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Department of Water Affairs and Forestry

Directorate: National Water Resource Planning

The Assessment of Water Availability in the Berg Catchment (WMA 19) by means of Water Resource Related Models

Report No. 6: Water Quality

Volume 2: Updating of the ACRU Salinity Model for the Berg River

FINAL **August 2008**

Submitted by:
Ninham Shand (Pty) Ltd
in Association with
Umvoto Africa (Pty) Ltd

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DEPARTMENT OF WATER AFFAIRS AND FORESTRY

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THE ASSESSMENT OF WATER AVAILABILITY IN THE BERG CATCHMENT (WMA 19) BY MEANS OF WATER RESOURCE RELATED MODELS

REPORT NO. 6 : WATER QUALITY

Volume No. 2
Updating of the ACRU*Salinity* Model for the Berg River

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APPROVAL

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REPORT No	REPORT TITLE	VOLUME No.	VOLUME TITLE
1	Final Summary Report		
2	Rainfall Data Preparation and MAP Surface		
3	The Assessment of Flow Gauging Stations		
4	Land Use and Water Requirements	Vol 1	Data in Support of Catchment Modelling
		Vol 2	Invasive Alien Plant Mapping
		Vol 3	Water Use and Water Requirements
5	Update of Catchment Hydrology	Vol 1	Berg River
		Vol 2	Upper Breede River
		Vol 3	Peripheral Rivers
6	Water Quality	Vol 1	A Literature Review of Water Quality Related Studies in the Berg WMA, 1994 - 2006
		Vol 2	Updating of the ACRU Salinity Model for the Berg River
		Vol 3	Update Monthly FLOSAL Model to WQT
7	(Report No Not Used)		
8	System Analysis Status Report		
9	Groundwater Model	Vol 1	Overview of Methodology and Results
		Vol 2	Data Availability and Evaluation
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		Vol 6	Langebaan Road and Elandsfontein Aquifer System Model
		Vol 7	TMG Aquifer, Piketberg Model
		Vol 8	TMG Aquifer, Witzenberg – Nuy Model
		Vol 9	Breede River Alluvium Aquifer Model
10	Berg and Mhlathuze Assessment Studies (Refer to Report No.1)		
11	Applicability of the Sami Groundwater Model to the Berg WAAS Area		

THE ASSESSMENT OF WATER AVAILABILITY IN THE BERG CATCHMENT (WMA 19) BY MEANS OF WATER RESOURCE RELATED MODELS

Report No. 6
WATER QUALITY

Volume 2
Updating of the ACRU*Salinity* Model for the Berg River

EXECUTIVE SUMMARY

INTRODUCTION

The daily ACRU*Salinity* model for the Berg River was previously configured under the WRC project no. K5/1301 entitled "Improvements to the ACRU*Salinity* Model and Upgrading of the Berg River Water Quality Information System". In the aforementioned study the model was configured for the river reach between gauging stations G1H020 (Paarl) and G1R003 (Misverstand Dam).

Further extension to the catchment area configured in the model was undertaken as part of the West Coast Study commissioned by the Department of Water Affairs and Forestry (DWAF) (DWAF, 2006). In this study, the model configuration was extended from the gauging station G1R003 (Misverstand Dam) to the head of the estuary.

The objective of this study was to configure an up-to-date calibrated ACRU*Salinity* model that could be used as a water resource management tool in the Berg River Catchment. Specific aims required to meet the objective were as follows:

- Extend the daily rainfall and observed streamflow records for use in verification
- Produce naturalised flows to be compared the Pitman-based monthly flows
- Enable quantification of salt loads from the dryland portions of the catchment
- Configuration of the upper Berg catchment in ACRU*Salinity*
- To combine the loosely coupled models of the Berg into one configuration

Although only the abovementioned tasks were required for this study it was necessary to describe the model configuration and data requirements of the model so that the reader may have a full appreciation of the approach that was adopted.

RESULTS

In this study no further adjustment of the flow-related parameters were required after extension of the calibration periods and resulted only in extended rainfall and observed flow records.

An ACRU*Salinity* configuration for generating natural flows was, however, prepared using the Acocks (Acocks, 1975) veld types. The output from this simulation compared to those from previous studies is presented in **Table E1**.

Table E1 A comparison of simulated naturalised flows from selected studies

Gauge	ACRU MAR (Mm^3) (1921-1999)	WR 90 MAR (Mm^3) (1920 – 1989)	WCSA MAR (Mm^3) (1926 -1988)	WR2005 (Mm^3) (1920 -2004)
G1H020	403	412	384	329
G1H036	493	528	521	453
G1H013	789	Approx 782	871	Approx 615
G1R003	832	825	904	728
Head of Estuary	914	895	Not calculated	738

THE ASSESSMENT OF WATER AVAILABILITY IN THE BERG CATCHMENT (WMA 19) BY MEANS OF WATER RESOURCE RELATED MODELS

REPORT NO. 6 : WATER QUALITY

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ABBREVIATIONS

Text	Definition
ACRU	Agricultural Catchment Research Unit
CSIR	Council for Scientific and Industrial Research
CORPPT	Precipitation Correction Factor
DWAF	Department of Water Affairs and Forestry
GIS	Geographical Information System
MAP	Mean Annual Precipitation
NLCDP	National Landcover Database Project
RESCON	Reservoir Constant
RESEXP	Reservoir Exponent
SALTSAT	Salt Saturation Parameter
TDS	Total Dissolved Salts
VAFS	Voëlvlei Augmentation Feasibility Study
WfW	Working for Water
WRC	Water Research Commission

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

The daily ACRU*Salinity* model for the Berg River was previously configured under the WRC Project no. K5/1301 entitled "Improvements to the ACRUS*alinity* Model and Upgrading of the Berg River Water Quality Information System". In the aforementioned study the model was configured for the river reach between gauging stations G1H020 (Paarl) and G1R003 (Misverstand Dam).

Further extension to the catchment area configured in the model was undertaken as part of the West Coast Study commissioned by the Department of Water Affairs and Forestry (DWAF) (DWAF, 2006). In this study, the model configuration was extended from the gauging station G1R003 (Misverstand Dam) to the head of the estuary.

A map of the Berg River Catchment is depicted in **Figure 1.1**.

1.2 AIMS AND OBJECTIVES

The objective of this study was to configure an up-to-date calibrated ACRU*Salinity* model that could be used as a water resource management tool in the Berg River Catchment. Specific aims required to meet the objective were as follows:

- Extend the daily rainfall and observed streamflow records for use in verification
- Produce naturalised flows to be compared with the Pitman-based monthly flows
- Quantify salt loads from the dryland portions of the catchment
- Configuration of the upper Berg catchment in ACRU*Salinity*
- To combine the loosely coupled models of the Berg into one configuration.

Although only the abovementioned tasks were required for this study it was necessary to describe the model configuration and data requirements of the model so that the reader may have a full appreciation of the approach that was adopted.

1.3 REPORT STRUCTURE

The report starts with a brief description of the ACRU*Salinity* model configuration. This is then followed by the presentation of the updated flow verifications and the naturalised flow sequences produced. Finally, the updated salinity verifications are presented.

Figure 1.1 Map of Berg River catchment

CHAPTER 2: CONFIGURATION OF THE ACRU*Salinity* MODEL FOR CURRENT-DAY CONDITIONS

ACRU*Salinity* is the hydrosalinity module of the daily agrohydrological model ACRU2000. The latter is a catchment-scale model that can be used for small (lumped) or large (distributed) catchments. The original ACRU model was developed by the Department of Agricultural Engineering, University of Natal in Pietermaritzburg in 1975. ACRU2000 is programmed in Java language and enables a multi-layered soil-water budget to be determined for a catchment. The model requires daily rainfall and evaporation data and can be used to simulate the impacts of land-use and climate change on a hydrological system (Teweldebrhan *et al*., 2003).

The application of the ACRU hydrological model to a developed catchment such as the Berg is a challenging task. Several factors contribute to this level of complexity. These include:

- the presence of many farm dams
- the varying abstraction rates of irrigation water from these farm dams
- variation in Mean Annual Precipitation (MAP) throughout the catchment, and
- the spatial distribution of crops (irrigated and dry-land) within the catchments.

2.1 DELINEATION OF THE CATCHMENT

The delineation of the sub-catchment of interest is probably one of the most important steps in the configuration of the model and should be undertaken only when it is clear what the end product of the modelling exercise should be.

For this modelling task the salt contributions of the various tributaries of the Berg River were required to be determined in the form of a daily concentration and flow series. This output product required that the Berg River mainstem be treated as a watershed even though it is not a true application of the concept.

Only one rainfall file can be used for a primary catchment and it was therefore important to recognise areas that had a distinctly different MAP from the rest of the catchment at an early stage in the configuration.

Criteria used for the delineation of the sub-catchment are listed, as follows :

- points of interest, e.g. gauging stations with good records
- discharge points of tributaries into the Berg River mainstem, and
- areas with a distinctly different MAP from the rest of the catchment.

2.1.1 Origin to G1H020

The ACRU model configured as part of the project entiltled Streamflow Reduction Modelling in Water Resources Analysis (Dzvukamanja *et al*., 2005) was used to represent the current-day configuration of the upper Berg River catchment. Detailed description of this configuration can be found in the referenced report. Salinity appendages were added to this model to complete an ACRU*Salinity* configuration for the Upper Berg Catchment.

The sub-catchments defined in the aforementioned study are depicted in **Figure 2.1** which shows the sub-catchments used for monthly pitman modelling (red lines) and the ACRU sub-catchments (black lines) which were aggregated to for comparison with Pitman sub-catchments.

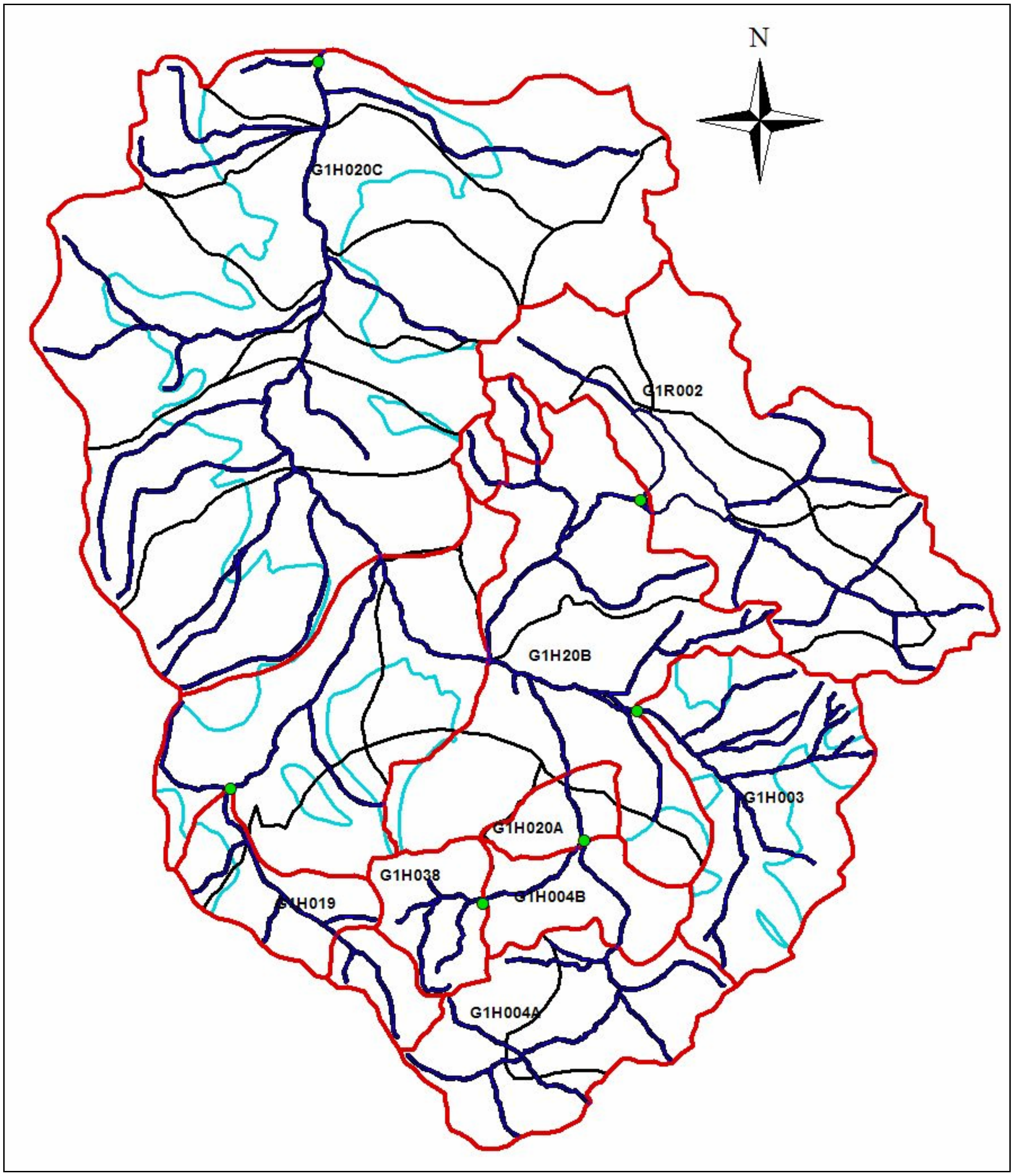

Figure 2.1 Primary sub-catchment defined for the Upper Berg River catchment (after Dzvukamanja, 2005)

2.1.2 G1H020 to G1H036

The sub-catchment between gauging stations G1H20 and G1H036 is depicted in **Figure 2.2**. In the initial delineation of this sub-catchment, the primary sub-catchments were defined based on watershed boundaries only. With this approach however, it was necessary to define internal dams within the primary sub-catchment and to specify the percentage of the primary sub-catchment that contributed run-off directly to this internal dam. Although this approach was entirely possible it had several practical drawbacks. These are explained below.

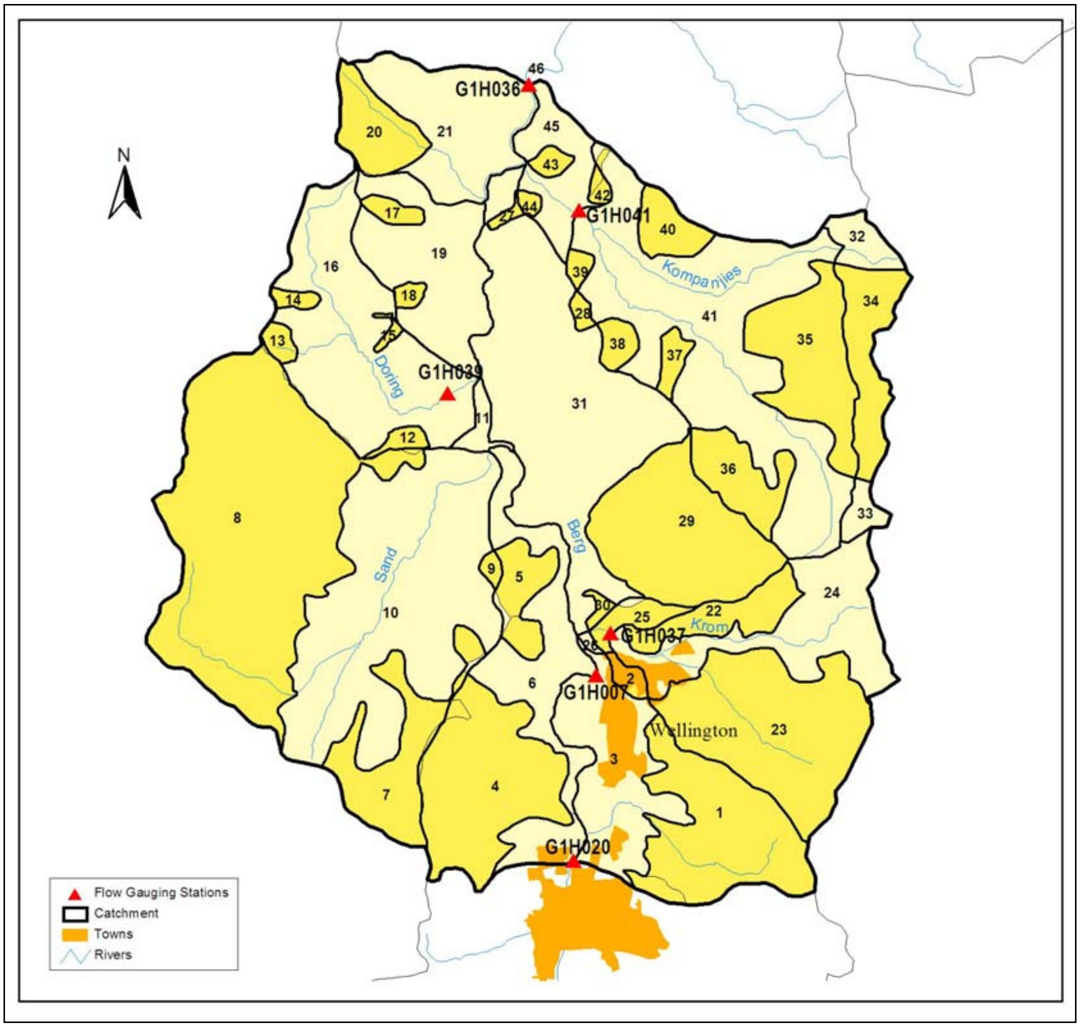

Figure 2.2 Primary sub-catchments defined for the Berg River catchment between gauging stations G1H020 and G1H036

The method of creating pseudo sub-catchments from a primary menu was done by using the CreateMenuFromGIS (Pike, 2004) pre-processor which automatically created a pseudo sub-catchment for each land-use within a particular primary sub-catchment, based on the land-use intersection data obtained from GIS. If the percentage of the total sub-catchment contributing run-off directly to the internal dam (dummy) was specified in the primary menu the CreateMenuFromGIS pre-processor would then create a farm dam in each pseudo sub-catchment in the primary sub-catchment. This method preserved the run-off into the dam but gave rise to numerous farm dams that had to be modelled.

An alternative method of dealing with the farm dams was to convert the primary menu (for the primary sub-catchments) into an exploded menu (for the pseudo sub-catchments) before adding the "dummy" farm dam. In this method, it was necessary to locate a reservoir (not internal) at a node where all the areas upstream of the node added up to the area upstream of the farm dam (i.e. contributing run-off directly do the dam) as it would be defined in the configuration of the primary sub-catchment. This proved to be a difficult task because the pseudo sub-catchments created would not necessarily group together such that their area represented exactly that which contributed run-off directly into the "dummy" farm dam. In fact, this was never the case and the approach was subsequently abandoned.

Because of the impracticalities of the above methods, it was decided that a further set of primary sub-catchments should be defined and that these should correspond to the farm dam boundaries as defined in the Western Cape Systems Analysis Study (WCSA) (DWAF, 1993). The resultant effect was that the number of primary sub-catchments now increased from 14 to 46 and was no longer based on watersheds only. In the WCSA (DWAF, 1993) these boundaries were demarcated at the 1990 level of development and represented the boundary of the sub-catchment area contributing run-off directly into the "dummy" farm dam, which represents the combined capacity of all the farm dams upstream of this boundary. In this way it was possible to create an exploded menu (i.e. containing pseudo sub-catchments) where artificial nodes were placed at the outlet of each primary catchment boundary, accumulating the run-off from all the upstream pseudo sub-catchments and thus marking the exact position within the configuration for the placement of "dummy" farm dams.

The primary catchments defined for the Berg River between gauging stations G1H020 and G1H036 are depicted in **Figure 2.2**.

Tributaries discharging into the Berg River mainstem from the west include the Doring River (G1H039) and Sand River while tributaries discharging from the east include the Kompanjies River and Krom River. Numerous other small tributaries discharge into the Berg River but these are mostly non-perennial and have no formal names.

In previous hydrological studies on the Berg River (DWAF, 1993 and DWAF, 1999) calibrations were undertaken at flow gauging stations G1H020, G1H037, G1H041 and G1H036. In one of the WCSA series of reports (DWAF, 1994) it was shown that the aforementioned gauges had an accuracy rating of 4 or higher (1 = low, 5 = high) and were suitable for calibration.

It should be noted that the aim of this modelling exercise was to obtain a daily time series of flow and concentrations of the tributaries discharging into the Berg River mainstem and that the delineation of sub-catchments had to be structured to provide this information as an output. The ACRU system configuration for the primary sub-catchment is depicted in **Figure 2.3**.

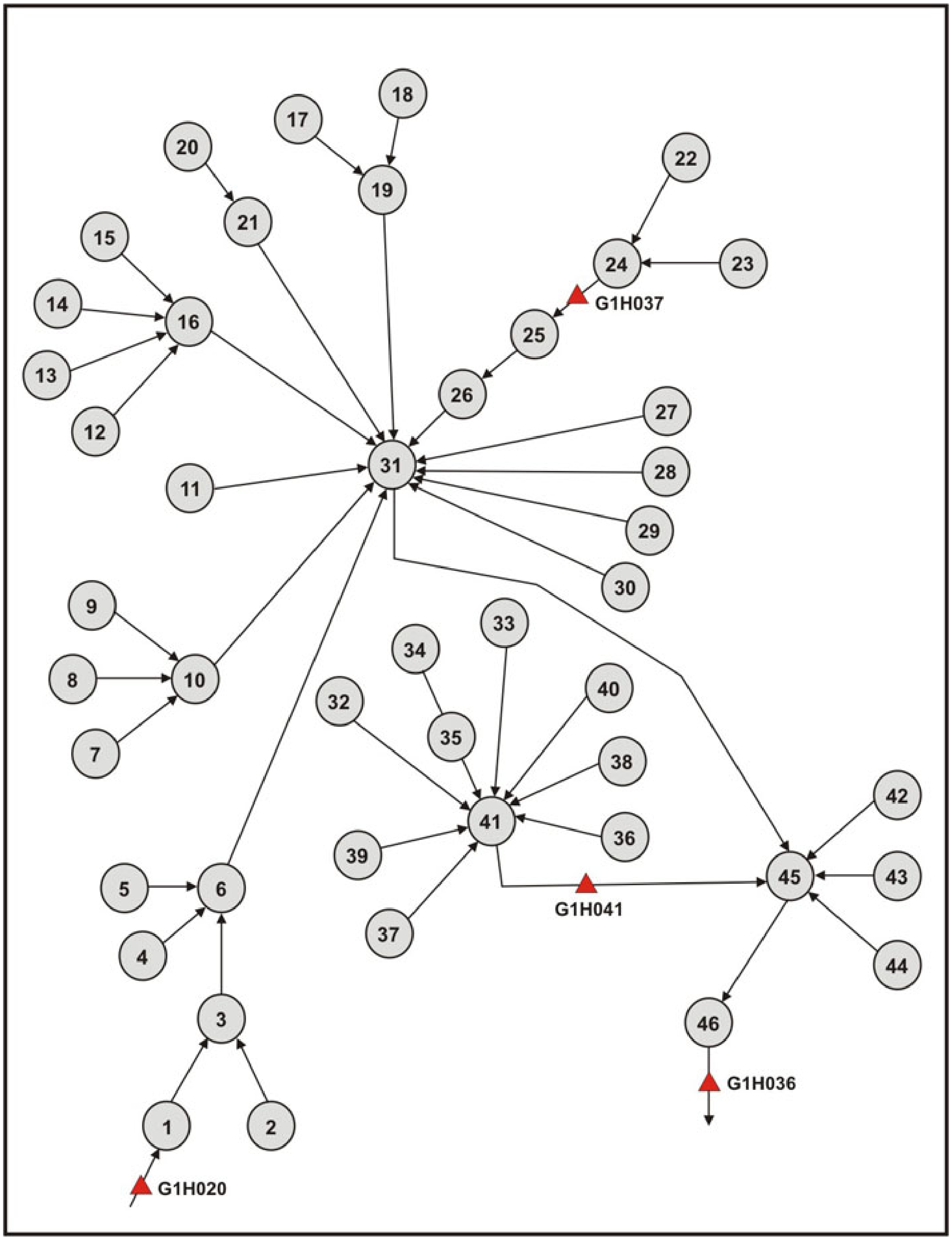

Figure 2.3 **ACRU system layout for the Berg River catchment between gauging stations G1H020 and G1H036**

2.1.3 G1H036 to G1H013

The sub-catchment between gauging stations G1H036 and G1H013 is depicted in **Figure 2.4**. This sub-catchment contains the Voëlvlei off-channel storage which is filled with flows diverted at gauging stations G1H028, G1H029 and G1H008. Voëlvlei Dam was not modelled as a dam in the ACRU configuration, instead the diversions were modelled as domestic abstractions and the release from the Dam was introduced into the receiving sub-catchment as a specified inflow constructed from the observed release record. Pertinent tributaries discharging into the Berg

River mainstem include the Sandspruit (G1H043) (which is important because of the salt load that it contributes to the mainstem), the Twenty-Four-Rivers (G1H028), the Leeu River (G1H029) and the Klein Berg River.

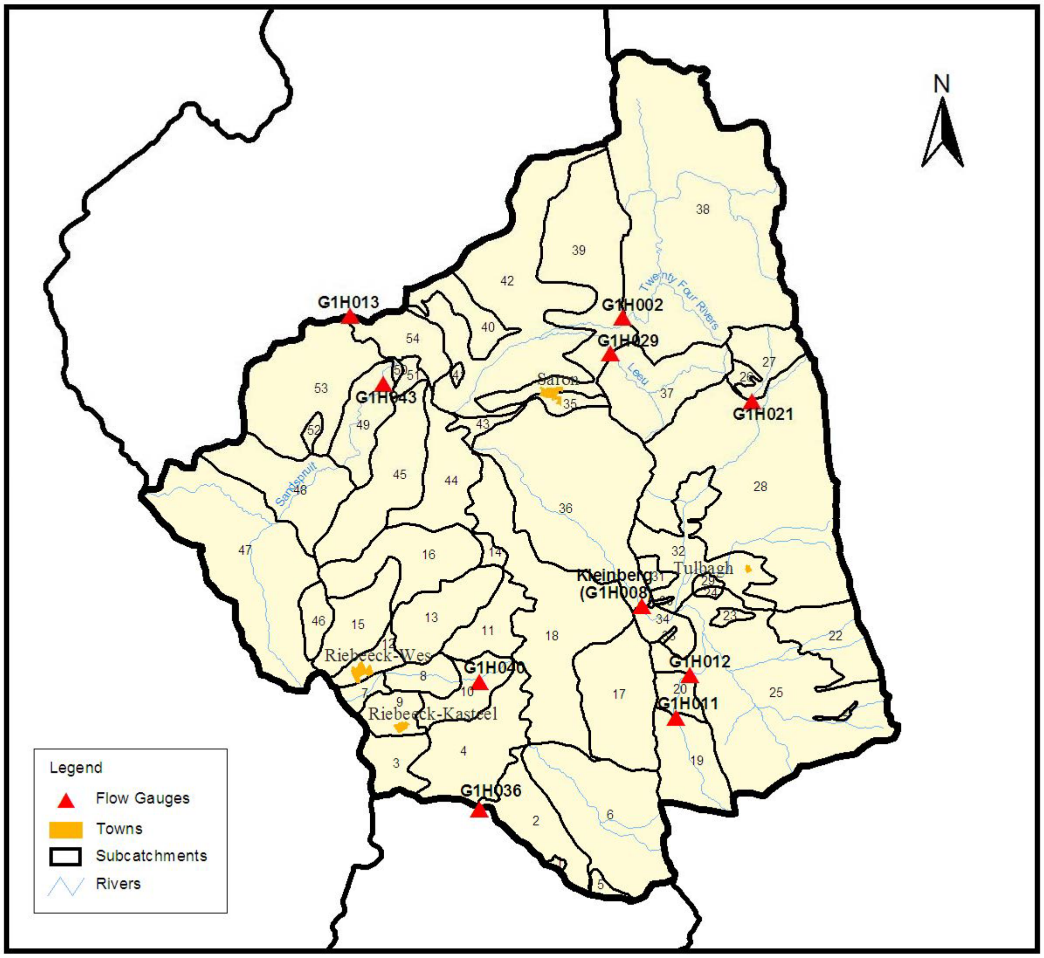

Figure 2.4 **Primary sub-catchments defined for the Berg River catchment between gauging stations G1H036 and G1H013**

It should be noted that **Figure 2.4** represents the initial delineation into primary catchments and that some refinement was expected, based on quality of the comparison between simulated and observed flows during the verification procedure.

The ACRU system configuration for the sub-catchment is depicted in **Figure 2.5**.

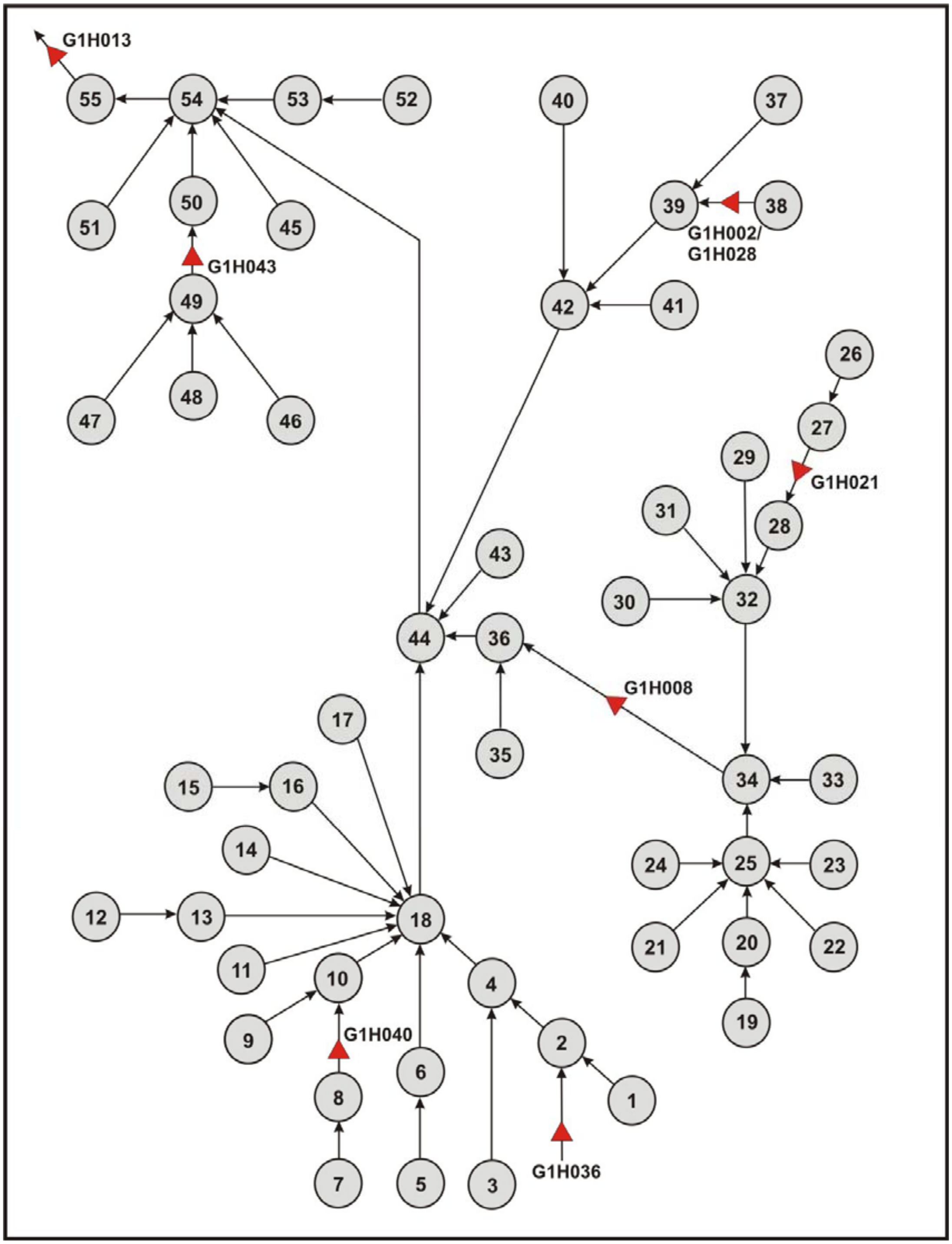

Figure 2.5 ACRU system layout for the Berg River catchment between gauging stations G1H036 and G1H013

2.1.4 G1H013 to G1R003

The initial sub-catchment delineation between gauging stations G1H013 and G1R003 is depicted in **Figure 2.6**. Although the run-off contribution from the sub-catchment between G1H013 and G1R003 was substantially less than that from the more upstream portions of the Berg River catchment, this sub-catchment still required a fairly detailed delineation because of the contributions to the salt load in the mainstem of the Berg River. This is particularly relevant for the sub-catchments upstream of gauging stations G1H035 and G1H034.

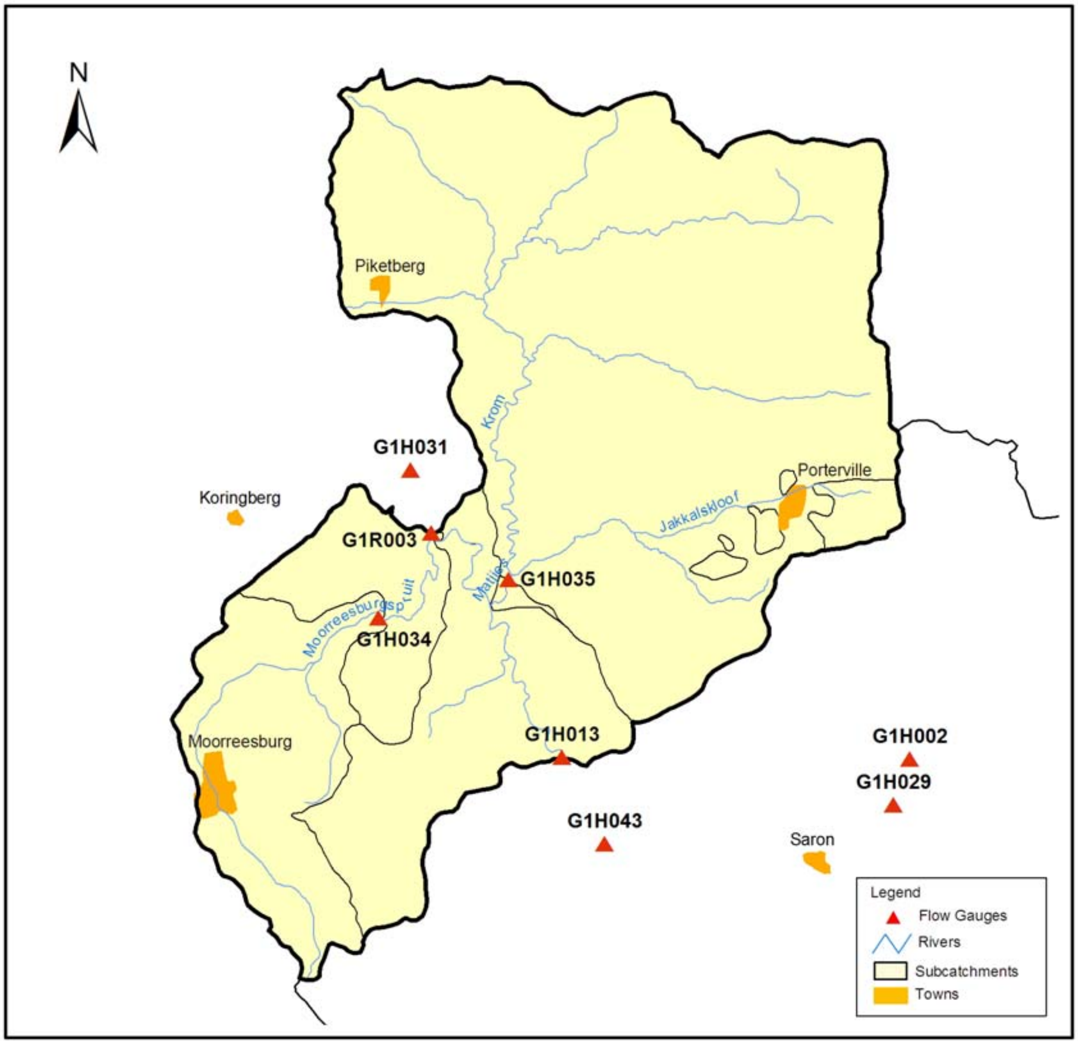

Figure 2.6 **Primary sub-catchments defined for the Berg River catchment between gauging stations G1H013 and G1R003**

The ACRU System layout for this catchment is depicted in **Figure 2.7**.

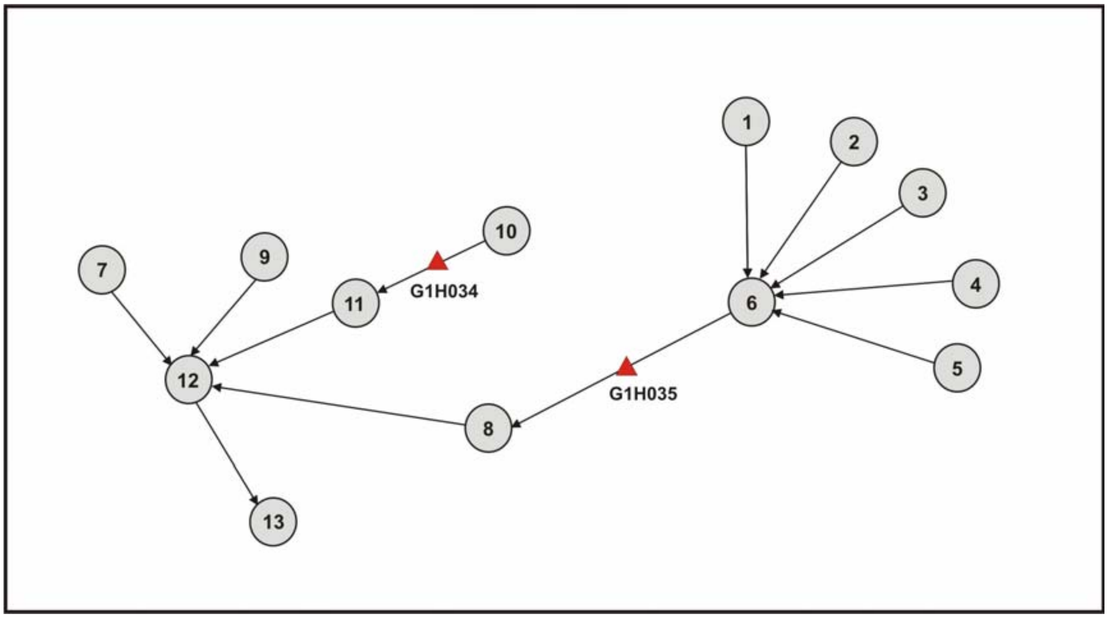

Figure 2.7 ACRU system layout for the Berg River catchment between gauging stations G1H013 and G1R003

2.1.5 G1R003 to Head of Estuary

The sub-catchments between Misverstand Dam and the head of the estuary are depicted in **Figure 2.8** while the system layout is depicted in **Figure 2.9**. It should be noted that the outflow from Sub-catchment 3 represents the abstraction point for Broodkraal Dam, which is situated in Sub-catchment 2. The head of the estuary is represented by the outflow from Sub-catchment 8. This section of the model includes the Sout River (Sub-catchment 7).

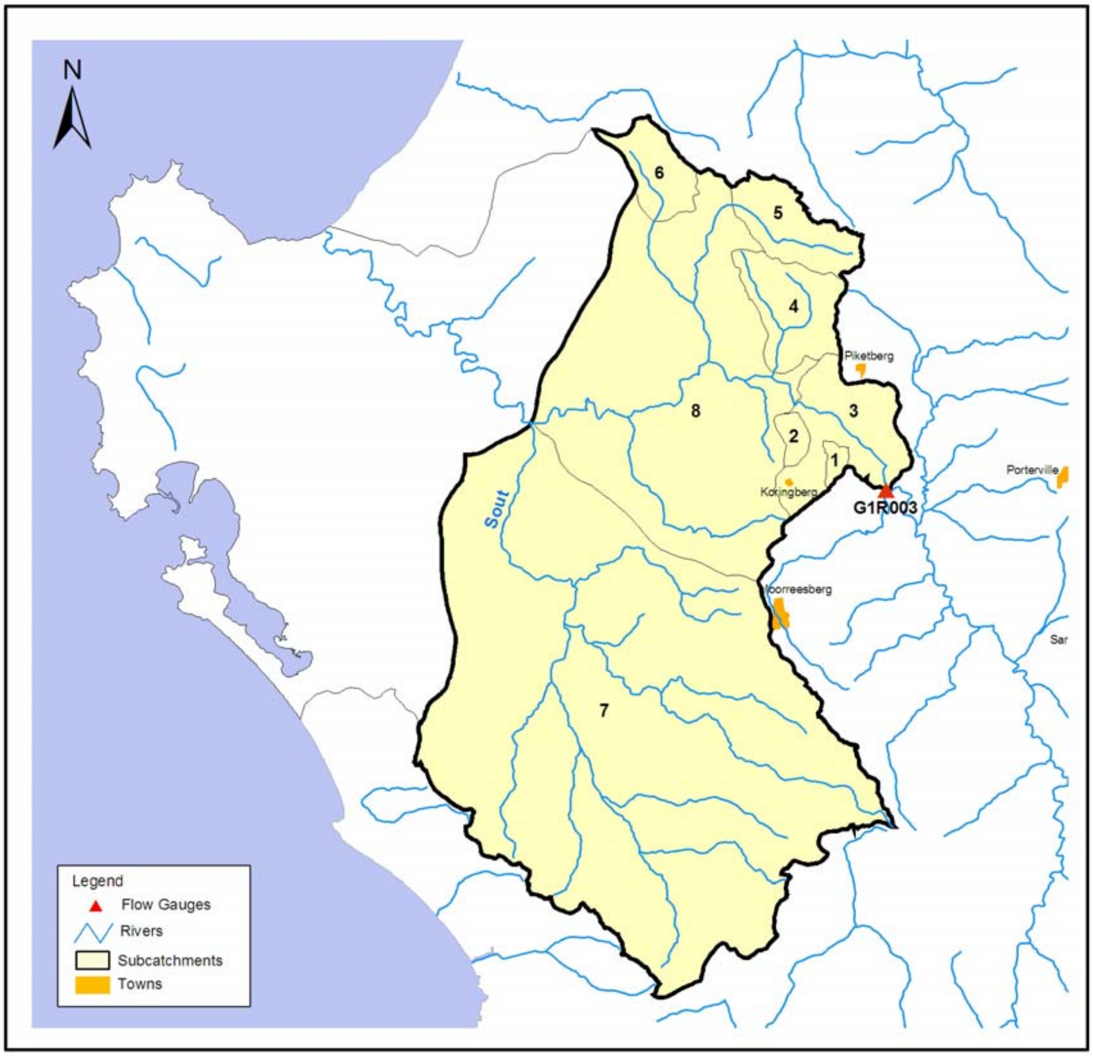

Figure 2.8 Primary sub-catchments between G1R003 and the head of the estuary

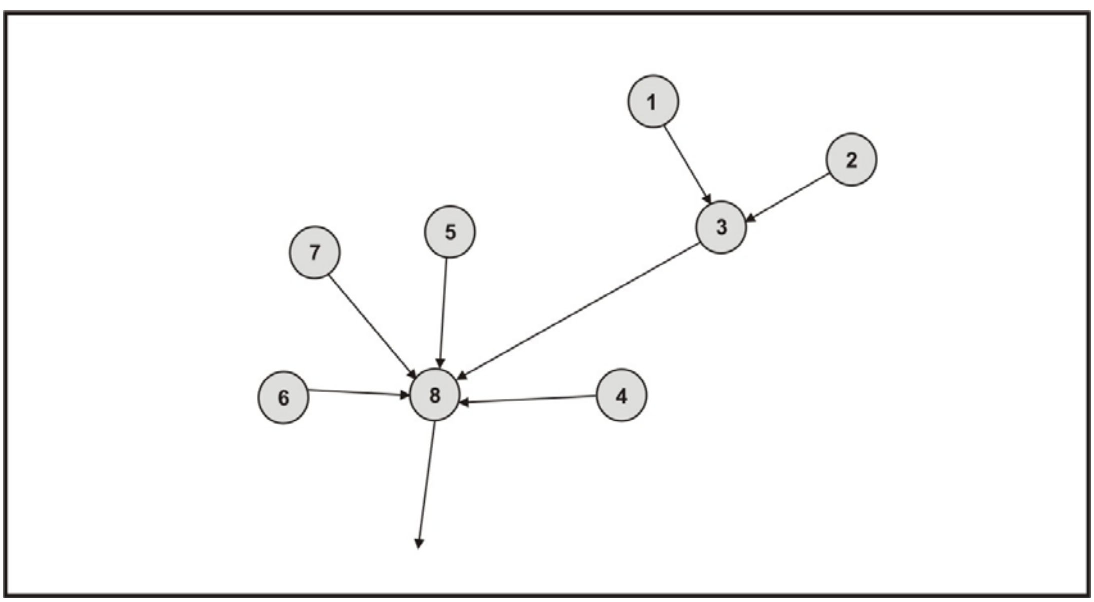

Figure 2.9 ACRU system layout between G1R003 and the head of the estuary

2.2 DATA PREPARATION FOR THE ACRU*Salinity* MODEL

As with any model, input parameters are required to run ACRU. In general it can be expected that a daily model, such as ACRU, would require many inputs and in many cases the preparation of this data is the most time consuming task in the modelling process. It is also usual that a daily model is supported by a suite of pre- and post-processors that are not necessarily developed by the developers of the model, but are useful in the preparation of the input data.

The major input parameters to ACRU include daily rainfall, farm dams' sizes and location and land-use data. The ensuing sections present not only the data that was prepared for the modelling but also the pre-processor programs that were used in the preparation as well as their availability to the model user.

2.2.1 Rainfall data records

This is probably the most important data set required to run the model and sufficient time and effort should be invested in the preparation of this data.

The preparation and manipulation of rainfall data can be tedious when done by hand and also allows for the possibility of many "finger errors" being made. With the aid of a Geographical Information System (GIS) and other pre-processor programs, however, it can be done faster and with a reduced possibility of mistakes occurring.

In this study the "Driver Rainfall Station" approach was used. This approach allows the Driver Rainfall station to be selected based on the following criteria:

- its proximity to the catchment
- its altitude relative to the catchment's mean altitude
- the length of the record, and
- the extent of missing data.

Where missing data is present in the best driver station it is then replaced with data from the next best driver station. Correction factors[1] are then applied to the rainfall of each month in the driver station so that it is more representative of the daily catchment rainfall.

This method is recommended when:

- the aim of the study is for planning rather than operational hydrology
- the catchment is smaller than 28 km^2 (Seed, 1992)[2]
- topography exerts little influence within the catchment, and
- rainfall is predominantly cyclonic.

[1] The correction factor for each month is calculated as the ratio of the median monthly precipitation of the driver rainfall station to the median monthly precipitation of the catchment (Schulze, *et al*., 1995)

[2] Seed (1992) showed that the rainfall at a rain gauge may be considered representative of the area within a 3 km radius around the rain gauge.

2.2.2 Land-use Information

The finalised 2006 level of development land-use information only became available towards the end of July 2007 and could not be used in the ACRU model configurations. As an alternative, land-use (crop types) for the Berg river catchment upstream of Misverstand Dam (G1R003) was obtained from the Voëlvlei Augmentation Feasibility Study (VAFS) (DWAF, 1999). In this study several sources of land-use were considered but the irrigation data obtained from the Department of Agriculture (1997) was eventually used. This data had sufficient detail on crop types and also compared favourably with the National Land Cover Database Project (1993) (NLCDP). The irrigated data from the Department of Agriculture, however, was over-estimated and it was decided, in the VAFS study, to reduce the original irrigated areas by 25 %. The land-use coverage used in the VAFS study was available from gauging stations G1H020 to G1R003 and is depicted in **Figure 2.10**.

Land-use for the Upper Berg River configuration (origin to G1H020) was obtained from the Skuifraam Dam Feasibility Study (DWAF, 1997) while updated alien vegetation coverages were obtained from the CSIR.

In this study a similar approach was adopted. The GIS coverage of the relevant sub-catchments was intersected with land-use information obtained from the Department of Agriculture to produce further sub-divisions of each primary sub-catchment. The database files produced during this intersection process were then opened in an Excel spreadsheet where they were manipulated by reducing the irrigated areas by 25 % and adding the excess area to the non-cultivated or natural vegetation portion of the catchment.

In addition, It should be noted that areas indicated as non-cultivated were replaced with the natural vegetation as obtained from the Acock's GIS coverage. This was necessary to prevent this area from being modelled as barren rock.

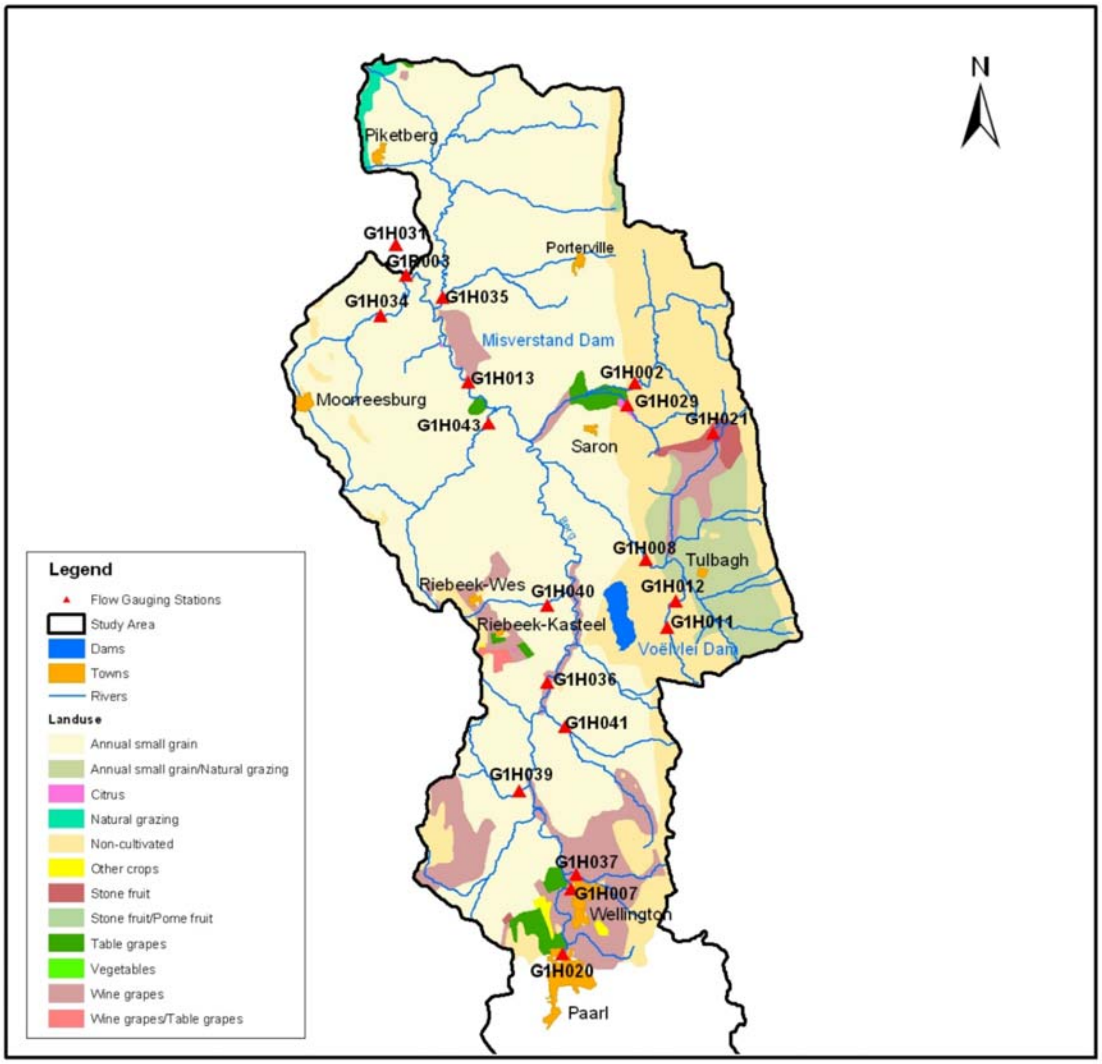

Figure 2.10 Land-use used in the VAFS study

Land-use information for the Berg River catchment, downstream of Misverstand Dam (G1R003) was available from several sources. These included the following:

- Working for Water (WfW) - aerial photography
- Council for Scientific and Industrial Research (CSIR) - satellite imagery
- Aerial photography commissioned by DWAF in 2001.

Although the aerial photography available from WfW was obtained at a 2003 level of development, only a limited number of photographs in the set had been previously geo-rectified, thus covering a limited portion of the catchment and focusing mainly on the mainstem of the river, where it was expected the bulk of the invasive alien plants in the catchment would occur.

The extent to which the aerial photography covered the Berg River catchment below Misverstand Dam is depicted in **Figure 2.11**.

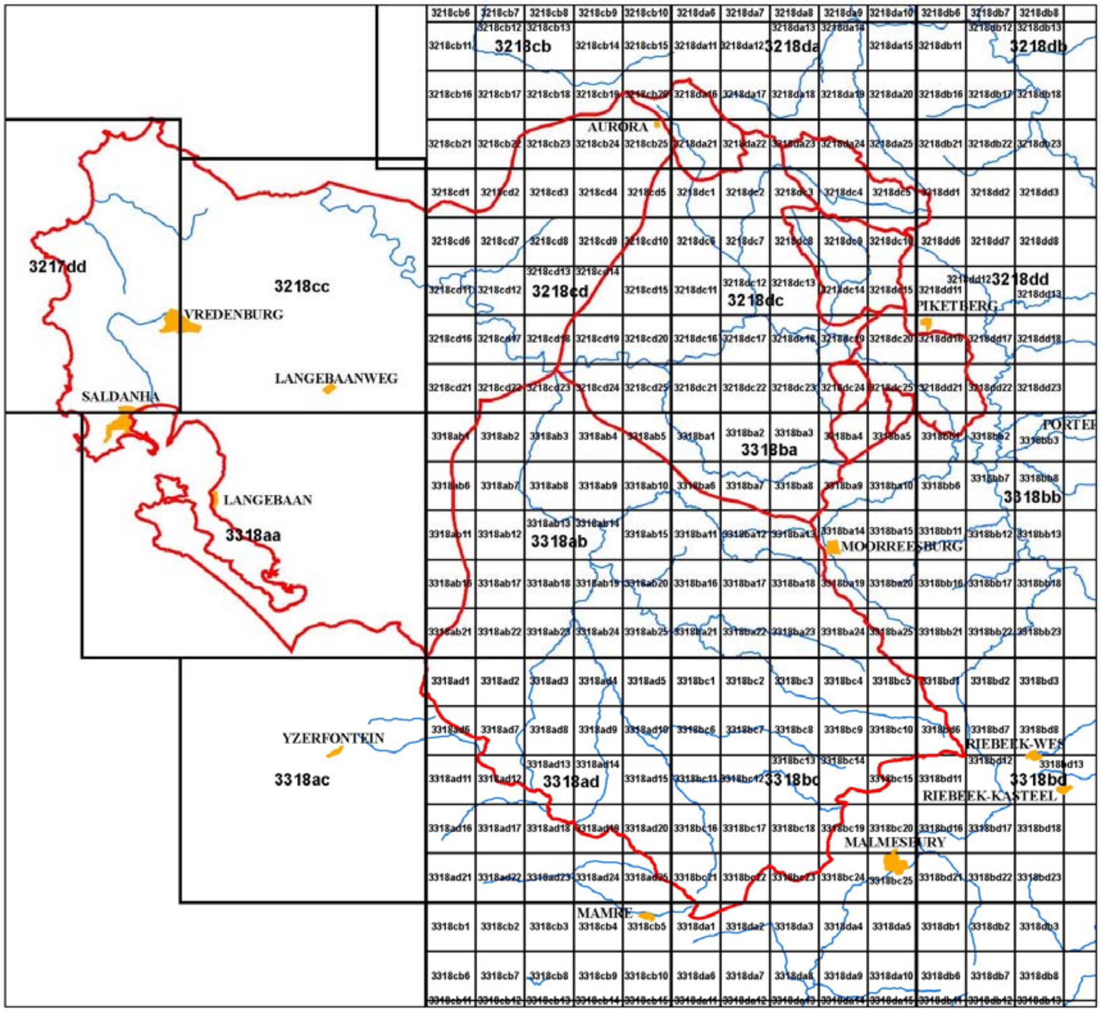

Figure 2.11 Extent of coverage of the WfW aerial photography

The satellite imagery obtained from the CSIR was in LANDSAT 5 TM format and was captured in December 2004. LANDSAT 5 TM format has a pixel resolution of 30 m x 30 m and due to this fairly coarse resolution it was not possible to easily identify the crop types and subsequently capture the areas on the GIS system.

The aerial photography commissioned by the DWAF in 2001 was available from the Surveyor General's office in Mowbray, Cape Town.

No aerial photography was available for the most southern portion of the lower Berg River catchment (i.e. the portion covered by topographical maps 3318ad, 3318bc) and land-use for this portion had to be obtained from the LANDSAT satellite imagery.

The irrigated areas in the lower Berg River were eventually obtained from the 2001 aerial photography with the assistance of the agricultural extension officer (Mr Johan Meij at the time) from the Department of Agriculture's office in Moorreesburg. The extent of the dryland crops were obtained from the National Landcover Database (NLCDP) Project with only the newly irrigated areas superseding the dryland crops. The remaining areas were then assigned the natural vegetation as indicated in the Acocks coverage. The resulting land-use coverage for the lower Berg River is shown in **Figure 2.12.**

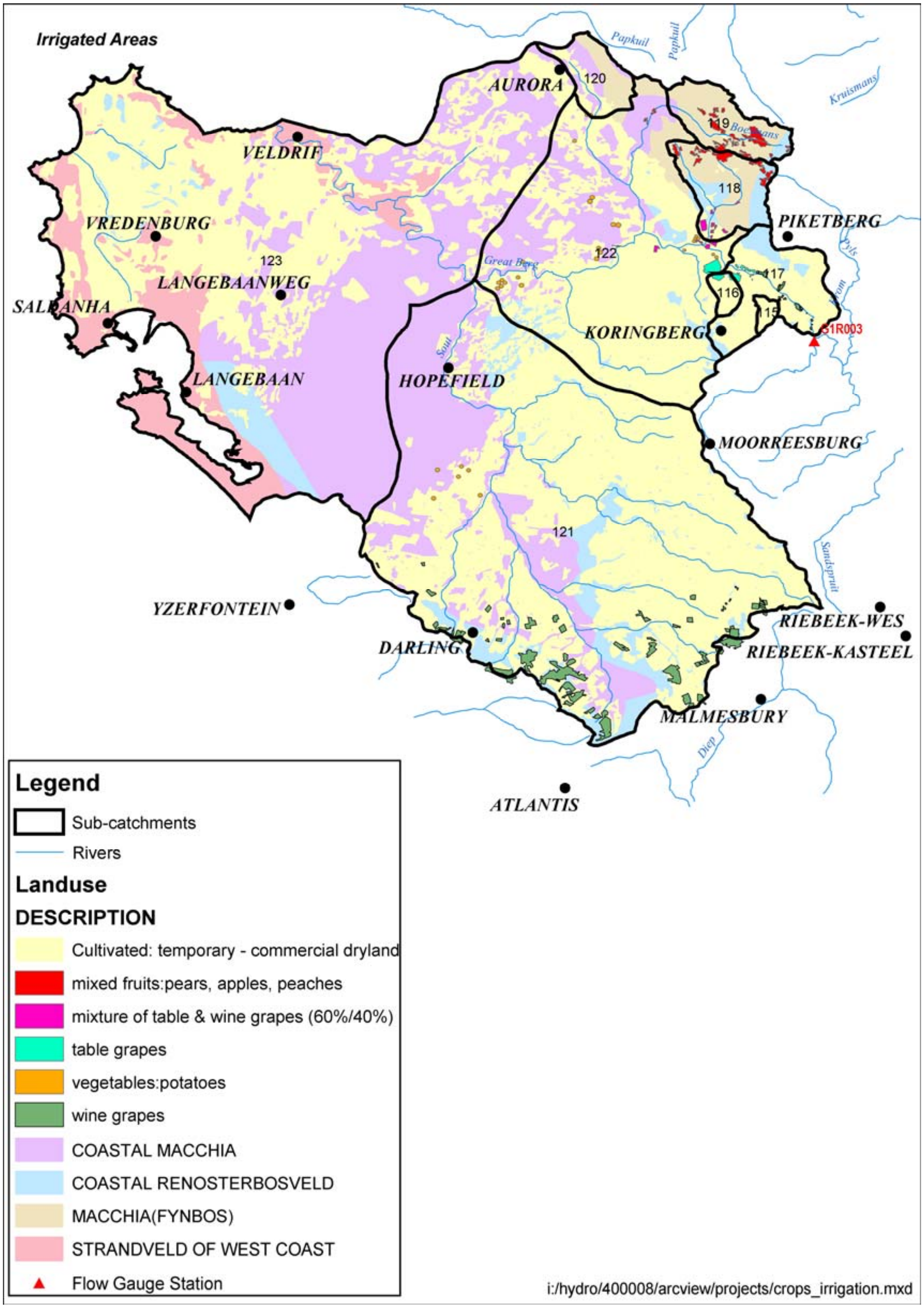

Figure 2.12 Land-use coverage for the lower Berg River catchment

The ensuing sections refer to various portions of the Berg River catchment and show the irrigated areas obtained from the Department of Agriculture's GIS coverage as well as the irrigated area after the 25 % reduction in this area.

2.2.3 Farm dams

Farm dam information for this Study was obtained from two sources:

1. Western Cape System Analysis: Hydrology of the Berg River Basin (DWAF, 1993)
2. Voëlvlei Augmentation Feasibility Study: Hydrology Report (Volume 1) (DWAF, 1999)

The delineation of the sub-catchments required for the ACRU model was quite different from that required for the Pitman monthly modelling. For this reason it was necessary to develop an approach that would on the one hand satisfy the practical requirements of the ACRU model and on the other reflect the actual land-use areas, farm dam capacities and abstractions used in previous studies.

The major farm dams in the Berg River Valley (at a 1990 level of development) were identified and digitized during the early 1990's as part of the Western Cape System Analysis. This process allowed for the demarcation of farm dam boundaries as well as for the determination of capacities using a numerical model and information extracted from the digital terrain data (DWAF, 1993). The area-capacity relationships of these farm dams were approximated using the following relationship:

$$\text{Area} = A.(\text{Capacity})^{B} \quad \ldots\ldots (1)$$

Where area is in km^2, capacity is in Mm^3 and A and B are constants.

It was considered impractical to provide each farm dam with its own sub-catchment and the "dummy dam" [3] approach was employed instead.

In this study a decision was made to use the most up-to-date input data available and in the case of farm dams this was the data from the VAFS study (DWAF, 1999), which was based on the 1996 level of development. This study showed that there had been an increase in farm dam surface area (and thus capacity) from 20.97 km^2 in 1990 to 23.39 km^2 in 1996. The VAFS study, however, gave no indication in which part of the catchment the growth in farm dams had occurred.

The A and B coefficients required for Equation 1 for each calibration sub-catchment were obtained from the WCSA (DWAF, 1999). It was then assumed that the pseudo sub-catchments that comprised these calibration sub-catchments would inherit these coefficients. Unlike the configuration in the WCSA study where one farm dam (dummy dam) was created per calibration sub-catchment, the ACRU configuration created a dummy farm dam for each primary sub-catchment that contained a number of smaller farm dams. This meant that a calibration catchment, say the catchment gauged by G1H041, which originally contained one dummy farm dam in the WCSA now contained 6 farm dams in the ACRU configuration, each with realistic representation of the area upstream of the dam.

Using the 1990 GIS coverage for the farm dams it was possible to determine the surface area of the farm dams within the sub-catchment and to convert this to the corresponding volume. It should be noted at this point that the area/volume relationship (equation 1) and the appropriate coefficients are applicable to the single dummy farm dam that was created in that sub-catchment. Since this ACRU setup resulted in the formation of more than one dummy dam it was necessary

[3] The "dummy dam" represents the total capacity of all the farm dams and is situated at the outlet of the catchment upstream of the farm dam boundary.

to develop a ratio that could be used to scale up the combined capacity of the farm dams in the Berg River catchment such that it matched the capacity quoted in the VAFS study. This ratio was developed as follows:

1. The surface area of the farm dams in each of the catchments was determined from the GIS coverage information.
2. The VAFS study indicated that there was growth (1990 to 1996) in the farm dam capacity in the catchment gauged by G1H037.
3. Using the A and B coefficients a volume for each dummy dam was calculated and summed to obtain a total capacity of farm dams, in the sub-catchment. In the sub-catchment gauged by G1H037 this volume was $0.73Mm^3$.
4. Using the surface area data (1990 level of development) from the WCSA, it was possible to calculate the total farm dam capacity in the sub-catchment gauged by G1H037 ($3.59 Mm^3$).
5. Ratio 1, relating the capacity from the WCSA to that of this study was determined by dividing the area determined in (4.) above by that determined in (3.) to obtain 4.92.
6. Ratio 2, relating the 1996 capacity ($4.24 Mm^3$) to the 1990 ($3.59 Mm^3$) capacity was obtained by dividing the 1996 farm dam capacity by the 1990 capacity to obtain 1.18.
7. Ratio 3 was then obtained by multiplying ratio 1 with ratio 2 to obtain 5.78, which was used to scale each of the farm dam capacities in the catchment gauged by G1H037 up to the 1996 level of development.

By using the procedure described above it was possible to obtain the 1996 capacity of farm dams as reported in the VAFS study for each of the catchments used in the ACRU configuration.

It should be noted that the ACRU model requires the volume and surface area to be specified in units of m^3 and m^2, respectively. The A and B coefficients, however, are applicable to Equation 1 where the units for capacity and surface area are Mm^3 and km^2, respectively. The equivalent parameters, in ACRU, for the "A" and "B" parameters are RESCON and RESEXP. These parameters were obtained by plotting volume in m^3 against the surface area in m^2 and then fitting a curve with the form as shown in Equation 1, to obtain the values to be used for RESCON and RESEXP. An example of these curves for the catchment gauged by G1H037 is depicted in **Figure 2.13**.

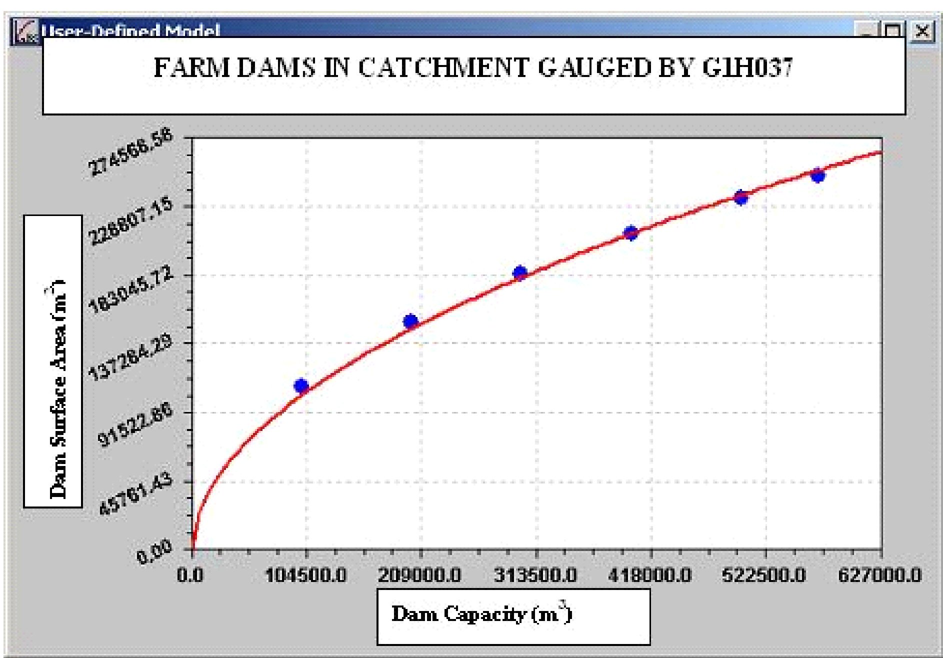

Figure 2.13 Example of farm dam surface area and capacity relationship

CHAPTER 3: UPDATED VERIFICATION OF THE FLOW MODULE

The updated flow verification of the ACRU model was achieved through consideration of both the daily time series of flow and the flow duration curves for the relevant calibration period. The gauges used for verification and the periods over which the verification was performed are shown in **Table 3.1** and discussed in the more detail in the following sections. It should be noted that changes to the ACRU flow-related parameters were only attempted if the updated verifications were significantly different from previous verification attempts (WRC, 2007).

Table 3.1 Gauges used for the verification of daily flow

Gauge	Verification Period
G1H037	1982 – 1992
G1H041	1980 – 1999
G1H036	1980 – 1999
G1H002	1951 – 1963
G1H028	1972 – 1999
G1H008	1960 – 1999
G1H043	1980 – 1999
G1H013	1983 – 1999
G1H035	1980 – 1999

The location of the gauges and their incremental catchment areas are shown in **Figure 3.1**.

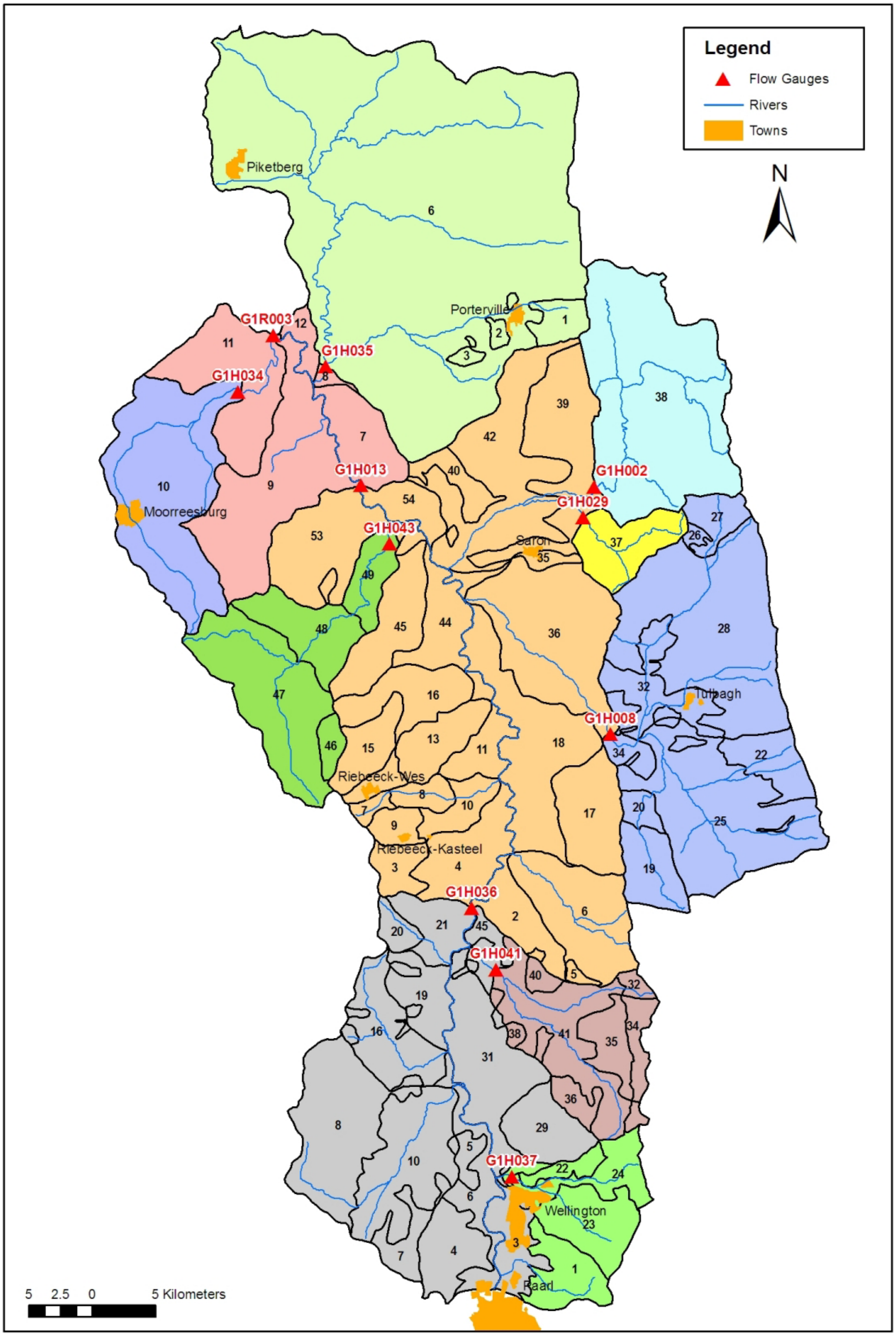

Figure 3.1 Location of gauges and incremental catchments used for validation of the ACRU model

3.1 VERIFICATION AT G1H037

Flow verification at this gauge (see **Figure 3.1**) was completed over the period 1980 to 1992, using land-use data obtained at the 1998 level of development. The modelling process did not account for the variation in land-use during the verification period and it was therefore necessary to identify the possible effects of this on the simulated streamflow record.

Irrigation water use was identified as the biggest user of water in this sub-catchment and because of this, it was expected that there would be some differences between the observed record and the simulated flow records, especially for the period prior to 1990 when the 1998 irrigated area (26.91 km^2 based on the area obtained from the GIS coverage) was approximately 400% more than the irrigated area in 1990 (6 127 km^2).

In the WCSA (DWAF, 1993) it was reported that water was transferred from the adjacent Breede River catchment at an estimated 0.22 Mm^3/month. In the ACRU configuration this import enters the catchment upstream of the abstractions made for run-of-river (directly from the river) irrigation, increasing the possibility of satisfying that irrigation demand. Winter abstraction to fill the farm dams was not modelled due to the lack of up-to-date information on this.

Observed flow data at gauging station G1H037 was available from 1978 up until 1992. A large portion of dataset (June 1980 to October 1981), however, was missing and consequently only the latter portion of the record was used for flow verification. No patching of the observed record was required after January 1982.

The monthly comparison of the simulated and observed flows at G1H037 is depicted in **Figure 3.2,** which shows that for most of the winter months the simulated flows are below the observed flows with the exception of winter in 1991 when the simulated flows markedly exceeded the observed flows. This could be due to the catchment not being delineated into sufficient primary sub-catchments that could adequately capture the spatial variability of the catchment rainfall.

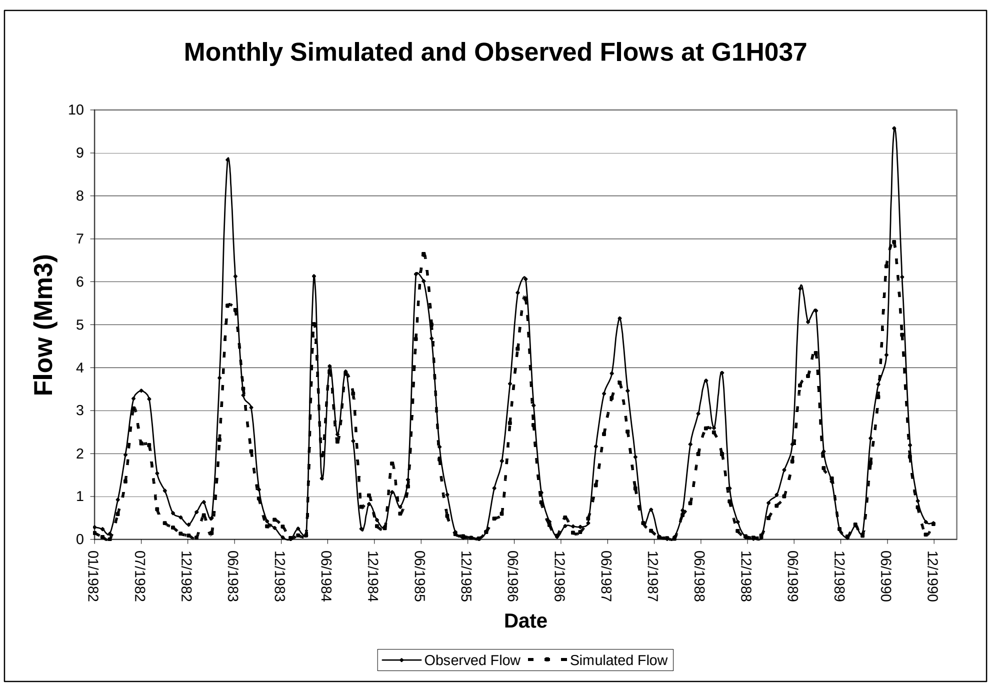

Figure 3.2 Monthly simulated and observed flows at gauging station G1H037

A comparison of the simulated and observed daily flows is depicted in **Figure 3.3** which shows that the daily trends of the observed record are well represented by the simulated daily flows.

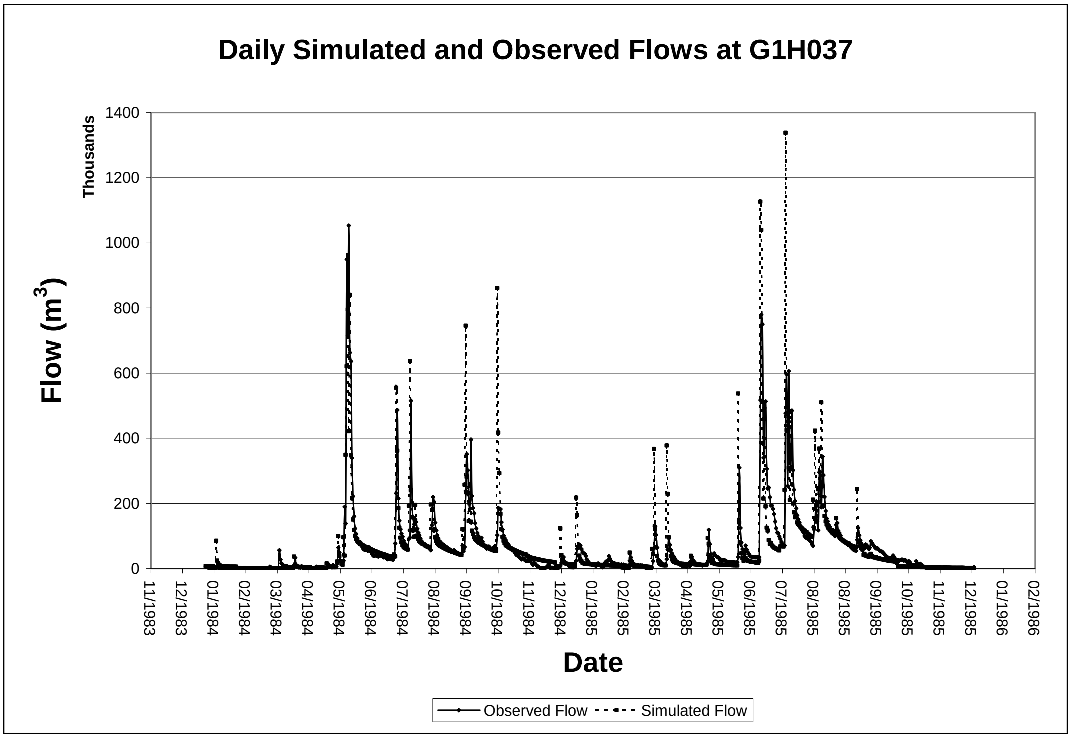

Figure 3.3 Daily simulated and observed flows at gauging station G1H037

A comparison of the daily flow duration curves for the observed and simulated flows is depicted in **Figure 3.4**. The figure shows that percentage exceedance at the various flows are not always comparable, possibly caused by the over-simulated daily flows for the winter of 1990.

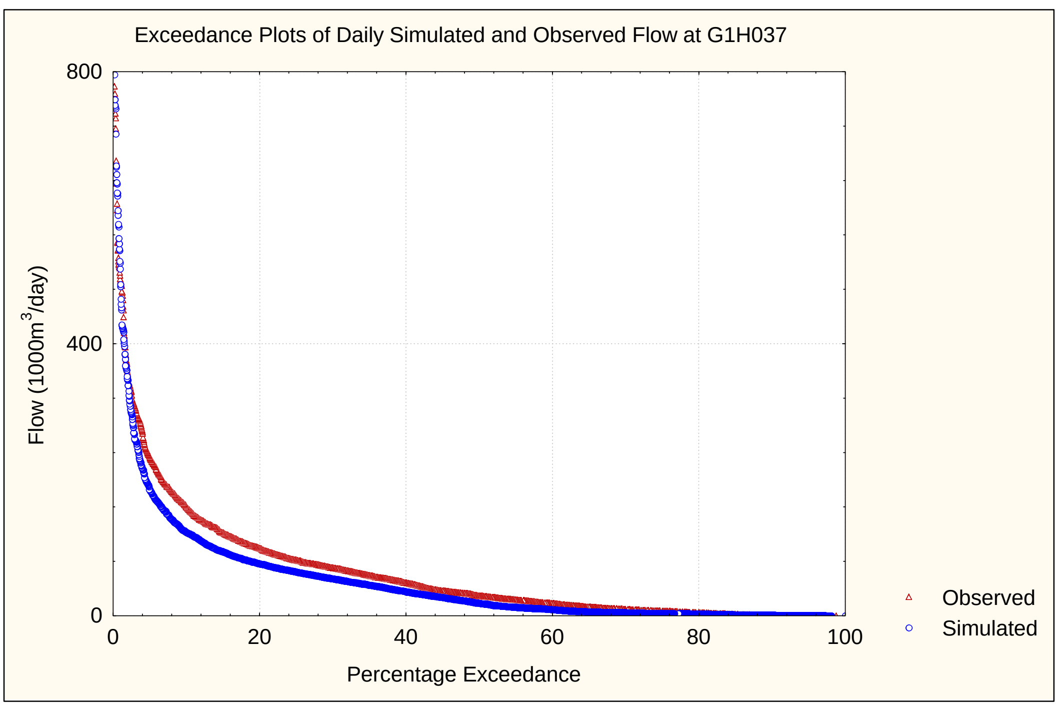

Figure 3.4 Flow duration curves for simulated and observed flows at G1H037

By eliminating the winter of 1990 from the flow duration analysis the comparison shown in **Figure 3.5** was obtained.

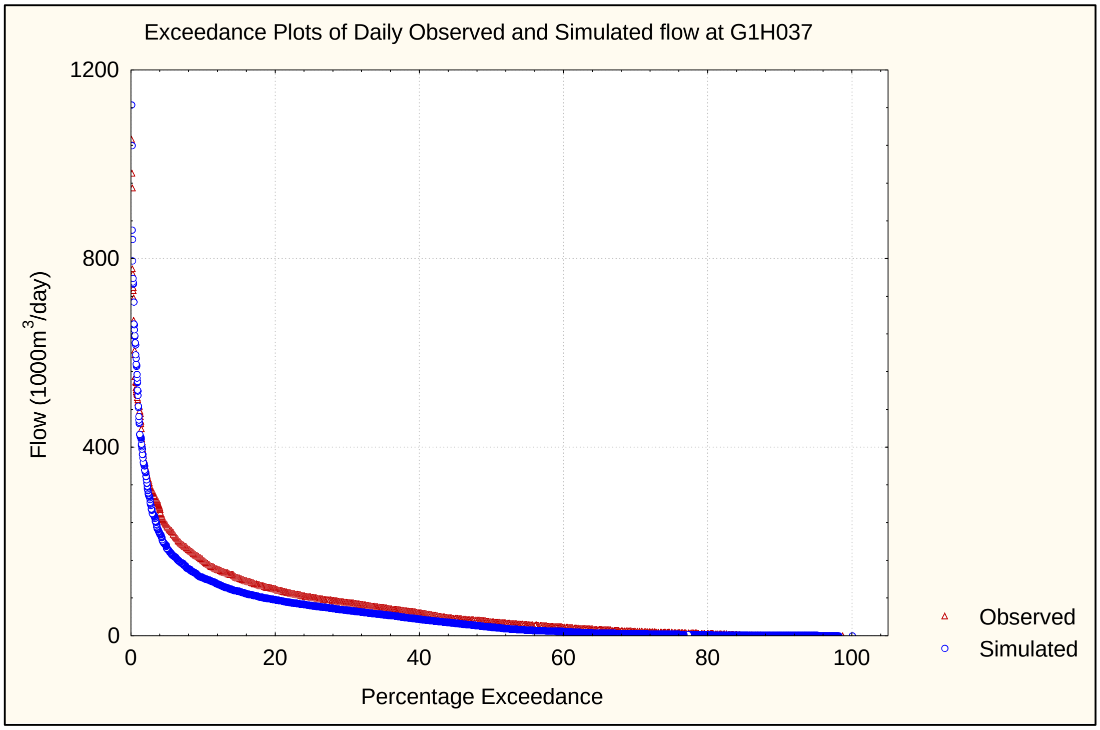

Figure 3.5 Flow duration curves for daily simulated and observed flows at G1H037 (flow of winter 1990 removed)

Pertinent objective function values for the monthly observed and simulated flows at gauging station G1H037 are shown in **Table 3.2** which shows an 11% under-simulation of streamflow over the 10 year period from 1982 to 1992. Acceptable values (Schulze *et al*, 1995) for the coefficient of determination, 'r2' and coefficient of efficiency of 0.8 and 0.78 were obtained, respectively.

Table 3.2 Statistics for simulated and observed flows at G1H037

Statistics for G1H037 (1980 –1994)	Monthly totals of daily simulation
Mean observed streamflow (Mm^3/month)	1.8
Mean simulated streamflow (Mm^3/month)	1.6
% difference in standard deviation	1.53
Coefficient of determination (r^2)	0.80
Coefficient of efficiency	0.78

3.1.1 Verification at G1H041 (Kompanjies River at De Eikeboomen)

Based on the WCSA report (DWAF,1993) the mean annual rainfall in this catchment varies from 500 mm in the west to 1800 mm in the east and this can clearly be seen from **Figure 3.6** which shows the rainfall distribution for this portion of the catchment. The increased rainfall in the eastern parts of the catchment can be attributed to the topography of this region.

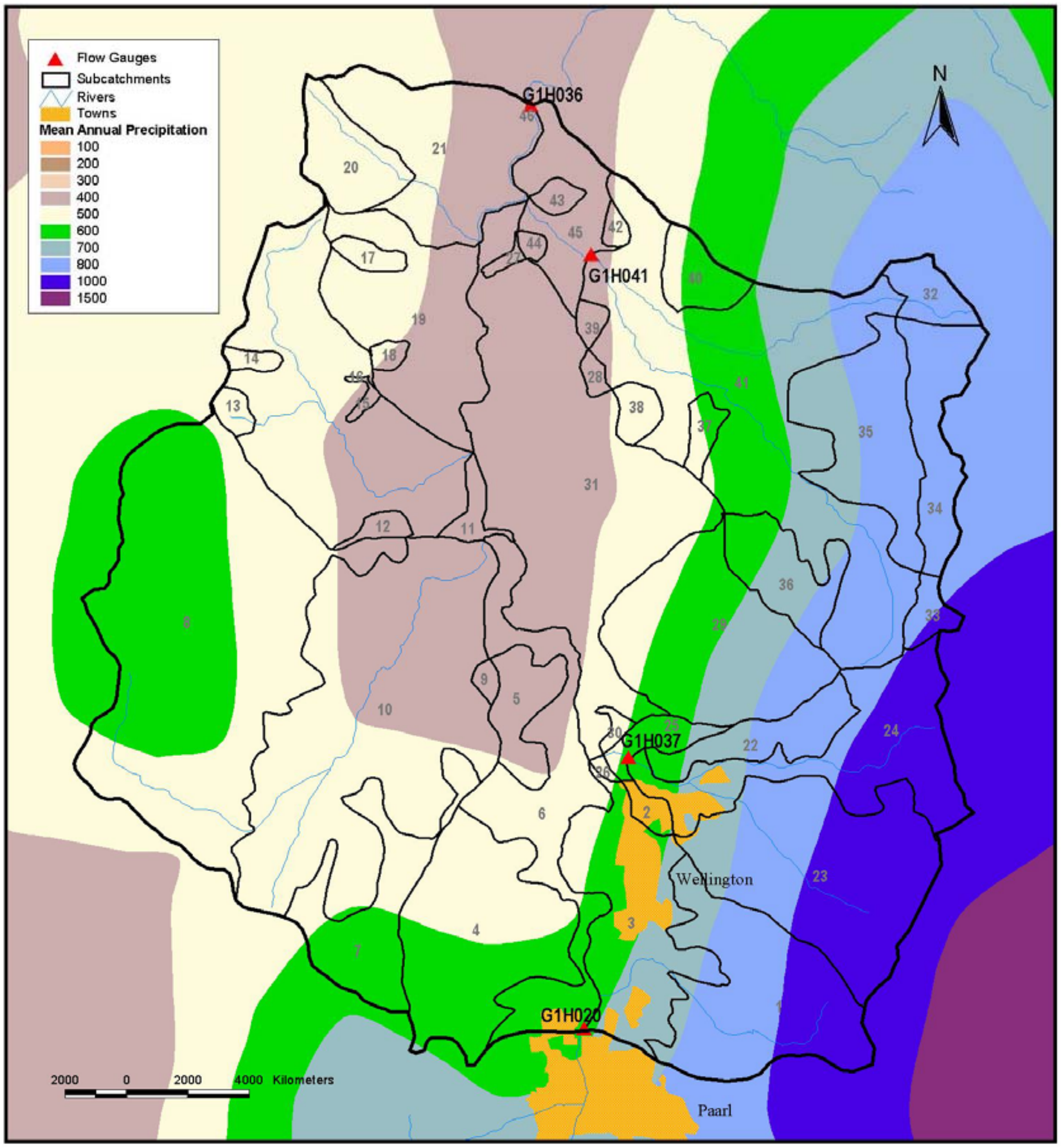

Figure 3.6 **Rainfall distribution in the Berg River catchment between gauging stations G1H020 and G1H036**

As a result of the above, the catchment was split into a high Mean Annual Precipitation (MAP) and Low MAP region with different driver rainfall stations being assigned to each of these regions. In this way it was possible to capture the observed spatial variability in rainfall in the catchment.

The available land-use information at the 1998 level of development showed that 15.73 km^2 were irrigated as opposed to the 2.72 km^2 in 1990 (DWAF,1993) which indicates an increase of approximately 480%. Since the ACRU model was run at a static level of development it was expected that this may affect the streamflow volumes observed during the summer months when the over-estimated irrigation demand would be imposed on the water resources. Winter abstraction to fill farm dams were not modelled because of the small volumes compared to the natural inflow.

The monthly comparison of observed and simulated flows is shown in **Figure 3.7**.

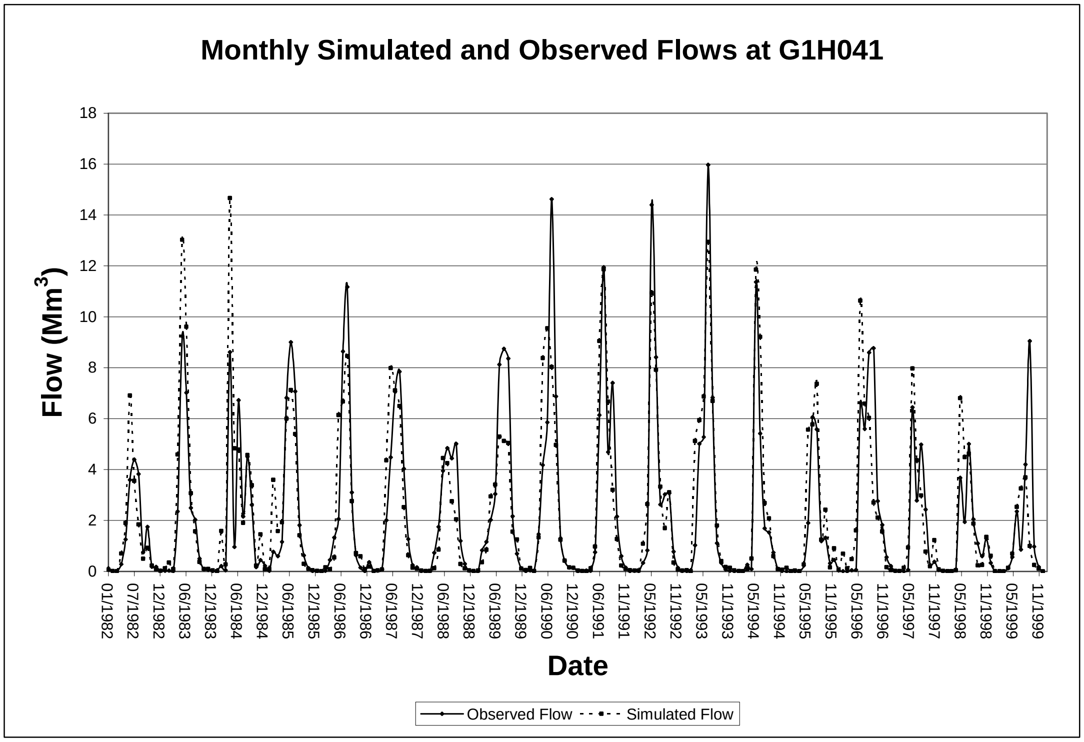

Figure 3.7 Monthly simulated and observed flows at G1H041

The differences in, particularly the simulated and observed winter flows could mainly be ascribed to the rainfall measured at the driver rainfall station. Further sub-division of the catchment upstream of G1H037 could possibly be attempted if refinement was required. Although this may not result in the selection of a different driver rainfall station for the new sub-catchment it would at least provide different monthly Rainfall Adjustment Factors (CORPPT) which could in turn lead to different aerial rainfall and run-off patterns. Adjusting the values of the flow-related parameters did not significantly improve the fit between the simulated and observed flow records.

A comparison of daily simulated and observed flows is depicted in **Figure 3.8**, which shows that daily simulated trends are representative of the observed trends, both for high flows and recession flows.

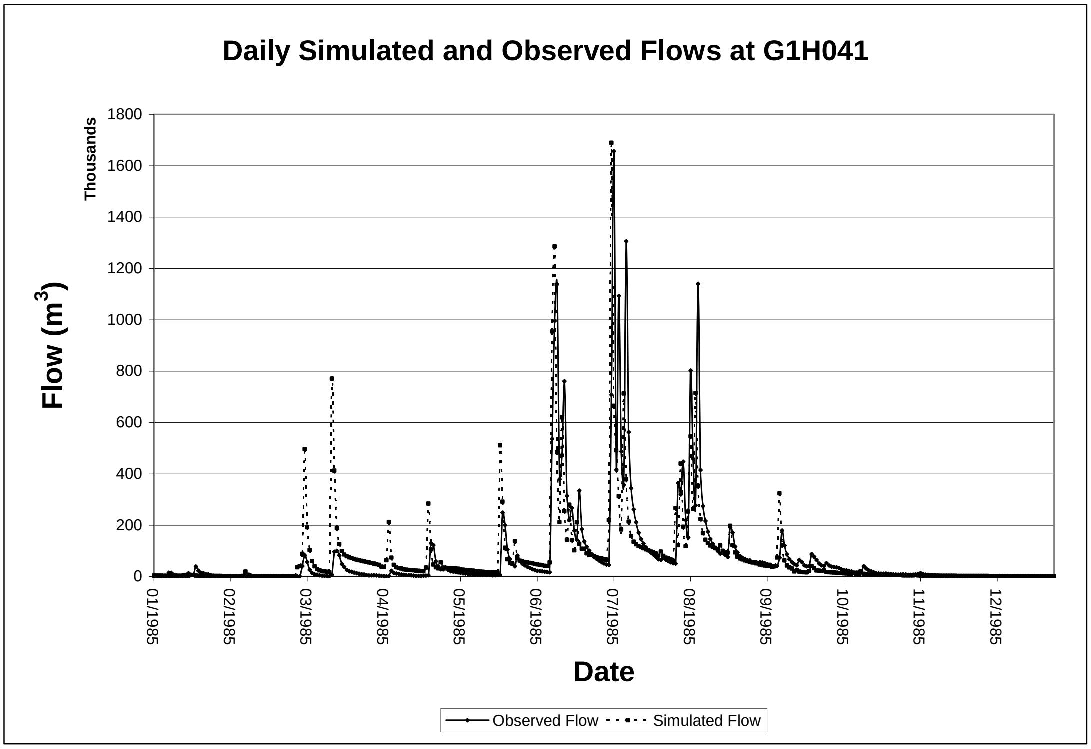

Figure 3.8 **Daily simulated and observed flows at gauging station G1H041**

The daily flow duration curve for the simulated and observed flows at gauging station G1H041 is depicted in **Figure 3.9**, from which it can be seen that the flow duration curve of the simulated flows is representative of the flow duration curve of the observed flows over the entire range of flows.

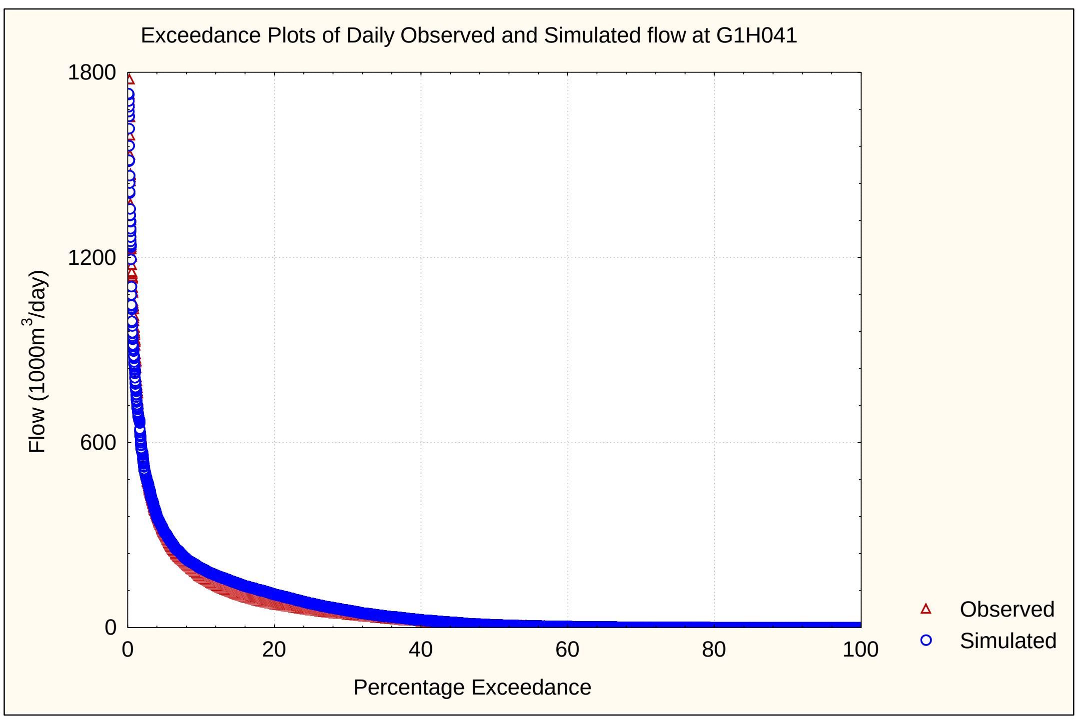

Figure 3.9 **Flow duration curves for daily simulated and observed flows at G1H041**

Pertinent objective function values for the monthly observed and simulated flows at gauging station G1H041 are shown in **Table 3.3** which shows a 6% over-simulation of streamflow over the 19 year period from 1980 to 1999. Acceptable values for 'r^2' and coefficient of efficiency of 0.74 and 0.72 were obtained, respectively.

Table 3.3 Objective function values for simulated and observed flows at G1H041

Statistics for G1H041 (1980 –1999)	Monthly totals of daily simulation
Mean observed streamflow (Mm^3/month)	2.1
Mean simulated streamflow (Mm^3/month)	2.2
% difference in standard deviation	1.4
Coefficient of determination (r^2)	0.74
Coefficient of efficiency	0.72

3.1.2 Verification at G1H036 (Berg River at Vleesbank)

In order to verify the simulated flows at gauging station G1H036 (see **Figure 3.6**), observed flows measured at gauging station G1H020 were used as a specified input from the Upper Berg River, while the simulated flows at gauging stations G1H037 and G1H041 were used as the tributary inflows.

The irrigated area, at the 1990-level of development, reported for the incremental G1H036 catchment (i.e. excluding the flows measured at gauging stations G1H037, G1H041 and G1H020) in the WCSA (DWAF,1993) was 57.04 km^2 as opposed to the 124.26 km^2 obtained from the Department of Agriculture Survey (1998). This was an increase of approximately 117% and could affect the comparison of the simulated and observed flows in the early years of the calibration period, especially during the summer months when an increased irrigation demand would be imposed on the water resources in ACRU.

Discharges into the catchment included the Paarl and Wellington wastewater treatment works return flows, while abstractions included that for the Malmesbury water treatment works and the winter abstractions to farm dams. The magnitudes of these imports were obtained from the WCSA (DWAF, 1993) and are shown in **Table 3.4**.

Winter abstractions to farm dams were split based on the percentage of the total cultivated area irrigated from farm dams which occurred in the particular primary sub-catchment.

Table 3.4 Water transferred into and out of the catchment gauged by G1H036

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Paarl and Wellington return flows (transferred in)												
Mm^3	0.5	0.5	0.6	0.5	0.6	0.7	0.8	0.8	0.7	0.6	0.5	0.5
$1000m^3$/day	16.1	16.1	19.4	16.7	19.4	23.3	25.8	25.8	23.3	19.4	16.7	16.1
Malmesbury Abstraction (transferred out)												
Mm^3	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.03	0.03	0.03	0.02
$1000m^3$/day	0.6	0.6	0.6	0.7	0.6	0.3	0.6	0.6	1.0	1.0	1.0	0.7
Winter Abstractions to Farm Dams (transferred out)												
Mm^3	0	0	0	0	7.16	3.17	0.41	0	0	0	0	0
$1000m^3$/day	0	0	0	0	231	106	13.2	0	0	0	0	0
Net Imports to Catchment												
Mm^3	0.48	0.48	0.58	0.48	-6.57	-2.49	0.78	0.78	0.67	0.57	0.47	0.48
$1000m^3$/day	15.5	15.5	18.7	16.0	-212	-83	25.2	25.2	22.3	18.4	15.7	15.5

The comparison of the monthly simulated and observed flows is shown in **Figure 3.10**.

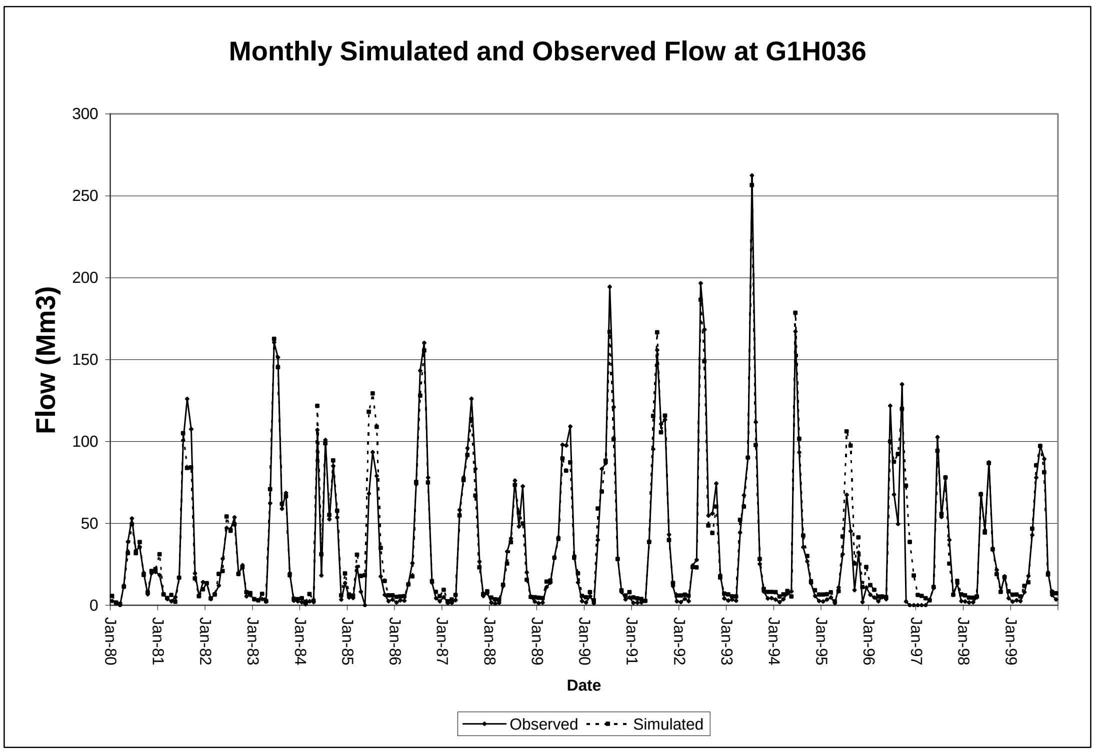

Figure 3.10 Monthly simulated and observed flows at G1H036

From **Figure 3.10** it is seen that the monthly simulated flows are representative of the observed flows. This was, however, to be expected because of the observed flows at gauging station G1H020 being used as a specified inflow to the incremental catchment. It was noted that the volume of flows generated upstream of gauging station G1H020 was much bigger than those generated from the incremental catchment gauged by gauging station G1H036 and, as a consequence, the flow-related parameters in incremental catchment G1H036 could be insensitive to changes in their respective values.

Pertinent objective function values for the monthly observed and simulated flows at gauging station G1H036 are shown in **Table 3.5** which shows a 0.32% over-simulation of streamflow over the 19 year period from 1980 to 1999. Excellent values for 'r^2' and coefficient of efficiency of 0.97 and 0.97 were obtained, respectively.

Table 3.5 Objective function values for simulated and observed flows at G1H036

Statistics for G1H036 (1980 –1999)	Monthly totals of daily simulation
Mean observed streamflow (Mm^3/month	36.2
Mean simulated streamflow (Mm^3/month)	36.3
% difference in standard deviation	5.44
Coefficient of determination (r^2)	0.97
Coefficient of efficiency	0.97

A comparison of the simulated and observed daily flows is depicted in **Figure 3.11**, which shows that the daily trends in the observed flow pattern are mimicked by the simulated flow record.

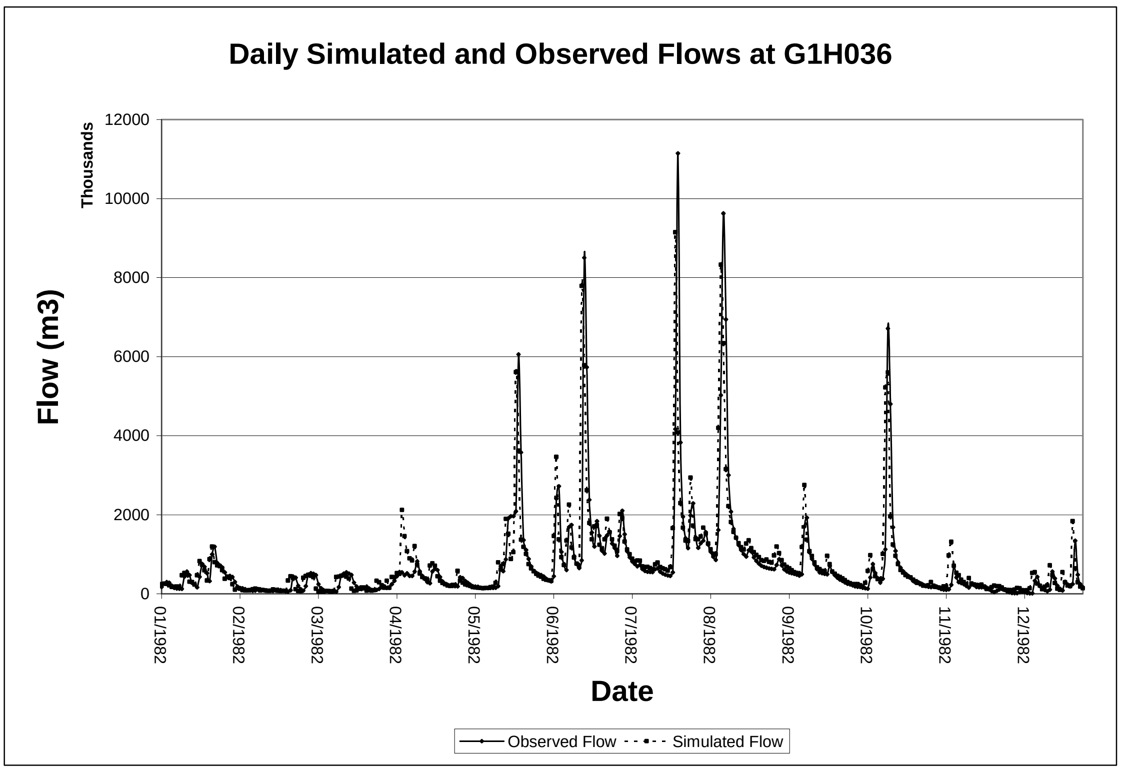

Figure 3.11 Daily simulated and observed flows at G1H036

The daily flow duration curve for the simulated and observed flows at gauging station G1H036 is depicted in **Figure 3.12**, from which it can be seen that the flow duration curve of the simulated flows is representative of the flow duration curve of the observed flows over the entire range of flows.

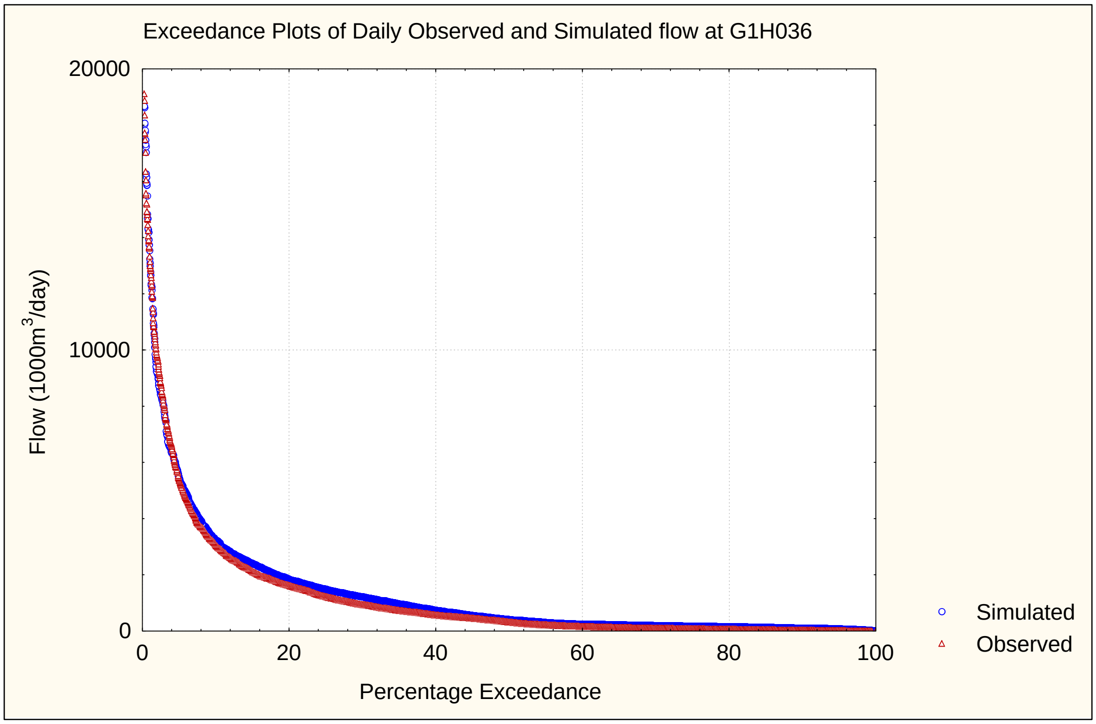

Figure 3.12 Flow duration curves for daily simulated and observed flows at G1H036

3.1.3 Verification at G1H002/G1H028 (24 Rivers at Drie-Das Bosch)

This is the site of the streamflow diversion into the Voëlvlei Canal. The flow verification at this gauge did not take account of the variation in land-use during the verification period but was instead completed with land-use data at a static 1998 level of development. The available land-use data for 1998 showed that no crops were cultivated upstream of the gauging station G1H002 while in the WCSA study (DWAF(1),1993) relatively small areas of irrigation (0.048 km^2 – 0.112 km^2) were used for calibration purposes.

According to previous studies on the hydrology of the Berg River catchment (DWAF, 1993 and DWAF, 1999), flow recordings at gauging station G1H002 were available since 1951 and extended up until 1970 when the station was closed and replaced with gauging station G1H028, situated just upstream of the original G1H002 gauging station. Flow records at gauging station G1H028 are available from 1972 and consist of the following two components:

1. The flow over the weir on the 24 Rivers River (measured by gauging station G1H028)
2. The flow in the diversion canal to Voëlvlei Dam (G1H058)

Although land-use at a 1998 level of development was used, verification could possibly be conducted over a much longer period taking into account that minimal development has occurred in the catchment since 1950. Both the WCSA (DWAF, 1993) and VAFS (DWAF, 1999) studies reported that a large portion of the flow entering the diversion canal is allowed to spill from a silt trap located upstream of gauging station G1H058, leading to some underestimation of total flow at gauging station G1H028. For this reason these studies did not use the flow records from 1972 onwards in the calibration process and instead opted for the observed flows recorded at gauging station G1H002 during the period 1951 to 1970.

For this study, the model was verified for the period 1951 to 1969 and was then checked (in recognition of the inaccuracies in flow measurement) over the period 1972 to 1999.

Verification (Period : 1951 - 1969)

Initial delineation of the catchment upstream of gauging station G1H002 proved too coarse (see **Figure 2.4**) and further subdivision was required to allow for the usage of different monthly Rainfall Adjustment Factors (CORPPT) which could in turn lead to different aerial rainfall and runoff patterns. The monthly comparison of observed and simulated flows is shown in **Figure 3.13** which highlights several shortcomings in the simulation, i.e. the ACRU recessions are often too fast, while the wetter months are sometimes over-simulated. The high flow-over-simulations are directly related to over-estimated daily rainfalls, whereas the imperfect recessions are related to non-optimal soil water and groundwater constants in this ACRU configuration.

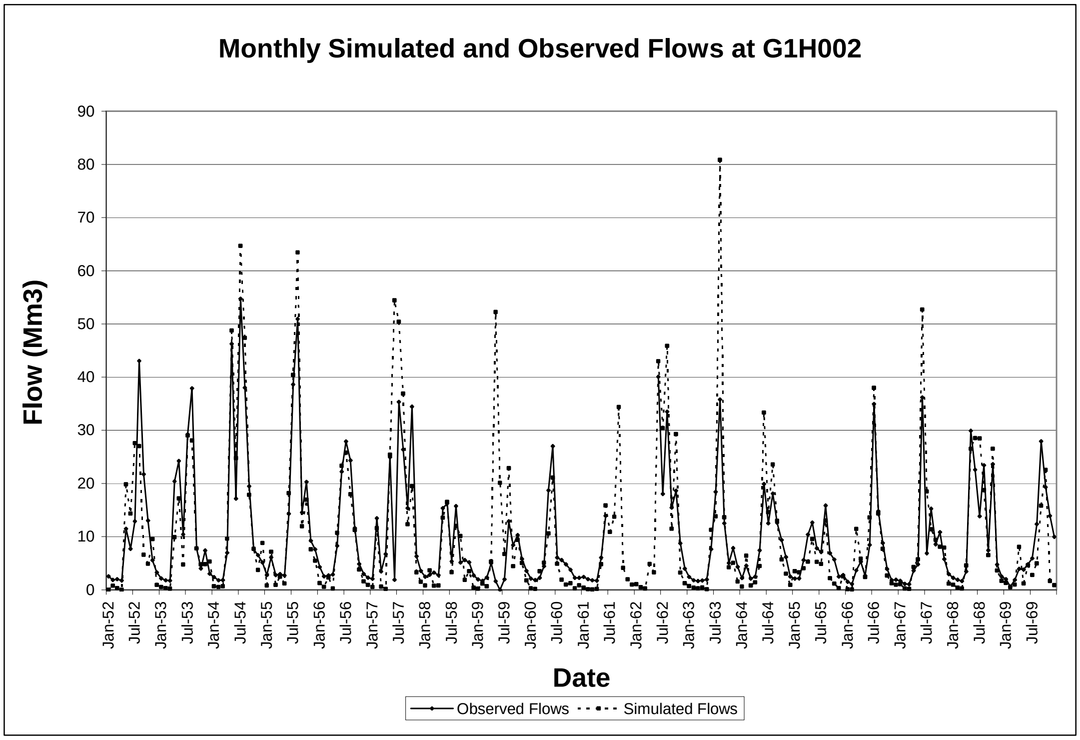

Figure 3.13 Monthly simulated and observed flows at G1H002

Pertinent objective function values for the monthly observed and simulated flows at gauging station G1H002 are shown in **Table 3.6**, which shows that the simulated flow under-estimated the observed flow by 5%. Values for r^2 and the coefficient of efficiency of 0.82 and 0.81 were obtained, respectively.

Table 3.6 Statistics for simulated and observed flows at G1H002

Statistics for G1H002 (1951 –1969)	Monthly totals of daily simulation
Mean observed streamflow (Mm^3/month)	9.9
Mean simulated streamflow (Mm^3/month)	9.5
% difference in standard deviation	25.26
Coefficient of determination (r^2)	0.82
Coefficient of efficiency	0.81

The daily flow duration curve for the simulated and observed flows at gauging station G1H002 is depicted in **Figure 3.14** where it is evident that the low flows are consistently under-estimated.

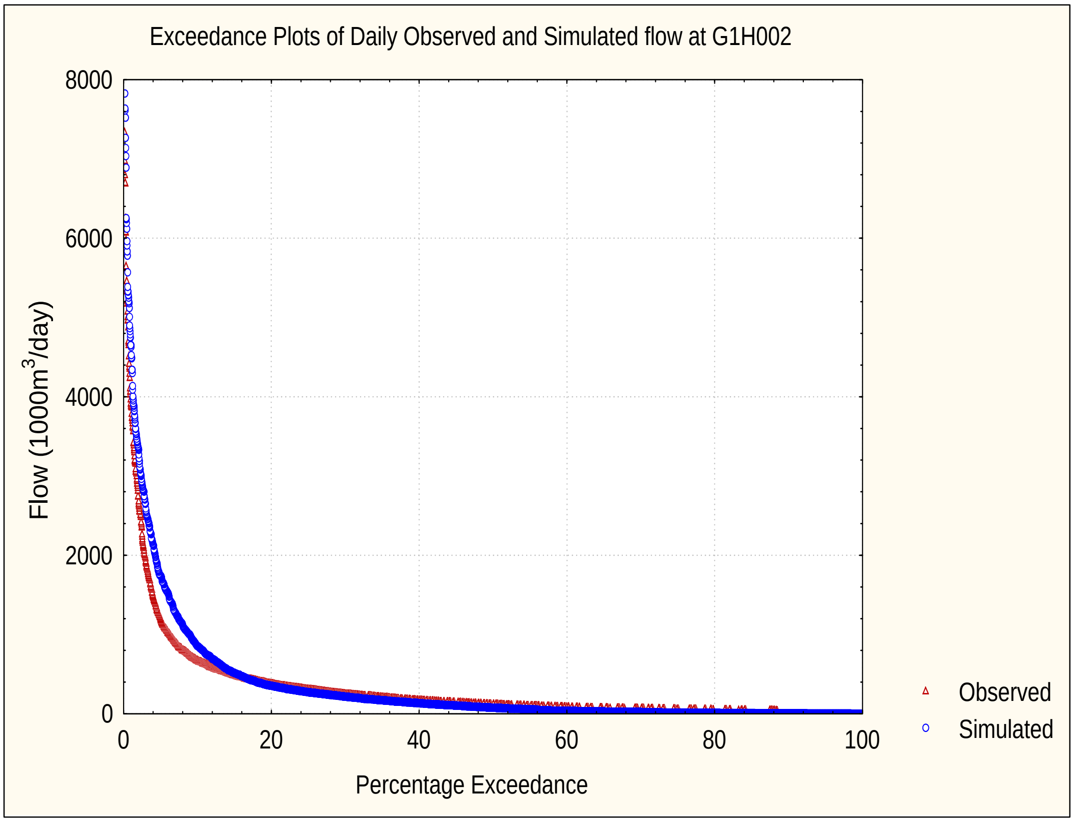

Figure 3.14 Flow duration curves for daily simulated and observed flows at G1H002

Verification (Period: 1972 – 1999)

Despite the fact that the observed record for G1H028 was unreliable (DWAF, 1993; DWAF, 1999) the model was also verified for the period 1972 to 1999 using the same set of flow-related parameters obtained from the 1951 to 1963 verification. In this way it was be possible to confirm whether the flow-related parameters obtained from the 1951 to 1963 verification were in fact applicable to this catchment. The observed flow record used was constructed as the sum of the flows measured at gauging stations G1H028 and G1H058.

A number of gaps in the observed record occurred during the winter months when it was more likely that there would be some streamflow rather than zero streamflow. These gaps were subsequently patched with simulated flows. Although gaps of several months existed in certain cases, it was still useful to evaluate the models performance relative to the portion of the observed flow record that was intact.

The monthly flow comparison of simulated and observed flows at gauging station G1H028 is depicted in **Figure 3.15**. It is evident that over-simulation of wet months occurred less frequently than for the earlier period and that simulated recession was mimicked well by the ACRU model.

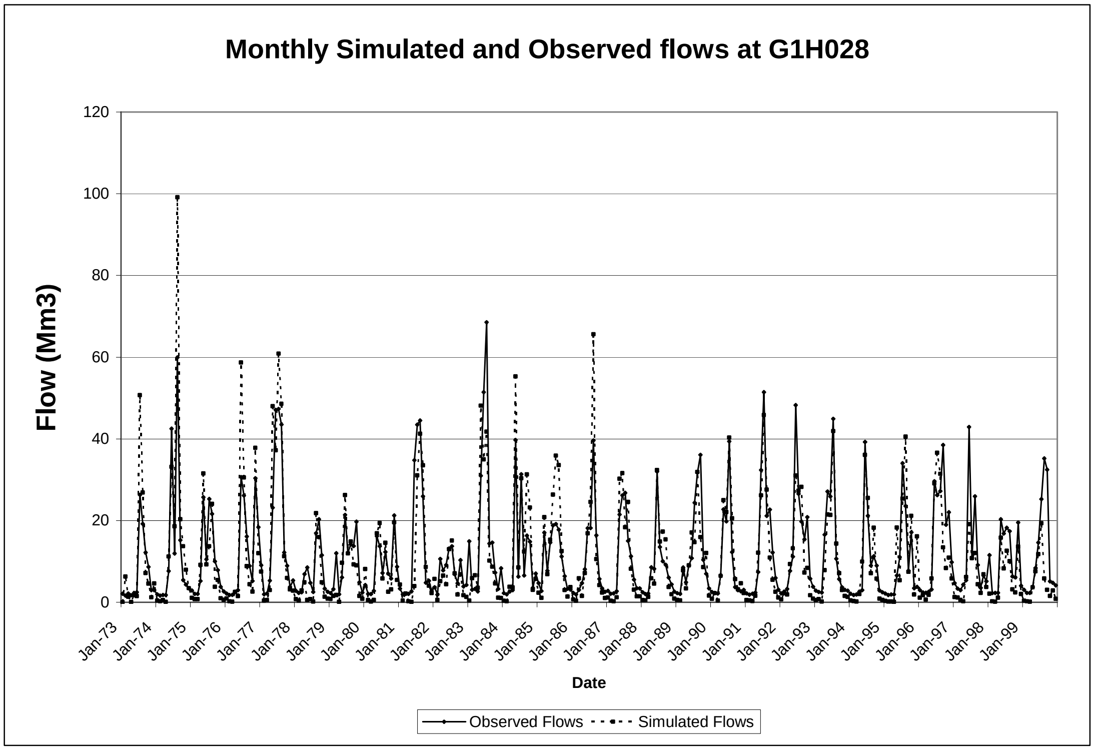

Figure 3.15 Monthly simulated and observed flows at gauging station G1H028

Pertinent objective function values for the monthly observed and simulated flows at gauging station G1H002 are shown in **Table 3.7**, which shows that the simulated flow underestimated the observed flow by 9%. Acceptable values for r^2 and coefficient of efficiency of 0.72 and 0.71 were obtained, respectively. These results seem to indicate that the flow-related parameters and driver rainfall stations are applicable to the catchment, resulting in a realistic representation of runoff in response to the rainfall.

Table 3.7 Objective function values for simulated and observed flows at G1H028

Statistics for G1H028 (1972 –1999)	Monthly totals of daily simulation
Mean observed streamflow (Mm^3/month)	11.3
Mean simulated streamflow (Mm^3/month)	10.3
% difference in standard deviation	13.19
Coefficient of determination (r^2)	0.72
Coefficient of efficiency	0.71

The daily flow duration curves for the simulated and observed flows at gauging station G1H028 are depicted in **Figure 3.16**.

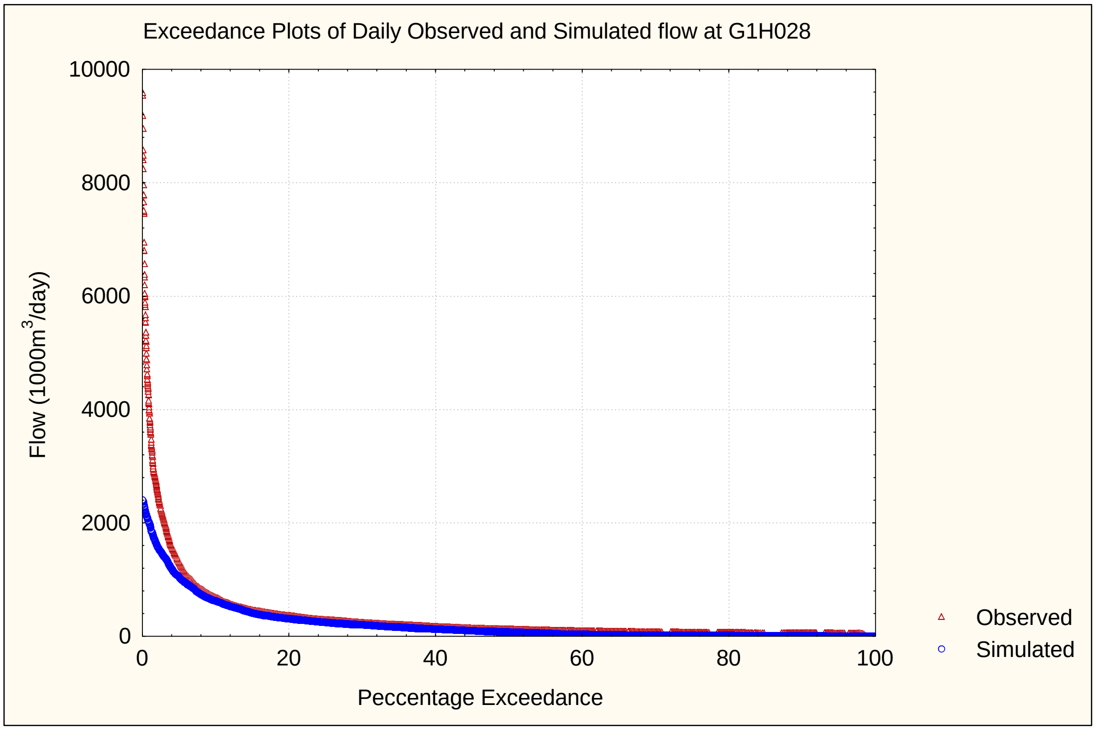

Figure 3.16 Flow duration curves for daily simulated and observed flows at G1H028

Figure 3.16 shows that the simulated flows are fairly representative of the observed flows at gauging station G1H028**. Figure 3.16** shows that the simulated flows are fairly representative of the observed flows for the low flow portion of the flow record. The model, however, could not replicate the higher flows satisfactorily. This is probably directly related to the rainfall events driving these simulated events.

3.1.4 Verification at G1H008 (Klein Berg at Nieuwkloof)

This gauging station is situated on the Klein Berg River and measures the flow generated in the catchment upstream of the diversion to Voëlvlei Dam. Verification was undertaken at a constant 1998 level of development which indicated that the irrigated area had increased from 19.27 km2 in 1990 to 42.35 km^2 in 1998. Imports to the catchment were assumed to consist of the "White Bridge Import" which is diverted from the Breede River at a constant rate of 0.53 Mm^3/month for irrigation and urban use.

The comparison of monthly simulated and observed flows at G1H008 is depicted in **Figure 3.17**, which shows that the monthly simulated flows are representative of the observed flows. It is, however obvious that too much flow is consistently being simulated during the summer months which can possibly be attributed to an overestimation of the flows imported from the Breede River during this period which are used directly for irrigation and urban user and do not contribute directly to the flow in the Klein Berg River.

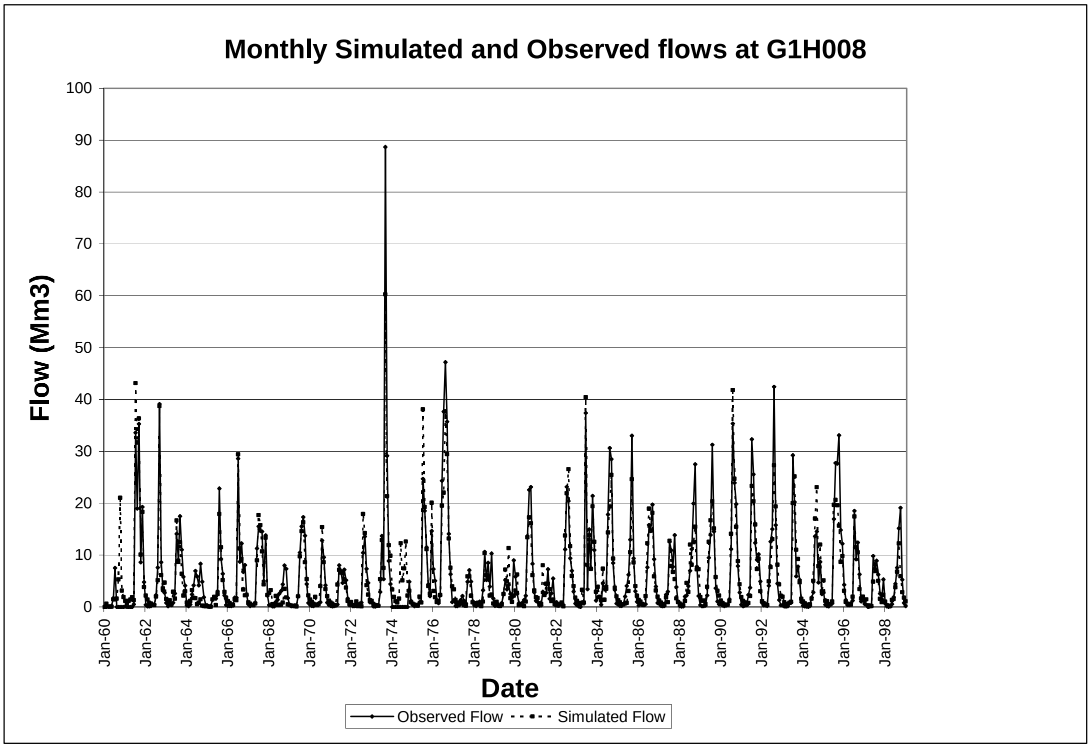

Figure 3.17 **Monthly simulated and observed flows at G1H008**

The pertinent objective function value parameters for the monthly simulated and observed flows at G1H008 are depicted in **Table 3.8**, which shows that the simulated flow underestimated the observed flow by 6%. Although acceptable values for r^2 and the coefficient of efficiencies of 0.87 and 0.82 were obtained, the catchment would probably require further refinement to obtain a more representative areal distribution of rainfall and to reduce the magnitude of under-simulation.

Table 3.8 **Objective function values for the simulated and observed flows at G1H008**

Statistics for G1H008 (1960 – 1999)	**Monthly totals of daily simulation**
Mean observed streamflow (Mm^3/month)	6.0
Mean simulated streamflow (Mm^3/month)	5.6
% difference in standard deviation	12.19
Coefficient of determination (r^2)	0.87
Coefficient of efficiency	0.82

A comparison of daily simulated and observed flows is depicted in **Figure 3.18**. As with the monthly flows there is an overestimation of daily flows during the summer months. The daily comparison also reveals that, compared to the observed record, the recession in simulated baseflows is not fast enough and thus contributing to the flows introduced by the “White Bridge Import”.

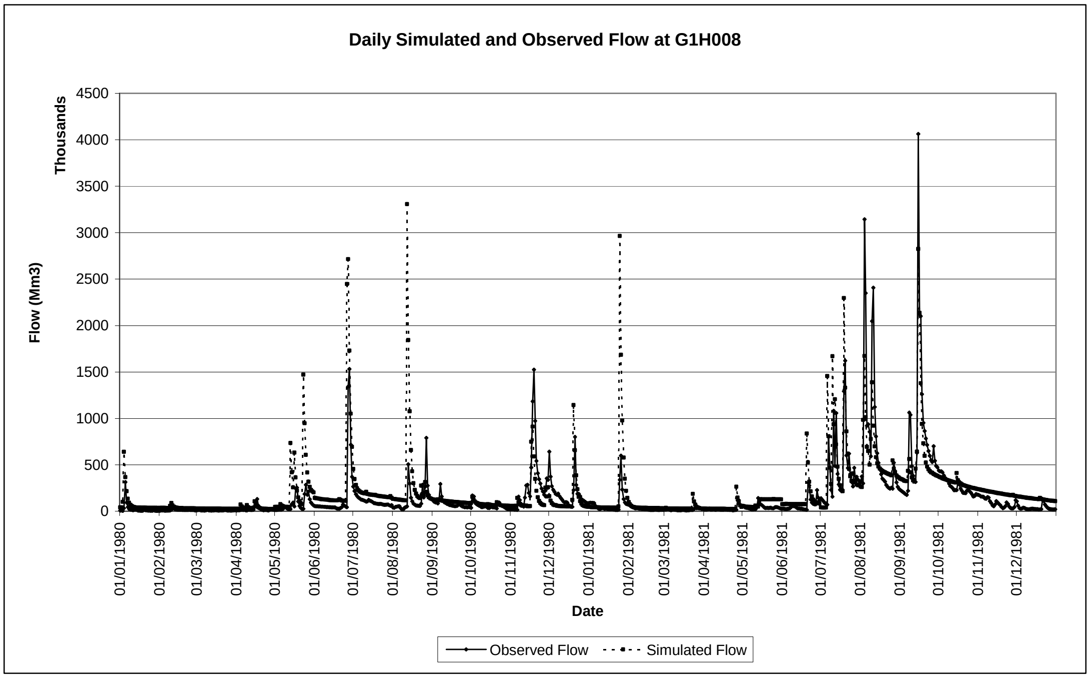

Figure 3.18 Daily simulated and observed flows at gauging station G1H008

The daily flow duration curves for the simulated and observed flows at gauging station G1H008 are depicted in **Figure 3.19**.

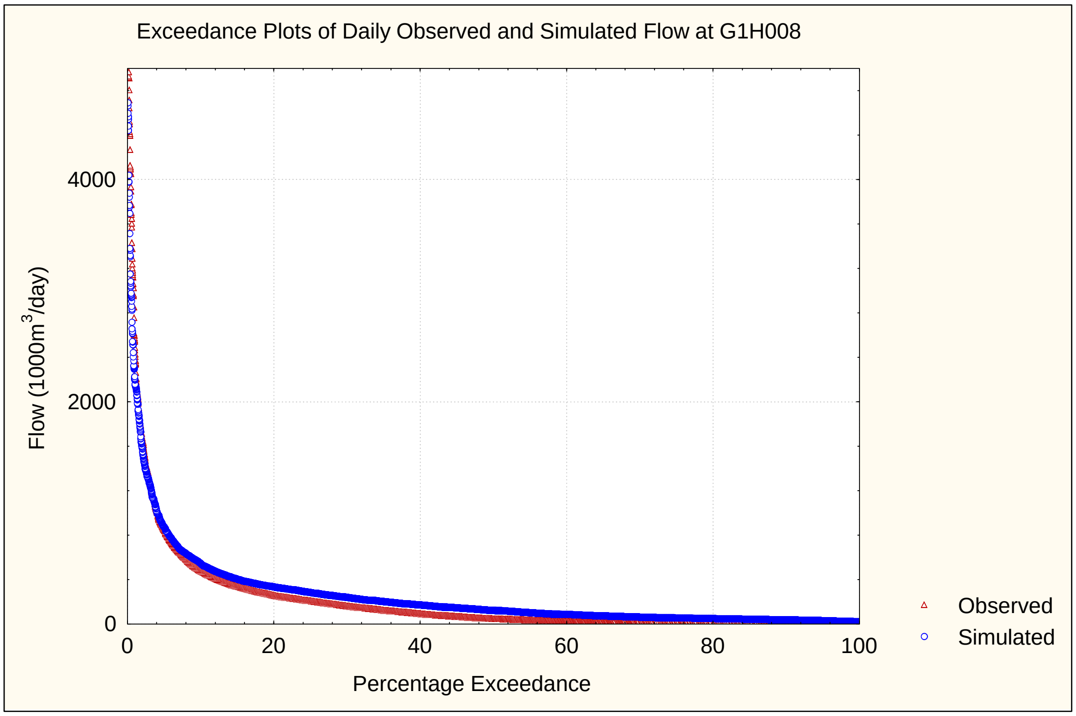

Figure 3.19 Daily flow duration curves for simulated and observed flows at G1H008

As expected, the higher simulated flow rates have an exceedance percentage compared to the observed flows but the lower simulated flow rates have higher exceedances compared to those of the observed.

3.1.5 Flow verification at G1H043 (Sandspruit River at Vrisgewaagd)

Although the unit run-off generated from the Sandspruit River catchment is relatively small compared to that generated in the upper portions of the Berg River catchment, it is the most upstream gauging station which measures flow from a catchment underlined by Malmesbury Shale and it was consequently necessary to obtain the most representative simulated flows to ensure that the salt loads entering the Berg River mainstem could be realistically represented. Verification for this sub-catchment did not account for the variation in irrigated area with time and was instead undertaken for a constant 1998 level of development. The irrigated area in the catchment had increased from 0.07 km^2 in 1990 to 1.75 km^2 in 1998.

The comparison of monthly simulated and observed flows is depicted in **Figure 3.20** which shows that the simulated monthly flows are often not representative of the observed flows. Particularly, the wet months during 1990 – 1995 were markedly under-simulated. This is mainly the result of the absence of a driver rainfall station within the catchment boundaries. The driver stations actually used, 41684W and 41347A, are some distance away from the approximate centroid of the catchment. A particular short-coming of the monthly flows is the very slow recession of the simulated response. This indicates non-optimal soil-water-related and groundwater-related settings in ACRU for this case.

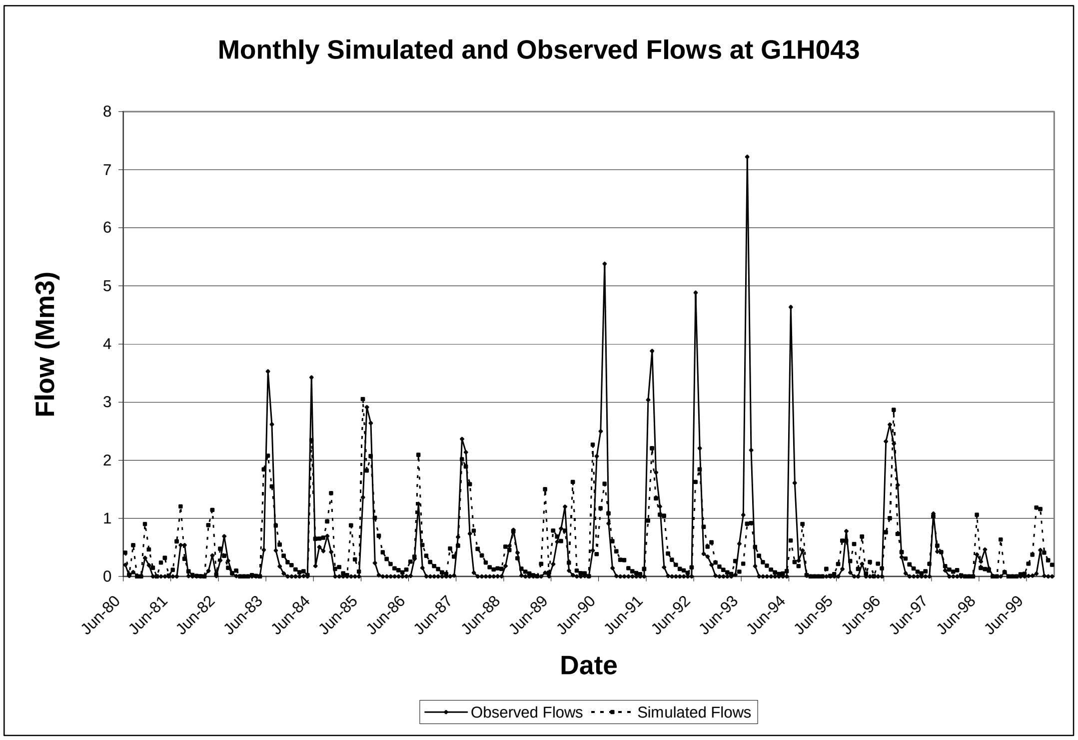

Figure 3.20 Monthly simulated and observed flows at gauging station G1H043

The values of the objective functions for the observed and simulated flows are shown in **Table 3.9**, which shows that the simulated flow over-estimated the observed flow by 5%. Unacceptable values for r^2 and coefficient of efficiency of 0.40 and -0.862 were obtained, respectively. As expected, statistical parameters echo the poor fit between the observed and simulated flows as depicted in **Figure 3.20**.

Table 3.9 Objective function values for simulated and observed flows at G1H043

Statistics for G1H043 (1980 – 1999)	Monthly totals of daily simulation
Mean observed streamflow (Mm^3/month)	0.42
Mean simulated streamflow (Mm^3/month)	0.44
% difference in standard deviation	43.0
Coefficient of determination (r^2)	0.40
Coefficient of efficiency	-0.862

A comparison of the daily simulated and observed flows is shown below in **Figure 3.21**. It can be seen that the model is responding to the various storm events, but that the magnitude of the response is not entirely representative of the observed flows. As mentioned previously, the major reason for the poor simulated outputs is probably the choice of driver rainfall station, which is not within the confines of the catchment boundary.

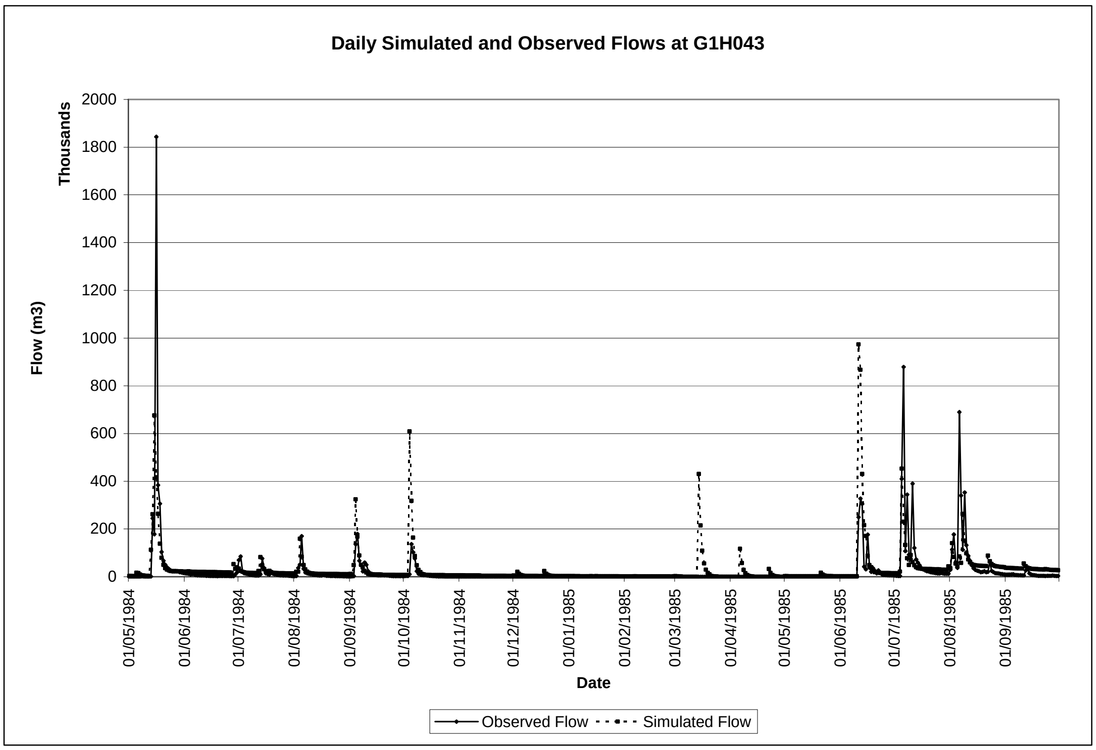

Figure 3.21 Daily simulated and observed flows at G1H043

The flow duration curves for the simulated and observed flows at gauging station G1H043 are depicted in **Figure 3.22** which reflects the differences seen in the daily time series comparison.

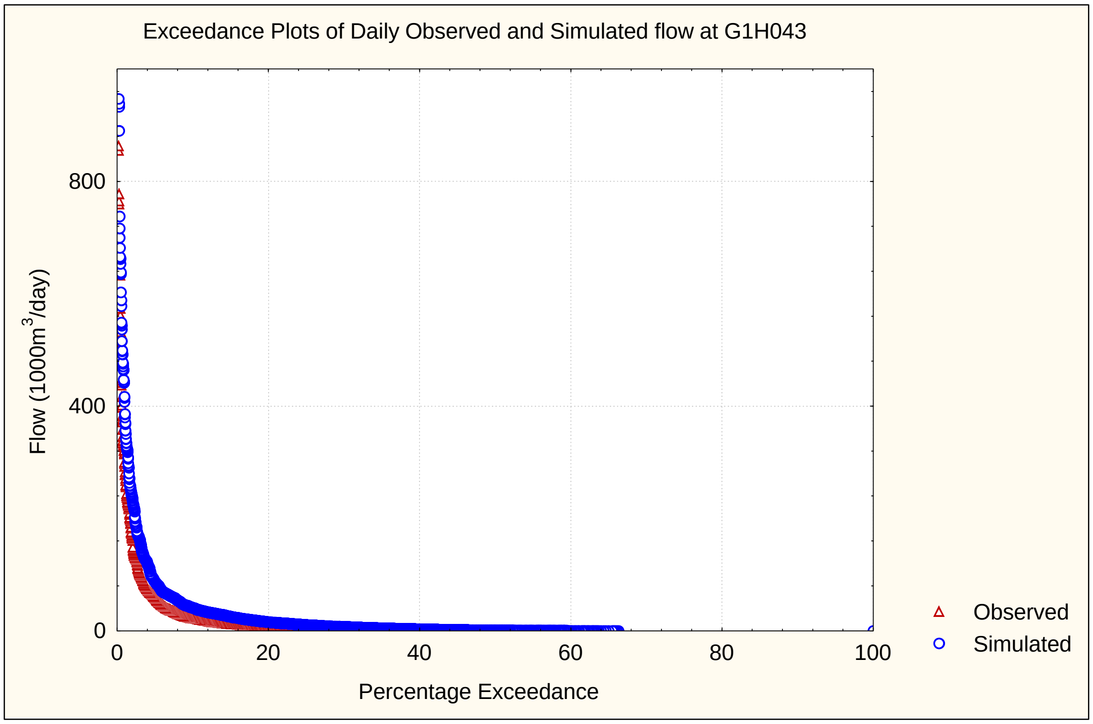

Figure 3.22 Flow duration curves for daily simulated and observed flows at G1H043

3.1.6 Verification at G1H013 (Berg River at Drieheuwels)

Gauging station G1H013 is the last gauging station before Misverstand Weir. The comparison between monthly simulated and observed flows at this gauge is depicted in **Figure 3.23**.

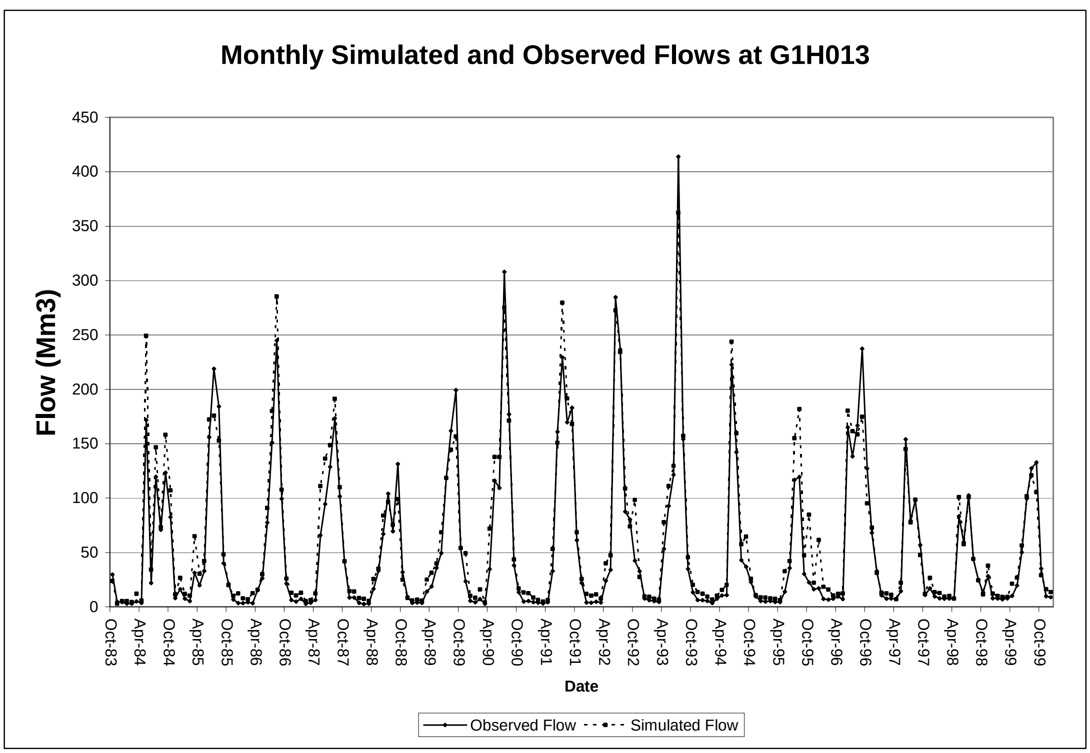

Figure 3.23 Monthly simulated and observed flows at gauging station G1H013

Figure 3.23 shows that the simulated monthly flows are representative of the observed flows. This was, however, expected since the observed record at G1H036 was used as input to the ACRU configuration between gauging stations G1H036 and G1H013.

The objective function values for the observed and simulated flows are shown in **Table 3.10**, which shows that the simulated flow over-estimated the observed flow by 10.7%. Acceptable values for r^2 and coefficient of efficiency of 0.95 and 0.94 were obtained, respectively.

Table 3.10 Objective function values for simulated and observed flows at G1H013

Statistics for G1H013 (1983 – 1999)	Monthly totals of daily simulation
Mean observed streamflow (Mm^3/month)	55.0
Mean simulated streamflow (Mm^3/month)	60.9
% difference in standard deviation	1.17
Coefficient of determination (r^2)	0.95
Coefficient of efficiency	0.94

3.1.7 Flow verification at G1H035 (Matjies River at Matjiesfontein)

As with the Sandspruit River (G1H043), this catchment produces very little run-off but is the most important tributary affecting the Total Dissolved Salts (TDS) concentration at Misverstand Dam (G1R003). This catchment was not verified taking into account the changing irrigated area but was instead verified at a constant 1998 level of development. The irrigated area in this catchment had changed from 5.01 km^2 in 1990 to 4.51km^2 in 1998.

The comparison of monthly simulated and observed flows is depicted in **Figure 3.24**, which shows that the simulated flows are responding to the rainfall but that a more appropriate driver rainfall station is probably required to produce representative simulated flows. Additionally, finer delineation of the catchment may still be possible. It is particularly important to capture the higher flows that occur in winter because these flows are associated with high TDS values and consequently high salt loads.

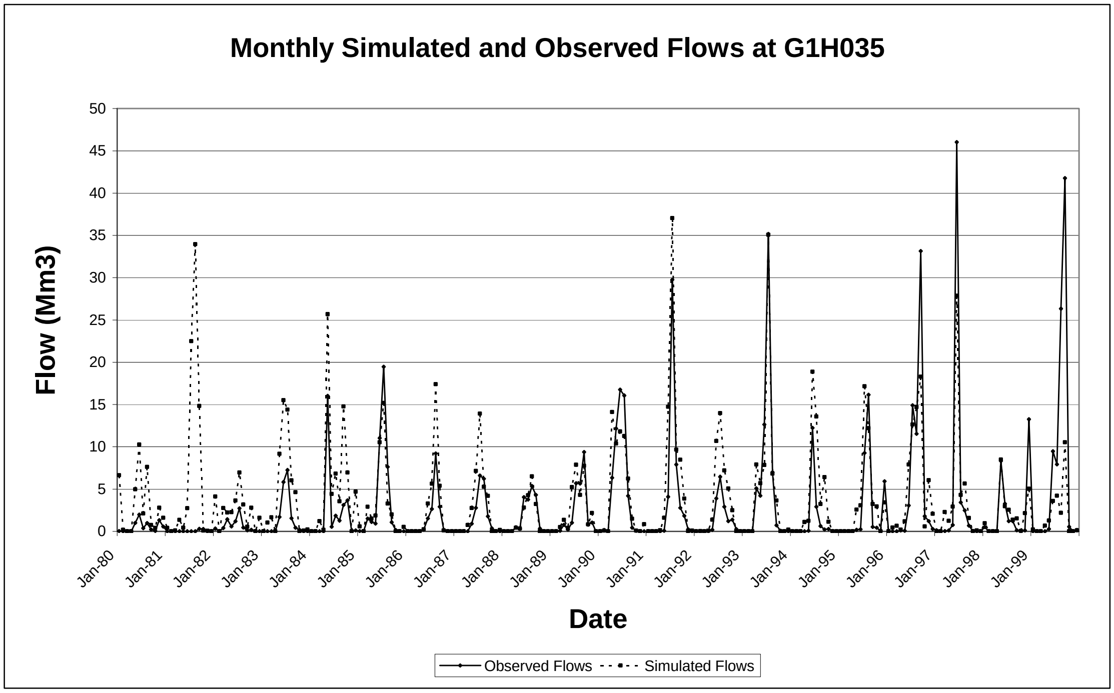

Figure 3.24 Monthly simulated and observed flows at G1H035

The comparison of daily simulated and observed flows is depicted in **Figure 3.25**, which also shows that the simulated flows are responding to the rainfall input but that the magnitude is not always representative. This could probably, to a greater extent, be ascribed to the selection of driver rainfall stations for each of the primary sub-catchments comprising the calibration catchment and to a lesser extent to the delineation of the catchment.

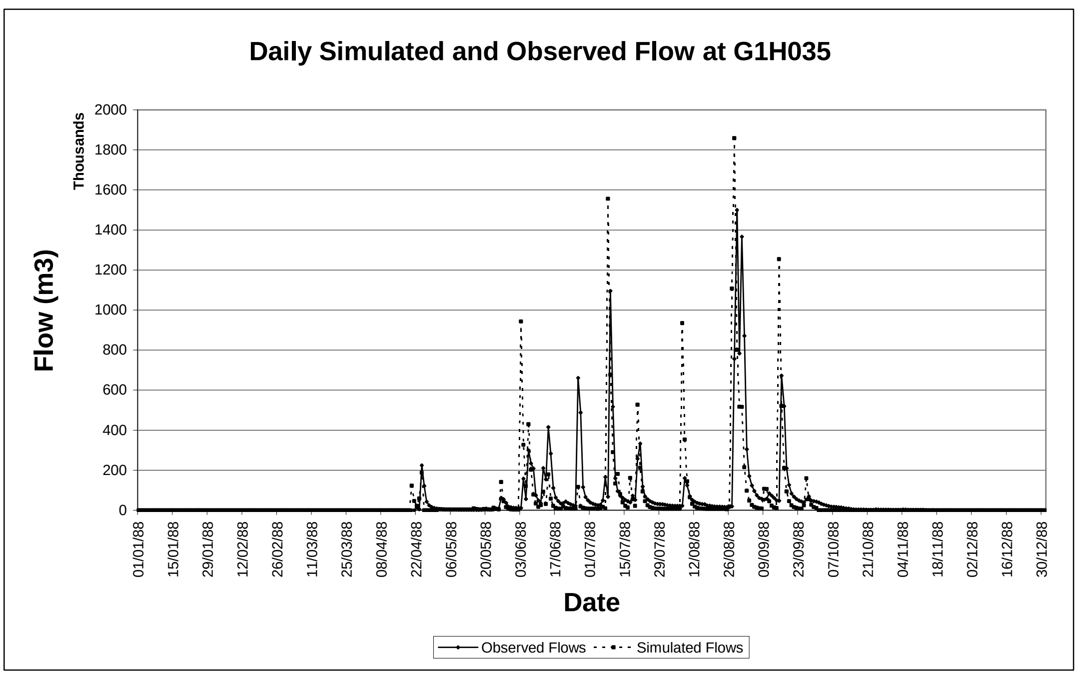

Figure 3.25 Daily simulated and observed flows at G1H035

The pertinent objective function values for the observed and simulated flows are shown in **Table 3.11**, which shows that the simulated flow over-estimated the observed flow by 27%. Unacceptable values for r^2 and the coefficient of determination of 0.60 and 0.45 were obtained, respectively. As expected, statistical parameters echo the goodness of fit seen between the observed and simulated flows as depicted in **Figure 3.25**.

Table 3.11 Objective function values for simulated and observed flows at G1H035

Statistics for G1H043 (1980 – 1999)	Monthly totals of daily simulation
Mean observed streamflow (Mm^3/month)	2.8
Mean simulated streamflow (Mm^3/month)	3.5
% difference in standard deviation	12.84
Coefficient of determination (r^2)	0.60
Coefficient of efficiency	0.45

The flow duration curves for the simulated and observed flows at gauging station G1H035 are depicted in **Figure 3.26** which shows that the exceedance percentages of the simulated flows compare favourably with those of the observed flows despite the relatively poor fits depicted by the monthly and daily comparisons.

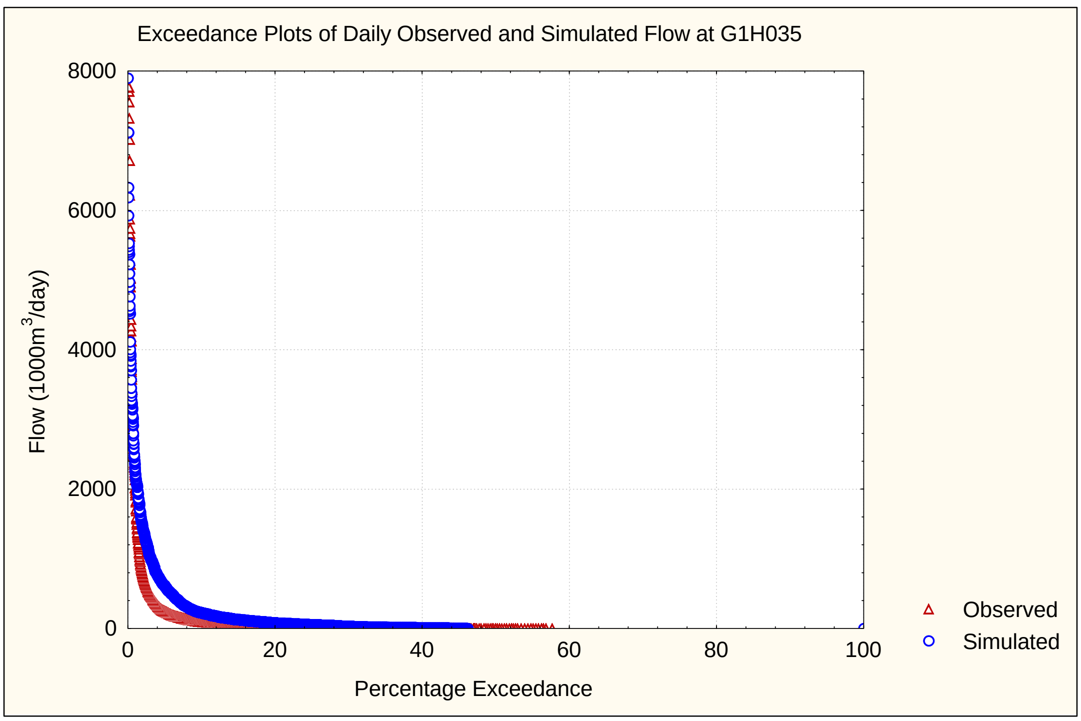

Figure 3.26 Flow duration curves for daily simulated and observed flows at G1H035

CHAPTER 4: SIMULATED NATURALISED FLOW RECORDS

Simulated naturalised flow sequences for the period 1921 to 1999 were produced at various gauges for comparison with the Pitman-based flow sequences. For these runs the irrigated land-use was replaced with the Acocks (Acocks, 1975) veld types, all transfers of water were removed and all dams were removed, resulting in an un-impacted catchment. A comparison of the simulated naturalised Mean Annual Runoffs (MARs) obtained from the ACRU configurations, the Western Cape System Analysis (DWAF, 1993) and the Surface Water Resources of South Africa 1990 (WRC,1994) is shown in **Table 4.1**.

Table 4.1 Simulated naturalised MARs

Gauge	ACRU MAR (Mm^3) (1921-1999)	WR 90 MAR (Mm^3) (1920 – 1989)	WCSA MAR (Mm^3) (1926 -1988)	WR2005 (Mm^3) (1920 -2004)
G1H020	403	412	384	329
G1H036	493	528	521	453
G1H013	789	Approx 782	871	Approx 615
G1R003	832	825	904	728
Head of Estuary	914	895	Not calculated	738

CHAPTER 5: SALINITY CALIBRATION OF THE ACRU MODEL

5.1 BACKGROUND

The possible deterioration in water quality at Misverstand Dam (G1R003) due to the construction (see **Figure 1.1**) of the Berg River Dam was addressed in the Western Cape System Analysis (WCSA) (DWAF, 1993). The major shortcoming of the approach used in the WCSA was that the model had been calibrated only on the monthly salt loads from the various contributing catchments and as a result lacked the required daily variations of TDS concentrations necessary to address water quality in the Berg River. It was previously shown (Fourie and Görgens, 1977 and DWAF, 2005) that two peaks in TDS concentrations occur in the Lower Berg River. The summer peak is associated with the irrigation return flows and the winter peak is associated with the natural mobilisation of salts from the catchment.

It is usually expected in semi arid winter-rainfall catchments that the highest concentration of salts will occur in summer when the flow is made up almost entirely of irrigation return flows. At Misverstand Dam, however, this is not true and high concentrations of TDS are also experienced during the winter months. This phenomenon is depicted in **Figure 5.1**.

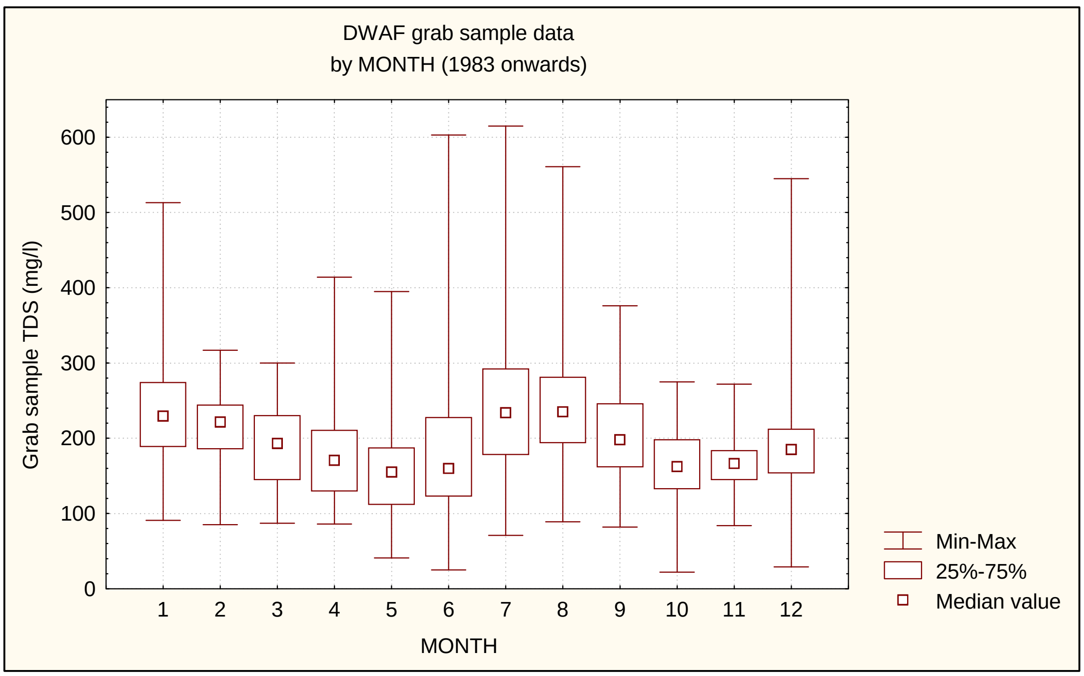

Figure 5.1 Seasonal distribution of TDS concentrations at Misverstand Dam (month 1 = January)

The grab sample data show an increase in TDS over the winter months which is contrary to expectation because one would assume that enough fresh water is generated in winter to cause a substantial dilution of salts washed out from the more saline catchments. The pulse of TDS in mid to late winter is likely mobilised by the infiltration of excess rainfall into the shale dominated profiles of the middle to Lower Berg catchment and augmented by tillage practices in the dry-land grain farming area during the preceding summer.

Bath (DWAF, 1993a) showed that between gauging station G1H036 and Misverstand Dam (G1R003), the biggest contributions to salt load are made by the Matjies River (G1H035) and the Sandspruit River (G1H043). This is highlighted in a summary of the total load contributions from the various tributaries for the 1988 hydrological year as depicted in **Figure 5.2**.

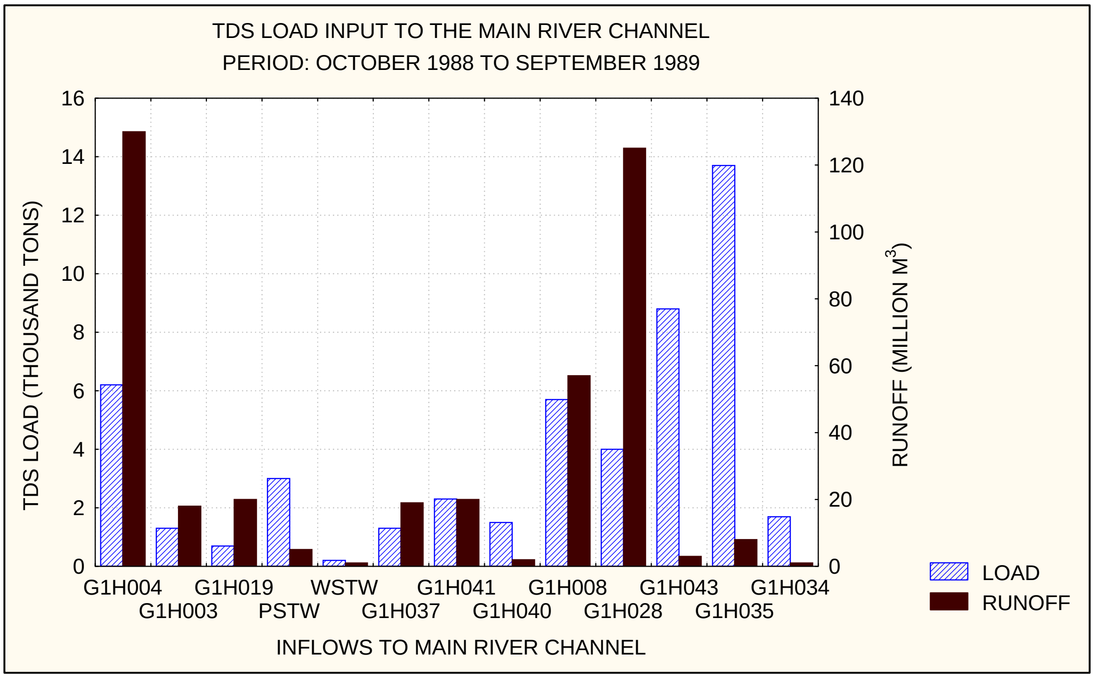

Figure 5.2 **TDS load and runoff for tributaries of the Berg (after DWAF, 1993)**

From **Figure 5.2** it can be seen that the flows contributed by the Matjies (G1H035) and Sandspruit (G1H043) rivers are small in comparison to their loads, indicating that high concentrations could be expected in these rivers. The seasonal distribution of the TDS grab samples collected for the Matjies River is depicted in **Figure 5.3**, which shows a marked increase in TDS concentration over the winter months. These high concentrations are also accompanied by higher flows that lead to high TDS loads. Although fairly high concentrations also occur during the dry summer months, the resultant contribution to the main stem, in term of the TDS load, is insignificant (the Matjies River is non-perennial).

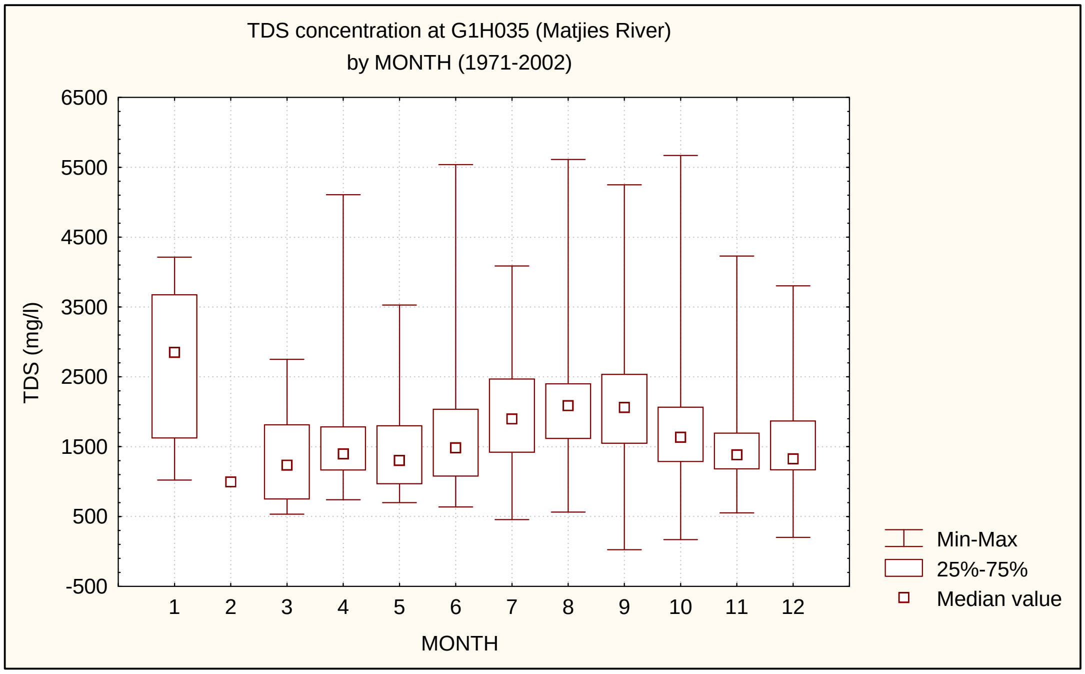

Figure 5.3 Seasonal distribution of TDS concentrations for the Matjies River

Based on the argument above, it is reasonable to assume that the TDS load contributed by the Matjies River (and probably the Sandspruit) would have a marked effect on TDS distribution at Misverstand Dam – especially during winter when these loads are mobilised.

The ensuing sections describe the salinity calibrations undertaken for the Berg River at the various gauges. Based on the preceding discussion the focus was placed on the highly saline catchments and the ability of the model to capture the high TDS concentrations during the winter months. It should be noted that salinity calibrations were only undertaken at gauges where a sufficient number of grab samples were taken. The gauges used for verification of the salt module and the periods of verification are given in **Table 5.1**.

Table 5.1 Gauges used for the verification of the salt module

Gauge	Period of Verification
G1H037	1982 – 1992
G1H041	1980 – 1999
G1H036	1980 – 1999
G1H043	1980 – 1997
G1H013	1983 – 1999
G1H035	1980 – 1999
G1R003	1980 – 1999
Head of Estuary	Simulated only (1980 -1999)

5.2 SALINITY CALIBRATION AT G1H037 (KROM RIVER AT WELLINGTON)

Analysis of the TDS grab sample record for the period 1979 to 1992 shows that the average, maximum and minimum recorded TDS concentrations at this gauge were 95 mg/l, 692 mg/l and 36 mg/l, respectively. The seasonal variation of the TDS values is depicted in **Figure 5.4** which is typical of what is expected from a semi-arid region with slightly higher TDS concentrations during the summer months. This results from the irrigation return flows and the evapo-concentrating effect and comparatively lower TDS values during winter, and as a result of good quality run-off.

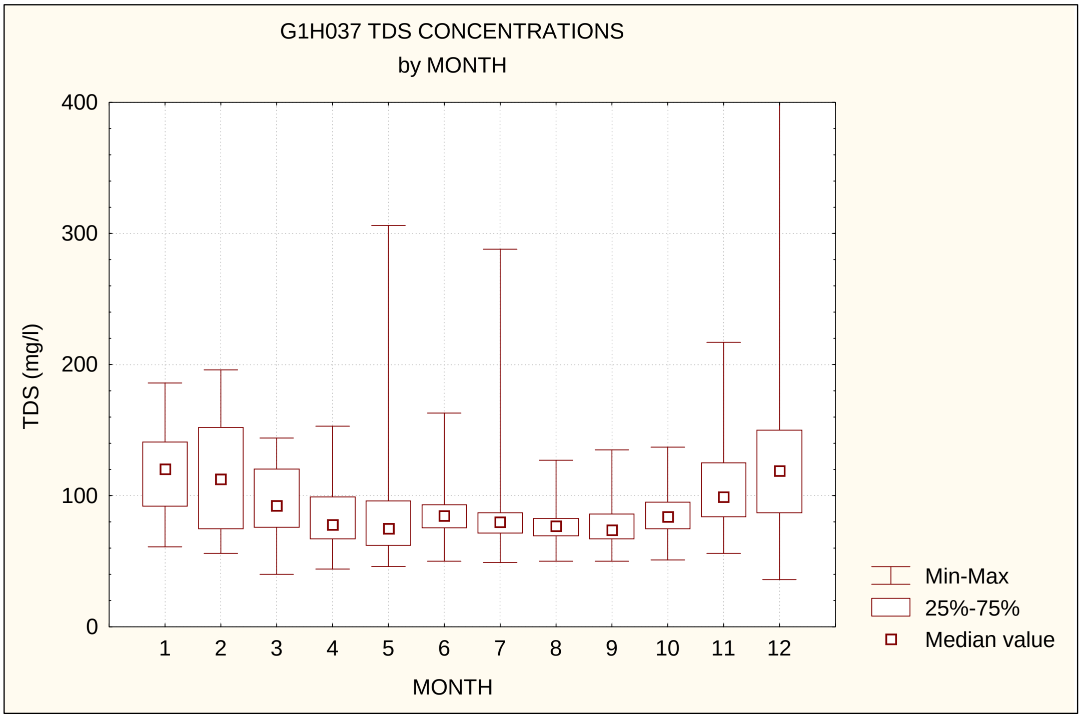

Figure 5.4 Seasonal distribution of TDS concentrations at gauging station G1H037

As discussed previously (see **Section 3.1**), the water from the Wit River (in the Breede River catchment) was assumed to be imported to the catchment at a constant monthly flow rate of 0.22 Mm^3/month.

The comparison of daily simulated and observed TDS exceedance percentages at gauging station G1H037 is depicted in **Figure 5.5** which shows that TDS concentrations rarely exceed 150 mg/l and that fairly good quality water (with regard to TDS) is discharged from this catchment. The simulated record closely replicates the observed record except for exceedances of less than 3% and greater than 85%, however the departures are relatively small (less than 50 mg/l) compared with the effects of the downstream saline tributary inflows on the salinity at Misverstand Dam.

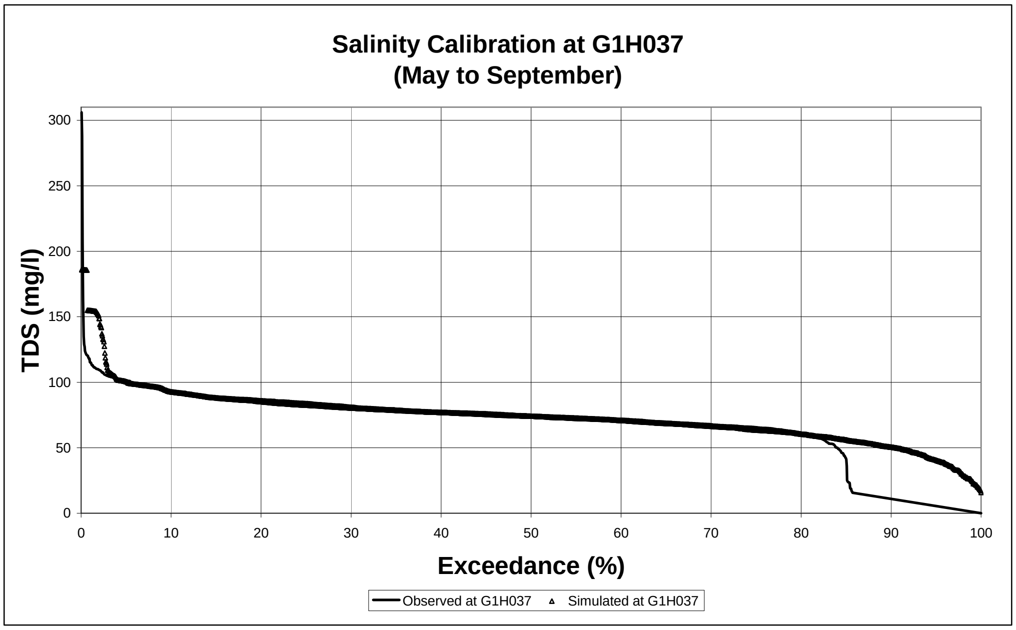

Figure 5.5 Exceedance of observed and simulated TDS at gauging station G1H037

5.3 SALINITY VERIFICATION AT G1H041

Analysis of the TDS grab sample data for the period 1979 to 2002 showed that the minimum, average and maximum TDS concentration were 39 mg/l, 164 mg/l and 5 499 mg/l, respectively. The seasonal distribution of the TDS concentrations at the gauge is depicted in **Figure 5.6**. As is typical of this part of the Berg River catchment, the higher TDS concentrations occur during the summer months with the lower TDS concentrations occurring in the winter months.

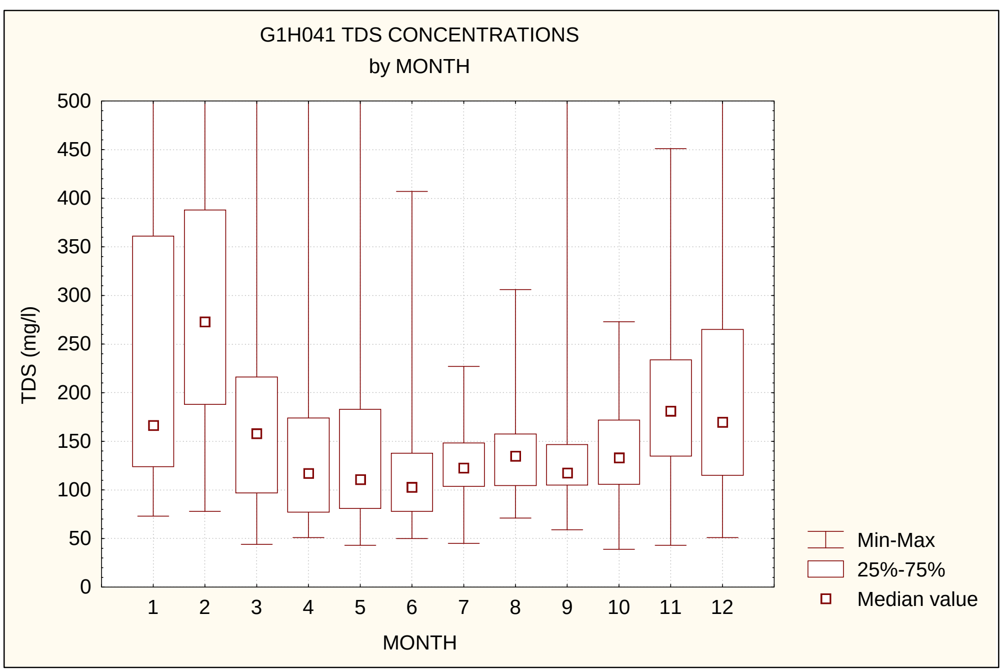

Figure 5.6 Seasonal distribution of TDS concentrations at gauging station G1H041

The comparison of the daily simulated and observed TDS exceedance percentage at gauge G1H041 is depicted in **Figure 5.7** which shows that the exceedance percentage of the simulated TDS is representative of the observed record with a slight under-estimation of the exceedance percentage for simulated TDS values above 200 mg/l.

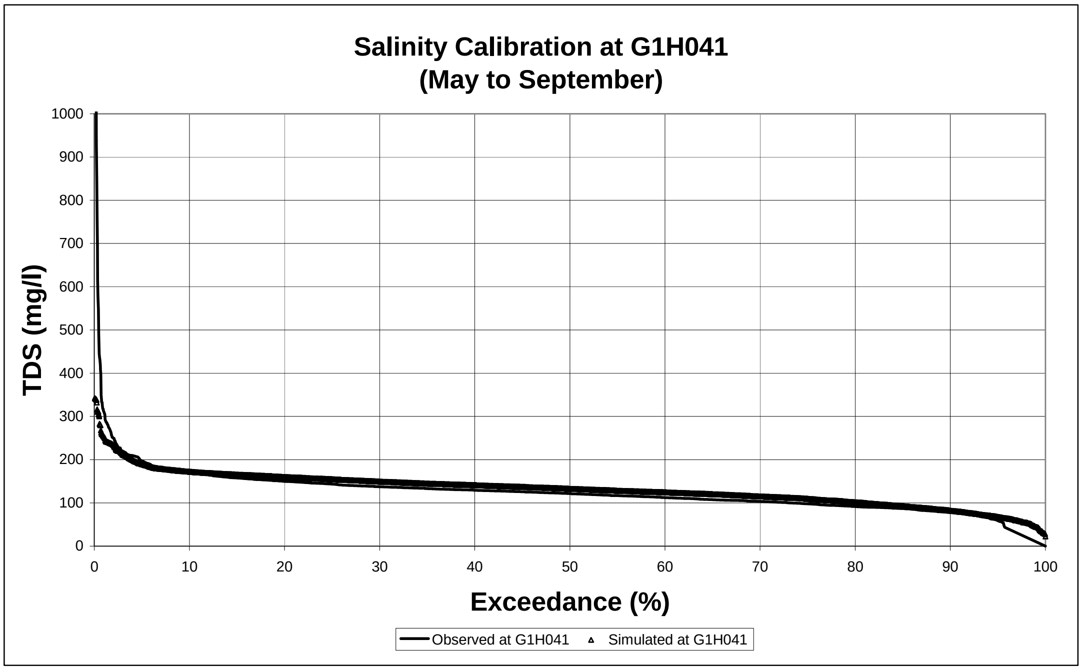

Figure 5.7 Exceedance of observed and simulated TDS at gauging station G1H041

5.4 SALINITY VERIFICATION AT G1H036 (BERG RIVER AT VLEESBANK)

Salinity calibration at gauge G1H036 was essentially completed to ensure that the values of the salinity-parameters transferred from the rest of the catchment resulted in representative TDS concentrations at gauge G1H036. During the calibration process the observed flow and TDS measured at gauging station G1H020 were used as specified inflows, while the calibrated model for the catchments gauged by G1H037 and G1H041 was used to generate input from these catchments.

Analysis of the TDS grab sample data over the period 1978 to 2002 revealed that the minimum, average and maximum TDS concentrations were 35 mg/l, 123 mg/l and 418 mg/l, respectively. The seasonal distribution of the TDS concentration at gauge G1H036 (see **Figure 5.8**) shows that no marked increase in TDS is experienced over the winter months with 75% of the observed TDS values in winter being less than 150 mg/l.

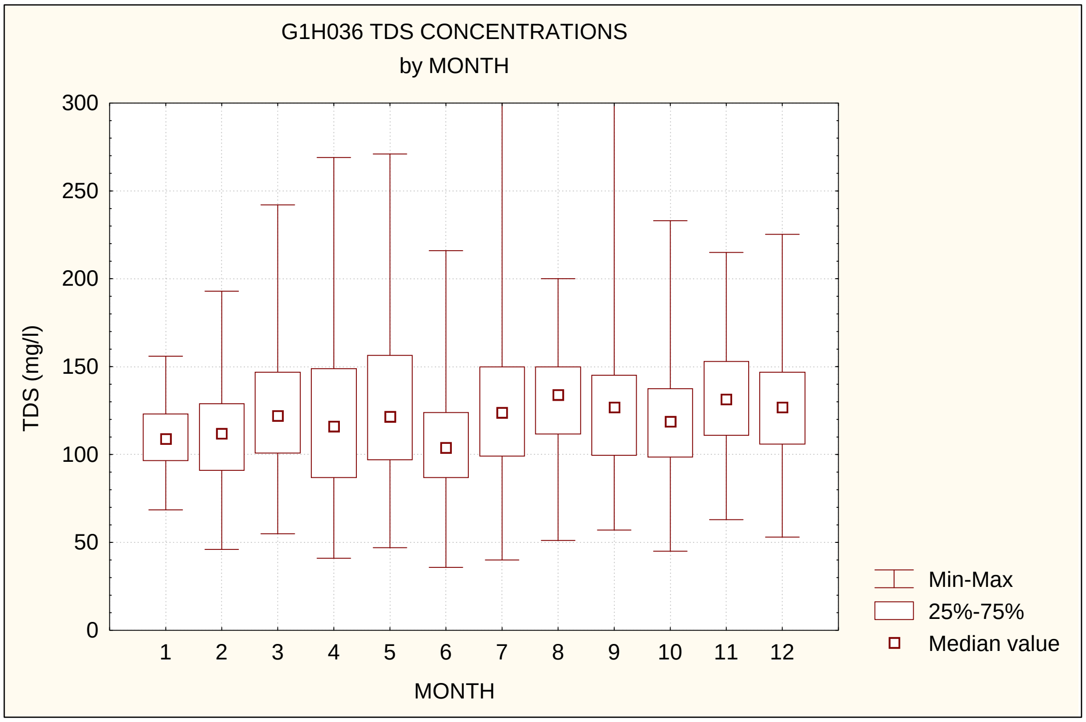

Figure 5.8 Seasonal distribution of TDS at gauging station G1H036

The comparison of the daily simulated and observed TDS exceedance percentage at gauge G1H036 is depicted in **Figure 5.9** which shows that the exceedance percentage of the simulated TDS is representative of the observed record over the entire range of TDS values.

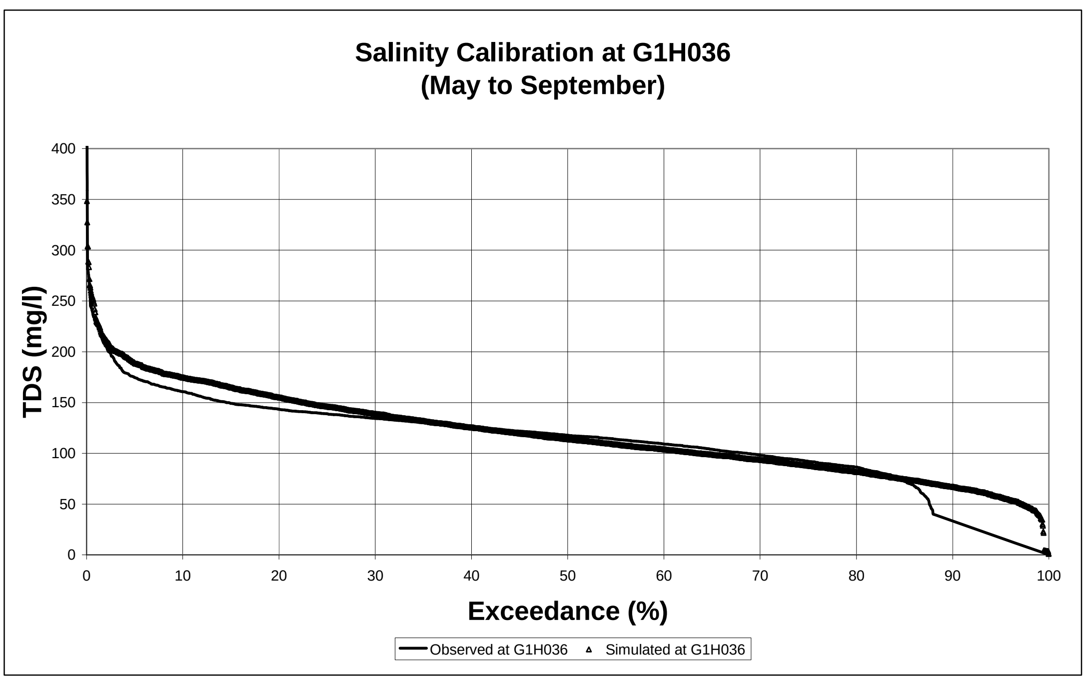

Figure 5.9 Exceedance of observed and simulated TDS at gauging station G1H036

5.5 SALINITY VERIFICATION AT G1H043 (SAND SPRUIT AT VRISGEWAAGD)

As mentioned previously in the report, this catchment naturally produces high TDS concentrations during the winter months when previously dissolved salts are mobilised. Analysis of the grab TDS sample record spanning the years 1980 to 1997 showed that the minimum, maximum and mean TDS concentrations of the run-off produced in this catchment were 1 005 mg/l, 10 989 mg/l and 5 039 mg/l, respectively. The seasonal distribution of TDS concentrations are depicted in **Figure 5.10**. It should be noted that, contrary to expectation, the TDS concentration increases over the winter months implying that high TDS loads can be expected from this catchment.

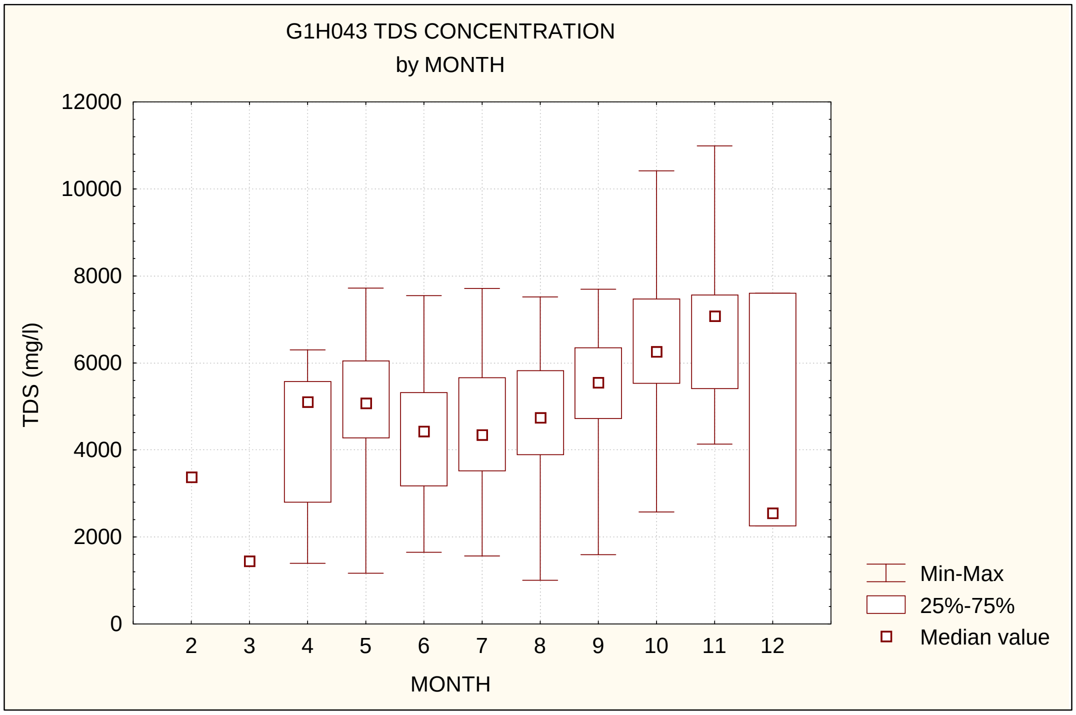

Figure 5.10 Seasonal variation of TDS concentration at gauging station G1H043

It is reasonable to assume that the winter run-off would consist of a substantial percentage of "quickflow" (immediate surface runoff) and it can be deduced empirically that it would be accompanied by high TDS concentrations. Initial versions of the ACRU*Salinity* model were unable to reproduce the observed effect of high TDS concentrations associated with the "quickflow" because it allowed for no interaction between this component of the flow and the soil profile. In subsequent versions, however, a thin surface layer had been introduced allowing for higher TDS values to be associated with the "quickflow" component of the flow.

The salinity calibration of the daily TDS concentrations is depicted on an exceedance basis in **Figure 5.11** which shows that for TDS concentrations above 5 000 mg/l, the simulated exceedance percentage is representative of the exceedance percentage displayed by the observed record. Below 5 000 mg/l, however, the exceedance percentage of the simulated record at any given TDS value is under-estimated by approximately 18%. Adjustment of the value for salt saturation (SALTSAT) during the months which most frequently produce TDS values below 5 000 mg/l may be a point of departure for increasing the exceedance percentage of these TDS values.

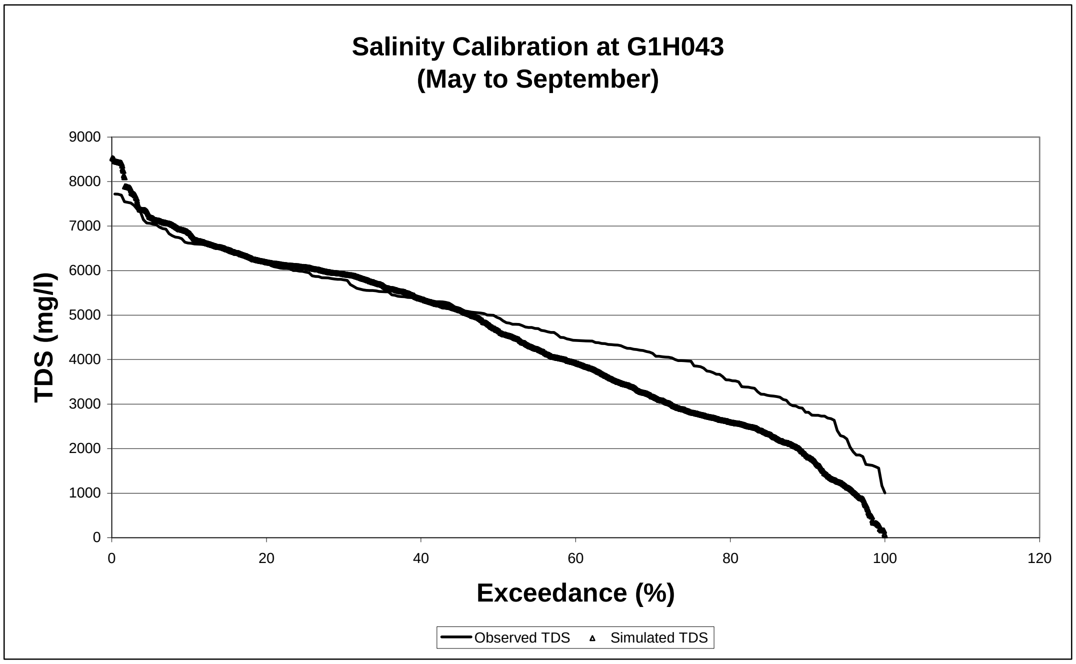

Figure 5.11 Exceedance of simulated and observed TDS concentrations at gauging station G1H043

5.6 SALINITY VERIFICATION AT G1H013 (BERG RIVER AT DRIEHEUWELS)

Previous studies (Fourie and Görgens, 1977 and DWAF, 2005) have shown that two peaks in TDS concentration occur in the Lower Berg River with the winter peak probably being caused by the mobilisation of salts from the downstream sub-catchments. In the analysis of the TDS grab samples for the period 1965 to 2002 it was shown that the minimum, average and maximum TDS concentrations at this gauge were 18 mg/l, 142 mg/l and 1 170 mg/l, respectively. The seasonal distribution of the TDS concentrations is shown in **Figure 5.12**.

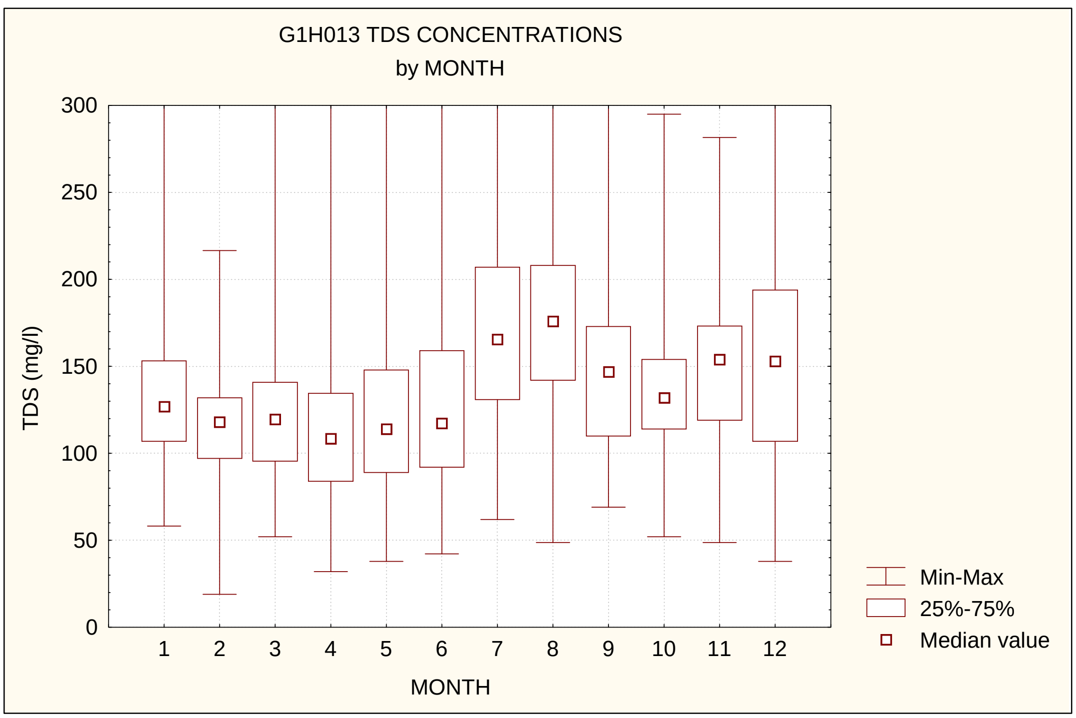

Figure 5.12 Seasonal distribution of TDS concentration at gauging station G1H013

This shows that a significant increase in daily TDS concentrations is experienced over the winter months, consistent with the increase in TDS observed at gauging station G1H043. Based on this empirical relationship between the seasonal distribution of TDS at G1H043 and G1H013, it can be accepted that the concentration of the run-off generated in the catchment gauged by G1H043 has a marked effect on the TDS in the Berg River mainstem. The salinity calibration for G1H013 is depicted in **Figure 5.13** which shows a representative comparison between the observed and simulated exceedance percentage for TDS over almost the entire range of TDS values.

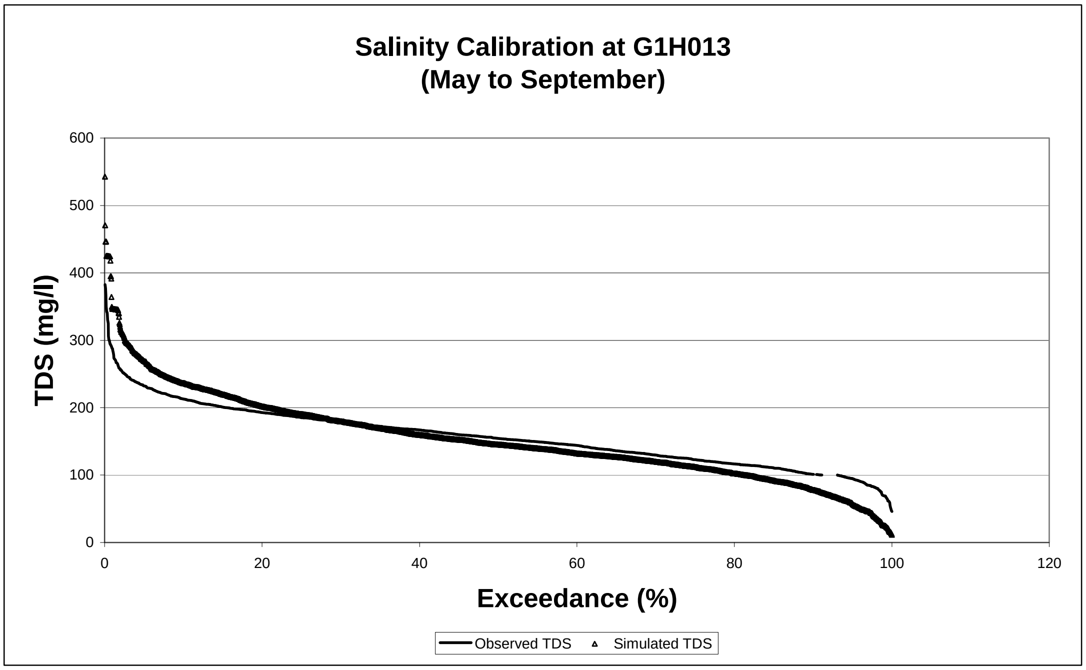

Figure 5.13 Exceedance of observed and simulated TDS at gauging station G1H013

5.7 SALINITY VERIFICATION AT G1H035 (MATJIES RIVER AT MATJIESFONTEIN)

According to Bath (DWAF,1993a), the largest salt load contribution to the Berg River mainstem is from the Matjies River (G1H035). Analysis of the TDS grab sample record for the period 1971 to 2002 showed that the minimum, average and maximum TDS concentrations were 25 mg/l, 1 814 mg/l and 5 669 mg/l, respectively. The seasonal distribution of TDS concentrations at gauge G1H035 is depicted in **Figure 5.14** which shows that more than 75% of the winter grab samples had TDS concentrations over 1 000 mg/l while at least 25% of the observations had concentrations above 2 000 mg/l.

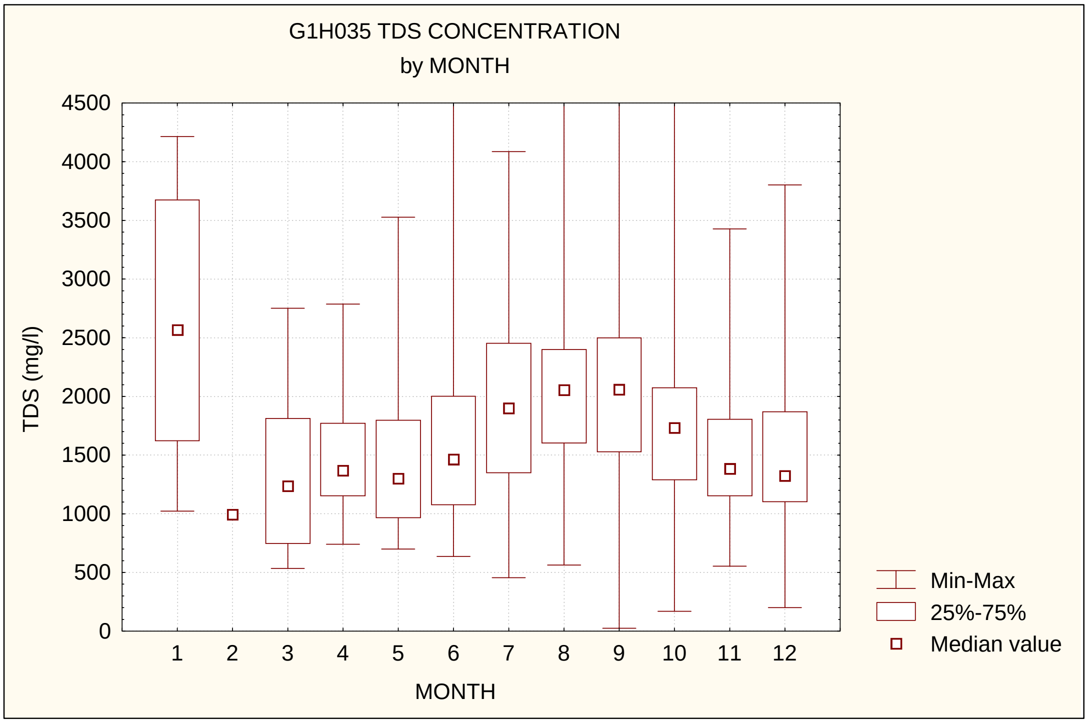

Figure 5.14 Seasonal distribution of TDS concentration at gauging station G1H035

The daily salinity verification at G1H035 is depicted in **Figure 5.15** which shows a representative exceedance comparison between the observed and simulated exceedance percentage for TDS over almost the entire range of concentrations.

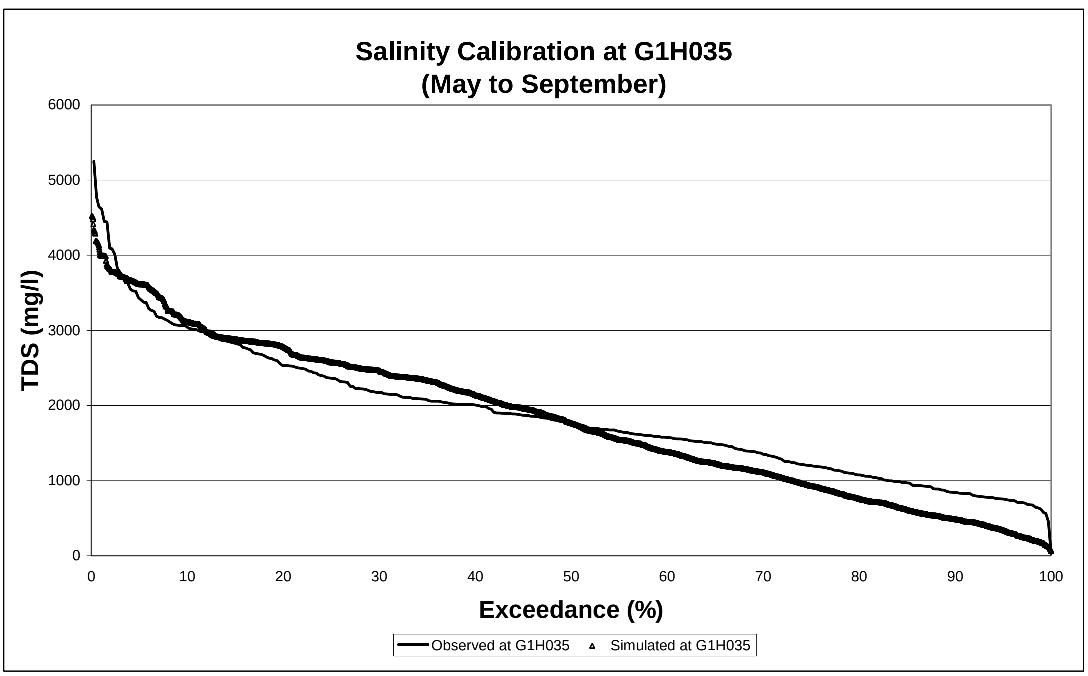

Figure 5.15 Exceedance of observed and simulated TDS at gauging station G1H035

5.8 SALINITY VERIFICATION AT G1R003 (BERG RIVER AT MISVERSTAND DAM)

Analysis of the TDS grab sample record for the period 1977 to 2002 showed that the minimum, average and maximum TDS concentrations were 22 mg/l, 197 mg/l and 615 mg/l, respectively. The seasonal distribution of TDS concentrations at gauge G1R003 is depicted in **Figure 5.16** which shows that more than 75% of the winter grab samples had TDS concentrations less than 300 mg/l and that 500 mg/l was seldom exceeded.

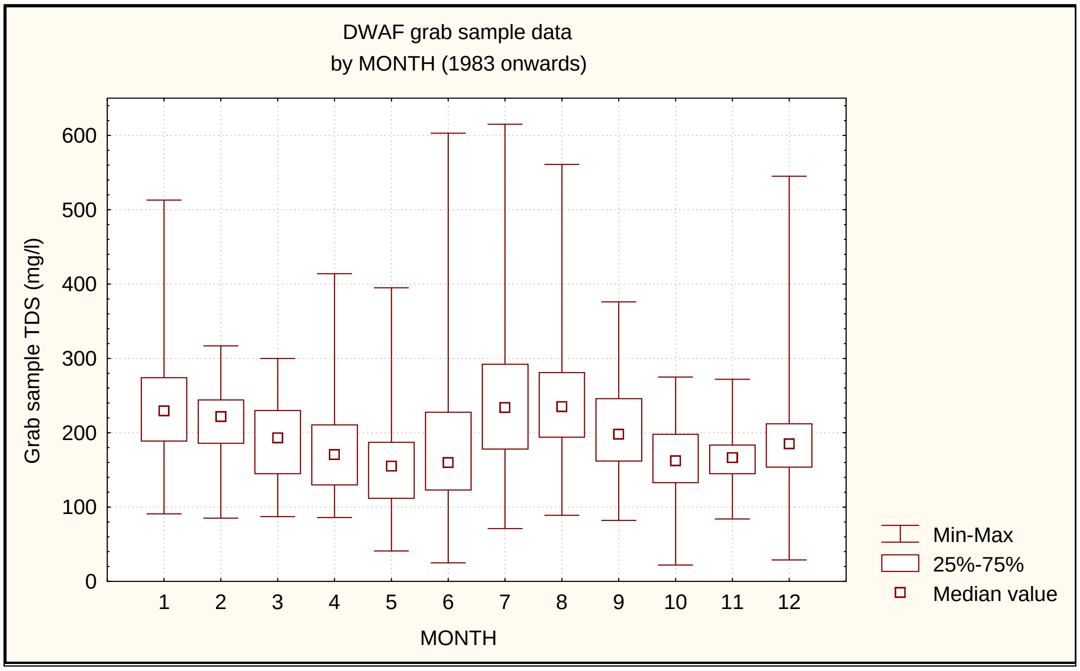

Figure 5.16 Seasonal distribution of TDS concentration at gauging station G1R003

The daily salinity verification at G1R003 is depicted in **Figure 5.17** which shows a representative exceedance comparison between the observed and simulated exceedance percentage for TDS over almost the entire range of concentrations.

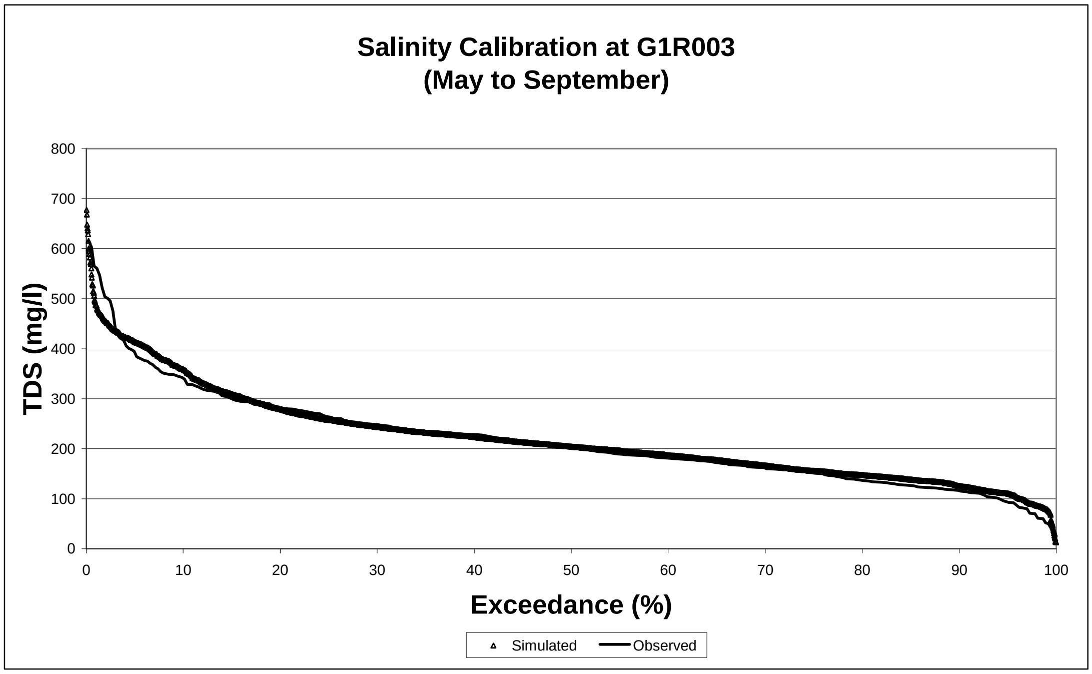

Figure 5.17 Exceedance of observed and simulated TDS at gauging station G1R003

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