	34.0	0.284	0.0	0.95
111	0.000	280.0	1.00	31.0	0.300	0.0	0.95
112	0.000	280.0	1.00	31.0	0.300	0.0	0.95
113	0.000	280.0	1.00	31.0	0.300	0.0	0.95
114	0.000	280.0	1.00	31.0	0.300	0.0	0.95
115	0.000	280.0	1.00	31.0	0.300	0.0	0.95
116	0.000	280.0	1.00	31.0	0.300	0.0	0.95
117	0.000	280.0	1.00	31.0	0.300	0.0	0.95
118	0.000	280.0	1.00	31.0	0.300	0.0	0.95
121	0.000	280.0	1.00	51.0	0.202	0.0	0.95
122	0.000	280.0	1.00	51.0	0.202	0.0	0.95
123	0.000	280.0	1.00	51.0	0.202	0.0	0.95
124	0.000	280.0	1.00	51.0	0.202	0.0	0.95
125	0.000	280.0	1.00	51.0	0.202	0.0	0.95
126	0.000	280.0	1.00	51.0	0.202	0.0	0.95
127	0.000	280.0	1.00	51.0	0.202	0.0	0.95
128	0.000	280.0	1.00	51.0	0.202	0.0	0.95
131	0.000	280.0	1.00	55.0	0.181	0.0	0.95
132	0.000	280.0	1.00	55.0	0.181	0.0	0.95
133	0.000	280.0	1.00	55.0	0.181	0.0	0.95
134	0.000	280.0	1.00	55.0	0.181	0.0	0.95
135	0.000	280.0	1.00	55.0	0.181	0.0	0.95
136	0.000	280.0	1.00	55.0	0.181	0.0	0.95
137	0.000	280.0	1.00	55.0	0.181	0.0	0.95
138	0.000	280.0	1.00	55.0	0.181	0.0	0.95
141	0.000	280.0	1.00	84.0	0.115	0.0	0.95

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142          0.000    280.0     1.00      84.0    0.115      0.0    0.95
143          0.000    280.0     1.00      84.0    0.115      0.0    0.95
144          0.000    280.0     1.00      84.0    0.115      0.0    0.95
145          0.000    280.0     1.00      84.0    0.115      0.0    0.95
146          0.000    280.0     1.00      84.0    0.115      0.0    0.95
147          0.000    280.0     1.00      84.0    0.115      0.0    0.95
148          0.000    280.0     1.00      84.0    0.115      0.0    0.95
151          0.000    300.0     1.00      72.0    0.133      0.0    0.95
152          0.000    300.0     1.00      72.0    0.133      0.0    0.95
153          0.000    300.0     1.00      72.0    0.133      0.0    0.95
154          0.000    300.0     1.00      72.0    0.133      0.0    0.95
155          0.000    300.0     1.00      72.0    0.133      0.0    0.95
156          0.000    300.0     1.00      72.0    0.133      0.0    0.95
157          0.000    300.0     1.00      72.0    0.133      0.0    0.95
158          0.000    300.0     1.00      72.0    0.133      0.0    0.95
161          0.000    300.0     1.00      77.0    0.126      0.0    0.95
162          0.000    300.0     1.00      77.0    0.126      0.0    0.95
163          0.000    300.0     1.00      77.0    0.126      0.0    0.95
164          0.000    300.0     1.00      77.0    0.126      0.0    0.95
165          0.000    300.0     1.00      77.0    0.126      0.0    0.95
166          0.000    300.0     1.00      77.0    0.126      0.0    0.95
167          0.000    300.0     1.00      77.0    0.126      0.0    0.95
168          0.000    300.0     1.00      77.0    0.126      0.0    0.95
171          0.000    300.0     1.00     126.0    0.050      0.0    0.95
172          0.000    300.0     1.00     126.0    0.050      0.0    0.95
173          0.000    300.0     1.00     126.0    0.050      0.0    0.95
174          0.000    300.0     1.00     126.0    0.050      0.0    0.95
175          0.000    300.0     1.00     126.0    0.050      0.0    0.95
176          0.000    300.0     1.00     126.0    0.050      0.0    0.95
177          0.000    300.0     1.00     126.0    0.050      0.0    0.95
178          0.000    300.0     1.00     126.0    0.050      0.0    0.95
181          0.000    300.0     1.00     101.0    0.089      0.0    0.95
182          0.000    300.0     1.00     101.0    0.089      0.0    0.95
183          0.000    300.0     1.00     101.0    0.089      0.0    0.95
184          0.000    300.0     1.00     101.0    0.089      0.0    0.95
185          0.000    300.0     1.00     101.0    0.089      0.0    0.95
186          0.000    300.0     1.00     101.0    0.089      0.0    0.95
187          0.000    300.0     1.00     101.0    0.089      0.0    0.95
188          0.000    300.0     1.00     101.0    0.089      0.0    0.95
191          0.000    300.0     1.00     133.0    0.039      0.0    0.95
192          0.000    300.0     1.00     133.0    0.039      0.0    0.95
193          0.000    300.0     1.00     133.0    0.039      0.0    0.95
194          0.000    300.0     1.00     133.0    0.039      0.0    0.95
195          0.000    300.0     1.00     133.0    0.039      0.0    0.95
196          0.000    300.0     1.00     133.0    0.039      0.0    0.95
197          0.000    300.0     1.00     133.0    0.039      0.0    0.95
198          0.000    300.0     1.00     133.0    0.039      0.0    0.95
201          0.000    300.0     1.00     136.0    0.035      0.0    0.95
202          0.000    300.0     1.00     136.0    0.035      0.0    0.95
203          0.000    300.0     1.00     136.0    0.035      0.0    0.95
204          0.000    300.0     1.00     136.0    0.035      0.0    0.95
205          0.000    300.0     1.00     136.0    0.035      0.0    0.95
206          0.000    300.0     1.00     136.0    0.035      0.0    0.95
207          0.000    300.0     1.00     136.0    0.035      0.0    0.95
208          0.000    300.0     1.00     136.0    0.035      0.0    0.95
END PWAT-PARM2

PWAT-PARM3
  <PLS > ***  PWATER input info: Part 3
  # -  # ***PETMAX    PETMIN   INFEXP   INFILD   DEEPFR   BASETP   AGWETP
  11                              2.0      2.0     0.00      0.0     0.00
  12                              2.0      2.0     0.00      0.0     0.00
  13                              2.0      2.0     0.00      0.0     0.00
  14                              2.0      2.0     0.00      0.0     0.00
  15                              2.0      2.0     0.00      0.0     0.00
  16                              2.0      2.0     0.00      0.0     0.00
  17                              2.0      2.0     0.00      0.0     0.00
  18                              2.0      2.0     0.00      0.0     0.00
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21	2.0	2.0	0.00	0.0	0.00
22	2.0	2.0	0.00	0.0	0.00
23	2.0	2.0	0.00	0.0	0.00
24	2.0	2.0	0.00	0.0	0.00
25	2.0	2.0	0.00	0.0	0.00
26	2.0	2.0	0.00	0.0	0.00
27	2.0	2.0	0.00	0.0	0.00
28	2.0	2.0	0.00	0.0	0.00
31	2.0	2.0	0.00	0.0	0.00
32	2.0	2.0	0.00	0.0	0.00
33	2.0	2.0	0.00	0.0	0.00
34	2.0	2.0	0.00	0.0	0.00
35	2.0	2.0	0.00	0.0	0.00
36	2.0	2.0	0.00	0.0	0.00
37	2.0	2.0	0.00	0.0	0.00
38	2.0	2.0	0.00	0.0	0.00
41	2.0	2.0	0.00	0.0	0.00
42	2.0	2.0	0.00	0.0	0.00
43	2.0	2.0	0.00	0.0	0.00
44	2.0	2.0	0.00	0.0	0.00
45	2.0	2.0	0.00	0.0	0.00
46	2.0	2.0	0.00	0.0	0.00
47	2.0	2.0	0.00	0.0	0.00
48	2.0	2.0	0.00	0.0	0.00
51	2.0	2.0	0.00	0.0	0.00
52	2.0	2.0	0.00	0.0	0.00
53	2.0	2.0	0.00	0.0	0.00
54	2.0	2.0	0.00	0.0	0.00
55	2.0	2.0	0.00	0.0	0.00
56	2.0	2.0	0.00	0.0	0.00
57	2.0	2.0	0.00	0.0	0.00
58	2.0	2.0	0.00	0.0	0.00
61	2.0	2.0	0.00	0.0	0.00
62	2.0	2.0	0.00	0.0	0.00
63	2.0	2.0	0.00	0.0	0.00
64	2.0	2.0	0.00	0.0	0.00
65	2.0	2.0	0.00	0.0	0.00
66	2.0	2.0	0.00	0.0	0.00
67	2.0	2.0	0.00	0.0	0.00
68	2.0	2.0	0.00	0.0	0.00
71	2.0	2.0	0.00	0.0	0.00
72	2.0	2.0	0.00	0.0	0.00
73	2.0	2.0	0.00	0.0	0.00
74	2.0	2.0	0.00	0.0	0.00
75	2.0	2.0	0.00	0.0	0.00
76	2.0	2.0	0.00	0.0	0.00
77	2.0	2.0	0.00	0.0	0.00
78	2.0	2.0	0.00	0.0	0.00
81	2.0	2.0	0.00	0.0	0.00
82	2.0	2.0	0.00	0.0	0.00
83	2.0	2.0	0.00	0.0	0.00
84	2.0	2.0	0.00	0.0	0.00
85	2.0	2.0	0.00	0.0	0.00
86	2.0	2.0	0.00	0.0	0.00
87	2.0	2.0	0.00	0.0	0.00
88	2.0	2.0	0.00	0.0	0.00
91	2.0	2.0	0.00	0.0	0.00
92	2.0	2.0	0.00	0.0	0.00
93	2.0	2.0	0.00	0.0	0.00
94	2.0	2.0	0.00	0.0	0.00
95	2.0	2.0	0.00	0.0	0.00
96	2.0	2.0	0.00	0.0	0.00
97	2.0	2.0	0.00	0.0	0.00
98	2.0	2.0	0.00	0.0	0.00
101	2.0	2.0	0.00	0.0	0.00
102	2.0	2.0	0.00	0.0	0.00
103	2.0	2.0	0.00	0.0	0.00
104	2.0	2.0	0.00	0.0	0.00

105	2.0	2.0	0.00	0.0	0.00
106	2.0	2.0	0.00	0.0	0.00
107	2.0	2.0	0.00	0.0	0.00
108	2.0	2.0	0.00	0.0	0.00
111	2.0	2.0	0.00	0.0	0.00
112	2.0	2.0	0.00	0.0	0.00
113	2.0	2.0	0.00	0.0	0.00
114	2.0	2.0	0.00	0.0	0.00
115	2.0	2.0	0.00	0.0	0.00
116	2.0	2.0	0.00	0.0	0.00
117	2.0	2.0	0.00	0.0	0.00
118	2.0	2.0	0.00	0.0	0.00
121	2.0	2.0	0.00	0.0	0.00
122	2.0	2.0	0.00	0.0	0.00
123	2.0	2.0	0.00	0.0	0.00
124	2.0	2.0	0.00	0.0	0.00
125	2.0	2.0	0.00	0.0	0.00
126	2.0	2.0	0.00	0.0	0.00
127	2.0	2.0	0.00	0.0	0.00
128	2.0	2.0	0.00	0.0	0.00
131	2.0	2.0	0.00	0.0	0.00
132	2.0	2.0	0.00	0.0	0.00
133	2.0	2.0	0.00	0.0	0.00
134	2.0	2.0	0.00	0.0	0.00
135	2.0	2.0	0.00	0.0	0.00
136	2.0	2.0	0.00	0.0	0.00
137	2.0	2.0	0.00	0.0	0.00
138	2.0	2.0	0.00	0.0	0.00
141	2.0	2.0	0.00	0.0	0.00
142	2.0	2.0	0.00	0.0	0.00
143	2.0	2.0	0.00	0.0	0.00
144	2.0	2.0	0.00	0.0	0.00
145	2.0	2.0	0.00	0.0	0.00
146	2.0	2.0	0.00	0.0	0.00
147	2.0	2.0	0.00	0.0	0.00
148	2.0	2.0	0.00	0.0	0.00
151	2.0	2.0	0.00	0.0	0.00
152	2.0	2.0	0.00	0.0	0.00
153	2.0	2.0	0.00	0.0	0.00
154	2.0	2.0	0.00	0.0	0.00
155	2.0	2.0	0.00	0.0	0.00
156	2.0	2.0	0.00	0.0	0.00
157	2.0	2.0	0.00	0.0	0.00
158	2.0	2.0	0.00	0.0	0.00
161	2.0	2.0	0.00	0.0	0.00
162	2.0	2.0	0.00	0.0	0.00
163	2.0	2.0	0.00	0.0	0.00
164	2.0	2.0	0.00	0.0	0.00
165	2.0	2.0	0.00	0.0	0.00
166	2.0	2.0	0.00	0.0	0.00
167	2.0	2.0	0.00	0.0	0.00
168	2.0	2.0	0.00	0.0	0.00
171	2.0	2.0	0.00	0.0	0.00
172	2.0	2.0	0.00	0.0	0.00
173	2.0	2.0	0.00	0.0	0.00
174	2.0	2.0	0.00	0.0	0.00
175	2.0	2.0	0.00	0.0	0.00
176	2.0	2.0	0.00	0.0	0.00
177	2.0	2.0	0.00	0.0	0.00
178	2.0	2.0	0.00	0.0	0.00
181	2.0	2.0	0.00	0.0	0.00
182	2.0	2.0	0.00	0.0	0.00
183	2.0	2.0	0.00	0.0	0.00
184	2.0	2.0	0.00	0.0	0.00
185	2.0	2.0	0.00	0.0	0.00
186	2.0	2.0	0.00	0.0	0.00
187	2.0	2.0	0.00	0.0	0.00
188	2.0	2.0	0.00	0.0	0.00

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191                       2.0       2.0      0.00       0.0      0.00
192                       2.0       2.0      0.00       0.0      0.00
193                       2.0       2.0      0.00       0.0      0.00
194                       2.0       2.0      0.00       0.0      0.00
195                       2.0       2.0      0.00       0.0      0.00
196                       2.0       2.0      0.00       0.0      0.00
197                       2.0       2.0      0.00       0.0      0.00
198                       2.0       2.0      0.00       0.0      0.00
201                       2.0       2.0      0.00       0.0      0.00
202                       2.0       2.0      0.00       0.0      0.00
203                       2.0       2.0      0.00       0.0      0.00
204                       2.0       2.0      0.00       0.0      0.00
205                       2.0       2.0      0.00       0.0      0.00
206                       2.0       2.0      0.00       0.0      0.00
207                       2.0       2.0      0.00       0.0      0.00
208                       2.0       2.0      0.00       0.0      0.00
END PWAT-PARM3

PWAT-PARM4
  <PLS >      PWATER input info: Part 4                          ***
  # -  #     CEPSC      UZSN      NSUR     INTFW       IRC     LZETP ***
 11           4.45     19.40      0.40       2.5      0.70      0.80
 21           4.45     19.40      0.40       2.5      0.70      0.80
 31           4.45     19.40      0.40       2.5      0.70      0.80
 41           4.45     19.40      0.40       2.5      0.70      0.80
 51           4.45     19.40      0.40       2.5      0.70      0.80
 61           4.45     29.40      0.40       2.5      0.70      0.80
 71           4.45     29.40      0.40       2.5      0.70      0.80
 81           4.45     29.40      0.40       2.5      0.70      0.80
 91           4.45     29.40      0.40       2.5      0.70      0.80
101           4.45     29.40      0.40       2.5      0.70      0.80
111           4.45     29.40      0.40       2.5      0.70      0.80
121           4.45     29.40      0.40       2.5      0.70      0.80
131           4.45     29.40      0.40       2.5      0.70      0.80
141           4.45     29.40      0.40       2.5      0.70      0.80
151           4.45     29.40      0.40       2.5      0.70      0.80
161           4.45     29.40      0.40       2.5      0.70      0.80
171           4.45     29.40      0.40       2.5      0.70      0.80
181           4.45     29.40      0.40       2.5      0.70      0.80
191           4.45     29.40      0.40       2.5      0.70      0.80
201           4.45     29.40      0.40       2.5      0.70      0.80
 12           3.50     16.80      0.25       3.0      0.70      0.60
 22           3.50     16.80      0.25       3.0      0.70      0.60
 32           3.50     16.80      0.25       3.0      0.70      0.60
 42           3.50     16.80      0.25       3.0      0.70      0.60
 52           3.50     16.80      0.25       3.0      0.70      0.60
 62           3.50     16.80      0.25       3.0      0.70      0.60
 72           3.50     16.80      0.25       3.0      0.70      0.60
 82           3.50     16.80      0.25       3.0      0.70      0.60
 92           3.50     16.80      0.25       3.0      0.70      0.60
102           3.50     16.80      0.25       3.0      0.70      0.60
112           3.50     16.80      0.25       3.0      0.70      0.60
122           3.50     16.80      0.25       3.0      0.70      0.60
132           3.50     16.80      0.25       3.0      0.70      0.60
142           3.50     16.80      0.25       3.0      0.70      0.60
152           3.50     16.80      0.25       3.0      0.70      0.60
162           3.50     16.80      0.25       3.0      0.70      0.60
172           3.50     16.80      0.25       3.0      0.70      0.60
182           3.50     16.80      0.25       3.0      0.70      0.60
192           3.50     16.80      0.25       3.0      0.70      0.60
202           3.50     16.80      0.25       3.0      0.70      0.60
 13           2.54      5.80      0.20       3.0      0.70      0.50
 23           2.54      5.80      0.20       3.0      0.70      0.50
 33           2.54      5.80      0.20       3.0      0.70      0.50
 43           2.54      5.80      0.20       3.0      0.70      0.50
 53           2.54      5.80      0.20       3.0      0.70      0.50
 63           2.54     16.80      0.20       3.0      0.70      0.50
 73           2.54     16.80      0.20       3.0      0.70      0.50
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83	2.54	16.80	0.20	3.0	0.70	0.50
93	2.54	16.80	0.20	3.0	0.70	0.50
103	2.54	16.80	0.20	3.0	0.70	0.50
113	2.54	16.80	0.20	3.0	0.70	0.50
123	2.54	16.80	0.20	3.0	0.70	0.50
133	2.54	16.80	0.20	3.0	0.70	0.50
143	2.54	16.80	0.20	3.0	0.70	0.50
153	2.54	16.80	0.20	3.0	0.70	0.50
163	2.54	16.80	0.20	3.0	0.70	0.50
173	2.54	16.80	0.20	3.0	0.70	0.50
183	2.54	16.80	0.20	3.0	0.70	0.50
193	2.54	16.80	0.20	3.0	0.70	0.50
203	2.54	16.80	0.20	3.0	0.70	0.50
14	0.25	2.54	0.10	1.5	0.70	0.10
24	0.25	2.54	0.10	1.5	0.70	0.10
34	0.25	2.54	0.10	1.5	0.70	0.10
44	0.25	2.54	0.10	1.5	0.70	0.10
54	0.25	2.54	0.10	1.5	0.70	0.10
64	0.25	2.54	0.10	1.5	0.70	0.10
74	0.25	2.54	0.10	1.5	0.70	0.10
84	0.25	2.54	0.10	1.5	0.70	0.10
94	0.25	2.54	0.10	1.5	0.70	0.10
104	0.25	2.54	0.10	1.5	0.70	0.10
114	0.25	2.54	0.10	1.5	0.70	0.10
124	0.25	2.54	0.10	1.5	0.70	0.10
134	0.25	2.54	0.10	1.5	0.70	0.10
144	0.25	2.54	0.10	1.5	0.70	0.10
154	0.25	2.54	0.10	1.5	0.70	0.10
164	0.25	2.54	0.10	1.5	0.70	0.10
174	0.25	2.54	0.10	1.5	0.70	0.10
184	0.25	2.54	0.10	1.5	0.70	0.10
194	0.25	2.54	0.10	1.5	0.70	0.10
204	0.25	2.54	0.10	1.5	0.70	0.10
15	1.05	6.50	0.14	1.5	0.70	0.20
25	1.05	6.50	0.14	1.5	0.70	0.20
35	1.05	6.50	0.14	1.5	0.70	0.20
45	1.05	6.50	0.14	1.5	0.70	0.20
55	1.05	6.50	0.14	1.5	0.70	0.20
65	1.05	6.50	0.14	1.5	0.70	0.20
75	1.05	6.50	0.14	1.5	0.70	0.20
85	1.05	6.50	0.14	1.5	0.70	0.20
95	1.05	6.50	0.14	1.5	0.70	0.20
105	1.05	6.50	0.14	1.5	0.70	0.20
115	1.05	6.50	0.14	1.5	0.70	0.20
125	1.05	6.50	0.14	1.5	0.70	0.20
135	1.05	6.50	0.14	1.5	0.70	0.20
145	1.05	6.50	0.14	1.5	0.70	0.20
155	1.05	6.50	0.14	1.5	0.70	0.20
165	1.05	6.50	0.14	1.5	0.70	0.20
175	1.05	6.50	0.14	1.5	0.70	0.20
185	1.05	6.50	0.14	1.5	0.70	0.20
195	1.05	6.50	0.14	1.5	0.70	0.20
205	1.05	6.50	0.14	1.5	0.70	0.20
16	1.85	10.00	0.15	1.8	0.70	0.35
26	1.85	10.00	0.15	1.8	0.70	0.35
36	1.85	10.00	0.15	1.8	0.70	0.35
46	1.85	10.00	0.15	1.8	0.70	0.35
56	1.85	10.00	0.15	1.8	0.70	0.35
66	1.85	10.00	0.15	1.8	0.70	0.40
76	1.85	10.00	0.15	1.8	0.70	0.40
86	1.85	10.00	0.15	1.8	0.70	0.40
96	1.85	10.00	0.15	1.8	0.70	0.40
106	1.85	10.00	0.15	1.8	0.70	0.40
116	1.85	10.00	0.15	1.8	0.70	0.40
126	1.85	10.00	0.15	1.8	0.70	0.40
136	1.85	10.00	0.15	1.8	0.70	0.40
146	1.85	10.00	0.15	1.8	0.70	0.40
156	1.85	10.00	0.15	1.8	0.70	0.40

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166           1.85   10.00    0.15     1.8     0.70     0.40
176           1.85   10.00    0.15     1.8     0.70     0.40
186           1.85   10.00    0.15     1.8     0.70     0.40
196           1.85   10.00    0.15     1.8     0.70     0.40
206           1.85   10.00    0.15     1.8     0.70     0.40
 17           0.76    3.50    0.12     1.0     0.70     0.15
 27           0.76    3.50    0.12     1.0     0.70     0.15
 37           0.76    3.50    0.12     1.0     0.70     0.15
 47           0.76    3.50    0.12     1.0     0.70     0.15
 57           0.76    3.50    0.12     1.0     0.70     0.15
 67           0.76    3.50    0.12     1.0     0.70     0.15
 77           0.76    3.50    0.12     1.0     0.70     0.15
 87           0.76    3.50    0.12     1.0     0.70     0.15
 97           0.76    3.50    0.12     1.0     0.70     0.15
107           0.76    3.50    0.12     1.0     0.70     0.15
117           0.76    3.50    0.12     1.0     0.70     0.15
127           0.76    3.50    0.12     1.0     0.70     0.15
137           0.76    3.50    0.12     1.0     0.70     0.15
147           0.76    3.50    0.12     1.0     0.70     0.15
157           0.76    3.50    0.12     1.0     0.70     0.15
167           0.76    3.50    0.12     1.0     0.70     0.15
177           0.76    3.50    0.12     1.0     0.70     0.15
187           0.76    3.50    0.12     1.0     0.70     0.15
197           0.76    3.50    0.12     1.0     0.70     0.15
207           0.76    3.50    0.12     1.0     0.70     0.15
 18           2.00   10.00    0.30     2.0     0.70     0.75
 28           2.00   10.00    0.30     2.0     0.70     0.75
 38           2.00   10.00    0.30     2.0     0.70     0.75
 48           2.00   10.00    0.30     2.0     0.70     0.75
 58           2.00   10.00    0.30     2.0     0.70     0.75
 68           2.00   10.00    0.30     2.0     0.70     0.75
 78           2.00   10.00    0.30     2.0     0.70     0.75
 88           2.00   10.00    0.30     2.0     0.70     0.75
 98           2.00   10.00    0.30     2.0     0.70     0.75
108           2.00   10.00    0.30     2.0     0.70     0.75
118           2.00   10.00    0.30     2.0     0.70     0.75
128           2.00   10.00    0.30     2.0     0.70     0.75
138           2.00   10.00    0.30     2.0     0.70     0.75
148           2.00   10.00    0.30     2.0     0.70     0.75
158           2.00   10.00    0.30     2.0     0.70     0.75
168           2.00   10.00    0.30     2.0     0.70     0.75
178           2.00   10.00    0.30     2.0     0.70     0.75
188           2.00   10.00    0.30     2.0     0.70     0.75
198           2.00   10.00    0.30     2.0     0.70     0.75
208           2.00   10.00    0.30     2.0     0.70     0.75
END PWAT-PARM4

PWAT-PARM5 Defaults used ***

MON-INTERCEP
  <PLS>    Only required if VCSFG=1 in PWAT-PARM1                       ***
  # -  #   Interception storage capacity at start of each month         ***
           JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC ***
 12       4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
 13       4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
 22       4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
 23       4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
 32       4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
 33       4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
 42       4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
 43       4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
 52       4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
 53       4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
 62       4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
 63       4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
 72       4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
 73       4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
 82       4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
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 83       4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
 92       4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
 93       4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
102       4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
103       4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
112       4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
113       4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
122       4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
123       4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
132       4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
133       4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
142       4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
143       4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
152       4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
153       4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
162       4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
163       4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
172       4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
173       4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
182       4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
183       4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
192       4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
193       4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
202       4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
203       4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
END MON-INTERCEP

MON-LZETPARM
  <PLS >  Only required if VLEFG=1 in PWAT-PARM1                        ***
  # -  #  Lower zone ET parameter at start of each month               ***
           JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC   ***
 12       0.65 0.70 0.60 0.30 0.20 0.15 0.15 0.15 0.20 0.25 0.30 0.40
 13       0.55 0.60 0.50 0.20 0.20 0.20 0.20 0.20 0.25 0.30 0.35 0.40
 22       0.65 0.70 0.60 0.30 0.20 0.15 0.15 0.15 0.20 0.25 0.30 0.40
 23       0.55 0.60 0.50 0.20 0.20 0.20 0.20 0.20 0.25 0.30 0.35 0.40
 32       0.65 0.70 0.60 0.30 0.20 0.15 0.15 0.15 0.20 0.25 0.30 0.40
 33       0.55 0.60 0.50 0.20 0.20 0.20 0.20 0.20 0.25 0.30 0.35 0.40
 42       0.65 0.70 0.60 0.30 0.20 0.15 0.15 0.15 0.20 0.25 0.30 0.40
 43       0.55 0.60 0.50 0.20 0.20 0.20 0.20 0.20 0.25 0.30 0.35 0.40
 52       0.65 0.70 0.60 0.30 0.20 0.15 0.15 0.15 0.20 0.25 0.30 0.40
 53       0.55 0.60 0.50 0.20 0.20 0.20 0.20 0.20 0.25 0.30 0.35 0.40
 62       0.60 0.70 0.60 0.30 0.20 0.15 0.15 0.15 0.20 0.25 0.30 0.40
 63       0.55 0.60 0.50 0.20 0.20 0.20 0.20 0.20 0.25 0.30 0.35 0.40
 72       0.60 0.70 0.60 0.20 0.20 0.15 0.15 0.15 0.20 0.25 0.30 0.40
 73       0.55 0.60 0.50 0.20 0.20 0.20 0.20 0.20 0.25 0.30 0.35 0.40
 82       0.60 0.70 0.60 0.20 0.20 0.15 0.15 0.15 0.20 0.25 0.30 0.40
 83       0.55 0.60 0.50 0.20 0.20 0.20 0.20 0.20 0.25 0.30 0.35 0.40
 92       0.60 0.70 0.60 0.20 0.20 0.15 0.15 0.15 0.20 0.25 0.30 0.40
 93       0.55 0.60 0.50 0.20 0.20 0.20 0.20 0.20 0.25 0.30 0.35 0.40
102       0.60 0.70 0.60 0.20 0.20 0.15 0.15 0.15 0.20 0.25 0.30 0.40
103       0.55 0.60 0.50 0.20 0.20 0.20 0.20 0.20 0.25 0.30 0.35 0.40
112       0.60 0.70 0.60 0.20 0.20 0.15 0.15 0.15 0.20 0.25 0.30 0.40
113       0.55 0.60 0.50 0.20 0.20 0.20 0.20 0.20 0.25 0.30 0.35 0.40
122       0.60 0.70 0.60 0.20 0.20 0.15 0.15 0.15 0.20 0.25 0.30 0.40
123       0.55 0.60 0.50 0.20 0.20 0.20 0.20 0.20 0.25 0.30 0.35 0.40
132       0.60 0.70 0.60 0.20 0.20 0.15 0.15 0.15 0.20 0.25 0.30 0.40
133       0.55 0.60 0.50 0.20 0.20 0.20 0.20 0.20 0.25 0.30 0.35 0.40
142       0.60 0.70 0.60 0.20 0.20 0.15 0.15 0.15 0.20 0.25 0.30 0.40
143       0.55 0.60 0.50 0.20 0.20 0.20 0.20 0.20 0.25 0.30 0.35 0.40
152       0.60 0.70 0.60 0.20 0.20 0.15 0.15 0.15 0.20 0.25 0.30 0.40
153       0.55 0.60 0.50 0.20 0.20 0.20 0.20 0.20 0.25 0.30 0.35 0.40
162       0.60 0.70 0.60 0.20 0.20 0.15 0.15 0.15 0.20 0.25 0.30 0.40
163       0.55 0.60 0.50 0.20 0.20 0.20 0.20 0.20 0.25 0.30 0.35 0.40
172       0.60 0.70 0.60 0.20 0.20 0.15 0.15 0.15 0.20 0.25 0.30 0.40
173       0.55 0.60 0.50 0.20 0.20 0.20 0.20 0.20 0.25 0.30 0.35 0.40
182       0.60 0.70 0.60 0.20 0.20 0.15 0.15 0.15 0.20 0.25 0.30 0.40
183       0.55 0.60 0.50 0.20 0.20 0.20 0.20 0.20 0.25 0.30 0.35 0.40
192       0.60 0.70 0.60 0.20 0.20 0.15 0.15 0.15 0.20 0.25 0.30 0.40
```

```
193       0.55 0.60 0.50 0.20 0.20 0.20 0.20 0.20 0.25 0.30 0.35 0.40
202       0.60 0.70 0.60 0.20 0.20 0.15 0.15 0.15 0.20 0.25 0.30 0.40
203       0.55 0.60 0.50 0.20 0.20 0.20 0.20 0.20 0.25 0.30 0.35 0.40
END MON-LZETPARM

PWAT-STATE1
  <PLS > *** Initial conditions at start of simulation
  # -  # ***  CEPS      SURS       UZS      IFWS       LZS      AGWS      GWVS
 11  208      0.00       0.0     11.94       0.0     300.0      25.4       0.0
END PWAT-STATE1

END PERLND

IMPLND
ACTIVITY
  <ILS >  Active Sections              ***
  # -  # ATMP SNOW IWAT  SLD  IWG IQAL ***
 14  207            1              1
END ACTIVITY

PRINT-INFO
  <ILS >  Print-flags                            ***
  # -  # ATMP SNOW IWAT  SLD  IWG IQAL PIVL  PYR ***
 14  207            4                         09
END PRINT-INFO

GEN-INFO
  <ILS ><-------Name------->  Unit-systems   Printer ***
  # -  #                        t-series Engl Metr ***
                                 in  out          ***
 14       HD Urban, Indust.       2    2    0   64
 15       MD Residential          2    2    0   64
 17       HD Residential          2    2    0   64
 24       HD Urban, Indust.       2    2    0   64
 25       MD Residential          2    2    0   64
 27       HD Residential          2    2    0   64
 34       HD Urban, Indust.       2    2    0   64
 35       MD Residential          2    2    0   64
 37       HD Residential          2    2    0   64
 44       HD Urban, Indust.       2    2    0   64
 45       MD Residential          2    2    0   64
 47       HD Residential          2    2    0   64
 54       HD Urban, Indust.       2    2    0   64
 55       MD Residential          2    2    0   64
 57       HD Residential          2    2    0   64
 64       HD Urban, Indust.       2    2    0   64
 65       MD Residential          2    2    0   64
 67       HD Residential          2    2    0   64
 74       HD Urban, Indust.       2    2    0   64
 75       MD Residential          2    2    0   64
 77       HD Residential          2    2    0   64
 84       HD Urban, Indust.       2    2    0   64
 85       MD Residential          2    2    0   64
 87       HD Residential          2    2    0   64
 94       HD Urban, Indust.       2    2    0   64
 95       MD Residential          2    2    0   64
 97       HD Residential          2    2    0   64
104       HD Urban, Indust.       2    2    0   64
105       MD Residential          2    2    0   64
107       HD Residential          2    2    0   64
114       HD Urban, Indust.       2    2    0   64
115       MD Residential          2    2    0   64
117       HD Residential          2    2    0   64
124       HD Urban, Indust.       2    2    0   64
125       MD Residential          2    2    0   64
127       HD Residential          2    2    0   64
134       HD Urban, Indust.       2    2    0   64
135       MD Residential          2    2    0   64
```

```
  193       0.55 0.60 0.50 0.20 0.20 0.20 0.20 0.20 0.25 0.30 0.35 0.40
  202       0.60 0.70 0.60 0.20 0.20 0.15 0.15 0.15 0.20 0.25 0.30 0.40
  203       0.55 0.60 0.50 0.20 0.20 0.20 0.20 0.20 0.25 0.30 0.35 0.40
  END MON-LZETPARM

  PWAT-STATE1
    <PLS > *** Initial conditions at start of simulation
    # -  # ***  CEPS      SURS       UZS      IFWS       LZS      AGWS      GWVS
   11  208      0.00       0.0     11.94       0.0     300.0      25.4       0.0
  END PWAT-STATE1

END PERLND

IMPLND
  ACTIVITY
    <ILS >  Active Sections                    ***
    # -  # ATMP SNOW IWAT  SLD  IWG IQAL ***
   14  207              1              1
  END ACTIVITY

  PRINT-INFO
    <ILS >  Print-flags                                   ***
    # -  # ATMP SNOW IWAT  SLD  IWG IQAL PIVL  PYR ***
   14  207              4                        09
  END PRINT-INFO

  GEN-INFO
    <ILS ><-------Name-------> Unit-systems  Printer ***
    # -  #                       t-series Engl Metr ***
                                   in  out           ***
   14       HD Urban, Indust.       2    2    0   64
   15       MD Residential          2    2    0   64
   17       HD Residential          2    2    0   64
   24       HD Urban, Indust.       2    2    0   64
   25       MD Residential          2    2    0   64
   27       HD Residential          2    2    0   64
   34       HD Urban, Indust.       2    2    0   64
   35       MD Residential          2    2    0   64
   37       HD Residential          2    2    0   64
   44       HD Urban, Indust.       2    2    0   64
   45       MD Residential          2    2    0   64
   47       HD Residential          2    2    0   64
   54       HD Urban, Indust.       2    2    0   64
   55       MD Residential          2    2    0   64
   57       HD Residential          2    2    0   64
   64       HD Urban, Indust.       2    2    0   64
   65       MD Residential          2    2    0   64
   67       HD Residential          2    2    0   64
   74       HD Urban, Indust.       2    2    0   64
   75       MD Residential          2    2    0   64
   77       HD Residential          2    2    0   64
   84       HD Urban, Indust.       2    2    0   64
   85       MD Residential          2    2    0   64
   87       HD Residential          2    2    0   64
   94       HD Urban, Indust.       2    2    0   64
   95       MD Residential          2    2    0   64
   97       HD Residential          2    2    0   64
  104       HD Urban, Indust.       2    2    0   64
  105       MD Residential          2    2    0   64
  107       HD Residential          2    2    0   64
  114       HD Urban, Indust.       2    2    0   64
  115       MD Residential          2    2    0   64
  117       HD Residential          2    2    0   64
  124       HD Urban, Indust.       2    2    0   64
  125       MD Residential          2    2    0   64
  127       HD Residential          2    2    0   64
  134       HD Urban, Indust.       2    2    0   64
  135       MD Residential          2    2    0   64
```

```
137       HD Residential               2     2     0    64
144       HD Urban, Indust.            2     2     0    64
145       MD Residential               2     2     0    64
147       HD Residential               2     2     0    64
154       HD Urban, Indust.            2     2     0    64
155       MD Residential               2     2     0    64
157       HD Residential               2     2     0    64
164       HD Urban, Indust.            2     2     0    64
165       MD Residential               2     2     0    64
177       HD Residential               2     2     0    64
184       HD Urban, Indust.            2     2     0    64
185       MD Residential               2     2     0    64
187       HD Residential               2     2     0    64
194       HD Urban, Indust.            2     2     0    64
195       MD Residential               2     2     0    64
197       HD Residential               2     2     0    64
204       HD Urban, Indust.            2     2     0    64
205       MD Residential               2     2     0    64
207       HD Residential               2     2     0    64
END GEN-INFO
*** Section IWATER ***

IWAT-PARM1 defaults used ***

IWAT-PARM2
  <ILS >                                           ***
   # -  #       LSUR     SLSUR       NSUR      RETSC ***
  14            29.0     0.117      0.050       2.54
  15            29.0     0.117      0.100       2.54
  17            29.0     0.117      0.075       2.54
  24            16.0     0.147      0.050       2.54
  25            16.0     0.147      0.100       2.54
  27            16.0     0.147      0.075       2.54
  34            40.0     0.092      0.050       2.54
  35            40.0     0.092      0.100       2.54
  37            40.0     0.092      0.075       2.54
  44            17.0     0.146      0.050       2.54
  45            17.0     0.146      0.100       2.54
  47            17.0     0.146      0.075       2.54
  54            15.0     0.150      0.050       2.54
  55            15.0     0.150      0.100       2.54
  57            15.0     0.150      0.075       2.54
  64            16.0     0.149      0.050       2.54
  65            16.0     0.149      0.100       2.54
  67            16.0     0.149      0.075       2.54
  74            15.0     0.150      0.050       2.54
  75            15.0     0.150      0.100       2.54
  77            15.0     0.150      0.075       2.54
  84            15.0     0.150      0.050       2.54
  85            15.0     0.150      0.100       2.54
  87            15.0     0.150      0.075       2.54
  94            15.0     0.150      0.050       2.54
  95            15.0     0.150      0.100       2.54
  97            15.0     0.150      0.075       2.54
 104            15.0     0.150      0.050       2.54
 105            15.0     0.150      0.100       2.54
 107            15.0     0.150      0.075       2.54
 114            15.0     0.150      0.050       2.54
 115            15.0     0.150      0.100       2.54
 117            15.0     0.150      0.075       2.54
 124            15.0     0.150      0.050       2.54
 125            15.0     0.150      0.100       2.54
 127            15.0     0.150      0.075       2.54
 134            15.0     0.150      0.050       2.54
 135            15.0     0.150      0.100       2.54
 137            15.0     0.150      0.075       2.54
 144            30.0     0.115      0.050       2.54
 145            30.0     0.115      0.100       2.54
```

```
  147            30.0    0.115     0.075      2.54
  154            22.0    0.133     0.050      2.54
  155            22.0    0.133     0.100      2.54
  157            22.0    0.133     0.075      2.54
  164            26.0    0.126     0.050      2.54
  165            26.0    0.126     0.100      2.54
  167            26.0    0.126     0.075      2.54
  174            59.0    0.050     0.050      2.54
  175            59.0    0.050     0.100      2.54
  177            59.0    0.050     0.075      2.54
  184            42.0    0.089     0.050      2.54
  185            42.0    0.089     0.100      2.54
  187            42.0    0.089     0.075      2.54
  194            63.0    0.039     0.050      2.54
  195            63.0    0.039     0.100      2.54
  197            63.0    0.039     0.075      2.54
  204            65.0    0.035     0.050      2.54
  205            65.0    0.035     0.100      2.54
  207            65.0    0.035     0.075      2.54
  END IWAT-PARM2

  IWAT-PARM3 *** defaults used

  IWAT-STATE1
    <ILS >  IWATER state variables ***
    # -  #        RETS      SURS      ***
   14  207        0.00      0.00
  END IWAT-STATE1

END IMPLND

RCHRES

  ACTIVITY
    RCHRES  Active Sections (1=Active; 0=Inactive)           ***
    # -  # HYFG ADFG CNFG HTFG SDFG GQFG OXFG NUFG PKFG PHFG ***
    1   20    1
  END ACTIVITY

  PRINT-INFO
              Print-flags                                          ***
    # -  # HYDR ADCA CONS HEAT  SED  GQL OXRX NUTR PLNK   PH     PYR ***
    1   20    5    6    6    6    6    6    6    6    6    6      09
  END PRINT-INFO

  GEN-INFO
    RCHRES<-------Name------->Nexit   Unit Systems   Printer      ***
    # -  #                          User t-series  Engl Metr LKFG ***
                                           in  out                ***
    1      Reach 1                 1       2    2     0   62    0
    2      Reach 2                 1       2    2     0   62    0
    3      Reach 3                 1       2    2     0   62    0
    4      Reach 4                 1       2    2     0   62    0
    5      Reach 5                 1       2    2     0   62    0
    6      Reach 6                 1       2    2     0   62    0
    7      Reach 7                 1       2    2     0   62    0
    8      Reach 8                 1       2    2     0   62    0
    9      Henley Dam              3       2    2     0   62    1
   10      Reach 10                1       2    2     0   62    0
   11      Reach 11                1       2    2     0   62    0
   12      Reach 12                1       2    2     0   62    0
   13      Reach 13                1       2    2     0   62    0
   14      Reach 14                1       2    2     0   62    0
   15      Reach 15                1       2    2     0   62    0
   16      Reach 16                1       2    2     0   62    0
   17      Reach 17                1       2    2     0   62    0
   18      Reach 18                1       2    2     0   62    0
   19      Reach 19                1       2    2     0   62    0
```

```
 20    Camp's Drift weir           1          2    2    0   62    1
END GEN-INFO

HYDR-PARM1
  RCHRES  Flags for HYDR section                              ***
  # -  #  VC A1 A2 A3  ODFVFG for each      ODGTFG for each *** FUNCT  for each
          FG FG FG FG  possible   exit      possible   exit *** possible   exit
              1  2  3    1  2  3  4  5        1  2  3  4  5 ***    1  2  3  4  5
  1    8   0  1  0  0    4
  9        0  1  0  0       4  5              1
 10   20   0  1  0  0    4
END HYDR-PARM1

HYDR-PARM2
  RCHRES ***
  # -  #     FTABNO       LEN      DELTH      STCOR         KS      DB50 ***
  *** The values of DB50 are needed by the Colby and Toffaleti sediment
  *** transport methods.  We will use the default (6.35mm)
  1              1     12.893     292.50                   0.5
  2              2     13.460     195.00                   0.5
  3              3      1.702      10.53                   0.5
  4              4      5.355     288.12                   0.5
  5              5     12.446     100.74                   0.5
  6              6      0.576       0.50                   0.5
  7              7      9.538     326.25                   0.5
  8              8      5.237     300.00                   0.5
  9              9      2.423       3.75                   0.5
 10             10      9.450     172.50                   0.5
 11             11      9.227     405.00                   0.5
 12             12      5.692      29.06                   0.5
 13             13      9.233     422.81                   0.5
 14             14      4.777      29.43                   0.5
 15             15     10.215     243.75                   0.5
 16             16      7.869     213.75                   0.5
 17             17      1.779      11.25                   0.5
 18             18      1.784       0.07                   0.5
 19             19      1.140       0.09                   0.5
 20             20      0.918       1.08                   0.5 ***
 20             20      2.900       1.72                   0.5
END HYDR-PARM2

HYDR-INIT
  Reaches are assumed initially empty, except Henley Dam ***
RCHRES          VOL  CAT Initial value  of COLIND *** initial  value  of OUTDGT
  # -  #        Mm3      for each possible   exit *** for  each  possible  exit
                           EX1  EX2  EX3  EX4  EX5 ***   EX1  EX2  EX3  EX4  EX5
  1    8        0.0
  9             1.4
 10   20        0.0
END HYDR-INIT

END RCHRES

PLTGEN
  PLOTINFO
  # -  # FILE  NPT  NMN LABL  PYR PIVL ***
  1        92    1    1              1
  END PLOTINFO

  GEN-LABELS
  # -  #<----------------Title----------------->   ***   <------Y axis------>
  1     OBSERVED FLOW                                     m3/s
  END GEN-LABELS

  SCALING
  # -  #      YMIN      YMAX     IVLIN    THRESH ***
  1             0.      100.       20.
  END SCALING
```

```
  CURV-DATA          (first curve)
             <-Curve label--> Line Intg  Col Tran ***
   # - #                      type  eqv code code ***
   1         SIM FLOW                 1    1 AVER
 END CURV-DATA

 CURV-DATA          (second curve)
             <-Curve label--> Line Intg  Col Tran ***
   # - #                      type  eqv code code ***
   1         OBS FLOW                 2    2 AVER
 END CURV-DATA

END PLTGEN

*** FTABLES

FTABLES

  FTABLE      1
 ROWS COLS ***
  20    4
     DEPTH      AREA    VOLUME     DISCH  FLO-THRU ***
     ( m)    (   HA)    (Mm3)     (CMS)     (MIN) ***
     0.000     0.000     0.000     0.000      0.00
     0.250     2.580     0.003     0.205    262.44
     0.500     5.160     0.013     1.301    165.29
     0.750     7.740     0.029     3.836    126.12
     0.975     8.170     0.047     8.063     96.99
     1.200     8.600     0.066    13.429     81.65
     1.425     9.030     0.086    19.834     71.95
     1.650     9.460     0.106    27.223     65.16
     1.875     9.890     0.128    35.566     60.07
     2.100    10.320     0.151    44.846     56.09
     2.550    11.180     0.199    66.200     50.18
     3.000    12.040     0.252    91.300     45.92
     3.450    12.900     0.308   120.215     42.65
     4.350    38.030     0.537   227.077     39.40
     5.250    63.160     0.992   447.162     36.98
     6.150    88.290     1.674   838.172     33.28
     7.050   113.419     2.581  1447.822     29.72
     7.950   138.549     3.715  2318.668     26.71
     8.850   163.679     5.075  3489.855     24.24
     9.750   188.809     6.662  4998.028     22.21
  END FTABLE  1

  FTABLE      2
 ROWS COLS ***
  20    4
     DEPTH      AREA    VOLUME     DISCH  FLO-THRU ***
     ( m)    (   HA)    (Mm3)     (CMS)     (MIN) ***
     0.000     0.000     0.000     0.000      0.00
     0.250     2.250     0.003     0.122    385.61
     0.500     4.500     0.011     0.772    242.86
     0.750     6.750     0.025     2.277    185.31
     1.017     7.256     0.044     5.288    138.65
     1.283     7.762     0.064     9.212    115.81
     1.550     8.269     0.085    13.976    101.83
     1.817     8.775     0.108    19.544     92.19
     2.083     9.281     0.132    25.906     85.04
     2.350     9.788     0.158    33.060     79.46
     2.883    10.800     0.213    49.774     71.16
     3.417    11.812     0.273    69.780     65.16
     3.950    12.825     0.339    93.205     60.53
     5.017    41.284     0.627   189.419     55.18
     6.083    69.742     1.219   410.871     49.46
     7.150    98.201     2.115   823.976     42.78
     8.217   126.659     3.314  1483.643     37.23
     9.283   155.118     4.817  2438.824     32.92
```

```
   10.350    183.576      6.623  3734.532       29.56
   11.417    212.035      8.733  5412.887       26.89
 END FTABLE   2

 FTABLE       3
ROWS COLS ***
  20     4
    DEPTH       AREA    VOLUME      DISCH   FLO-THRU ***
     ( m)    (   HA)     (Mm3)      (CMS)      (MIN) ***
    0.000      0.000     0.000      0.000       0.00
    0.250      0.283     0.000      0.099      59.41
    0.500      0.567     0.001      0.631      37.41
    0.750      0.850     0.003      1.861      28.55
    0.950      0.914     0.005      3.628      22.75
    1.150      0.978     0.007      5.855      19.48
    1.350      1.041     0.009      8.523      17.33
    1.550      1.105     0.011     11.624      15.78
    1.750      1.169     0.013     15.157      14.60
    1.950      1.233     0.016     19.127      13.67
    2.350      1.360     0.021     28.401      12.25
    2.750      1.488     0.027     39.512      11.20
    3.150      1.615     0.033     52.536      10.40
    3.950      4.478     0.057     99.617       9.56
    4.750      7.341     0.104    190.467       9.14
    5.550     10.204     0.175    346.318       8.40
    6.350     13.068     0.268    584.747       7.63
    7.150     15.931     0.384    921.441       6.94
    7.950     18.794     0.523   1370.844       6.35
    8.750     21.657     0.684   1946.482       5.86
 END FTABLE   3

 FTABLE       4
ROWS COLS ***
  20     4
    DEPTH       AREA    VOLUME      DISCH   FLO-THRU ***
     ( m)    (   HA)     (Mm3)      (CMS)      (MIN) ***
    0.000      0.000     0.000      0.000       0.00
    0.250      0.936     0.001      0.304      64.07
    0.500      1.872     0.005      1.933      40.35
    0.750      2.808     0.011      5.700      30.79
    0.958      3.010     0.017     11.388      24.28
    1.167      3.213     0.023     18.589      20.69
    1.375      3.415     0.030     27.222      18.35
    1.583      3.618     0.037     37.255      16.69
    1.792      3.820     0.045     48.679      15.43
    2.000      4.023     0.053     61.500      14.42
    2.417      4.428     0.071     91.398      12.92
    2.833      4.833     0.090    127.133      11.81
    3.250      5.238     0.111    168.930      10.96
    4.083     14.712     0.194    320.322      10.11
    4.917     24.185     0.356    614.467       9.66
    5.750     33.659     0.597   1121.005       8.88
    6.583     43.133     0.917   1897.574       8.06
    7.417     52.606     1.316   2995.624       7.32
    8.250     62.080     1.794   4462.507       6.70
    9.083     71.554     2.351   6342.574       6.18
 END FTABLE   4

 FTABLE       5
ROWS COLS ***
  20     4
    DEPTH       AREA    VOLUME      DISCH   FLO-THRU ***
     ( m)    (   HA)     (Mm3)      (CMS)      (MIN) ***
    0.000      0.000     0.000      0.000       0.00
    0.250      5.580     0.007      0.315     368.51
    0.500     11.160     0.028      2.004     232.09
    0.750     16.740     0.063      5.908     177.10
    0.925     17.722     0.093     10.903     142.06
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     1.100     18.703     0.125     17.146     121.31
     1.275     19.685     0.158     24.592     107.35
     1.450     20.667     0.194     33.219      97.18
     1.625     21.648     0.231     43.020      89.39
     1.800     22.630     0.269     53.998      83.17
     2.150     24.593     0.352     79.522      73.80
     2.500     26.557     0.442    109.900      66.97
     2.850     28.520     0.538    145.280      61.72
     3.550     41.894     0.784    250.661      52.16
     4.250     55.269     1.125    397.011      47.21
     4.950     68.643     1.558    595.612      43.60
     5.650     82.018     2.086    855.894      40.61
     6.350     95.392     2.706   1186.367      38.02
     7.050    108.767     3.421   1594.936      35.75
     7.750    122.141     4.229   2089.057      33.74
  END FTABLE   5

  FTABLE       6
 ROWS COLS ***
   16    4
     DEPTH       AREA    VOLUME      DISCH   FLO-THRU ***
      ( m)     (   HA)    (Mm3)      (CMS)      (MIN) ***
     0.000      0.000     0.000      0.000       0.00
     0.750      0.246     0.001      0.492      31.27
     1.050      0.383     0.002      1.193      26.08
     1.350      0.520     0.003      2.424      22.15
     1.500      0.588     0.004      3.276      20.61
     1.650      0.657     0.005      4.305      19.30
     1.950      0.794     0.007      6.949      17.18
     2.250      0.931     0.010     10.459      15.54
     2.550      1.068     0.013     14.932      14.23
     3.150      1.774     0.021     30.957      11.45
     3.750      2.480     0.034     57.257       9.91
     4.350      3.186     0.051     97.544       8.72
     4.950      3.892     0.072    154.920       7.77
     5.550      4.597     0.098    232.178       7.02
     6.150      5.303     0.127    331.905       6.40
     6.750      6.009     0.161    456.531       5.89
  END FTABLE   6

  FTABLE       7
 ROWS COLS ***
   20    4
     DEPTH       AREA    VOLUME      DISCH   FLO-THRU ***
      ( m)     (   HA)    (Mm3)      (CMS)      (MIN) ***
     0.000      0.000     0.000      0.000       0.00
     0.250      2.850     0.004      0.344     172.55
     0.500      5.700     0.014      2.185     108.68
     0.750      8.550     0.032      6.444      82.92
     0.975      8.946     0.052     13.704      62.93
     1.200      9.342     0.072     22.988      52.43
     1.425      9.738     0.094     34.118      45.81
     1.650     10.133     0.116     46.989      41.19
     1.875     10.529     0.139     61.536      37.75
     2.100     10.925     0.164     77.720      35.07
     2.550     11.717     0.214    114.916      31.10
     3.000     12.508     0.269    158.508      28.28
     3.450     13.300     0.327    208.533      26.14
     4.350     24.988     0.499    365.687      22.76
     5.250     36.677     0.777    615.980      21.02
     6.150     48.365     1.160    997.245      19.38
     7.050     60.053     1.647   1540.859      17.82
     7.950     71.742     2.240   2274.906      16.41
     8.850     83.430     2.939   3225.292      15.19
     9.750     95.118     3.742   4416.323      14.12
  END FTABLE   7
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 FTABLE       8
ROWS COLS ***
  20     4
    DEPTH      AREA    VOLUME      DISCH  FLO-THRU ***
     ( m)    (  HA)     (Mm3)      (CMS)     (MIN) ***
    0.000     0.000     0.000      0.000      0.00
    0.250     1.005     0.001      0.296     70.84
    0.500     2.011     0.005      1.878     44.62
    0.750     3.016     0.011      5.537     34.04
    0.933     3.198     0.017     10.353     27.38
    1.117     3.380     0.023     16.331     23.51
    1.300     3.562     0.029     23.407     20.93
    1.483     3.744     0.036     31.551     19.07
    1.667     3.926     0.043     40.747     17.64
    1.850     4.108     0.050     50.991     16.50
    2.217     4.472     0.066     74.649     14.79
    2.583     4.836     0.083    102.603     13.53
    2.950     5.200     0.102    134.977     12.56
    3.683    10.413     0.159    236.425     11.20
    4.417    15.626     0.254    386.962     10.96
    5.150    20.839     0.388    603.574     10.72
    5.883    26.052     0.560    900.394     10.37
    6.617    31.265     0.770   1290.109      9.95
    7.350    36.478     1.019   1784.458      9.51
    8.083    41.691     1.305   2394.474      9.08
 END FTABLE   8

*** Henley Dam

 FTABLE       9
ROWS COLS ***
  19     5
    DEPTH      AREA    VOLUME      DISCH     DISCH ***
     ( m)    (  HA)     (Mm3)      (CMS)     (CMS) ***
    0.000     0.000     0.000      0.000      0.00
    2.000     1.100     0.001      0.558      0.00
    3.000     3.900     0.020      1.000     00.00
    4.000     6.300     0.061      1.000     00.00
    5.000     9.100     0.125      1.000     00.00
    6.000    12.200     0.216      1.000     00.00
    7.000    15.100     0.343      1.000     00.00
    8.000    18.300     0.508      2.000     00.00
    9.000    22.200     0.714      2.000     00.00
   10.000    26.100     0.964      3.000     00.00
   11.000    29.700     1.257      3.000     00.00
   11.800    32.100     1.522      4.000     00.00
   12.000    33.000     1.590      4.000     00.00
   13.000    38.000     1.971      5.000     00.00
   13.200    39.000     2.053     10.000     13.00
   13.400    40.000     2.134     20.000     36.00
   13.600    40.800     2.219     20.000     67.00
   13.800    41.600     2.306    100.000    105.00
   14.000    42.300     2.392    200.000    249.00
 END FTABLE   9

 FTABLE      10
ROWS COLS ***
  20     4
    DEPTH      AREA    VOLUME      DISCH  FLO-THRU ***
     ( m)    (  HA)     (Mm3)      (CMS)     (MIN) ***
    0.000     0.000    0.0000      0.000      0.00
    0.250     1.943     0.002      0.172    235.89
    0.500     3.885     0.010      1.090    148.57
    0.750     5.828     0.022      3.213    113.36
    0.942     6.556     0.034      6.083     92.39
    1.133     7.285     0.047      9.809     79.84
    1.325     8.013     0.062     14.417     71.27
    1.517     8.742     0.078     19.943     64.94
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      1.708     9.470     0.095    26.430     60.01
      1.900    10.199     0.114    33.917     56.02
      2.283    11.656     0.156    52.072     49.90
      2.667    13.113     0.203    74.756     45.34
      3.050    14.570     0.256   102.311     41.77
      3.817    28.701     0.422   196.058     35.90
      4.583    42.831     0.697   348.689     33.29
      5.350    56.962     1.079   582.947     30.85
      6.117    71.093     1.570   917.760     28.51
      6.883    85.224     2.169  1370.109     26.39
      7.650    99.354     2.877  1955.685     24.52
      8.417   113.485     3.693  2689.228     22.88
   END FTABLE 10

   FTABLE     11
  ROWS COLS ***
    20    4
      DEPTH      AREA    VOLUME     DISCH  FLO-THRU ***
       ( m)    (   HA)    (Mm3)     (CMS)     (MIN) ***
      0.000     0.000     0.000     0.000      0.00
      0.250     1.503     0.002     0.231    135.63
      0.500     3.005     0.008     1.466     85.42
      0.750     4.508     0.017     4.323     65.18
      0.900     5.244     0.024     7.102     56.84
      1.050     5.980     0.033    10.682     50.92
      1.200     6.716     0.042    15.131     46.44
      1.350     7.452     0.053    20.514     42.88
      1.500     8.188     0.065    26.898     39.97
      1.650     8.924     0.077    34.345     37.54
      1.950    10.396     0.106    52.672     33.65
      2.250    11.868     0.140    75.969     30.65
      2.550    13.340     0.178   104.689     28.26
      3.150    24.852     0.292   204.730     23.78
      3.750    36.364     0.476   369.476     21.46
      4.350    47.876     0.728   623.969     19.46
      4.950    59.388     1.050   989.061     17.70
      5.550    70.900     1.441  1483.464     16.19
      6.150    82.412     1.901  2124.472     14.91
      6.750    93.924     2.430  2928.329     13.83
   END FTABLE 11

   FTABLE     12
  ROWS COLS ***
    20    4
      DEPTH      AREA    VOLUME     DISCH  FLO-THRU ***
       ( m)    (   HA)    (Mm3)     (CMS)     (MIN) ***
      0.000     0.000     0.000     0.000      0.00
      0.250     2.660     0.003     0.221    251.09
      0.500     5.320     0.013     1.402    158.14
      0.750     7.980     0.030     4.133    120.67
      0.967     8.327     0.048     8.654     91.66
      1.183     8.673     0.066    14.448     76.14
      1.400     9.020     0.085    21.419     66.28
      1.617     9.367     0.105    29.511     59.35
      1.833     9.714     0.126    38.688     54.18
      2.050    10.060     0.147    48.927     50.14
      2.483    10.754     0.192    72.548     44.17
      2.917    11.447     0.240   100.336     39.93
      3.350    12.141     0.291   132.314     36.72
      4.217    25.090     0.453   234.568     32.17
      5.083    38.039     0.726   412.457     29.35
      5.950    50.988     1.112   700.484     26.46
      6.817    63.937     1.610  1127.216     23.81
      7.683    76.885     2.220  1718.169     21.54
      8.550    89.834     2.943  2496.842     19.64
      9.417   102.783     3.778  3485.257     18.06
   END FTABLE 12
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 FTABLE     13
ROWS COLS ***
  20    4
    DEPTH       AREA    VOLUME     DISCH   FLO-THRU ***
     ( m)    (   HA)    (Mm3)      (CMS)      (MIN) ***
    0.000      0.000     0.000     0.000      0.00
    0.250      1.288     0.002     0.180    149.00
    0.500      2.576     0.006     1.144     93.84
    0.750      3.864     0.014     3.373     71.60
    0.892      4.117     0.020     5.519     60.83
    1.033      4.370     0.026     8.097     53.84
    1.175      4.623     0.033    11.094     48.86
    1.317      4.876     0.039    14.509     45.09
    1.458      5.129     0.046    18.343     42.11
    1.600      5.382     0.054    22.598     39.67
    1.883      5.888     0.070    32.401     35.88
    2.167      6.394     0.087    43.977     33.03
    2.450      6.900     0.106    57.393     30.78
    3.017     16.974     0.174   100.956     28.66
    3.583     27.048     0.298   170.127     29.23
    4.150     37.122     0.480   275.218     29.08
    4.717     47.196     0.719   424.783     28.21
    5.283     57.270     1.015   626.479     27.00
    5.850     67.344     1.368   887.373     25.70
    6.417     77.419     1.778  1214.095     24.41
 END FTABLE 13

 FTABLE     14
ROWS COLS ***
  20    4
    DEPTH       AREA    VOLUME     DISCH   FLO-THRU ***
     ( m)    (   HA)    (Mm3)      (CMS)      (MIN) ***
    0.000      0.000     0.000     0.000      0.00
    0.250      1.152     0.001     0.129    186.43
    0.500      2.304     0.006     0.818    117.42
    0.750      3.456     0.013     2.411     89.60
    0.950      3.720     0.020     4.738     70.84
    1.150      3.984     0.028     7.701     60.25
    1.350      4.248     0.036    11.281     53.29
    1.550      4.512     0.045    15.470     48.30
    1.750      4.776     0.054    20.271     44.50
    1.950      5.040     0.064    25.691     41.48
    2.350      5.568     0.085    38.431     36.93
    2.750      6.096     0.108    53.791     33.61
    3.150      6.624     0.134    71.889     31.05
    3.950     21.337     0.246   140.213     29.21
    4.750     36.049     0.475   284.561     27.84
    5.550     50.762     0.823   543.849     25.21
    6.350     65.475     1.287   950.263     22.58
    7.150     80.187     1.870  1532.510     20.34
    7.950     94.900     2.570  2317.000     18.49
    8.750    109.613     3.389  3328.455     16.97
 END FTABLE 14

 FTABLE     15
ROWS COLS ***
  20    4
    DEPTH       AREA    VOLUME     DISCH   FLO-THRU ***
     ( m)    (   HA)    (Mm3)      (CMS)      (MIN) ***
    0.000      0.000     0.000     0.000      0.00
    0.250      1.632     0.002     0.166    204.36
    0.500      3.264     0.008     1.057    128.71
    0.750      4.896     0.018     3.116     98.21
    0.892      5.312     0.026     5.090     83.80
    1.033      5.729     0.033     7.495     74.29
    1.175      6.146     0.042    10.337     67.43
    1.317      6.562     0.051    13.621     62.19
    1.458      6.978     0.060    17.360     58.00
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    1.600     7.395     0.071    21.565     54.56
    1.883     8.228     0.093    31.426     49.18
    2.167     9.061     0.117    43.316     45.10
    2.450     9.894     0.144    57.349     41.87
    3.017    21.431     0.233   105.276     36.86
    3.583    32.968     0.387   188.349     34.24
    4.150    44.505     0.606   322.141     31.38
    4.717    56.042     0.891   519.559     28.59
    5.283    67.579     1.242   792.141     26.12
    5.850    79.116     1.657  1150.521     24.01
    6.417    90.652     2.138  1604.669     22.21
  END FTABLE 15

  FTABLE     16
 ROWS COLS ***
   20     4
    DEPTH      AREA    VOLUME     DISCH  FLO-THRU ***
     ( m)   (    HA)    (Mm3)     (CMS)     (MIN) ***
    0.000     0.000     0.000     0.000      0.00
    0.250     1.554     0.002     0.220    147.24
    0.500     3.107     0.008     1.396     92.74
    0.750     4.661     0.017     4.117     70.76
    0.900     4.832     0.025     6.996     58.60
    1.050     5.003     0.032    10.437     51.06
    1.200     5.174     0.040    14.398     45.85
    1.350     5.346     0.047    18.849     42.00
    1.500     5.517     0.056    23.772     39.01
    1.650     5.688     0.064    29.153     36.62
    1.950     6.030     0.082    41.260     32.97
    2.250     6.373     0.100    55.132     30.30
    2.550     6.715     0.120    70.759     28.23
    3.150    17.415     0.192   123.234     26.00
    3.750    28.115     0.329   220.918     24.81
    4.350    38.814     0.530   386.038     22.87
    4.950    49.514     0.795   636.970     20.79
    5.550    60.214     1.124   990.105     18.92
    6.150    70.914     1.517  1460.522     17.31
    6.750    81.613     1.975  2062.341     15.96
  END FTABLE 16

  FTABLE     17
 ROWS COLS ***
   20     4
    DEPTH      AREA    VOLUME     DISCH  FLO-THRU ***
     ( m)   (    HA)    (Mm3)     (CMS)     (MIN) ***
    0.000     0.000     0.000     0.000      0.00
    0.250     0.288     0.000     0.096     62.54
    0.500     0.576     0.001     0.609     39.39
    0.750     0.864     0.003     1.797     30.05
    0.925     0.936     0.005     3.252     24.67
    1.100     1.008     0.007     5.067     21.43
    1.275     1.080     0.008     7.236     19.22
    1.450     1.152     0.010     9.759     17.58
    1.625     1.224     0.012    12.641     16.32
    1.800     1.296     0.015    15.891     15.29
    2.150     1.440     0.019    23.523     13.72
    2.500     1.584     0.025    32.731     12.56
    2.850     1.728     0.030    43.597     11.64
    3.550    10.696     0.074    95.727     12.87
    4.250    19.664     0.180   239.970     12.52
    4.950    28.632     0.349   528.169     11.02
    5.650    37.600     0.581  1003.147      9.65
    6.350    46.568     0.876  1703.045      8.57
    7.050    55.536     1.233  2662.914      7.72
    7.750    64.504     1.653  3915.531      7.04
  END FTABLE 17
```

FTABLE 18
ROWS COLS ***
20 4

DEPTH (m)	AREA (HA)	VOLUME (Mm3)	DISCH (CMS)	FLO-THRU (MIN) ***
0.000	0.000	0.000	0.000	0.00
0.250	3.300	0.004	0.061	1128.18
0.500	6.600	0.016	0.387	710.54
0.750	9.900	0.037	1.141	542.17
1.142	10.575	0.077	3.699	347.92
1.533	11.250	0.120	7.392	270.49
1.925	11.925	0.165	12.130	227.19
2.317	12.600	0.213	17.875	198.95
2.708	13.275	0.264	24.612	178.80
3.100	13.950	0.317	32.338	163.56
3.883	15.300	0.432	50.782	141.76
4.667	16.650	0.557	73.298	126.67
5.450	18.000	0.693	100.019	115.44
7.017	38.071	1.132	192.533	97.99
8.583	58.142	1.886	370.289	84.87
10.150	78.214	2.954	674.182	73.02
11.717	98.285	4.336	1138.079	63.50
13.283	118.356	6.033	1792.219	56.11
14.850	138.427	8.045	2664.445	50.32
16.417	158.498	10.371	3780.839	45.72

END FTABLE 18

FTABLE 19
ROWS COLS ***
20 4

DEPTH (m)	AREA (HA)	VOLUME (Mm3)	DISCH (CMS)	FLO-THRU (MIN) ***
0.000	0.000	0.000	0.000	0.00
0.250	2.017	0.003	0.078	538.80
0.500	4.033	0.010	0.495	339.34
0.750	6.050	0.023	1.460	258.93
1.142	6.609	0.047	4.712	167.94
1.533	7.168	0.074	9.445	131.39
1.925	7.727	0.104	15.580	110.86
2.317	8.287	0.135	23.097	97.41
2.708	8.846	0.169	32.003	87.77
3.100	9.405	0.204	42.319	80.45
3.883	10.523	0.282	67.303	69.92
4.667	11.642	0.369	98.332	62.57
5.450	12.760	0.465	135.725	57.07
7.017	25.026	0.761	266.643	47.55
8.583	37.291	1.249	510.398	40.78
10.150	49.557	1.929	918.941	34.99
11.717	61.823	2.802	1535.341	30.41
13.283	74.089	3.866	2398.096	26.87
14.850	86.354	5.123	3542.680	24.10
16.417	98.620	6.572	5002.338	21.90

END FTABLE 19

FTABLE 20
ROWS COLS ***
20 4

DEPTH (m)	AREA (HA)	VOLUME (Mm3)	DISCH (CMS)	FLO-THRU (MIN) ***
0.000	0.000	0.000	0.000	0.00
0.250	5.510	0.007	0.000	479.55
0.500	11.020	0.028	0.000	302.03
0.750	16.530	0.062	0.000	230.46
1.583	17.569	0.204	0.000	108.86
2.417	18.608	0.355	0.000	78.49
3.250	19.648	0.514	134.442	63.75
4.083	20.687	0.682	207.542	54.79
4.917	21.726	0.859	294.139	48.67

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      5.750     22.765     1.044   393.990     44.18
      7.417     24.843     1.441   633.208     37.93
      9.083     26.922     1.872   925.502     33.72
     10.750     29.000     2.338  1271.978     30.64
     14.083     97.802     4.452  2648.897     28.01
     17.417    166.604     8.859  5914.768     24.96
     20.750    235.406    15.559 12079.875     21.47
     24.083    304.208    24.552 21979.436     18.62
     27.417    373.009    35.839 36358.000     16.43
     30.750    441.811    49.420 55900.180     14.73
     34.083    510.613    65.293 81246.539     13.39
  END FTABLE 20


END FTABLES

*** For an understanding of EXT SOURCES, EXT TARGETS, SCHEMATIC, MASS-LINK
*** and NETWORK blocks, the user should be familiar with the Time Series
*** Linkages and the Time Series Catalog

EXT SOURCES
<-Volume-> <Member> SsysSgap<--Mult-->Tran <-Target vols> <-Grp> <-Member->  ***
<Name>   # <Name> # tem strg<-factor->strg <Name>   #   #        <Name> # #  ***
WDM      1 PRCP   3 METR       0.31        PERLND  11  18 EXTNL  PREC
WDM      2 PRCP   3 METR       0.69        PERLND  11  18 EXTNL  PREC
WDM      1 PRCP   3 METR       0.31        IMPLND  14  17 EXTNL  PREC
WDM      2 PRCP   3 METR       0.69        IMPLND  14  17 EXTNL  PREC

WDM      2 PRCP   3 METR                   PERLND  21  28 EXTNL  PREC
WDM      2 PRCP   3 METR                   IMPLND  24  27 EXTNL  PREC

WDM      2 PRCP   3 METR                   PERLND  31  38 EXTNL  PREC
WDM      2 PRCP   3 METR                   IMPLND  34  37 EXTNL  PREC

WDM      1 PRCP   3 METR       0.30        PERLND  41  48 EXTNL  PREC
WDM      2 PRCP   3 METR       0.62        PERLND  41  48 EXTNL  PREC
WDM      4 PRCP   3 METR       0.08        PERLND  41  48 EXTNL  PREC
WDM      1 PRCP   3 METR       0.30        IMPLND  44  47 EXTNL  PREC
WDM      2 PRCP   3 METR       0.62        IMPLND  44  47 EXTNL  PREC
WDM      4 PRCP   3 METR       0.08        IMPLND  44  47 EXTNL  PREC

WDM      1 PRCP   3 METR       0.02        PERLND  51  58 EXTNL  PREC
WDM      2 PRCP   3 METR       0.06        PERLND  51  58 EXTNL  PREC
WDM      4 PRCP   3 METR       0.90        PERLND  51  58 EXTNL  PREC
WDM      6 PRCP   3 METR       0.02        PERLND  51  58 EXTNL  PREC
WDM      1 PRCP   3 METR       0.02        IMPLND  54  57 EXTNL  PREC
WDM      2 PRCP   3 METR       0.06        IMPLND  54  57 EXTNL  PREC
WDM      4 PRCP   3 METR       0.90        IMPLND  54  57 EXTNL  PREC
WDM      6 PRCP   3 METR       0.02        IMPLND  54  57 EXTNL  PREC

WDM      4 PRCP   3 METR                   PERLND  61  68 EXTNL  PREC
WDM      4 PRCP   3 METR                   IMPLND  64  67 EXTNL  PREC

WDM      1 PRCP   3 METR       0.33        PERLND  71  78 EXTNL  PREC
WDM      4 PRCP   3 METR       0.67        PERLND  71  78 EXTNL  PREC
WDM      1 PRCP   3 METR       0.33        IMPLND  74  77 EXTNL  PREC
WDM      4 PRCP   3 METR       0.67        IMPLND  74  77 EXTNL  PREC

WDM      3 PRCP   3 METR       0.03        PERLND  81  88 EXTNL  PREC
WDM      4 PRCP   3 METR       0.97        PERLND  81  88 EXTNL  PREC
WDM      3 PRCP   3 METR       0.03        IMPLND  84  87 EXTNL  PREC
WDM      4 PRCP   3 METR       0.97        IMPLND  84  87 EXTNL  PREC

WDM      4 PRCP   3 METR                   PERLND  91  98 EXTNL  PREC
WDM      4 PRCP   3 METR                   IMPLND  94  97 EXTNL  PREC

WDM      3 PRCP   3 METR       0.06        PERLND 101 108 EXTNL  PREC
WDM      4 PRCP   3 METR       0.94        PERLND 101 108 EXTNL  PREC
```

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WDM       3 PRCP   3 METR      0.06      IMPLND 104 107 EXTNL   PREC
WDM       4 PRCP   3 METR      0.94      IMPLND 104 107 EXTNL   PREC

WDM       4 PRCP   3 METR      0.89      PERLND 111 118 EXTNL   PREC
WDM       6 PRCP   3 METR      0.11      PERLND 111 118 EXTNL   PREC
WDM       4 PRCP   3 METR      0.89      IMPLND 114 117 EXTNL   PREC
WDM       6 PRCP   3 METR      0.11      IMPLND 114 117 EXTNL   PREC

WDM       4 PRCP   3 METR      0.95      PERLND 121 128 EXTNL   PREC
WDM       5 PRCP   3 METR      0.05      PERLND 121 128 EXTNL   PREC
WDM       4 PRCP   3 METR      0.95      IMPLND 124 127 EXTNL   PREC
WDM       5 PRCP   3 METR      0.05      IMPLND 124 127 EXTNL   PREC

WDM       4 PRCP   3 METR      0.72      PERLND 131 138 EXTNL   PREC
WDM       5 PRCP   3 METR      0.05      PERLND 131 138 EXTNL   PREC
WDM       6 PRCP   3 METR      0.23      PERLND 131 138 EXTNL   PREC
WDM       4 PRCP   3 METR      0.72      IMPLND 134 137 EXTNL   PREC
WDM       5 PRCP   3 METR      0.05      IMPLND 134 137 EXTNL   PREC
WDM       6 PRCP   3 METR      0.23      IMPLND 134 137 EXTNL   PREC

WDM       5 PRCP   3 METR                PERLND 141 148 EXTNL   PREC
WDM       5 PRCP   3 METR                IMPLND 144 147 EXTNL   PREC

WDM       4 PRCP   3 METR      0.13      PERLND 151 158 EXTNL   PREC
WDM       5 PRCP   3 METR      0.03      PERLND 151 158 EXTNL   PREC
WDM       6 PRCP   3 METR      0.55      PERLND 151 158 EXTNL   PREC
WDM       8 PRCP   3 METR      0.29      PERLND 151 158 EXTNL   PREC
WDM       4 PRCP   3 METR      0.13      IMPLND 154 157 EXTNL   PREC
WDM       5 PRCP   3 METR      0.03      IMPLND 154 157 EXTNL   PREC
WDM       6 PRCP   3 METR      0.55      IMPLND 154 157 EXTNL   PREC
WDM       8 PRCP   3 METR      0.29      IMPLND 154 157 EXTNL   PREC

WDM       6 PRCP   3 METR      0.08      PERLND 161 168 EXTNL   PREC
WDM       8 PRCP   3 METR      0.92      PERLND 161 168 EXTNL   PREC
WDM       6 PRCP   3 METR      0.08      IMPLND 164 167 EXTNL   PREC
WDM       8 PRCP   3 METR      0.92      IMPLND 164 167 EXTNL   PREC

WDM       5 PRCP   3 METR      0.15      PERLND 171 178 EXTNL   PREC
WDM       8 PRCP   3 METR      0.85      PERLND 171 178 EXTNL   PREC
WDM       5 PRCP   3 METR      0.15      IMPLND 174 177 EXTNL   PREC
WDM       8 PRCP   3 METR      0.85      IMPLND 174 177 EXTNL   PREC

WDM       5 PRCP   3 METR      0.82      PERLND 181 188 EXTNL   PREC
WDM       8 PRCP   3 METR      0.18      PERLND 181 188 EXTNL   PREC
WDM       5 PRCP   3 METR      0.82      IMPLND 184 187 EXTNL   PREC
WDM       8 PRCP   3 METR      0.18      IMPLND 184 187 EXTNL   PREC

WDM       5 PRCP   3 METR      0.62      PERLND 191 198 EXTNL   PREC
WDM       8 PRCP   3 METR      0.38      PERLND 191 198 EXTNL   PREC
WDM       5 PRCP   3 METR      0.62      IMPLND 194 197 EXTNL   PREC
WDM       8 PRCP   3 METR      0.38      IMPLND 194 197 EXTNL   PREC

WDM       5 PRCP   3 METR      0.87      PERLND 201 208 EXTNL   PREC
WDM       8 PRCP   3 METR      0.12      PERLND 201 208 EXTNL   PREC
WDM       9 PRCP   3 METR      0.01      PERLND 201 208 EXTNL   PREC
WDM       5 PRCP   3 METR      0.87      IMPLND 204 207 EXTNL   PREC
WDM       8 PRCP   3 METR      0.12      IMPLND 204 207 EXTNL   PREC
WDM       9 PRCP   3 METR      0.01      IMPLND 204 207 EXTNL   PREC

Evap region 1 ***
Covers catchments 1-9 ***
WDM      13 EVAP   3 METR      0.85      PERLND  11  98 EXTNL   PETINP
WDM      13 EVAP   3 METR      0.85      IMPLND  14  98 EXTNL   PETINP

Evap region 2 ***
Covers catchments 10-14,17-30,34-37,41-42 ***
WDM      14 EVAP   3 METR      0.85      PERLND 101 148 EXTNL   PETINP
WDM      14 EVAP   3 METR      0.85      IMPLND 104 148 EXTNL   PETINP
```

```
WDM      14 EVAP    3 METR       0.85          PERLND 171 308 EXTNL   PETINP
WDM      14 EVAP    3 METR       0.85          IMPLND 174 308 EXTNL   PETINP
WDM      14 EVAP    3 METR       0.85          PERLND 341 378 EXTNL   PETINP
WDM      14 EVAP    3 METR       0.85          IMPLND 344 378 EXTNL   PETINP
WDM      14 EVAP    3 METR       0.85          PERLND 411 428 EXTNL   PETINP
WDM      14 EVAP    3 METR       0.85          IMPLND 414 428 EXTNL   PETINP

Evap region 3 ***
Covers catchments 15-16,31-33,38-40 ***
WDM      15 EVAP    3 METR       0.85          PERLND 151 168 EXTNL   PETINP
WDM      15 EVAP    3 METR       0.85          IMPLND 154 168 EXTNL   PETINP
WDM      15 EVAP    3 METR       0.85          PERLND 311 338 EXTNL   PETINP
WDM      15 EVAP    3 METR       0.85          IMPLND 314 338 EXTNL   PETINP
WDM      15 EVAP    3 METR       0.85          PERLND 381 408 EXTNL   PETINP
WDM      15 EVAP    3 METR       0.85          IMPLND 384 408 EXTNL   PETINP

Abstractions from Henley.  Values are in m3/month.                          ***
Factor converts from m3/day totals to m3/s.  HSPF automatically             ***
disaggregates from monthly to daily, so we don't have to take account of    ***
conversion from monthly to daily                                            ***
WDM     692 DISC    3 METR       0.000012      RCHRES    9      EXTNL   OUTDGT 1 1

END EXT SOURCES

SCHEMATIC
<-Source->                  <--Area-->         <-Target->  <ML->  ***
<Name>   #                  <-factor->         <Name>   #      #  ***
                              (ha)                                ***
PERLND  11                       235.8         RCHRES   1      1
PERLND  12                       523.0         RCHRES   1      1
PERLND  13                      1906.2         RCHRES   1      1
PERLND  14              ***                    RCHRES   1      1
PERLND  15                       164.8         RCHRES   1      1
IMPLND  15                        18.3         RCHRES   1      3
PERLND  16                       961.1         RCHRES   1      1
PERLND  17              ***                    RCHRES   1      1
PERLND  18                        87.5         RCHRES   1      1
PERLND  21                       200.7         RCHRES   2      1
PERLND  22                       652.1         RCHRES   2      1
PERLND  23                      3330.8         RCHRES   2      1
PERLND  24                         4.4         RCHRES   2      1
IMPLND  24                        26.9         RCHRES   2      3
PERLND  25              ***                    RCHRES   2      1
PERLND  26                       950.8         RCHRES   2      1
PERLND  27              ***                    RCHRES   2      1
PERLND  28                       200.0         RCHRES   2      1
PERLND  31                        14.2         RCHRES   3      1
PERLND  32              ***                    RCHRES   3      1
PERLND  33                        71.2         RCHRES   3      1
PERLND  34              ***                    RCHRES   3      1
PERLND  35              ***                    RCHRES   3      1
PERLND  36                        54.3         RCHRES   3      1
PERLND  37              ***                    RCHRES   3      1
PERLND  38              ***                    RCHRES   3      1
PERLND  41                       597.6         RCHRES   4      1
PERLND  42                       537.6         RCHRES   4      1
PERLND  43                      2100.8         RCHRES   4      1
PERLND  44              ***                    RCHRES   4      1
PERLND  45              ***                    RCHRES   4      1
PERLND  46                       635.4         RCHRES   4      1
PERLND  47                        18.5         RCHRES   4      1
IMPLND  47                         6.5         RCHRES   4      3
PERLND  48                        12.5         RCHRES   4      1
PERLND  51                       238.8         RCHRES   5      1
PERLND  52                       507.4         RCHRES   5      1
PERLND  53                      2386.4         RCHRES   5      1
PERLND  54              ***                    RCHRES   5      1
PERLND  55                        15.6         RCHRES   5      1
```

IMPLND	55	1.7	RCHRES	5	3
PERLND	56	1230.7	RCHRES	5	1
PERLND	57	***	RCHRES	5	1
PERLND	58	75.0	RCHRES	5	1
PERLND	61	4.6	RCHRES	6	1
PERLND	62	***	RCHRES	6	1
PERLND	63	12.4	RCHRES	6	1
PERLND	64	***	RCHRES	6	1
PERLND	65	17.8	RCHRES	6	1
IMPLND	65	2.0	RCHRES	6	3
PERLND	66	***	RCHRES	6	1
PERLND	67	***	RCHRES	6	1
PERLND	68	***	RCHRES	6	1
PERLND	71	515.2	RCHRES	7	1
PERLND	72	430.8	RCHRES	7	1
PERLND	73	1253.5	RCHRES	7	1
PERLND	74	***	RCHRES	7	1
PERLND	75	238.5	RCHRES	7	1
IMPLND	75	26.5	RCHRES	7	3
PERLND	76	571.8	RCHRES	7	1
PERLND	77	***	RCHRES	7	1
PERLND	78	***	RCHRES	7	1
PERLND	81	370.7	RCHRES	8	1
PERLND	82	34.5	RCHRES	8	1
PERLND	83	138.8	RCHRES	8	1
PERLND	84	***	RCHRES	8	1
PERLND	85	180.1	RCHRES	8	1
IMPLND	85	20.0	RCHRES	8	3
PERLND	86	***	RCHRES	8	1
PERLND	87	***	RCHRES	8	1
PERLND	88	***	RCHRES	8	1
PERLND	91	171.7	RCHRES	9	1
PERLND	92	***	RCHRES	9	1
PERLND	93	84.7	RCHRES	9	1
PERLND	94	***	RCHRES	9	1
PERLND	95	90.9	RCHRES	9	1
IMPLND	95	10.1	RCHRES	9	3
PERLND	96	***	RCHRES	9	1
PERLND	97	***	RCHRES	9	1
PERLND	98	***	RCHRES	9	1
PERLND	101	332.1	RCHRES	10	1
PERLND	102	269.3	RCHRES	10	1
PERLND	103	760.6	RCHRES	10	1
PERLND	104	6.6	RCHRES	10	1
IMPLND	104	40.8	RCHRES	10	3
PERLND	105	1405.4	RCHRES	10	1
IMPLND	105	156.2	RCHRES	10	3
PERLND	106	0.1	RCHRES	10	1
PERLND	107	12.3	RCHRES	10	1
IMPLND	107	4.3	RCHRES	10	3
PERLND	108	***	RCHRES	10	1
PERLND	111	1023.2	RCHRES	11	1
PERLND	112	***	RCHRES	11	1
PERLND	113	2119.3	RCHRES	11	1
PERLND	114	14.1	RCHRES	11	1
IMPLND	114	86.7	RCHRES	11	3
PERLND	115	42.8	RCHRES	11	1
IMPLND	115	4.8	RCHRES	11	3
PERLND	116	283.7	RCHRES	11	1
PERLND	117	0.1	RCHRES	11	1
PERLND	118	***	RCHRES	11	1
PERLND	121	170.5	RCHRES	12	1
PERLND	122	***	RCHRES	12	1
PERLND	123	653.1	RCHRES	12	1
PERLND	124	7.4	RCHRES	12	1
IMPLND	124	45.5	RCHRES	12	3
PERLND	125	598.3	RCHRES	12	1
IMPLND	125	66.5	RCHRES	12	3

PERLND 126	***	RCHRES	12	1
PERLND 127	291.6	RCHRES	12	1
IMPLND 127	102.4	RCHRES	12	3
PERLND 128	***	RCHRES	12	1
PERLND 131	80.8	RCHRES	13	1
PERLND 132	***	RCHRES	13	1
PERLND 133	1128.7	RCHRES	13	1
PERLND 134	21.8	RCHRES	13	1
IMPLND 134	133.6	RCHRES	13	3
PERLND 135	19.3	RCHRES	13	1
IMPLND 135	2.1	RCHRES	13	3
PERLND 136	103.6	RCHRES	13	1
PERLND 137	9.0	RCHRES	13	1
IMPLND 137	3.2	RCHRES	13	3
PERLND 138	***	RCHRES	13	1
PERLND 141	46.0	RCHRES	14	1
PERLND 142	***	RCHRES	14	1
PERLND 143	618.3	RCHRES	14	1
PERLND 144	30.2	RCHRES	14	1
IMPLND 144	185.8	RCHRES	14	3
PERLND 145	1.4	RCHRES	14	1
PERLND 146	***	RCHRES	14	1
PERLND 147	***	RCHRES	14	1
PERLND 148	***	RCHRES	14	1
PERLND 151	223.5	RCHRES	15	1
PERLND 152	174.0	RCHRES	15	1
PERLND 153	1646.5	RCHRES	15	1
PERLND 154	52.9	RCHRES	15	1
IMPLND 154	325.1	RCHRES	15	3
PERLND 155	14.5	RCHRES	15	1
IMPLND 155	1.6	RCHRES	15	3
PERLND 156	220.4	RCHRES	15	1
PERLND 157	***	RCHRES	15	1
PERLND 158	***	RCHRES	15	1
PERLND 161	105.4	RCHRES	16	1
PERLND 162	417.1	RCHRES	16	1
PERLND 163	1081.4	RCHRES	16	1
PERLND 164	19.2	RCHRES	16	1
IMPLND 164	117.8	RCHRES	16	3
PERLND 165	***	RCHRES	16	1
PERLND 166	49.6	RCHRES	16	1
PERLND 167	***	RCHRES	16	1
PERLND 168	***	RCHRES	16	1
PERLND 171	***	RCHRES	17	1
PERLND 172	***	RCHRES	17	1
PERLND 173	181.1	RCHRES	17	1
PERLND 174	2.3	RCHRES	17	1
IMPLND 174	14.4	RCHRES	17	3
PERLND 175	200.7	RCHRES	17	1
IMPLND 175	22.3	RCHRES	17	3
PERLND 176	***	RCHRES	17	1
PERLND 177	***	RCHRES	17	1
PERLND 178	***	RCHRES	17	1
PERLND 181	44.9	RCHRES	20	1
PERLND 182	***	RCHRES	20	1
PERLND 183	218.7	RCHRES	20	1
PERLND 184	2.9	RCHRES	20	1
IMPLND 184	17.9	RCHRES	20	3
PERLND 185	48.9	RCHRES	20	1
IMPLND 185	5.4	RCHRES	20	3
PERLND 186	***	RCHRES	20	1
PERLND 187	16.7	RCHRES	20	1
IMPLND 187	5.9	RCHRES	20	3
PERLND 188	***	RCHRES	20	1
PERLND 191	0.2	RCHRES	20	1
PERLND 192	75.8	RCHRES	20	1
PERLND 193	66.7	RCHRES	20	1
PERLND 194	***	RCHRES	20	1

```
PERLND 195                     110.0       RCHRES   20       1
IMPLND 195                      12.2       RCHRES   20       3
PERLND 196           ***                   RCHRES   20       1
PERLND 197           ***                   RCHRES   20       1
PERLND 198           ***                   RCHRES   20       1
PERLND 201                       5.1       RCHRES   20       1
PERLND 202                     147.6       RCHRES   20       1
PERLND 203                       1.5       RCHRES   20       1
PERLND 204           ***                   RCHRES   20       1
PERLND 205                      42.5       RCHRES   20       1
IMPLND 205                       4.7       RCHRES   20       3
PERLND 206           ***                   RCHRES   20       1
PERLND 207                       1.4       RCHRES   20       1
IMPLND 207                       0.5       RCHRES   20       3
PERLND 208           ***                   RCHRES   20       1
RCHRES    1                                RCHRES    3       2
RCHRES    2                                RCHRES    3       2
RCHRES    3                                RCHRES    4       2
RCHRES    4                                RCHRES    5       2
RCHRES    5                                RCHRES    6       2
RCHRES    6                                RCHRES    9       2
RCHRES    7                                RCHRES    9       2
RCHRES    8                                RCHRES    9       2
RCHRES    9                                RCHRES   10       4
RCHRES   10                                RCHRES   12       2
RCHRES   11                                RCHRES   12       2
RCHRES   12                                RCHRES   14       2
RCHRES   13                                RCHRES   14       2
RCHRES   14                                RCHRES   20       2
RCHRES   15                                RCHRES   17       2
RCHRES   16                                RCHRES   17       2
RCHRES   17                                RCHRES   20       2
RCHRES   18                                RCHRES   20       2***
RCHRES   19                                RCHRES   20       2***
END SCHEMATIC

MASS-LINK

  MASS-LINK       1
<Srce>     <-Grp> <-Member-><--Mult-->     <Targ>         <-Grp> <-Member-> ***
<Name>     <Name> <Name> # #<-factor->     <Name>         <Name> <Name> # # ***
                      Factor converts (mm.ha) to (million m3)               ***
PERLND     PWATER PERO        0.00001      RCHRES         INFLOW IVOL
  END MASS-LINK   1

  MASS-LINK       2
<Srce>     <-Grp> <-Member-><--Mult-->     <Targ>         <-Grp> <-Member-> ***
<Name>     <Name> <Name> # #<-factor->     <Name>         <Name> <Name> # # ***
RCHRES     ROFLOW                          RCHRES         INFLOW
  END MASS-LINK   2

  MASS-LINK       3
<Srce>     <-Grp> <-Member-><--Mult-->     <Targ>         <-Grp> <-Member-> ***
<Name>     <Name> <Name> # #<-factor->     <Name>         <Name> <Name> # # ***
                      Factor converts (mm.ha) to (million m3)               ***
IMPLND     IWATER SURO        0.00001      RCHRES         INFLOW IVOL
  END MASS-LINK   3

  MASS-LINK       4
<Srce>     <-Grp> <-Member-><--Mult-->     <Targ>         <-Grp> <-Member-> ***
<Name>     <Name> <Name> # #<-factor->     <Name>         <Name> <Name> # # ***
For dams, only spillway and flow-thru goes to next reach                    ***
RCHRES     OFLOW  OVOL   2 1               RCHRES         INFLOW IVOL
RCHRES     OFLOW  OVOL   3 1               RCHRES         INFLOW IVOL
  END MASS-LINK   4

END MASS-LINK
```

```
NETWORK
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Target vols> <-Grp> <-Member->  ***
<Name>   #        <Name> # #<-factor->strg <Name>   #   #        <Name> # #  ***
RCHRES   5 HYDR   RO                       PLTGEN   1      INPUT  POINT  1
RCHRES   9 HYDR   O      2                 COPY     1      INPUT  POINT  1
RCHRES   9 HYDR   O      3                 COPY     1      INPUT  POINT  1
END NETWORK


EXT TARGETS
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Volume-> <Member> Tsys Aggr Amd ***
<Name>   #        <Name> # #<-factor->strg <Name>   # <Name>qf  tem strg strg***

*** For selected reaches, we output the following simulated time series:
*** Total outflow rate (m3/s)

RCHRES   5 HYDR   RO                       WDM    805 HYDR    1 METR AGGR REPL
COPY     1 OUTPUT POINT  1                 WDM    809 HYDR    1 METR AGGR REPL
RCHRES  14 HYDR   RO                       WDM    814 HYDR    1 METR AGGR REPL
RCHRES  20 HYDR   ROVOL                    WDM    820 HYDR    1 METR AGGR REPL
END EXT TARGETS

END RUN
```

LOWER SUB-CATCHMENTS (21-42)

```
RUN
GLOBAL
  HSPF DEMONSTRATION RUN UPSTREAM OF MGENI CONFLUENCE
  START         1992/01/01          END     2000/06/01
  RUN INTERP OUTPUT LEVEL    4
  RESUME     0 RUN     1 TSSFL     0 WDMSFL     0 UNITS     2
END GLOBAL

FILES
<FILE>  <UN#>***<----FILE NAME------------------------------------------------->
WDM        21   msunduzi.wdm
MESSU      22   msunduzi.ech
           61   msunduzi.p61
           62   msunduzi.p62
           63   msunduzi.p63
           64   msunduzi.p64
           92   msunduzi.plt
END FILES

OPN SEQUENCE
    INGRP              INDELT 24:00
      Catchment    21 ******
      PERLND      211
      PERLND      212
      PERLND      213
      PERLND      214
      IMPLND      214
      PERLND      215
      IMPLND      215
      PERLND      216***
      PERLND      217
      IMPLND      217
      PERLND      218***
      RCHRES       21
      Catchment    22 ******
      PERLND      221
      PERLND      222
      PERLND      223
      PERLND      224***
      PERLND      225
      IMPLND      225
      PERLND      226***
      PERLND      227
      IMPLND      227
      PERLND      228***
      RCHRES       22
      Catchment    23 ******
      PERLND      231
      PERLND      232
      PERLND      233
      PERLND      234
      IMPLND      234
      PERLND      235
      IMPLND      235
      PERLND      236***
      PERLND      237
      IMPLND      237
      PERLND      238***
      RCHRES       23
      Catchment    24 ******
      PERLND      241
      PERLND      242
      PERLND      243
      PERLND      244
```

```
IMPLND     244
PERLND     245
IMPLND     245
PERLND     246***
PERLND     247
IMPLND     247
PERLND     248***
RCHRES      24
Catchment   25 ******
PERLND     251
PERLND     252
PERLND     253
PERLND     254
IMPLND     254
PERLND     255
IMPLND     255
PERLND     256***
PERLND     257
IMPLND     257
PERLND     258***
RCHRES      25
Catchment   26 ******
PERLND     261
PERLND     262
PERLND     263
PERLND     264
IMPLND     264
PERLND     265
IMPLND     265
PERLND     266***
PERLND     267***
PERLND     268***
RCHRES      26
Catchment   27 ******
PERLND     271
PERLND     272
PERLND     273
PERLND     274
IMPLND     274
PERLND     275***
PERLND     276***
PERLND     277
IMPLND     277
PERLND     278***
RCHRES      27
Catchment   28 ******
PERLND     281
PERLND     282
PERLND     283
PERLND     284
IMPLND     284
PERLND     285***
PERLND     286***
PERLND     287***
PERLND     288***
RCHRES      28
Catchment   29 ******
PERLND     291
PERLND     292
PERLND     293
PERLND     294
IMPLND     294
PERLND     295***
PERLND     296***
PERLND     297
IMPLND     297
PERLND     298***
RCHRES      29
```

```
Catchment   30 ******
PERLND     301
PERLND     302
PERLND     303
PERLND     304
PERLND     305***
PERLND     306***
PERLND     307
IMPLND     307
PERLND     308***
RCHRES      30
Catchment   31 ******
PERLND     311
PERLND     312
PERLND     313
PERLND     314
IMPLND     314
PERLND     315***
PERLND     316***
PERLND     317***
PERLND     318***
RCHRES      31
Catchment   32 ******
PERLND     321
PERLND     322
PERLND     323
PERLND     324***
PERLND     325***
PERLND     326***
PERLND     327***
PERLND     328***
RCHRES      32
Catchment   33 ******
PERLND     331
PERLND     332
PERLND     333
PERLND     334
IMPLND     334
PERLND     335***
PERLND     336***
PERLND     337***
PERLND     338***
RCHRES      33
Catchment   34 ******
PERLND     341
PERLND     342
PERLND     343
PERLND     344
IMPLND     344
PERLND     345***
PERLND     346***
PERLND     347
IMPLND     347
PERLND     348***
RCHRES      34
Catchment   35 ******
PERLND     351
PERLND     352
PERLND     353
PERLND     354
IMPLND     354
PERLND     355***
PERLND     356
PERLND     357***
PERLND     358***
RCHRES      35
Catchment   36 ******
PERLND     361
```

```
PERLND     362
PERLND     363
PERLND     364***
PERLND     365***
PERLND     366
PERLND     367***
PERLND     368***
RCHRES      36
Catchment   37 ******
PERLND     371
PERLND     372
PERLND     373
PERLND     374***
PERLND     375
IMPLND     375
PERLND     376
PERLND     377***
PERLND     378***
RCHRES      37
Catchment   38 ******
PERLND     381
PERLND     382
PERLND     383
PERLND     384***
PERLND     385
IMPLND     385
PERLND     386***
PERLND     387***
PERLND     388***
RCHRES      38
Catchment   39 ******
PERLND     391
PERLND     392
PERLND     393
PERLND     394
IMPLND     394
PERLND     395
IMPLND     395
PERLND     396***
PERLND     397***
PERLND     398***
RCHRES      39
Catchment   40 ******
PERLND     401
PERLND     402
PERLND     403
PERLND     404
IMPLND     404
PERLND     405
IMPLND     405
PERLND     406
PERLND     407***
PERLND     408***
RCHRES      40
Catchment   41 ******
PERLND     411
PERLND     412
PERLND     413***
PERLND     414***
PERLND     415
IMPLND     415
PERLND     416
PERLND     417***
PERLND     418***
RCHRES      41
Catchment   42 ******
PERLND     421
PERLND     422
```

```
      PERLND     423
      PERLND     424
      IMPLND     424
      PERLND     425
      IMPLND     425
      PERLND     426
      PERLND     427***
      PERLND     428***
      RCHRES      42
      PLTGEN       1***
    END INGRP
END OPN SEQUENCE


PERLND

  ACTIVITY
    <PLS >          Active Sections (1=Active; 0=Inactive)             ***
    # -  # ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC ***
   11  428             1
  END ACTIVITY

  PRINT-INFO
    <PLS >          Print-flags                                *** PIVL  PYR
    # -  # ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC       ***
   11  428    5        5                                                   09
  END PRINT-INFO

  GEN-INFO
    <PLS ><-------Name------->        Unit-systems   Printer ***
    # -  #                              t-series Engl Metr ***
                                         in  out          ***
  211      Catch 21, Forest              2    2    0   61
  212      Catch 21, Crops               2    2    0   61
  213      Catch 21, Grassland           2    2    0   61
  214      Catch 21, CBD                 2    2    0   61
  215      Catch 21, MD Res.             2    2    0   61
  216      Catch 21, LD Res.             2    2    0   61
  217      Catch 21, HD Res.             2    2    0   61
  218      Catch 21, Wetland             2    2    0   61
  221      Catch 22, Forest              2    2    0   61
  222      Catch 22, Crops               2    2    0   61
  223      Catch 22, Grassland           2    2    0   61
  224      Catch 22, CBD                 2    2    0   61
  225      Catch 22, MD Res.             2    2    0   61
  226      Catch 22, LD Res.             2    2    0   61
  227      Catch 22, HD Res.             2    2    0   61
  228      Catch 22, Wetland             2    2    0   61
  231      Catch 23, Forest              2    2    0   61
  232      Catch 23, Crops               2    2    0   61
  233      Catch 23, Grassland           2    2    0   61
  234      Catch 23, CBD                 2    2    0   61
  235      Catch 23, MD Res.             2    2    0   61
  236      Catch 23, LD Res.             2    2    0   61
  237      Catch 23, HD Res.             2    2    0   61
  238      Catch 23, Wetland             2    2    0   61
  241      Catch 24, Forest              2    2    0   61
  242      Catch 24, Crops               2    2    0   61
  243      Catch 24, Grassland           2    2    0   61
  244      Catch 24, CBD                 2    2    0   61
  245      Catch 24, MD Res.             2    2    0   61
  246      Catch 24, LD Res.             2    2    0   61
  247      Catch 24, HD Res.             2    2    0   61
  248      Catch 24, Wetland             2    2    0   61
  251      Catch 25, Forest              2    2    0   61
  252      Catch 25, Crops               2    2    0   61
  253      Catch 25, Grassland           2    2    0   61
  254      Catch 25, CBD                 2    2    0   61
```

255	Catch 25, MD Res.	2	2	0	61
256	Catch 25, LD Res.	2	2	0	61
257	Catch 25, HD Res.	2	2	0	61
258	Catch 25, Wetland	2	2	0	61
261	Catch 26, Forest	2	2	0	61
262	Catch 26, Crops	2	2	0	61
263	Catch 26, Grassland	2	2	0	61
264	Catch 26, CBD	2	2	0	61
265	Catch 26, MD Res.	2	2	0	61
266	Catch 26, LD Res.	2	2	0	61
267	Catch 26, HD Res.	2	2	0	61
268	Catch 26, Wetland	2	2	0	61
271	Catch 27, Forest	2	2	0	61
272	Catch 27, Crops	2	2	0	61
273	Catch 27, Grassland	2	2	0	61
274	Catch 27, CBD	2	2	0	61
275	Catch 27, MD Res.	2	2	0	61
276	Catch 27, LD Res.	2	2	0	61
277	Catch 27, HD Res.	2	2	0	61
278	Catch 27, Wetland	2	2	0	61
281	Catch 28, Forest	2	2	0	61
282	Catch 28, Crops	2	2	0	61
283	Catch 28, Grassland	2	2	0	61
284	Catch 28, CBD	2	2	0	61
285	Catch 28, MD Res.	2	2	0	61
286	Catch 28, LD Res.	2	2	0	61
287	Catch 28, HD Res.	2	2	0	61
288	Catch 28, Wetland	2	2	0	61
291	Catch 29, Forest	2	2	0	61
292	Catch 29, Crops	2	2	0	61
293	Catch 29, Grassland	2	2	0	61
294	Catch 29, CBD	2	2	0	61
295	Catch 29, MD Res.	2	2	0	61
296	Catch 29, LD Res.	2	2	0	61
297	Catch 29, HD Res.	2	2	0	61
298	Catch 29, Wetland	2	2	0	61
301	Catch 30, Forest	2	2	0	61
302	Catch 30, Crops	2	2	0	61
303	Catch 30, Grassland	2	2	0	61
304	Catch 30, CBD	2	2	0	61
305	Catch 30, MD Res.	2	2	0	61
306	Catch 30, LD Res.	2	2	0	61
307	Catch 30, HD Res.	2	2	0	61
308	Catch 30, Wetland	2	2	0	61
311	Catch 31, Forest	2	2	0	61
312	Catch 31, Crops	2	2	0	61
313	Catch 31, Grassland	2	2	0	61
314	Catch 31, CBD	2	2	0	61
315	Catch 31, MD Res.	2	2	0	61
316	Catch 31, LD Res.	2	2	0	61
317	Catch 31, HD Res.	2	2	0	61
318	Catch 31, Wetland	2	2	0	61
321	Catch 32, Forest	2	2	0	61
322	Catch 32, Crops	2	2	0	61
323	Catch 32, Grassland	2	2	0	61
324	Catch 32, CBD	2	2	0	61
325	Catch 32, MD Res.	2	2	0	61
326	Catch 32, LD Res.	2	2	0	61
327	Catch 32, HD Res.	2	2	0	61
328	Catch 32, Wetland	2	2	0	61
331	Catch 33, Forest	2	2	0	61
332	Catch 33, Crops	2	2	0	61
333	Catch 33, Grassland	2	2	0	61
334	Catch 33, CBD	2	2	0	61
335	Catch 33, MD Res.	2	2	0	61
336	Catch 33, LD Res.	2	2	0	61
337	Catch 33, HD Res.	2	2	0	61
338	Catch 33, Wetland	2	2	0	61

341	Catch 34, Forest	2	2	0	61
342	Catch 34, Crops	2	2	0	61
343	Catch 34, Grassland	2	2	0	61
344	Catch 34, CBD	2	2	0	61
345	Catch 34, MD Res.	2	2	0	61
346	Catch 34, LD Res.	2	2	0	61
347	Catch 34, HD Res.	2	2	0	61
348	Catch 34, Wetland	2	2	0	61
351	Catch 35, Forest	2	2	0	61
352	Catch 35, Crops	2	2	0	61
353	Catch 35, Grassland	2	2	0	61
354	Catch 35, CBD	2	2	0	61
355	Catch 35, MD Res.	2	2	0	61
356	Catch 35, LD Res.	2	2	0	61
357	Catch 35, HD Res.	2	2	0	61
358	Catch 35, Wetland	2	2	0	61
361	Catch 36, Forest	2	2	0	61
362	Catch 36, Crops	2	2	0	61
363	Catch 36, Grassland	2	2	0	61
364	Catch 36, CBD	2	2	0	61
365	Catch 36, MD Res.	2	2	0	61
366	Catch 36, LD Res.	2	2	0	61
367	Catch 36, HD Res.	2	2	0	61
368	Catch 36, Wetland	2	2	0	61
371	Catch 37, Forest	2	2	0	61
372	Catch 37, Crops	2	2	0	61
373	Catch 37, Grassland	2	2	0	61
374	Catch 37, CBD	2	2	0	61
375	Catch 37, MD Res.	2	2	0	61
376	Catch 37, LD Res.	2	2	0	61
377	Catch 37, HD Res.	2	2	0	61
378	Catch 37, Wetland	2	2	0	61
381	Catch 38, Forest	2	2	0	61
382	Catch 38, Crops	2	2	0	61
383	Catch 38, Grassland	2	2	0	61
384	Catch 38, CBD	2	2	0	61
385	Catch 38, MD Res.	2	2	0	61
386	Catch 38, LD Res.	2	2	0	61
387	Catch 38, HD Res.	2	2	0	61
388	Catch 38, Wetland	2	2	0	61
391	Catch 39, Forest	2	2	0	61
392	Catch 39, Crops	2	2	0	61
393	Catch 39, Grassland	2	2	0	61
394	Catch 39, CBD	2	2	0	61
395	Catch 39, MD Res.	2	2	0	61
396	Catch 39, LD Res.	2	2	0	61
397	Catch 39, HD Res.	2	2	0	61
398	Catch 39, Wetland	2	2	0	61
401	Catch 40, Forest	2	2	0	61
402	Catch 40, Crops	2	2	0	61
403	Catch 40, Grassland	2	2	0	61
404	Catch 40, CBD	2	2	0	61
405	Catch 40, MD Res.	2	2	0	61
406	Catch 40, LD Res.	2	2	0	61
407	Catch 40, HD Res.	2	2	0	61
408	Catch 40, Wetland	2	2	0	61
411	Catch 41, Forest	2	2	0	61
412	Catch 41, Crops	2	2	0	61
413	Catch 41, Grassland	2	2	0	61
414	Catch 41, CBD	2	2	0	61
415	Catch 41, MD Res.	2	2	0	61
416	Catch 41, LD Res.	2	2	0	61
417	Catch 41, HD Res.	2	2	0	61
418	Catch 41, Wetland	2	2	0	61
421	Catch 42, Forest	2	2	0	61
422	Catch 42, Crops	2	2	0	61
423	Catch 42, Grassland	2	2	0	61
424	Catch 42, CBD	2	2	0	61

```
425      Catch 42, MD Res.                        2    2    0    61
426      Catch 42, LD Res.                        2    2    0    61
427      Catch 42, HD Res.                        2    2    0    61
428      Catch 42, Wetland                        2    2    0    61
END GEN-INFO

PWAT-PARM1
  <PLS >  PWATER variable monthly parameter value flags    ***
  # -   # CSNO RTOP UZFG  VCS  VUZ  VNN VIFW VIRC  VLE IFFC ***
212         0    0    0    1    0    0    0    0    1
213         0    0    0    1    0    0    0    0    1
222         0    0    0    1    0    0    0    0    1
223         0    0    0    1    0    0    0    0    1
232         0    0    0    1    0    0    0    0    1
233         0    0    0    1    0    0    0    0    1
242         0    0    0    1    0    0    0    0    1
243         0    0    0    1    0    0    0    0    1
252         0    0    0    1    0    0    0    0    1
253         0    0    0    1    0    0    0    0    1
262         0    0    0    1    0    0    0    0    1
263         0    0    0    1    0    0    0    0    1
272         0    0    0    1    0    0    0    0    1
273         0    0    0    1    0    0    0    0    1
282         0    0    0    1    0    0    0    0    1
283         0    0    0    1    0    0    0    0    1
292         0    0    0    1    0    0    0    0    1
293         0    0    0    1    0    0    0    0    1
302         0    0    0    1    0    0    0    0    1
303         0    0    0    1    0    0    0    0    1
312         0    0    0    1    0    0    0    0    1
313         0    0    0    1    0    0    0    0    1
322         0    0    0    1    0    0    0    0    1
323         0    0    0    1    0    0    0    0    1
332         0    0    0    1    0    0    0    0    1
333         0    0    0    1    0    0    0    0    1
342         0    0    0    1    0    0    0    0    1
343         0    0    0    1    0    0    0    0    1
352         0    0    0    1    0    0    0    0    1
353         0    0    0    1    0    0    0    0    1
362         0    0    0    1    0    0    0    0    1
363         0    0    0    1    0    0    0    0    1
372         0    0    0    1    0    0    0    0    1
373         0    0    0    1    0    0    0    0    1
382         0    0    0    1    0    0    0    0    1
383         0    0    0    1    0    0    0    0    1
392         0    0    0    1    0    0    0    0    1
393         0    0    0    1    0    0    0    0    1
402         0    0    0    1    0    0    0    0    1
403         0    0    0    1    0    0    0    0    1
412         0    0    0    1    0    0    0    0    1
413         0    0    0    1    0    0    0    0    1
422         0    0    0    1    0    0    0    0    1
423         0    0    0    1    0    0    0    0    1
END PWAT-PARM1

PWAT-PARM2
  <PLS > ***  PWATER input info: Part 2
  # -   # ***FOREST      LZSN    INFILT      LSUR     SLSUR     KVARY     AGWRC
211          0.000     300.0      1.00     125.0     0.052       0.0      0.93
212          0.000     300.0      1.00     125.0     0.052       0.0      0.93
213          0.000     300.0      1.00     125.0     0.052       0.0      0.93
214          0.000     300.0      1.00     125.0     0.052       0.0      0.93
215          0.000     300.0      1.00     125.0     0.052       0.0      0.93
216          0.000     300.0      1.00     125.0     0.052       0.0      0.93
217          0.000     300.0      1.00     125.0     0.052       0.0      0.93
218          0.000     300.0      1.00     125.0     0.052       0.0      0.93
221          0.000     300.0      1.00      48.0     0.216       0.0      0.93
222          0.000     300.0      1.00      48.0     0.216       0.0      0.93
```

223	0.000	300.0	1.00	48.0	0.216	0.0	0.93
224	0.000	300.0	1.00	48.0	0.216	0.0	0.93
225	0.000	300.0	1.00	48.0	0.216	0.0	0.93
226	0.000	300.0	1.00	48.0	0.216	0.0	0.93
227	0.000	300.0	1.00	48.0	0.216	0.0	0.93
228	0.000	300.0	1.00	48.0	0.216	0.0	0.93
231	0.000	300.0	1.00	45.0	0.230	0.0	0.93
232	0.000	300.0	1.00	45.0	0.230	0.0	0.93
233	0.000	300.0	1.00	45.0	0.230	0.0	0.93
234	0.000	300.0	1.00	45.0	0.230	0.0	0.93
235	0.000	300.0	1.00	45.0	0.230	0.0	0.93
236	0.000	300.0	1.00	45.0	0.230	0.0	0.93
237	0.000	300.0	1.00	45.0	0.230	0.0	0.93
238	0.000	300.0	1.00	45.0	0.230	0.0	0.93
241	0.000	300.0	1.00	89.0	0.107	0.0	0.93
242	0.000	300.0	1.00	89.0	0.107	0.0	0.93
243	0.000	300.0	1.00	89.0	0.107	0.0	0.93
244	0.000	300.0	1.00	89.0	0.107	0.0	0.93
245	0.000	300.0	1.00	89.0	0.107	0.0	0.93
246	0.000	300.0	1.00	89.0	0.107	0.0	0.93
247	0.000	300.0	1.00	89.0	0.107	0.0	0.93
248	0.000	300.0	1.00	89.0	0.107	0.0	0.93
251	0.000	300.0	1.00	143.0	0.024	0.0	0.93
252	0.000	300.0	1.00	143.0	0.024	0.0	0.93
253	0.000	300.0	1.00	143.0	0.024	0.0	0.93
254	0.000	300.0	1.00	143.0	0.024	0.0	0.93
255	0.000	300.0	1.00	143.0	0.024	0.0	0.93
256	0.000	300.0	1.00	143.0	0.024	0.0	0.93
257	0.000	300.0	1.00	143.0	0.024	0.0	0.93
258	0.000	300.0	1.00	143.0	0.024	0.0	0.93
261	0.000	300.0	1.00	143.0	0.024	0.0	0.93
262	0.000	300.0	1.00	143.0	0.024	0.0	0.93
263	0.000	300.0	1.00	143.0	0.024	0.0	0.93
264	0.000	300.0	1.00	143.0	0.024	0.0	0.93
265	0.000	300.0	1.00	143.0	0.024	0.0	0.93
266	0.000	300.0	1.00	143.0	0.024	0.0	0.93
267	0.000	300.0	1.00	143.0	0.024	0.0	0.93
268	0.000	300.0	1.00	143.0	0.024	0.0	0.93
271	0.000	300.0	1.00	122.0	0.056	0.0	0.93
272	0.000	300.0	1.00	122.0	0.056	0.0	0.93
273	0.000	300.0	1.00	122.0	0.056	0.0	0.93
274	0.000	300.0	1.00	122.0	0.056	0.0	0.93
275	0.000	300.0	1.00	122.0	0.056	0.0	0.93
276	0.000	300.0	1.00	122.0	0.056	0.0	0.93
277	0.000	300.0	1.00	122.0	0.056	0.0	0.93
278	0.000	300.0	1.00	122.0	0.056	0.0	0.93
281	0.000	300.0	1.00	150.0	0.013	0.0	0.93
282	0.000	300.0	1.00	150.0	0.013	0.0	0.93
283	0.000	300.0	1.00	150.0	0.013	0.0	0.93
284	0.000	300.0	1.00	150.0	0.013	0.0	0.93
285	0.000	300.0	1.00	150.0	0.013	0.0	0.93
286	0.000	300.0	1.00	150.0	0.013	0.0	0.93
287	0.000	300.0	1.00	150.0	0.013	0.0	0.93
288	0.000	300.0	1.00	150.0	0.013	0.0	0.93
291	0.000	300.0	1.00	84.0	0.114	0.0	0.93
292	0.000	300.0	1.00	84.0	0.114	0.0	0.93
293	0.000	300.0	1.00	84.0	0.114	0.0	0.93
294	0.000	300.0	1.00	84.0	0.114	0.0	0.93
295	0.000	300.0	1.00	84.0	0.114	0.0	0.93
296	0.000	300.0	1.00	84.0	0.114	0.0	0.93
297	0.000	300.0	1.00	84.0	0.114	0.0	0.93
298	0.000	300.0	1.00	84.0	0.114	0.0	0.93
301	0.000	300.0	1.00	96.0	0.096	0.0	0.93
302	0.000	300.0	1.00	96.0	0.096	0.0	0.93
303	0.000	300.0	1.00	96.0	0.096	0.0	0.93
304	0.000	300.0	1.00	96.0	0.096	0.0	0.93
305	0.000	300.0	1.00	96.0	0.096	0.0	0.93
306	0.000	300.0	1.00	96.0	0.096	0.0	0.93

307	0.000	300.0	1.00	96.0	0.096	0.0	0.93
308	0.000	300.0	1.00	96.0	0.096	0.0	0.93
311	0.000	320.0	1.00	108.0	0.078	0.0	0.93
312	0.000	320.0	1.00	108.0	0.078	0.0	0.93
313	0.000	320.0	1.00	108.0	0.078	0.0	0.93
314	0.000	320.0	1.00	108.0	0.078	0.0	0.93
315	0.000	320.0	1.00	108.0	0.078	0.0	0.93
316	0.000	320.0	1.00	108.0	0.078	0.0	0.93
317	0.000	320.0	1.00	108.0	0.078	0.0	0.93
318	0.000	320.0	1.00	108.0	0.078	0.0	0.93
321	0.000	320.0	1.00	108.0	0.078	0.0	0.93
322	0.000	320.0	1.00	108.0	0.078	0.0	0.93
323	0.000	320.0	1.00	108.0	0.078	0.0	0.93
324	0.000	320.0	1.00	108.0	0.078	0.0	0.93
325	0.000	320.0	1.00	108.0	0.078	0.0	0.93
326	0.000	320.0	1.00	108.0	0.078	0.0	0.93
327	0.000	320.0	1.00	108.0	0.078	0.0	0.93
328	0.000	320.0	1.00	108.0	0.078	0.0	0.93
331	0.000	320.0	1.00	131.0	0.043	0.0	0.93
332	0.000	320.0	1.00	131.0	0.043	0.0	0.93
333	0.000	320.0	1.00	131.0	0.043	0.0	0.93
334	0.000	320.0	1.00	131.0	0.043	0.0	0.93
335	0.000	320.0	1.00	131.0	0.043	0.0	0.93
336	0.000	320.0	1.00	131.0	0.043	0.0	0.93
337	0.000	320.0	1.00	131.0	0.043	0.0	0.93
338	0.000	320.0	1.00	131.0	0.043	0.0	0.93
341	0.000	320.0	1.00	97.0	0.094	0.0	0.93
342	0.000	320.0	1.00	97.0	0.094	0.0	0.93
343	0.000	320.0	1.00	97.0	0.094	0.0	0.93
344	0.000	320.0	1.00	97.0	0.094	0.0	0.93
345	0.000	320.0	1.00	97.0	0.094	0.0	0.93
346	0.000	320.0	1.00	97.0	0.094	0.0	0.93
347	0.000	320.0	1.00	97.0	0.094	0.0	0.93
348	0.000	320.0	1.00	97.0	0.094	0.0	0.93
351	0.000	320.0	1.00	58.0	0.164	0.0	0.93
352	0.000	320.0	1.00	58.0	0.164	0.0	0.93
353	0.000	320.0	1.00	58.0	0.164	0.0	0.93
354	0.000	320.0	1.00	58.0	0.164	0.0	0.93
355	0.000	320.0	1.00	58.0	0.164	0.0	0.93
356	0.000	320.0	1.00	58.0	0.164	0.0	0.93
357	0.000	320.0	1.00	58.0	0.164	0.0	0.93
358	0.000	320.0	1.00	58.0	0.164	0.0	0.93
361	0.000	320.0	1.00	59.0	0.159	0.0	0.93
362	0.000	320.0	1.00	59.0	0.159	0.0	0.93
363	0.000	320.0	1.00	59.0	0.159	0.0	0.93
364	0.000	320.0	1.00	59.0	0.159	0.0	0.93
365	0.000	320.0	1.00	59.0	0.159	0.0	0.93
366	0.000	320.0	1.00	59.0	0.159	0.0	0.93
367	0.000	320.0	1.00	59.0	0.159	0.0	0.93
368	0.000	320.0	1.00	59.0	0.159	0.0	0.93
371	0.000	320.0	1.00	38.0	0.266	0.0	0.93
372	0.000	320.0	1.00	38.0	0.266	0.0	0.93
373	0.000	320.0	1.00	38.0	0.266	0.0	0.93
374	0.000	320.0	1.00	38.0	0.266	0.0	0.93
375	0.000	320.0	1.00	38.0	0.266	0.0	0.93
376	0.000	320.0	1.00	38.0	0.266	0.0	0.93
377	0.000	320.0	1.00	38.0	0.266	0.0	0.93
378	0.000	320.0	1.00	38.0	0.266	0.0	0.93
381	0.000	320.0	1.00	78.0	0.124	0.0	0.93
382	0.000	320.0	1.00	78.0	0.124	0.0	0.93
383	0.000	320.0	1.00	78.0	0.124	0.0	0.93
384	0.000	320.0	1.00	78.0	0.124	0.0	0.93
385	0.000	320.0	1.00	78.0	0.124	0.0	0.93
386	0.000	320.0	1.00	78.0	0.124	0.0	0.93
387	0.000	320.0	1.00	78.0	0.124	0.0	0.93
388	0.000	320.0	1.00	78.0	0.124	0.0	0.93
391	0.000	320.0	1.00	80.0	0.121	0.0	0.93
392	0.000	320.0	1.00	80.0	0.121	0.0	0.93

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END PWAT-PARM3

PWAT-PARM4
  <PLS >       PWATER input info: Part 4                                      ***
  # -  #       CEPSC       UZSN       NSUR      INTFW        IRC      LZETP ***
211             4.45      29.40       0.40        2.5       0.70       0.80
221             4.45      29.40       0.40        2.5       0.70       0.80
231             4.45      29.40       0.40        2.5       0.70       0.80
241             4.45      29.40       0.40        2.5       0.70       0.80
251             4.45      29.40       0.40        2.5       0.70       0.80
261             4.45      29.40       0.40        2.5       0.70       0.80
271             4.45      29.40       0.40        2.5       0.70       0.80
281             4.45      29.40       0.40        2.5       0.70       0.80
291             4.45      29.40       0.40        2.5       0.70       0.80
301             4.45      29.40       0.40        2.5       0.70       0.80
311             4.45      29.40       0.40        2.5       0.70       0.80
321             4.45      29.40       0.40        2.5       0.70       0.80
331             4.45      29.40       0.40        2.5       0.70       0.80
341             4.45      29.40       0.40        2.5       0.70       0.80
351             4.45      29.40       0.40        2.5       0.70       0.80
361             4.45      29.40       0.40        2.5       0.70       0.80
371             4.45      29.40       0.40        2.5       0.70       0.80
381             4.45      29.40       0.40        2.5       0.70       0.80
391             4.45      29.40       0.40        2.5       0.70       0.80
401             4.45      29.40       0.40        2.5       0.70       0.80
411             4.45      29.40       0.40        2.5       0.70       0.80
421             4.45      29.40       0.40        2.5       0.70       0.80
212             3.50      16.80       0.25        3.0       0.70       0.60
222             3.50      16.80       0.25        3.0       0.70       0.60
232             3.50      16.80       0.25        3.0       0.70       0.60
242             3.50      16.80       0.25        3.0       0.70       0.60
252             3.50      16.80       0.25        3.0       0.70       0.60
262             3.50      16.80       0.25        3.0       0.70       0.60
272             3.50      16.80       0.25        3.0       0.70       0.60
282             3.50      16.80       0.25        3.0       0.70       0.60
292             3.50      16.80       0.25        3.0       0.70       0.60
302             3.50      16.80       0.25        3.0       0.70       0.60
312             3.50      16.80       0.25        3.0       0.70       0.60
322             3.50      16.80       0.25        3.0       0.70       0.60
332             3.50      16.80       0.25        3.0       0.70       0.60
342             3.50      16.80       0.25        3.0       0.70       0.60
352             3.50      16.80       0.25        3.0       0.70       0.60
362             3.50      16.80       0.25        3.0       0.70       0.60
372             3.50      16.80       0.25        3.0       0.70       0.60
382             3.50      16.80       0.25        3.0       0.70       0.60
392             3.50      16.80       0.25        3.0       0.70       0.60
402             3.50      16.80       0.25        3.0       0.70       0.60
412             3.50      16.80       0.25        3.0       0.70       0.60
422             3.50      16.80       0.25        3.0       0.70       0.60
213             2.54      16.80       0.20        2.0       0.70       0.50
223             2.54      16.80       0.20        2.0       0.70       0.50
233             2.54      16.80       0.20        2.0       0.70       0.50
243             2.54      16.80       0.20        2.0       0.70       0.50
253             2.54      16.80       0.20        2.0       0.70       0.50
263             2.54      16.80       0.20        2.0       0.70       0.50
273             2.54      16.80       0.20        2.0       0.70       0.50
283             2.54      16.80       0.20        2.0       0.70       0.50
293             2.54      16.80       0.20        2.0       0.70       0.50
303             2.54      16.80       0.20        2.0       0.70       0.50
313             2.54      16.80       0.20        2.0       0.70       0.50
323             2.54      16.80       0.20        2.0       0.70       0.50
333             2.54      16.80       0.20        2.0       0.70       0.50
343             2.54      16.80       0.20        2.0       0.70       0.50
353             2.54      16.80       0.20        2.0       0.70       0.50
363             2.54      16.80       0.20        2.0       0.70       0.50
373             2.54      16.80       0.20        2.0       0.70       0.50
383             2.54      16.80       0.20        2.0       0.70       0.50
393             2.54      16.80       0.20        2.0       0.70       0.50
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403	2.54	16.80	0.20	2.0	0.70	0.50
413	2.54	16.80	0.20	2.0	0.70	0.50
423	2.54	16.80	0.20	2.0	0.70	0.50
214	0.25	2.54	0.10	1.0	0.70	0.10
224	0.25	2.54	0.10	1.0	0.70	0.10
234	0.25	2.54	0.10	1.0	0.70	0.10
244	0.25	2.54	0.10	1.0	0.70	0.10
254	0.25	2.54	0.10	1.0	0.70	0.10
264	0.25	2.54	0.10	1.0	0.70	0.10
274	0.25	2.54	0.10	1.0	0.70	0.10
284	0.25	2.54	0.10	1.0	0.70	0.10
294	0.25	2.54	0.10	1.0	0.70	0.10
304	0.25	2.54	0.10	1.0	0.70	0.10
314	0.25	2.54	0.10	1.0	0.70	0.10
324	0.25	2.54	0.10	1.0	0.70	0.10
334	0.25	2.54	0.10	1.0	0.70	0.10
344	0.25	2.54	0.10	1.0	0.70	0.10
354	0.25	2.54	0.10	1.0	0.70	0.10
364	0.25	2.54	0.10	1.0	0.70	0.10
374	0.25	2.54	0.10	1.0	0.70	0.10
384	0.25	2.54	0.10	1.0	0.70	0.10
394	0.25	2.54	0.10	1.0	0.70	0.10
404	0.25	2.54	0.10	1.0	0.70	0.10
414	0.25	2.54	0.10	1.0	0.70	0.10
424	0.25	2.54	0.10	1.0	0.70	0.10
215	1.05	6.50	0.14	1.5	0.70	0.20
225	1.05	6.50	0.14	1.5	0.70	0.20
235	1.05	6.50	0.14	1.5	0.70	0.20
245	1.05	6.50	0.14	1.5	0.70	0.20
255	1.05	6.50	0.14	1.5	0.70	0.20
265	1.05	6.50	0.14	1.5	0.70	0.20
275	1.05	6.50	0.14	1.5	0.70	0.20
285	1.05	6.50	0.14	1.5	0.70	0.20
295	1.05	6.50	0.14	1.5	0.70	0.20
305	1.05	6.50	0.14	1.5	0.70	0.20
315	1.05	6.50	0.14	1.5	0.70	0.20
325	1.05	6.50	0.14	1.5	0.70	0.20
335	1.05	6.50	0.14	1.5	0.70	0.20
345	1.05	6.50	0.14	1.5	0.70	0.20
355	1.05	6.50	0.14	1.5	0.70	0.20
365	1.05	6.50	0.14	1.5	0.70	0.20
375	1.05	6.50	0.14	1.5	0.70	0.20
385	1.05	6.50	0.14	1.5	0.70	0.20
395	1.05	6.50	0.14	1.5	0.70	0.20
405	1.05	6.50	0.14	1.5	0.70	0.20
415	1.05	6.50	0.14	1.5	0.70	0.20
425	1.05	6.50	0.14	1.5	0.70	0.20
216	1.85	10.00	0.15	1.8	0.70	0.40
226	1.85	10.00	0.15	1.8	0.70	0.40
236	1.85	10.00	0.15	1.8	0.70	0.40
246	1.85	10.00	0.15	1.8	0.70	0.40
256	1.85	10.00	0.15	1.8	0.70	0.40
266	1.85	10.00	0.15	1.8	0.70	0.40
276	1.85	10.00	0.15	1.8	0.70	0.40
286	1.85	10.00	0.15	1.8	0.70	0.40
296	1.85	10.00	0.15	1.8	0.70	0.40
306	1.85	10.00	0.15	1.8	0.70	0.40
316	1.85	10.00	0.15	1.8	0.70	0.40
326	1.85	10.00	0.15	1.8	0.70	0.40
336	1.85	10.00	0.15	1.8	0.70	0.40
346	1.85	10.00	0.15	1.8	0.70	0.40
356	1.85	10.00	0.15	1.8	0.70	0.40
366	1.85	10.00	0.15	1.8	0.70	0.40
376	1.85	10.00	0.15	1.8	0.70	0.40
386	1.85	10.00	0.15	1.8	0.70	0.40
396	1.85	10.00	0.15	1.8	0.70	0.40
406	1.85	10.00	0.15	1.8	0.70	0.40
416	1.85	10.00	0.15	1.8	0.70	0.40

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426          1.85    10.00    0.15    1.8    0.70    0.40
217          0.76     3.50    0.12    1.0    0.70    0.15
227          0.76     3.50    0.12    1.0    0.70    0.15
237          0.76     3.50    0.12    1.0    0.70    0.15
247          0.76     3.50    0.12    1.0    0.70    0.15
257          0.76     3.50    0.12    1.0    0.70    0.15
267          0.76     3.50    0.12    1.0    0.70    0.15
277          0.76     3.50    0.12    1.0    0.70    0.15
287          0.76     3.50    0.12    1.0    0.70    0.15
297          0.76     3.50    0.12    1.0    0.70    0.15
307          0.76     3.50    0.12    1.0    0.70    0.15
317          0.76     3.50    0.12    1.0    0.70    0.15
327          0.76     3.50    0.12    1.0    0.70    0.15
337          0.76     3.50    0.12    1.0    0.70    0.15
347          0.76     3.50    0.12    1.0    0.70    0.15
357          0.76     3.50    0.12    1.0    0.70    0.15
367          0.76     3.50    0.12    1.0    0.70    0.15
377          0.76     3.50    0.12    1.0    0.70    0.15
387          0.76     3.50    0.12    1.0    0.70    0.15
397          0.76     3.50    0.12    1.0    0.70    0.15
407          0.76     3.50    0.12    1.0    0.70    0.15
417          0.76     3.50    0.12    1.0    0.70    0.15
427          0.76     3.50    0.12    1.0    0.70    0.15
218          2.00    10.00    0.30    2.0    0.70    0.75
228          2.00    10.00    0.30    2.0    0.70    0.75
238          2.00    10.00    0.30    2.0    0.70    0.75
248          2.00    10.00    0.30    2.0    0.70    0.75
258          2.00    10.00    0.30    2.0    0.70    0.75
268          2.00    10.00    0.30    2.0    0.70    0.75
278          2.00    10.00    0.30    2.0    0.70    0.75
288          2.00    10.00    0.30    2.0    0.70    0.75
298          2.00    10.00    0.30    2.0    0.70    0.75
308          2.00    10.00    0.30    2.0    0.70    0.75
318          2.00    10.00    0.30    2.0    0.70    0.75
328          2.00    10.00    0.30    2.0    0.70    0.75
338          2.00    10.00    0.30    2.0    0.70    0.75
348          2.00    10.00    0.30    2.0    0.70    0.75
358          2.00    10.00    0.30    2.0    0.70    0.75
368          2.00    10.00    0.30    2.0    0.70    0.75
378          2.00    10.00    0.30    2.0    0.70    0.75
388          2.00    10.00    0.30    2.0    0.70    0.75
398          2.00    10.00    0.30    2.0    0.70    0.75
408          2.00    10.00    0.30    2.0    0.70    0.75
418          2.00    10.00    0.30    2.0    0.70    0.75
428          2.00    10.00    0.30    2.0    0.70    0.75
END PWAT-PARM4

PWAT-PARM5 Defaults used ***

MON-INTERCEP
  <PLS>   Only required if VCSFG=1 in PWAT-PARM1                      ***
  # -  #  Interception storage capacity at start of each month        ***
          JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC  ***
212      4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
213      4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
222      4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
223      4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
232      4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
233      4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
242      4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
243      4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
252      4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
253      4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
262      4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
263      4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
272      4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
273      4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
282      4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
```

```
283        4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
292        4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
293        4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
302        4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
303        4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
312        4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
313        4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
322        4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
323        4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
332        4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
333        4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
342        4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
343        4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
352        4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
353        4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
362        4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
363        4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
372        4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
373        4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
382        4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
383        4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
392        4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
393        4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
402        4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
403        4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
412        4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
413        4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
422        4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
423        4.25 4.45 3.50 1.25 1.00 0.75 0.75 0.75 1.00 1.25 1.50 2.50
END MON-INTERCEP

MON-LZETPARM
  <PLS >  Only required if VLEFG=1 in PWAT-PARM1                          ***
  # -  #  Lower zone ET parameter at start of each month                  ***
           JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC     ***
212        0.60 0.70 0.60 0.20 0.20 0.15 0.15 0.15 0.20 0.25 0.30 0.40
213        0.55 0.60 0.50 0.20 0.20 0.20 0.20 0.20 0.25 0.30 0.35 0.40
222        0.60 0.70 0.60 0.20 0.20 0.15 0.15 0.15 0.20 0.25 0.30 0.40
223        0.55 0.60 0.50 0.20 0.20 0.20 0.20 0.20 0.25 0.30 0.35 0.40
232        0.60 0.70 0.60 0.20 0.20 0.15 0.15 0.15 0.20 0.25 0.30 0.40
233        0.55 0.60 0.50 0.20 0.20 0.20 0.20 0.20 0.25 0.30 0.35 0.40
242        0.60 0.70 0.60 0.20 0.20 0.15 0.15 0.15 0.20 0.25 0.30 0.40
243        0.55 0.60 0.50 0.20 0.20 0.20 0.20 0.20 0.25 0.30 0.35 0.40
252        0.60 0.70 0.60 0.20 0.20 0.15 0.15 0.15 0.20 0.25 0.30 0.40
253        0.55 0.60 0.50 0.20 0.20 0.20 0.20 0.20 0.25 0.30 0.35 0.40
262        0.60 0.70 0.60 0.20 0.20 0.15 0.15 0.15 0.20 0.25 0.30 0.40
263        0.55 0.60 0.50 0.20 0.20 0.20 0.20 0.20 0.25 0.30 0.35 0.40
272        0.60 0.70 0.60 0.20 0.20 0.15 0.15 0.15 0.20 0.25 0.30 0.40
273        0.55 0.60 0.50 0.20 0.20 0.20 0.20 0.20 0.25 0.30 0.35 0.40
282        0.60 0.70 0.60 0.20 0.20 0.15 0.15 0.15 0.20 0.25 0.30 0.40
283        0.55 0.60 0.50 0.20 0.20 0.20 0.20 0.20 0.25 0.30 0.35 0.40
292        0.60 0.70 0.60 0.20 0.20 0.15 0.15 0.15 0.20 0.25 0.30 0.40
293        0.55 0.60 0.50 0.20 0.20 0.20 0.20 0.20 0.25 0.30 0.35 0.40
302        0.60 0.70 0.60 0.20 0.20 0.15 0.15 0.15 0.20 0.25 0.30 0.40
303        0.55 0.60 0.50 0.20 0.20 0.20 0.20 0.20 0.25 0.30 0.35 0.40
312        0.60 0.70 0.60 0.20 0.20 0.15 0.15 0.15 0.20 0.25 0.30 0.40
313        0.55 0.60 0.50 0.20 0.20 0.20 0.20 0.20 0.25 0.30 0.35 0.40
322        0.60 0.70 0.60 0.20 0.20 0.15 0.15 0.15 0.20 0.25 0.30 0.40
323        0.55 0.60 0.50 0.20 0.20 0.20 0.20 0.20 0.25 0.30 0.35 0.40
332        0.60 0.70 0.60 0.20 0.20 0.15 0.15 0.15 0.20 0.25 0.30 0.40
333        0.55 0.60 0.50 0.20 0.20 0.20 0.20 0.20 0.25 0.30 0.35 0.40
342        0.60 0.70 0.60 0.20 0.20 0.15 0.15 0.15 0.20 0.25 0.30 0.40
343        0.55 0.60 0.50 0.20 0.20 0.20 0.20 0.20 0.25 0.30 0.35 0.40
352        0.60 0.70 0.60 0.20 0.20 0.15 0.15 0.15 0.20 0.25 0.30 0.40
353        0.55 0.60 0.50 0.20 0.20 0.20 0.20 0.20 0.25 0.30 0.35 0.40
362        0.60 0.70 0.60 0.20 0.20 0.15 0.15 0.15 0.20 0.25 0.30 0.40
363        0.55 0.60 0.50 0.20 0.20 0.20 0.20 0.20 0.25 0.30 0.35 0.40
372        0.60 0.70 0.60 0.20 0.20 0.15 0.15 0.15 0.20 0.25 0.30 0.40
```

```
  373       0.55 0.60 0.50 0.20 0.20 0.20 0.20 0.20 0.25 0.30 0.35 0.40
  382       0.60 0.70 0.60 0.20 0.20 0.15 0.15 0.15 0.20 0.25 0.30 0.40
  383       0.55 0.60 0.50 0.20 0.20 0.20 0.20 0.20 0.25 0.30 0.35 0.40
  392       0.60 0.70 0.60 0.20 0.20 0.15 0.15 0.15 0.20 0.25 0.30 0.40
  393       0.55 0.60 0.50 0.20 0.20 0.20 0.20 0.20 0.25 0.30 0.35 0.40
  402       0.60 0.70 0.60 0.20 0.20 0.15 0.15 0.15 0.20 0.25 0.30 0.40
  403       0.55 0.60 0.50 0.20 0.20 0.20 0.20 0.20 0.25 0.30 0.35 0.40
  412       0.60 0.70 0.60 0.20 0.20 0.15 0.15 0.15 0.20 0.25 0.30 0.40
  413       0.55 0.60 0.50 0.20 0.20 0.20 0.20 0.20 0.25 0.30 0.35 0.40
  422       0.60 0.70 0.60 0.20 0.20 0.15 0.15 0.15 0.20 0.25 0.30 0.40
  423       0.55 0.60 0.50 0.20 0.20 0.20 0.20 0.20 0.25 0.30 0.35 0.40
  END MON-LZETPARM

  PWAT-STATE1
    <PLS > *** Initial conditions at start of simulation
    # -  # ***  CEPS      SURS       UZS      IFWS       LZS      AGWS      GWVS
   11  248      0.00       0.0     11.94       0.0     210.0      25.4      00.0
  251  428      0.00       0.0     11.94       0.0     210.0      25.4      00.0
  END PWAT-STATE1

END PERLND

IMPLND
  ACTIVITY
    <ILS >  Active Sections              ***
    # -  # ATMP SNOW IWAT  SLD  IWG IQAL ***
  214  427            1
  END ACTIVITY

  PRINT-INFO
    <ILS >  Print-flags                            ***
    # -  # ATMP SNOW IWAT  SLD  IWG IQAL PIVL  PYR ***
  214  427            4                          09
  END PRINT-INFO

  GEN-INFO
    <ILS ><-------Name-------> Unit-systems   Printer ***
    # -  #                         t-series Engl Metr ***
                                     in  out          ***
  214       HD Urban, Indust.        2    2    0   64
  215       MD Residential           2    2    0   64
  217       HD Residential           2    2    0   64
  224       HD Urban, Indust.        2    2    0   64
  225       MD Residential           2    2    0   64
  227       HD Residential           2    2    0   64
  234       HD Urban, Indust.        2    2    0   64
  235       MD Residential           2    2    0   64
  237       HD Residential           2    2    0   64
  244       HD Urban, Indust.        2    2    0   64
  245       MD Residential           2    2    0   64
  247       HD Residential           2    2    0   64
  254       HD Urban, Indust.        2    2    0   64
  255       MD Residential           2    2    0   64
  257       HD Residential           2    2    0   64
  264       HD Urban, Indust.        2    2    0   64
  265       MD Residential           2    2    0   64
  267       HD Residential           2    2    0   64
  274       HD Urban, Indust.        2    2    0   64
  275       MD Residential           2    2    0   64
  277       HD Residential           2    2    0   64
  284       HD Urban, Indust.        2    2    0   64
  285       MD Residential           2    2    0   64
  287       HD Residential           2    2    0   64
  294       HD Urban, Indust.        2    2    0   64
  295       MD Residential           2    2    0   64
  297       HD Residential           2    2    0   64
  304       HD Urban, Indust.        2    2    0   64
  305       MD Residential           2    2    0   64
```

```
307       HD Residential             2    2    0   64
314       HD Urban, Indust.          2    2    0   64
315       MD Residential             2    2    0   64
317       HD Residential             2    2    0   64
324       HD Urban, Indust.          2    2    0   64
325       MD Residential             2    2    0   64
327       HD Residential             2    2    0   64
334       HD Urban, Indust.          2    2    0   64
335       MD Residential             2    2    0   64
337       HD Residential             2    2    0   64
344       HD Urban, Indust.          2    2    0   64
345       MD Residential             2    2    0   64
347       HD Residential             2    2    0   64
354       HD Urban, Indust.          2    2    0   64
355       MD Residential             2    2    0   64
357       HD Residential             2    2    0   64
364       HD Urban, Indust.          2    2    0   64
365       MD Residential             2    2    0   64
367       HD Residential             2    2    0   64
374       HD Urban, Indust.          2    2    0   64
375       MD Residential             2    2    0   64
377       HD Residential             2    2    0   64
384       HD Urban, Indust.          2    2    0   64
385       MD Residential             2    2    0   64
387       HD Residential             2    2    0   64
394       HD Urban, Indust.          2    2    0   64
395       MD Residential             2    2    0   64
397       HD Residential             2    2    0   64
404       HD Urban, Indust.          2    2    0   64
405       MD Residential             2    2    0   64
407       HD Residential             2    2    0   64
414       HD Urban, Indust.          2    2    0   64
415       MD Residential             2    2    0   64
417       HD Residential             2    2    0   64
424       HD Urban, Indust.          2    2    0   64
425       MD Residential             2    2    0   64
427       HD Residential             2    2    0   64
END GEN-INFO
*** Section IWATER ***

IWAT-PARM1 defaults used ***

IWAT-PARM2
  <ILS >                                            ***
  # -  #       LSUR      SLSUR      NSUR      RETSC ***
214            58.0      0.052     0.050       2.54
215            58.0      0.052     0.100       2.54
217            58.0      0.052     0.075       2.54
224            15.0      0.150     0.050       2.54
225            15.0      0.150     0.100       2.54
227            15.0      0.150     0.075       2.54
234            15.0      0.150     0.050       2.54
235            15.0      0.150     0.100       2.54
237            15.0      0.150     0.075       2.54
244            34.0      0.107     0.050       2.54
245            34.0      0.107     0.100       2.54
247            34.0      0.107     0.075       2.54
254            70.0      0.024     0.050       2.54
255            70.0      0.024     0.100       2.54
257            70.0      0.024     0.075       2.54
264            70.0      0.024     0.050       2.54
265            70.0      0.024     0.100       2.54
267            70.0      0.024     0.075       2.54
274            56.0      0.056     0.050       2.54
275            56.0      0.056     0.100       2.54
277            56.0      0.056     0.075       2.54
284            75.0      0.013     0.050       2.14
285            75.0      0.013     0.100       2.54
```

```
  287          75.0    0.013     0.075      2.54
  294          31.0    0.114     0.050      2.54
  295          31.0    0.114     0.100      2.54
  297          31.0    0.114     0.075      2.54
  304          39.0    0.096     0.050      2.54
  305          39.0    0.096     0.100      2.54
  307          39.0    0.096     0.075      2.54
  314          46.0    0.078     0.050      2.54
  315          46.0    0.078     0.100      2.54
  317          46.0    0.078     0.075      2.54
  324          46.0    0.078     0.050      2.54
  325          46.0    0.078     0.100      2.54
  327          46.0    0.078     0.075      2.54
  334          62.0    0.043     0.050      2.54
  335          62.0    0.043     0.100      2.54
  337          62.0    0.043     0.075      2.54
  344          39.0    0.094     0.050      2.54
  345          39.0    0.094     0.100      2.54
  347          39.0    0.094     0.075      2.54
  354          15.0    0.150     0.050      2.54
  355          15.0    0.150     0.100      2.54
  357          15.0    0.150     0.075      2.54
  364          15.0    0.150     0.050      2.54
  365          15.0    0.150     0.100      2.54
  367          15.0    0.150     0.075      2.54
  374          15.0    0.150     0.050      2.54
  375          15.0    0.150     0.100      2.54
  377          15.0    0.150     0.075      2.54
  384          26.0    0.124     0.050      2.54
  385          26.0    0.124     0.100      2.54
  387          26.0    0.124     0.075      2.54
  394          28.0    0.121     0.050      2.54
  395          28.0    0.121     0.100      2.54
  397          28.0    0.121     0.075      2.54
  404          15.0    0.150     0.050      2.54
  405          15.0    0.150     0.100      2.54
  407          15.0    0.150     0.075      2.54
  414          35.0    0.104     0.050      2.54
  415          35.0    0.104     0.100      2.54
  417          35.0    0.104     0.075      2.54
  424          25.0    0.128     0.050      2.54
  425          25.0    0.128     0.100      2.54
  427          25.0    0.128     0.075      2.54
  END IWAT-PARM2

  IWAT-PARM3 *** defaults used

  IWAT-STATE1
    <ILS >  IWATER state variables ***
    # -  #       RETS       SURS      ***
  214  427       0.00       0.00
  END IWAT-STATE1

END IMPLND

RCHRES

  ACTIVITY
    RCHRES  Active Sections (1=Active; 0=Inactive)           ***
    # -  # HYFG ADFG CNFG HTFG SDFG GQFG OXFG NUFG PKFG PHFG ***
   21   42    1
  END ACTIVITY

  PRINT-INFO
              Print-flags                                              ***
    # -  # HYDR ADCA CONS HEAT  SED  GQL OXRX NUTR PLNK   PH     PYR ***
    1   42    5    6    6    6    6    6    6    6    6    6       09
  END PRINT-INFO
```

```
  287           75.0    0.013    0.075     2.54
  294           31.0    0.114    0.050     2.54
  295           31.0    0.114    0.100     2.54
  297           31.0    0.114    0.075     2.54
  304           39.0    0.096    0.050     2.54
  305           39.0    0.096    0.100     2.54
  307           39.0    0.096    0.075     2.54
  314           46.0    0.078    0.050     2.54
  315           46.0    0.078    0.100     2.54
  317           46.0    0.078    0.075     2.54
  324           46.0    0.078    0.050     2.54
  325           46.0    0.078    0.100     2.54
  327           46.0    0.078    0.075     2.54
  334           62.0    0.043    0.050     2.54
  335           62.0    0.043    0.100     2.54
  337           62.0    0.043    0.075     2.54
  344           39.0    0.094    0.050     2.54
  345           39.0    0.094    0.100     2.54
  347           39.0    0.094    0.075     2.54
  354           15.0    0.150    0.050     2.54
  355           15.0    0.150    0.100     2.54
  357           15.0    0.150    0.075     2.54
  364           15.0    0.150    0.050     2.54
  365           15.0    0.150    0.100     2.54
  367           15.0    0.150    0.075     2.54
  374           15.0    0.150    0.050     2.54
  375           15.0    0.150    0.100     2.54
  377           15.0    0.150    0.075     2.54
  384           26.0    0.124    0.050     2.54
  385           26.0    0.124    0.100     2.54
  387           26.0    0.124    0.075     2.54
  394           28.0    0.121    0.050     2.54
  395           28.0    0.121    0.100     2.54
  397           28.0    0.121    0.075     2.54
  404           15.0    0.150    0.050     2.54
  405           15.0    0.150    0.100     2.54
  407           15.0    0.150    0.075     2.54
  414           35.0    0.104    0.050     2.54
  415           35.0    0.104    0.100     2.54
  417           35.0    0.104    0.075     2.54
  424           25.0    0.128    0.050     2.54
  425           25.0    0.128    0.100     2.54
  427           25.0    0.128    0.075     2.54
  END IWAT-PARM2

  IWAT-PARM3 *** defaults used

  IWAT-STATE1
    <ILS >  IWATER state variables ***
    # -  #       RETS       SURS     ***
  214  427       0.00       0.00
  END IWAT-STATE1

END IMPLND

RCHRES

  ACTIVITY
    RCHRES  Active Sections (1=Active; 0=Inactive)           ***
    # -  # HYFG ADFG CNFG HTFG SDFG GQFG OXFG NUFG PKFG PHFG ***
   21   42    1
  END ACTIVITY

  PRINT-INFO
            Print-flags                                                ***
    # -  # HYDR ADCA CONS HEAT  SED  GQL OXRX NUTR PLNK  PH        PYR ***
    1   42    5    6    6    6    6    6    6    6    6    6         09
  END PRINT-INFO
```

```
GEN-INFO
  RCHRES<-------Name------->Nexit   Unit Systems   Printer      ***
  # -  #                         User t-series  Engl Metr LKFG ***
                                        in  out                ***
 21      Reach 11              1         2    2     0   62     0
 22      Reach 12              1         2    2     0   62     0
 23      Reach 13              1         2    2     0   62     0
 24      Reach 14              1         2    2     0   62     0
 25      Reach 15              1         2    2     0   62     0
 26      Reach 16              1         2    2     0   62     0
 27      Reach 17              1         2    2     0   62     0
 28      Reach 27              1         2    2     0   62     0
 29      Reach 28              1         2    2     0   62     0
 30      Reach 29              1         2    2     0   62     0
 31      Reach 30              1         2    2     0   62     0
 32      Reach 31              1         2    2     0   62     0
 33      Reach 32              1         2    2     0   62     0
 34      Reach 33              1         2    2     0   62     0
 35      Reach 35              1         2    2     0   62     0
 36      Reach 36              1         2    2     0   62     0
 37      Reach 37              1         2    2     0   62     0
 38      Reach 38              1         2    2     0   62     0
 39      Reach 39              1         2    2     0   62     0
 40      Reach 40              1         2    2     0   62     0
 41      Reach 41              1         2    2     0   62     0
 42      Reach 42              1         2    2     0   62     0
END GEN-INFO

HYDR-PARM1
  RCHRES  Flags for HYDR section                       ***
  # -  #  VC A1 A2 A3  ODFVFG for each     ODGTFG for each *** FUNCT  for each
          FG FG FG FG  possible   exit     possible   exit *** possible   exit
             1  2  3     1  2  3  4  5       1  2  3  4  5 ***   1  2  3  4  5
 21   42   0  1  1  1    4
END HYDR-PARM1

HYDR-PARM2
  RCHRES ***
  # -  #    FTABNO       LEN     DELTH     STCOR        KS      DB50 ***
  *** The values of DB50 are needed by the Colby and Toffaleti sediment
  *** transport methods.  We will use the default (6.35mm)
 21             21     2.888       1.1                 0.5
 22             22     5.663     235.1                 0.5
 23             23     4.571     234.6                 0.5
 24             24    10.695      81.3                 0.5
 25             25     3.351       6.6                 0.5
 26             26     6.437     122.3                 0.5
 27             27     2.618       6.0                 0.5
 28             28     1.832       1.5                 0.5
 29             29     6.054     150.7                 0.5
 30             30     5.767      30.1                 0.5
 31             31     8.237     128.0                 0.5
 32             32    11.891     195.5                 0.5
 33             33     4.187      30.4                 0.5
 34             34    18.140      65.4                 0.5
 35             35     7.510      42.6                 0.5
 36             36     4.208       9.1                 0.5
 37             37    12.403      40.1                 0.5
 38             38    11.583     184.6                 0.5
 39             39    11.460     210.5                 0.5
 40             40    10.972      71.0                 0.5
 41             41     6.120      13.1                 0.5
 42             42    15.075      56.4                 0.5
END HYDR-PARM2
```

```
 HYDR-INIT
    Reaches are assumed initially empty ***
  RCHRES          VOL  CAT Initial value  of COLIND *** initial  value  of OUTDGT
    # -  #        Mm3      for each possible   exit *** for  each  possible  exit
                             EX1  EX2  EX3  EX4  EX5 ***   EX1  EX2  EX3  EX4  EX5
   21   42        0.0
  END HYDR-INIT

END RCHRES

PLTGEN
  PLOTINFO
    # -  # FILE  NPT  NMN LABL  PYR PIVL ***
    1       92         2              1
  END PLOTINFO

  GEN-LABELS
    # -  #<----------------Title----------------->   ***    <------Y axis------>
    1      OBSERVED ECOLI                                   Count
  END GEN-LABELS

  SCALING
    # -  #       YMIN       YMAX      IVLIN     THRESH ***
    1              0.       100.        20.
  END SCALING

  CURV-DATA            (first curve)
              <-Curve label--> Line Intg  Col Tran ***
    # -  #                     type  eqv code code ***
    1         OBS ECOLI                 1    1 AVER
  END CURV-DATA

  CURV-DATA            (second curve)
              <-Curve label--> Line Intg  Col Tran ***
    # -  #                     type  eqv code code ***
    1         SIM ECOLI                 2    2 AVER
  END CURV-DATA

END PLTGEN

*** FTABLES

FTABLES

  FTABLE     21
 ROWS COLS ***
   20    4
     DEPTH       AREA    VOLUME      DISCH  FLO-THRU ***
      ( m)    (   HA)     (Mm3)      (CMS)     (MIN) ***
     0.000      0.000     0.000      0.000      0.00
     0.250      1.943     0.002      0.063    646.89
     0.500      3.886     0.010      0.397    407.42
     0.750      5.829     0.022      1.172    310.88
     1.100      6.092     0.043      3.451    206.31
     1.450      6.356     0.065      6.624    162.31
     1.800      6.619     0.087     10.593    137.22
     2.150      6.883     0.111     15.305    120.70
     2.500      7.146     0.135     20.728    108.86
     2.850      7.410     0.161     26.842     99.88
     3.550      7.936     0.215     41.096     87.02
     4.250      8.463     0.272     58.024     78.12
     4.950      8.990     0.333     77.627     71.51
     6.350     18.249     0.524    141.016     61.90
     7.750     27.508     0.844    252.741     55.66
     9.150     36.767     1.294    434.810     49.60
    10.550     46.025     1.873    705.454     44.26
    11.950     55.284     2.583   1080.959     39.82
    13.350     64.543     3.421   1576.327     36.18
```

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    14.750    73.802     4.390  2205.617     33.17
  END FTABLE 21
  FTABLE     22
 ROWS COLS ***
   20    4
     DEPTH      AREA    VOLUME     DISCH  FLO-THRU ***
      ( m)    (  HA)    (Mm3)     (CMS)     (MIN) ***
     0.000     0.000     0.000     0.000      0.00
     0.250     1.311     0.002     0.319     85.57
     0.500     2.622     0.007     2.027     53.89
     0.750     3.933     0.015     5.978     41.12
     0.942     4.194     0.023    11.481     32.72
     1.133     4.455     0.031    18.407     27.91
     1.325     4.717     0.040    26.691     24.74
     1.517     4.978     0.049    36.306     22.45
     1.708     5.239     0.059    47.243     20.71
     1.900     5.500     0.069    59.507     19.32
     2.283     6.023     0.091    88.069     17.24
     2.667     6.545     0.115   122.142     15.72
     3.050     7.068     0.141   161.921     14.54
     3.817    15.512     0.228   292.643     12.97
     4.583    23.957     0.379   510.020     12.39
     5.350    32.401     0.595   850.764     11.66
     6.117    40.846     0.876  1345.325     10.85
     6.883    49.290     1.221  2020.939     10.07
     7.650    57.735     1.632  2902.726      9.37
     8.417    66.179     2.107  4014.241      8.75
  END FTABLE 22

  FTABLE     23
 ROWS COLS ***
   20    4
     DEPTH      AREA    VOLUME     DISCH  FLO-THRU ***
      ( m)    (  HA)    (Mm3)     (CMS)     (MIN) ***
     0.000     0.000     0.000     0.000      0.00
     0.250     1.104     0.001     0.417     55.12
     0.500     2.208     0.006     2.650     34.71
     0.750     3.312     0.012     7.815     26.49
     0.950     3.527     0.019    15.390     20.86
     1.150     3.741     0.027    24.975     17.70
     1.350     3.956     0.034    36.470     15.64
     1.550     4.171     0.042    49.824     14.17
     1.750     4.385     0.051    65.022     13.05
     1.950     4.600     0.060    82.064     12.16
     2.350     5.029     0.079   121.738     10.84
     2.750     5.459     0.100   169.030      9.87
     3.150     5.888     0.123   224.190      9.13
     3.950    11.519     0.192   397.096      8.08
     4.750    17.150     0.307   654.950      7.82
     5.550    22.782     0.467  1027.060      7.58
     6.350    28.413     0.672  1537.829      7.28
     7.150    34.044     0.921  2209.170      6.95
     7.950    39.675     1.216  3061.356      6.62
     8.750    45.307     1.556  4113.454      6.31
  END FTABLE 23

  FTABLE     24
 ROWS COLS ***
   20    4
     DEPTH      AREA    VOLUME     DISCH  FLO-THRU ***
      ( m)    (  HA)    (Mm3)     (CMS)     (MIN) ***
     0.000     0.000     0.000     0.000      0.00
     0.250     2.675     0.003     0.168    331.88
     0.500     5.350     0.013     1.066    209.02
     0.750     8.025     0.030     3.145    159.49
     0.958     8.560     0.047     6.344    124.45
     1.167     9.095     0.066    10.423    105.15
     1.375     9.630     0.085    15.336     92.67
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    1.583    10.165     0.106    21.062     83.79
    1.792    10.700     0.128    27.595     77.08
    2.000    11.235     0.150    34.937     71.78
    2.417    12.305     0.200    52.071     63.86
    2.833    13.375     0.253    72.551     58.12
    3.250    14.445     0.311    96.492     53.71
    4.083    67.679     0.653   195.269     55.75
    4.917   120.913     1.439   433.736     55.29
    5.750   174.146     2.668   887.714     50.10
    6.583   227.380     4.341  1619.854     44.67
    7.417   280.614     6.458  2685.990     40.07
    8.250   333.848     9.018  4137.443     36.33
    9.083   387.082    12.022  6022.229     33.27
  END FTABLE 24

  FTABLE     25
 ROWS COLS ***
   20    4
    DEPTH      AREA    VOLUME     DISCH  FLO-THRU ***
     ( m)   (    HA)    (Mm3)     (CMS)     (MIN) ***
    0.000     0.000     0.000     0.000      0.00
    0.250     1.417     0.002     0.114    258.64
    0.500     2.833     0.007     0.725    162.90
    0.750     4.250     0.016     2.137    124.30
    1.050     4.403     0.029     5.551     86.83
    1.350     4.556     0.042    10.112     69.81
    1.650     4.709     0.056    15.676     59.81
    1.950     4.862     0.071    22.157     53.11
    2.250     5.015     0.085    29.499     48.26
    2.550     5.168     0.101    37.662     44.56
    3.150     5.474     0.133    56.351     39.23
    3.750     5.780     0.166    78.093     35.51
    4.350     6.086     0.202   102.828     32.74
    5.550    20.503     0.362   191.922     31.39
    6.750    34.920     0.694   381.171     30.35
    7.950    49.337     1.200   722.790     27.66
    9.150    63.754     1.878  1259.939     24.84
   10.350    78.171     2.730  2031.092     22.40
   11.550    92.588     3.754  3071.630     20.37
   12.750   107.005     4.952  4414.662     18.69
  END FTABLE 25

  FTABLE     26
 ROWS COLS ***
   20    4
    DEPTH      AREA    VOLUME     DISCH  FLO-THRU ***
     ( m)   (    HA)    (Mm3)     (CMS)     (MIN) ***
    0.000     0.000     0.000     0.000      0.00
    0.250     0.832     0.001     0.153    113.19
    0.500     1.664     0.004     0.973     71.29
    0.750     2.496     0.009     2.868     54.40
    0.883     2.805     0.013     4.503     47.72
    1.017     3.115     0.017     6.529     42.99
    1.150     3.424     0.021     8.969     39.40
    1.283     3.733     0.026    11.844     36.55
    1.417     4.043     0.031    15.179     34.21
    1.550     4.352     0.037    18.996     32.24
    1.817     4.971     0.049    28.169     29.10
    2.083     5.589     0.063    39.539     26.67
    2.350     6.208     0.079    53.279     24.71
    2.883    14.230     0.133   101.859     21.84
    3.417    22.252     0.231   187.417     20.52
    3.950    30.274     0.371   326.191     18.95
    4.483    38.296     0.554   531.652     17.36
    5.017    46.318     0.779   815.850     15.92
    5.550    54.340     1.048  1189.894     14.68
    6.083    62.362     1.359  1664.203     13.61
  END FTABLE 26
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 FTABLE     27
ROWS COLS ***
  20    4
    DEPTH       AREA    VOLUME      DISCH  FLO-THRU ***
     ( m)   (    HA)    (Mm3)      (CMS)     (MIN) ***
    0.000      0.000     0.000      0.000      0.00
    0.250      2.167     0.003      0.250    180.75
    0.500      4.333     0.011      1.586    113.84
    0.750      6.500     0.024      4.677     86.86
    1.075      6.717     0.046     13.044     58.58
    1.400      6.933     0.068     24.524     46.24
    1.725      7.150     0.091     38.767     39.09
    2.050      7.367     0.115     55.566     34.35
    2.375      7.583     0.139     74.788     30.93
    2.700      7.800     0.164     96.338     28.34
    3.350      8.233     0.216    146.178     24.62
    4.000      8.667     0.271    204.760     22.04
    4.650      9.100     0.329    271.931     20.14
    5.950     20.385     0.520    476.605     18.19
    7.250     31.671     0.859    814.956     17.56
    8.550     42.956     1.344   1344.642     16.65
    9.850     54.242     1.975   2113.438     15.58
   11.150     65.527     2.754   3164.052     14.51
   12.450     76.813     3.679   4535.846     13.52
   13.750     88.098     4.751   6265.725     12.64
 END FTABLE 27

 FTABLE     28
ROWS COLS ***
  20    4
    DEPTH       AREA    VOLUME      DISCH  FLO-THRU ***
     ( m)   (    HA)    (Mm3)      (CMS)     (MIN) ***
    0.000      0.000     0.000      0.000      0.00
    0.250      0.810     0.001      0.101    167.07
    0.500      1.620     0.004      0.641    105.23
    0.750      2.430     0.009      1.892     80.29
    1.008      2.572     0.016      4.419     58.74
    1.267      2.715     0.022      7.768     48.07
    1.525      2.857     0.030     11.881     41.53
    1.783      3.000     0.037     16.727     37.03
    2.042      3.142     0.045     22.291     33.72
    2.300      3.285     0.053     28.568     31.16
    2.817      3.570     0.071     43.259     27.40
    3.333      3.855     0.090     60.836     24.74
    3.850      4.140     0.111     81.365     22.73
    4.883     11.132     0.190    149.450     21.17
    5.917     18.125     0.341    270.170     21.04
    6.950     25.117     0.564    467.477     20.12
    7.983     32.110     0.860    761.213     18.83
    9.017     39.102     1.228   1169.106     17.51
   10.050     46.095     1.668   1707.491     16.28
   11.083     53.087     2.181   2391.672     15.20
 END FTABLE 28

 FTABLE     29
ROWS COLS ***
  20    4
    DEPTH       AREA    VOLUME      DISCH  FLO-THRU ***
     ( m)   (    HA)    (Mm3)      (CMS)     (MIN) ***
    0.000      0.000     0.000      0.000      0.00
    0.250      1.403     0.002      0.247    118.32
    0.500      2.806     0.007      1.569     74.52
    0.750      4.209     0.016      4.626     56.86
    0.917      4.494     0.023      8.248     46.55
    1.083      4.778     0.031     12.728     40.28
    1.250      5.063     0.039     18.043     35.99
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      1.417      5.348      0.048     24.183      32.83
      1.583      5.632      0.057     31.151      30.38
      1.750      5.917      0.066     38.954      28.42
      2.083      6.486      0.087     57.110      25.41
      2.417      7.056      0.110     78.768      23.20
      2.750      7.625      0.134    104.064      21.48
      3.417     25.306      0.244    196.042      20.73
      4.083     42.987      0.472    382.328      20.56
      4.750     60.668      0.817    710.503      19.17
      5.417     78.350      1.280   1219.921      17.49
      6.083     96.031      1.862   1945.687      15.95
      6.750    113.712      2.561   2920.096      14.62
      7.417    131.393      3.378   4173.383      13.49
   END FTABLE 29

   FTABLE      30
  ROWS COLS ***
    20     4
      DEPTH       AREA     VOLUME      DISCH   FLO-THRU ***
       ( m)    (    HA)     (Mm3)      (CMS)      (MIN) ***
      0.000      0.000      0.000      0.000       0.00
      0.250      2.397      0.003      0.154     323.30
      0.500      4.795      0.012      0.981     203.62
      0.750      7.192      0.027      2.893     155.37
      1.117      7.390      0.054      8.746     102.34
      1.483      7.588      0.081     16.738      80.82
      1.850      7.786      0.109     26.508      68.75
      2.217      7.985      0.138     37.837      60.90
      2.583      8.183      0.168     50.583      55.32
      2.950      8.381      0.198     64.643      51.12
      3.683      8.777      0.261     96.428      45.14
      4.417      9.174      0.327    132.799      41.04
      5.150      9.570      0.396    173.530      38.01
      6.617     30.192      0.687    321.759      35.60
      8.083     50.814      1.281    639.572      33.39
      9.550     71.437      2.178   1216.028      29.85
     11.017     92.059      3.377   2124.724      26.49
     12.483    112.681      4.878   3431.263      23.70
     13.950    133.303      6.682   5195.961      21.43
     15.417    153.926      8.789   7475.262      19.59
   END FTABLE 30

   FTABLE      31
  ROWS COLS ***
    20     4
      DEPTH       AREA     VOLUME      DISCH   FLO-THRU ***
       ( m)    (    HA)     (Mm3)      (CMS)      (MIN) ***
      0.000      0.000      0.000      0.000       0.00
      0.250      1.039      0.001      0.100     215.89
      0.500      2.077      0.005      0.637     135.97
      0.750      3.116      0.012      1.877     103.75
      0.892      3.403      0.016      3.050      89.09
      1.033      3.690      0.021      4.481      79.33
      1.175      3.977      0.027      6.174      72.23
      1.317      4.264      0.033      8.135      66.78
      1.458      4.551      0.039     10.373      62.40
      1.600      4.838      0.045     12.896      58.79
      1.883      5.412      0.060     18.833      53.11
      2.167      5.986      0.076     26.022      48.78
      2.450      6.560      0.094     34.539      45.33
      3.017     15.947      0.158     65.055      40.40
      3.583     25.334      0.275    122.029      37.51
      4.150     34.722      0.445    217.970      34.01
      4.717     44.109      0.668    363.235      30.66
      5.283     53.496      0.945    567.075      27.77
      5.850     62.883      1.274    838.006      25.35
      6.417     72.270      1.657   1184.010      23.33
   END FTABLE 31
```

```
 FTABLE      32
ROWS COLS ***
  20     4
     DEPTH       AREA     VOLUME      DISCH   FLO-THRU ***
      ( m)    (   HA)     (Mm3)      (CMS)      (MIN) ***
     0.000      0.000     0.000      0.000       0.00
     0.250      2.063     0.003      0.169     254.44
     0.500      4.125     0.010      1.073     160.25
     0.750      6.188     0.023      3.163     122.28
     0.917      6.644     0.034      5.604     100.82
     1.083      7.100     0.045      8.617      87.72
     1.250      7.556     0.058     12.189      78.71
     1.417      8.013     0.071     16.318      72.05
     1.583      8.469     0.084     21.005      66.87
     1.750      8.925     0.099     26.260      62.69
     2.083      9.837     0.130     38.509      56.28
     2.417     10.750     0.164     53.161      51.53
     2.750     11.662     0.202     70.320      47.81
     3.417     29.041     0.337    131.058      42.90
     4.083     46.419     0.589    245.617      39.96
     4.750     63.798     0.956    439.822      36.24
     5.417     81.176     1.440    735.051      32.64
     6.083     98.555     2.039   1150.387      29.54
     6.750    115.934     2.754   1703.400      26.94
     7.417    133.312     3.584   2410.546      24.78
 END FTABLE 32

 FTABLE      33
ROWS COLS ***
  20     4
     DEPTH       AREA     VOLUME      DISCH   FLO-THRU ***
      ( m)    (   HA)     (Mm3)      (CMS)      (MIN) ***
     0.000      0.000     0.000      0.000       0.00
     0.250      0.896     0.001      0.124     150.87
     0.500      1.792     0.004      0.786      95.02
     0.750      2.688     0.010      2.317      72.50
     0.925      2.814     0.015      4.246      58.47
     1.100      2.940     0.020      6.613      50.23
     1.275      3.066     0.025      9.387      44.71
     1.450      3.192     0.031     12.551      40.71
     1.625      3.318     0.036     16.091      37.66
     1.800      3.444     0.042     20.003      35.22
     2.150      3.696     0.055     28.927      31.56
     2.500      3.948     0.068     39.317      28.89
     2.850      4.200     0.082     51.190      26.83
     3.550     13.069     0.143     94.036      25.32
     4.250     21.938     0.265    182.194      24.28
     4.950     30.806     0.450    338.987      22.12
     5.650     39.675     0.697    583.692      19.89
     6.350     48.544     1.005    933.499      17.95
     7.050     57.413     1.376   1404.213      16.34
     7.750     66.281     1.809   2010.631      15.00
 END FTABLE 33

 FTABLE      34
ROWS COLS ***
  20     4
     DEPTH       AREA     VOLUME      DISCH   FLO-THRU ***
      ( m)    (   HA)     (Mm3)      (CMS)      (MIN) ***
     0.000      0.000     0.000      0.000       0.00
     0.250      8.447     0.011      0.145    1209.88
     0.500     16.893     0.042      0.924     762.00
     0.750     25.340     0.095      2.724     581.44
     1.050     26.999     0.174      7.071     409.03
     1.350     28.658     0.257     12.991     329.74
     1.650     30.318     0.345     20.366     282.72
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     1.950    31.977     0.439    29.141    251.04
     2.250    33.636     0.537    39.288    227.95
     2.550    35.295     0.641    50.802    210.21
     3.150    38.613     0.862    77.951    184.40
     3.750    41.932     1.104   110.688    166.25
     4.350    45.250     1.366   149.180    152.57
     5.550    84.105     2.142   271.627    131.42
     6.750   122.960     3.384   465.325    121.21
     7.950   161.815     5.093   757.699    112.02
     9.150   200.670     7.268  1171.545    103.39
    10.350   239.525     9.909  1727.296     95.61
    11.550   278.381    13.016  2443.824     88.77
    12.750   317.236    16.590  3338.857     82.81
  END FTABLE 34

  FTABLE      35
 ROWS COLS ***
   20    4
     DEPTH      AREA    VOLUME     DISCH  FLO-THRU ***
      ( m)    (   HA)    (Mm3)     (CMS)     (MIN) ***
     0.000     0.000     0.000     0.000      0.00
     0.250     3.900     0.005     0.222    366.26
     0.500     7.800     0.020     1.409    230.68
     0.750    11.700     0.044     4.154    176.02
     1.013    13.050     0.076     9.704    131.15
     1.275    14.400     0.112    17.272    108.45
     1.538    15.750     0.152    26.856     94.31
     1.800    17.100     0.195    38.496     84.46
     2.062    18.450     0.242    52.256     77.10
     2.325    19.800     0.292    68.209     71.33
     2.850    22.500     0.403   107.011     62.76
     3.375    25.200     0.528   155.562     56.59
     3.900    27.900     0.668   214.537     51.86
     4.950    42.403     1.037   404.482     42.72
     6.000    56.906     1.558   683.210     38.01
     7.050    71.408     2.232  1076.674     34.55
     8.100    85.911     3.058  1606.642     31.72
     9.150   100.414     4.036  2292.781     29.34
    10.200   114.917     5.166  3153.366     27.31
    11.250   129.419     6.449  4205.640     25.56
  END FTABLE 35

  FTABLE      36
 ROWS COLS ***
   20    4
     DEPTH      AREA    VOLUME     DISCH  FLO-THRU ***
      ( m)    (   HA)    (Mm3)     (CMS)     (MIN) ***
     0.000     0.000     0.000     0.000      0.00
     0.250     1.932     0.002     0.112    360.61
     0.500     3.864     0.010     0.709    227.12
     0.750     5.796     0.022     2.090    173.30
     1.008     6.188     0.037     4.876    127.20
     1.267     6.580     0.054     8.584    104.27
     1.525     6.972     0.071    13.160     90.19
     1.783     7.364     0.090    18.580     80.49
     2.042     7.756     0.109    24.835     73.32
     2.300     8.148     0.130    31.927     67.76
     2.817     8.932     0.174    48.643     59.59
     3.333     9.716     0.222    68.817     53.79
     3.850    10.500     0.274    92.565     49.39
     4.883    23.732     0.451   172.215     43.67
     5.917    36.963     0.765   313.668     40.64
     6.950    50.195     1.215   544.859     37.17
     7.983    63.427     1.802   888.939     33.79
     9.017    76.659     2.526  1366.597     30.81
    10.050    89.890     3.386  1996.897     28.26
    11.083   103.122     4.384  2797.709     26.11
  END FTABLE 36
```

```
 FTABLE     37
ROWS COLS ***
  20    4
    DEPTH       AREA    VOLUME      DISCH   FLO-THRU ***
     ( m)    (    HA)    (Mm3)      (CMS)      (MIN) ***
    0.000      0.000     0.000      0.000       0.00
    0.250      7.440     0.009      0.177     874.83
    0.500     14.880     0.037      1.125     550.98
    0.750     22.320     0.084      3.318     420.42
    1.017     23.818     0.145      7.931     305.15
    1.283     25.317     0.211     14.120     248.74
    1.550     26.815     0.280     21.791     214.33
    1.817     28.313     0.354     30.906     190.76
    2.083     29.812     0.431     41.450     173.40
    2.350     31.310     0.513     53.423     159.96
    2.883     34.307     0.688     81.706     140.28
    3.417     37.303     0.879    115.901     126.35
    3.950     40.300     1.086    156.209     115.83
    5.017     73.785     1.694    285.837      98.78
    6.083    107.270     2.660    498.366      88.95
    7.150    140.756     3.983    827.747      80.19
    8.217    174.241     5.662   1302.168      72.48
    9.283    207.726     7.700   1946.864      65.91
   10.350    241.211    10.094   2785.120      60.40
   11.417    274.697    12.845   3838.789      55.77
 END FTABLE 37

 FTABLE     38
ROWS COLS ***
  20    4
    DEPTH       AREA    VOLUME      DISCH   FLO-THRU ***
     ( m)    (    HA)    (Mm3)      (CMS)      (MIN) ***
    0.000      0.000     0.000      0.000       0.00
    0.250      2.088     0.003      0.173     251.47
    0.500      4.176     0.010      1.099     158.38
    0.750      6.264     0.023      3.240     120.85
    0.892      6.602     0.033      5.340     101.76
    1.033      6.941     0.042      7.858      89.50
    1.175      7.279     0.052     10.777      80.84
    1.317      7.617     0.063     14.088      74.32
    1.458      7.956     0.074     17.787      69.20
    1.600      8.294     0.085     21.875      65.04
    1.883      8.971     0.110     31.221      58.62
    2.167      9.647     0.136     42.154      53.85
    2.450     10.324     0.164     54.714      50.11
    3.017     21.298     0.254     95.012      44.57
    3.583     32.272     0.406    160.327      42.19
    4.150     43.246     0.620    261.223      39.55
    4.717     54.219     0.896    406.455      36.74
    5.283     65.193     1.234    603.851      34.07
    5.850     76.167     1.635    860.628      31.66
    6.417     87.141     2.098   1183.554      29.54
 END FTABLE 38

 FTABLE     39
ROWS COLS ***
  20    4
    DEPTH       AREA    VOLUME      DISCH   FLO-THRU ***
     ( m)    (    HA)    (Mm3)      (CMS)      (MIN) ***
    0.000      0.000     0.000      0.000       0.00
    0.250      2.415     0.003      0.194     259.85
    0.500      4.830     0.012      1.230     163.66
    0.750      7.245     0.027      3.626     124.88
    0.900      7.600     0.038      6.158     103.66
    1.050      7.954     0.050      9.213      90.39
    1.200      8.309     0.062     12.765      81.16
```

```
 FTABLE     37
ROWS COLS ***
  20    4
    DEPTH       AREA     VOLUME       DISCH  FLO-THRU ***
     ( m)    (   HA)     (Mm3)      (CMS)     (MIN) ***
    0.000      0.000      0.000      0.000      0.00
    0.250      7.440      0.009      0.177    874.83
    0.500     14.880      0.037      1.125    550.98
    0.750     22.320      0.084      3.318    420.42
    1.017     23.818      0.145      7.931    305.15
    1.283     25.317      0.211     14.120    248.74
    1.550     26.815      0.280     21.791    214.33
    1.817     28.313      0.354     30.906    190.76
    2.083     29.812      0.431     41.450    173.40
    2.350     31.310      0.513     53.423    159.96
    2.883     34.307      0.688     81.706    140.28
    3.417     37.303      0.879    115.901    126.35
    3.950     40.300      1.086    156.209    115.83
    5.017     73.785      1.694    285.837     98.78
    6.083    107.270      2.660    498.366     88.95
    7.150    140.756      3.983    827.747     80.19
    8.217    174.241      5.662   1302.168     72.48
    9.283    207.726      7.700   1946.864     65.91
   10.350    241.211     10.094   2785.120     60.40
   11.417    274.697     12.845   3838.789     55.77
 END FTABLE 37

 FTABLE     38
ROWS COLS ***
  20    4
    DEPTH       AREA     VOLUME       DISCH  FLO-THRU ***
     ( m)    (   HA)     (Mm3)      (CMS)     (MIN) ***
    0.000      0.000      0.000      0.000      0.00
    0.250      2.088      0.003      0.173    251.47
    0.500      4.176      0.010      1.099    158.38
    0.750      6.264      0.023      3.240    120.85
    0.892      6.602      0.033      5.340    101.76
    1.033      6.941      0.042      7.858     89.50
    1.175      7.279      0.052     10.777     80.84
    1.317      7.617      0.063     14.088     74.32
    1.458      7.956      0.074     17.787     69.20
    1.600      8.294      0.085     21.875     65.04
    1.883      8.971      0.110     31.221     58.62
    2.167      9.647      0.136     42.154     53.85
    2.450     10.324      0.164     54.714     50.11
    3.017     21.298      0.254     95.012     44.57
    3.583     32.272      0.406    160.327     42.19
    4.150     43.246      0.620    261.223     39.55
    4.717     54.219      0.896    406.455     36.74
    5.283     65.193      1.234    603.851     34.07
    5.850     76.167      1.635    860.628     31.66
    6.417     87.141      2.098   1183.554     29.54
 END FTABLE 38

 FTABLE     39
ROWS COLS ***
  20    4
    DEPTH       AREA     VOLUME       DISCH  FLO-THRU ***
     ( m)    (   HA)     (Mm3)      (CMS)     (MIN) ***
    0.000      0.000      0.000      0.000      0.00
    0.250      2.415      0.003      0.194    259.85
    0.500      4.830      0.012      1.230    163.66
    0.750      7.245      0.027      3.626    124.88
    0.900      7.600      0.038      6.158    103.66
    1.050      7.954      0.050      9.213     90.39
    1.200      8.309      0.062     12.765     81.16
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     1.350      8.663     0.075    16.799     74.30
     1.500      9.018     0.088    21.305     68.96
     1.650      9.372     0.102    26.280     64.65
     1.950     10.082     0.131    37.634     58.07
     2.250     10.791     0.162    50.874     53.22
     2.550     11.500     0.196    66.032     49.44
     3.150     21.845     0.296   113.850     43.32
     3.750     32.190     0.458   190.148     40.15
     4.350     42.534     0.682   306.731     37.07
     4.950     52.879     0.968   473.386     34.10
     5.550     63.224     1.317   698.864     31.40
     6.150     73.569     1.727   991.237     29.04
     6.750     83.914     2.200  1358.074     26.99
  END FTABLE 39

  FTABLE      40
 ROWS COLS ***
   20    4
     DEPTH       AREA    VOLUME     DISCH  FLO-THRU ***
      ( m)    (    HA)    (Mm3)     (CMS)     (MIN) ***
     0.000      0.000     0.000     0.000      0.00
     0.250      2.603     0.003     0.117    463.41
     0.500      5.207     0.013     0.743    291.86
     0.750      7.810     0.029     2.192    222.70
     0.917      8.259     0.043     3.918    181.54
     1.083      8.708     0.057     6.043    156.69
     1.250      9.157     0.072     8.550    139.78
     1.417      9.607     0.087    11.428    127.38
     1.583     10.056     0.104    14.676    117.80
     1.750     10.505     0.121    18.291    110.13
     2.083     11.403     0.157    26.634     98.48
     2.417     12.302     0.197    36.486     89.94
     2.750     13.200     0.239    47.889     83.31
     3.417     27.750     0.376    83.786     74.77
     4.083     42.301     0.609   139.606     72.75
     4.750     56.851     0.940   223.098     70.22
     5.417     71.401     1.367   340.691     66.89
     6.083     85.951     1.892   498.148     63.30
     6.750    100.502     2.513   700.785     59.78
     7.417    115.052     3.232   953.595     56.49
  END FTABLE 40

  FTABLE      41
 ROWS COLS ***
   20    4
     DEPTH       AREA    VOLUME     DISCH  FLO-THRU ***
      ( m)    (    HA)    (Mm3)     (CMS)     (MIN) ***
     0.000      0.000     0.000     0.000      0.00
     0.250      2.562     0.003     0.101    529.37
     0.500      5.124     0.013     0.640    333.40
     0.750      7.686     0.029     1.888    254.40
     0.987      8.799     0.048     4.075    197.66
     1.223      9.912     0.070     7.046    166.69
     1.460     11.026     0.095    10.831    146.57
     1.697     12.139     0.123    15.468    132.16
     1.933     13.252     0.153    21.002    121.19
     2.170     14.365     0.185    27.476    112.46
     2.643     16.592     0.259    43.430     99.26
     3.117     18.819     0.342    63.694     89.61
     3.590     21.045     0.437    88.624     82.14
     4.537     32.560     0.691   171.372     67.16
     5.483     44.075     1.053   296.504     59.20
     6.430     55.589     1.525   477.311     53.25
     7.377     67.104     2.106   724.932     48.41
     8.323     78.619     2.796  1049.413     44.40
     9.270     90.134     3.594  1460.080     41.03
    10.217    101.649     4.502  1965.723     38.17
  END FTABLE 41
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```
  FTABLE     42
 ROWS COLS ***
   20    4
     DEPTH      AREA     VOLUME     DISCH  FLO-THRU ***
     ( m)    (   HA)     (Mm3)      (CMS)     (MIN) ***
     0.000     0.000     0.000      0.000      0.00
     0.250    20.133     0.025      0.364   1153.33
     0.500    40.267     0.101      2.310    726.38
     0.750    60.400     0.227      6.811    554.26
     1.042    63.923     0.408     17.459    389.29
     1.333    67.447     0.599     31.979    312.38
     1.625    70.970     0.801     50.104    266.53
     1.917    74.493     1.013     71.702    235.55
     2.208    78.017     1.236     96.712    212.97
     2.500    81.540     1.468    125.110    195.62
     3.083    88.587     1.965    192.098    170.46
     3.667    95.633     2.502    272.861    152.82
     4.250   102.680     3.080    367.741    139.61
     5.417   135.888     4.472    646.784    115.24
     6.583   169.095     6.251   1028.910    101.26
     7.750   202.303     8.418   1538.860     91.17
     8.917   235.511    10.972   2197.427     83.21
    10.083   268.718    13.913   3023.461     76.69
    11.250   301.926    17.242   4034.537     71.23
    12.417   335.134    20.958   5247.278     66.57
  END FTABLE 42

END FTABLES

*** For an understanding of EXT SOURCES, EXT TARGETS, SCHEMATIC, MASS-LINK
*** and NETWORK blocks, the user should be familiar with the Time Series
*** Linkages and the Time Series Catalog

EXT SOURCES
<-Volume-> <Member> SsysSgap<--Mult-->Tran <-Target vols> <-Grp> <-Member->  ***
<Name>   # <Name> # tem strg<-factor->strg <Name>   #   #        <Name> # #  ***
WDM      5 PRCP   3 METR      0.02         PERLND 211 218 EXTNL  PREC
WDM      7 PRCP   3 METR      0.14         PERLND 211 218 EXTNL  PREC
WDM      8 PRCP   3 METR      0.69         PERLND 211 218 EXTNL  PREC
WDM      9 PRCP   3 METR      0.15         PERLND 211 218 EXTNL  PREC
WDM      5 PRCP   3 METR      0.02         IMPLND 214 217 EXTNL  PREC
WDM      7 PRCP   3 METR      0.14         IMPLND 214 217 EXTNL  PREC
WDM      8 PRCP   3 METR      0.69         IMPLND 214 217 EXTNL  PREC
WDM      9 PRCP   3 METR      0.15         IMPLND 214 217 EXTNL  PREC

WDM      3 PRCP   3 METR      0.17         PERLND 221 228 EXTNL  PREC
WDM      4 PRCP   3 METR      0.08         PERLND 221 228 EXTNL  PREC
WDM      5 PRCP   3 METR      0.43         PERLND 221 228 EXTNL  PREC
WDM      7 PRCP   3 METR      0.32         PERLND 221 228 EXTNL  PREC
WDM      3 PRCP   3 METR      0.17         IMPLND 224 227 EXTNL  PREC
WDM      4 PRCP   3 METR      0.08         IMPLND 224 227 EXTNL  PREC
WDM      5 PRCP   3 METR      0.43         IMPLND 224 227 EXTNL  PREC
WDM      7 PRCP   3 METR      0.32         IMPLND 224 227 EXTNL  PREC

WDM      3 PRCP   3 METR      0.18         PERLND 231 238 EXTNL  PREC
WDM      7 PRCP   3 METR      0.82         PERLND 231 238 EXTNL  PREC
WDM      3 PRCP   3 METR      0.18         IMPLND 234 237 EXTNL  PREC
WDM      7 PRCP   3 METR      0.82         IMPLND 234 237 EXTNL  PREC

WDM      5 PRCP   3 METR      0.37         PERLND 241 248 EXTNL  PREC
WDM      7 PRCP   3 METR      0.60         PERLND 241 248 EXTNL  PREC
WDM      9 PRCP   3 METR      0.03         PERLND 241 248 EXTNL  PREC
WDM      5 PRCP   3 METR      0.37         IMPLND 244 247 EXTNL  PREC
WDM      7 PRCP   3 METR      0.60         IMPLND 244 247 EXTNL  PREC
WDM      9 PRCP   3 METR      0.03         IMPLND 244 247 EXTNL  PREC
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WDM       7 PRCP    3 METR      0.08        PERLND 251 258 EXTNL   PREC
WDM       9 PRCP    3 METR      0.92        PERLND 251 258 EXTNL   PREC
WDM       7 PRCP    3 METR      0.08        IMPLND 254 257 EXTNL   PREC
WDM       9 PRCP    3 METR      0.92        IMPLND 254 257 EXTNL   PREC

WDM       8 PRCP    3 METR      0.70        PERLND 261 268 EXTNL   PREC
WDM       9 PRCP    3 METR      0.30        PERLND 261 268 EXTNL   PREC
WDM       8 PRCP    3 METR      0.70        IMPLND 264 267 EXTNL   PREC
WDM       9 PRCP    3 METR      0.30        IMPLND 264 267 EXTNL   PREC

WDM       9 PRCP    3 METR                  PERLND 271 278 EXTNL   PREC
WDM       9 PRCP    3 METR                  IMPLND 274 277 EXTNL   PREC

WDM       9 PRCP    3 METR                  PERLND 281 288 EXTNL   PREC
WDM       9 PRCP    3 METR                  IMPLND 284 287 EXTNL   PREC

WDM       7 PRCP    3 METR      0.32        PERLND 291 298 EXTNL   PREC
WDM       9 PRCP    3 METR      0.68        PERLND 291 298 EXTNL   PREC
WDM       7 PRCP    3 METR      0.32        IMPLND 294 297 EXTNL   PREC
WDM       9 PRCP    3 METR      0.68        IMPLND 294 297 EXTNL   PREC

WDM       9 PRCP    3 METR                  PERLND 301 308 EXTNL   PREC
WDM       9 PRCP    3 METR                  IMPLND 304 307 EXTNL   PREC

WDM       8 PRCP    3 METR                  PERLND 311 318 EXTNL   PREC
WDM       8 PRCP    3 METR                  IMPLND 314 317 EXTNL   PREC

WDM       6 PRCP    3 METR      0.09        PERLND 321 328 EXTNL   PREC
WDM       8 PRCP    3 METR      0.76        PERLND 321 328 EXTNL   PREC
WDM      10 PRCP    3 METR      0.15        PERLND 321 328 EXTNL   PREC
WDM       6 PRCP    3 METR      0.09        IMPLND 324 327 EXTNL   PREC
WDM       8 PRCP    3 METR      0.76        IMPLND 324 327 EXTNL   PREC
WDM      10 PRCP    3 METR      0.15        IMPLND 324 327 EXTNL   PREC

WDM       8 PRCP    3 METR      0.73        PERLND 331 338 EXTNL   PREC
WDM       9 PRCP    3 METR      0.05        PERLND 331 338 EXTNL   PREC
WDM      10 PRCP    3 METR      0.22        PERLND 331 338 EXTNL   PREC
WDM       8 PRCP    3 METR      0.73        IMPLND 334 337 EXTNL   PREC
WDM       9 PRCP    3 METR      0.05        IMPLND 334 337 EXTNL   PREC
WDM      10 PRCP    3 METR      0.22        IMPLND 334 337 EXTNL   PREC

WDM       8 PRCP    3 METR      0.15        PERLND 341 348 EXTNL   PREC
WDM       9 PRCP    3 METR      0.73        PERLND 341 348 EXTNL   PREC
WDM      10 PRCP    3 METR      0.12        PERLND 341 348 EXTNL   PREC
WDM       8 PRCP    3 METR      0.15        IMPLND 344 347 EXTNL   PREC
WDM       9 PRCP    3 METR      0.73        IMPLND 344 347 EXTNL   PREC
WDM      10 PRCP    3 METR      0.12        IMPLND 344 347 EXTNL   PREC

WDM       9 PRCP    3 METR      0.56        PERLND 351 358 EXTNL   PREC
WDM      10 PRCP    3 METR      0.24        PERLND 351 358 EXTNL   PREC
WDM      11 PRCP    3 METR      0.20        PERLND 351 358 EXTNL   PREC
WDM       9 PRCP    3 METR      0.56        IMPLND 354 357 EXTNL   PREC
WDM      10 PRCP    3 METR      0.24        IMPLND 354 357 EXTNL   PREC
WDM      11 PRCP    3 METR      0.20        IMPLND 354 357 EXTNL   PREC

WDM      11 PRCP    3 METR                  PERLND 361 368 EXTNL   PREC
WDM      11 PRCP    3 METR                  IMPLND 364 367 EXTNL   PREC

WDM      10 PRCP    3 METR      0.18        PERLND 371 378 EXTNL   PREC
WDM      11 PRCP    3 METR      0.82        PERLND 371 378 EXTNL   PREC
WDM      10 PRCP    3 METR      0.18        IMPLND 374 377 EXTNL   PREC
WDM      11 PRCP    3 METR      0.82        IMPLND 374 377 EXTNL   PREC

WDM      10 PRCP    3 METR                  PERLND 381 388 EXTNL   PREC
WDM      10 PRCP    3 METR                  IMPLND 384 387 EXTNL   PREC

WDM      10 PRCP    3 METR                  PERLND 391 398 EXTNL   PREC
WDM      10 PRCP    3 METR                  IMPLND 394 397 EXTNL   PREC
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WDM      10 PRCP    3 METR      0.78         PERLND 401 408 EXTNL   PREC
WDM      11 PRCP    3 METR      0.02         PERLND 401 408 EXTNL   PREC
WDM      12 PRCP    3 METR      0.20         PERLND 401 408 EXTNL   PREC
WDM      10 PRCP    3 METR      0.78         IMPLND 404 407 EXTNL   PREC
WDM      11 PRCP    3 METR      0.02         IMPLND 404 407 EXTNL   PREC
WDM      12 PRCP    3 METR      0.20         IMPLND 404 407 EXTNL   PREC

WDM      11 PRCP    3 METR      0.85         PERLND 411 418 EXTNL   PREC
WDM      12 PRCP    3 METR      0.15         PERLND 411 418 EXTNL   PREC
WDM      11 PRCP    3 METR      0.85         IMPLND 414 417 EXTNL   PREC
WDM      12 PRCP    3 METR      0.15         IMPLND 414 417 EXTNL   PREC

WDM      11 PRCP    3 METR      0.57         PERLND 421 428 EXTNL   PREC
WDM      12 PRCP    3 METR      0.43         PERLND 421 428 EXTNL   PREC
WDM      11 PRCP    3 METR      0.57         IMPLND 424 427 EXTNL   PREC
WDM      12 PRCP    3 METR      0.43         IMPLND 424 427 EXTNL   PREC

Evap region 1 ***
Covers catchments 1-9 ***
WDM      13 EVAP    3 METR      0.85         PERLND  11  98 EXTNL   PETINP
WDM      13 EVAP    3 METR      0.85         IMPLND  14  98 EXTNL   PETINP

Evap region 2 ***
Covers catchments 10-14,17-30,34-37,41-42 ***
WDM      14 EVAP    3 METR      0.85         PERLND 101 148 EXTNL   PETINP
WDM      14 EVAP    3 METR      0.85         IMPLND 104 148 EXTNL   PETINP
WDM      14 EVAP    3 METR      0.85         PERLND 171 308 EXTNL   PETINP
WDM      14 EVAP    3 METR      0.85         IMPLND 174 308 EXTNL   PETINP
WDM      14 EVAP    3 METR      0.85         PERLND 341 378 EXTNL   PETINP
WDM      14 EVAP    3 METR      0.85         IMPLND 344 378 EXTNL   PETINP
WDM      14 EVAP    3 METR      0.85         PERLND 411 428 EXTNL   PETINP
WDM      14 EVAP    3 METR      0.85         IMPLND 414 428 EXTNL   PETINP

Evap region 3 ***
Covers catchments 15-16,31-33,38-40 ***
WDM      15 EVAP    3 METR      0.85         PERLND 151 168 EXTNL   PETINP
WDM      15 EVAP    3 METR      0.85         IMPLND 154 168 EXTNL   PETINP
WDM      15 EVAP    3 METR      0.85         PERLND 311 338 EXTNL   PETINP
WDM      15 EVAP    3 METR      0.85         IMPLND 314 338 EXTNL   PETINP
WDM      15 EVAP    3 METR      0.85         PERLND 381 408 EXTNL   PETINP
WDM      15 EVAP    3 METR      0.85         IMPLND 384 408 EXTNL   PETINP


<-Volume-> <Member> SsysSgap<--Mult-->Tran <-Target vols> <-Grp> <-Member-> ***
<Name>   # <Name> # tem strg<-factor->strg <Name>   #   #        <Name> # # ***

Darvill sewage treatment plant inflow                                        ***
Values are in megalitres per day, so divide by 1 000                         ***
The RCHRES module expects IVOL to be in Mm3 per interval of the data         ***
WDM     600 FLOW    3 METR       1E-3        RCHRES  30     EXTNL   IVOL

Upstream simulations feed into downstream simulation                         ***
WDM     820 HYDR    3 METR                   RCHRES  21     EXTNL   IVOL


END EXT SOURCES

SCHEMATIC
<-Source->                   <--Area-->      <-Target->  <ML->  ***
<Name>   #                   <-factor->      <Name>   #      #  ***
                               (ha)                             ***
PERLND 211                      132.8        RCHRES  21      1
PERLND 212                      254.5        RCHRES  21      1
PERLND 213                      317.9        RCHRES  21      1
PERLND 214                       13.3        RCHRES  21      1
IMPLND 214                       81.4        RCHRES  21      3
PERLND 215                      463.0        RCHRES  21      1
```

IMPLND 215		51.4	RCHRES	21	3
PERLND 216	***		RCHRES	21	1
PERLND 217		4.2	RCHRES	21	1
IMPLND 217		1.5	RCHRES	21	3
PERLND 218	***		RCHRES	21	1
PERLND 221		1037.8	RCHRES	22	1
PERLND 222		396.3	RCHRES	22	1
PERLND 223		240.9	RCHRES	22	1
PERLND 224	***		RCHRES	22	1
PERLND 225		168.6	RCHRES	22	1
IMPLND 225		18.7	RCHRES	22	3
PERLND 226	***		RCHRES	22	1
PERLND 227		38.5	RCHRES	22	1
IMPLND 227		13.6	RCHRES	22	3
PERLND 228	***		RCHRES	22	1
PERLND 231		1747.4	RCHRES	23	1
PERLND 232		421.7	RCHRES	23	1
PERLND 233		229.6	RCHRES	23	1
PERLND 234		0.2	RCHRES	23	1
IMPLND 234		1.1	RCHRES	23	3
PERLND 235		495.4	RCHRES	23	1
IMPLND 235		55.0	RCHRES	23	3
PERLND 236	***		RCHRES	23	1
PERLND 237		77.3	RCHRES	23	1
IMPLND 237		27.2	RCHRES	23	3
PERLND 238	***		RCHRES	23	1
PERLND 241		103.6	RCHRES	24	1
PERLND 242		78.2	RCHRES	24	1
PERLND 243		304.2	RCHRES	24	1
PERLND 244		74.2	RCHRES	24	1
IMPLND 244		455.5	RCHRES	24	3
PERLND 245		973.1	RCHRES	24	1
IMPLND 245		108.1	RCHRES	24	3
PERLND 246	***		RCHRES	24	1
PERLND 247		244.5	RCHRES	24	1
IMPLND 247		85.9	RCHRES	24	3
PERLND 248	***		RCHRES	24	1
PERLND 251		6.1	RCHRES	25	1
PERLND 252		41.6	RCHRES	25	1
PERLND 253		160.9	RCHRES	25	1
PERLND 254		16.4	RCHRES	25	1
IMPLND 254		101.1	RCHRES	25	3
PERLND 255		115.2	RCHRES	25	1
IMPLND 255		12.8	RCHRES	25	3
PERLND 256	***		RCHRES	25	1
PERLND 257		101.3	RCHRES	25	1
IMPLND 257		35.6	RCHRES	25	3
PERLND 258	***		RCHRES	25	1
PERLND 261		22.6	RCHRES	26	1
PERLND 262		169.7	RCHRES	26	1
PERLND 263		399.4	RCHRES	26	1
PERLND 264		28.1	RCHRES	26	1
IMPLND 264		172.8	RCHRES	26	3
PERLND 265		607.2	RCHRES	26	1
IMPLND 265		67.5	RCHRES	26	3
PERLND 266	***		RCHRES	26	1
PERLND 267	***		RCHRES	26	1
PERLND 268	***		RCHRES	26	1
PERLND 271		163.6	RCHRES	27	1
PERLND 272		70.6	RCHRES	27	1
PERLND 273		146.9	RCHRES	27	1
PERLND 274		5.3	RCHRES	27	1
IMPLND 274		32.8	RCHRES	27	3
PERLND 275	***		RCHRES	27	1
PERLND 276	***		RCHRES	27	1
PERLND 277		12.0	RCHRES	27	1
IMPLND 277		4.2	RCHRES	27	3
PERLND 278	***		RCHRES	27	1

PERLND	281	54.9	RCHRES	28	1
PERLND	282	8.4	RCHRES	28	1
PERLND	283	45.4	RCHRES	28	1
PERLND	284	3.8	RCHRES	28	1
IMPLND	284	23.6	RCHRES	28	3
PERLND	285	***	RCHRES	28	1
PERLND	286	***	RCHRES	28	1
PERLND	287	***	RCHRES	28	1
PERLND	288	***	RCHRES	28	1
PERLND	291	443.8	RCHRES	29	1
PERLND	292	1010.7	RCHRES	29	1
PERLND	293	263.3	RCHRES	29	1
PERLND	294	37.4	RCHRES	29	1
IMPLND	294	229.8	RCHRES	29	3
PERLND	295	***	RCHRES	29	1
PERLND	296	***	RCHRES	29	1
PERLND	297	617.0	RCHRES	29	1
IMPLND	297	216.8	RCHRES	29	3
PERLND	298	***	RCHRES	29	1
PERLND	301	71.2	RCHRES	30	1
PERLND	302	415.3	RCHRES	30	1
PERLND	303	545.1	RCHRES	30	1
PERLND	304	0.2	RCHRES	30	1
PERLND	305	***	RCHRES	30	1
PERLND	306	***	RCHRES	30	1
PERLND	307	56.8	RCHRES	30	1
IMPLND	307	20.0	RCHRES	30	3
PERLND	308	***	RCHRES	30	1
PERLND	311	324.5	RCHRES	31	1
PERLND	312	401.4	RCHRES	31	1
PERLND	313	746.4	RCHRES	31	1
PERLND	314	2.6	RCHRES	31	1
IMPLND	314	16.2	RCHRES	31	3
PERLND	315	***	RCHRES	31	1
PERLND	316	***	RCHRES	31	1
PERLND	317	***	RCHRES	31	1
PERLND	318	***	RCHRES	31	1
PERLND	321	745.8	RCHRES	32	1
PERLND	322	4175.8	RCHRES	32	1
PERLND	323	646.1	RCHRES	32	1
PERLND	324	***	RCHRES	32	1
PERLND	325	***	RCHRES	32	1
PERLND	326	***	RCHRES	32	1
PERLND	327	***	RCHRES	32	1
PERLND	328	***	RCHRES	32	1
PERLND	331	80.1	RCHRES	33	1
PERLND	332	876.0	RCHRES	33	1
PERLND	333	358.4	RCHRES	33	1
PERLND	334	1.8	RCHRES	33	1
IMPLND	334	10.8	RCHRES	33	3
PERLND	335	***	RCHRES	33	1
PERLND	336	***	RCHRES	33	1
PERLND	337	***	RCHRES	33	1
PERLND	338	***	RCHRES	33	1
PERLND	341	1340.9	RCHRES	34	1
PERLND	342	3366.2	RCHRES	34	1
PERLND	343	1697.9	RCHRES	34	1
PERLND	344	9.4	RCHRES	34	1
IMPLND	344	58.1	RCHRES	34	3
PERLND	345	***	RCHRES	34	1
PERLND	346	***	RCHRES	34	1
PERLND	347	20.4	RCHRES	34	1
IMPLND	347	7.2	RCHRES	34	3
PERLND	348	***	RCHRES	34	1
PERLND	351	1907.6	RCHRES	35	1
PERLND	352	1807.1	RCHRES	35	1
PERLND	353	53.1	RCHRES	35	1
PERLND	354	0.8	RCHRES	35	1

IMPLND	354		4.7	RCHRES	35	3
PERLND	355	***		RCHRES	35	1
PERLND	356		277.2	RCHRES	35	1
PERLND	357	***		RCHRES	35	1
PERLND	358	***		RCHRES	35	1
PERLND	361		341.4	RCHRES	36	1
PERLND	362		101.7	RCHRES	36	1
PERLND	363		9.4	RCHRES	36	1
PERLND	364	***		RCHRES	36	1
IMPLND	364	***		RCHRES	36	1
PERLND	365	***	674.7	RCHRES	36	1
PERLND	366		214.4	RCHRES	36	1
PERLND	367	***		RCHRES	36	1
PERLND	368	***		RCHRES	36	1
PERLND	371		1470.1	RCHRES	37	1
PERLND	372		1616.3	RCHRES	37	1
PERLND	373		593.8	RCHRES	37	1
PERLND	374	***		RCHRES	37	1
PERLND	375		206.5	RCHRES	37	1
IMPLND	375		23.0	RCHRES	37	3
PERLND	376		733.9	RCHRES	37	1
PERLND	377	***		RCHRES	37	1
PERLND	378	***		RCHRES	37	1
PERLND	381		2058.6	RCHRES	38	1
PERLND	382		148.8	RCHRES	38	1
PERLND	383		16.4	RCHRES	38	1
PERLND	384	***		RCHRES	38	1
PERLND	385		2.2	RCHRES	38	1
IMPLND	385		0.3	RCHRES	38	3
PERLND	386	***		RCHRES	38	1
PERLND	387	***		RCHRES	38	1
PERLND	388	***		RCHRES	38	1
PERLND	391		2334.3	RCHRES	39	1
PERLND	392		624.3	RCHRES	39	1
PERLND	393		172.2	RCHRES	39	1
PERLND	394		4.3	RCHRES	39	1
IMPLND	394		26.8	RCHRES	39	3
PERLND	395		135.0	RCHRES	39	1
IMPLND	395		15.0	RCHRES	39	3
PERLND	396	***		RCHRES	39	1
PERLND	397	***		RCHRES	39	1
PERLND	398	***		RCHRES	39	1
PERLND	401		929.8	RCHRES	40	1
PERLND	402		1345.2	RCHRES	40	1
PERLND	403		796.1	RCHRES	40	1
PERLND	404		0.5	RCHRES	40	1
IMPLND	404		3.0	RCHRES	40	3
PERLND	405		84.3	RCHRES	40	1
IMPLND	405		9.4	RCHRES	40	3
PERLND	406		464.6	RCHRES	40	1
PERLND	407	***		RCHRES	40	1
PERLND	408	***		RCHRES	40	1
PERLND	411		274.2	RCHRES	41	1
PERLND	412		466.3	RCHRES	41	1
PERLND	413	***		RCHRES	41	1
PERLND	414	***		RCHRES	41	1
PERLND	415		1.4	RCHRES	41	1
IMPLND	415		0.2	RCHRES	41	3
PERLND	416		112.1	RCHRES	41	1
PERLND	417	***		RCHRES	41	1
PERLND	418	***		RCHRES	41	1
PERLND	421		774.7	RCHRES	42	1
PERLND	422		698.5	RCHRES	42	1
PERLND	423		65.5	RCHRES	42	1
PERLND	424		1.1	RCHRES	42	1
IMPLND	424		6.9	RCHRES	42	3
PERLND	425		112.9	RCHRES	42	1
IMPLND	425		12.5	RCHRES	42	3

```
PERLND 426                          144.6       RCHRES  42        1
PERLND 427                ***                   RCHRES  42        1
PERLND 428                ***                   RCHRES  42        1
RCHRES   21                                     RCHRES  25        2
RCHRES   22                                     RCHRES  24        2
RCHRES   23                                     RCHRES  24        2
RCHRES   24                                     RCHRES  25        2
RCHRES   25                                     RCHRES  27        2
RCHRES   26                                     RCHRES  27        2
RCHRES   27                                     RCHRES  28        2
RCHRES   28                                     RCHRES  30        2
RCHRES   29                                     RCHRES  30        2
RCHRES   30                                     RCHRES  34        2
RCHRES   31                                     RCHRES  34        2
RCHRES   32                                     RCHRES  33        2
RCHRES   33                                     RCHRES  34        2
RCHRES   34                                     RCHRES  35        2
RCHRES   35                                     RCHRES  36        2
RCHRES   36                                     RCHRES  37        2
RCHRES   38                                     RCHRES  40        2
RCHRES   39                                     RCHRES  40        2
RCHRES   37                                     RCHRES  41        2
RCHRES   40                                     RCHRES  41        2
RCHRES   41                                     RCHRES  42        2
END SCHEMATIC

MASS-LINK

  MASS-LINK        1
<Srce>      <-Grp> <-Member-><--Mult-->     <Targ>         <-Grp> <-Member-> ***
<Name>      <Name> <Name> # #<-factor->     <Name>         <Name> <Name> # # ***
                        Factor converts (mm.ha) to (million m3)                ***
PERLND      PWATER PERO         0.00001     RCHRES         INFLOW IVOL
  END MASS-LINK    1

  MASS-LINK        2
<Srce>      <-Grp> <-Member-><--Mult-->     <Targ>         <-Grp> <-Member-> ***
<Name>      <Name> <Name> # #<-factor->     <Name>         <Name> <Name> # # ***
RCHRES      ROFLOW                          RCHRES         INFLOW
  END MASS-LINK    2

  MASS-LINK        3
<Srce>      <-Grp> <-Member-><--Mult-->     <Targ>         <-Grp> <-Member-> ***
<Name>      <Name> <Name> # #<-factor->     <Name>         <Name> <Name> # # ***
                        Factor converts (mm.ha) to (million m3)                ***
IMPLND      IWATER SURO         0.00001     RCHRES         INFLOW IVOL
  END MASS-LINK    3

END MASS-LINK

EXT TARGETS
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Volume-> <Member> Tsys Aggr Amd ***
<Name>    #       <Name> # #<-factor->strg <Name>    # <Name>qf  tem strg strg***

*** For selected reaches, we output the following simulated time series:
*** Total outflow rate (m3/s)

RCHRES   30 HYDR   RO                       WDM     830 HYDR    1 METR AGGR REPL
RCHRES   41 HYDR   RO                       WDM     841 HYDR    1 METR AGGR REPL
END EXT TARGETS

END RUN
```