A Classification System for Defining Hydrological Zones to provide more Representative Rainfall-Runoff Response in Ungauged Catchments

Methodology Application and Testing

Report to the
Water Research Commission

by

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DISCLAIMER

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

AGIS	-	Agricultural Geo-Referenced Information System
DWAF	-	The Department of Water Affairs and Forestry
GIS	-	Geographical Information System
VTI	-	Variable Time Interval model
WRC	-	Water Research Commission
WRSM2000	-	Water Resources Simulation Model 2000
WR2005	-	Water Resources Study (2005)
WR90	-	Water Resources Study (1990)

1 INTRODUCTION

A better understanding of basic hydrological processes is critical for effective catchment management. Reliable predictions of runoff from ungauged catchments are therefore essential. To permit the extrapolation of results to ungauged catchments from that of gauged catchments, typical parameters for flow and surface runoff, as those used in the Pitman model or Water Resources Simulation Model (WRSM2000), have in this study been related to the physiological and environmental characteristics of the catchment. Owing to the difficulty in quantifying the runoff characteristics of different soils or the average permeability of catchments, this has limited the enhancement in achieving accurate representative runoff from catchments (Casenave, 1992).

This study sets out to derive a "hydrological fingerprint" for selected quaternary catchments in the study area, specifically in the Western Cape (Gouritz), the interior of South Africa (Upper Vaal River) and Eastern Escarpment (upper Thukela River), totalling 21 quaternary catchments as shown in **Figure 1.1**. This exploratory pilot study is aimed at ascertaining whether the concept of hydrological response finger printing is feasible. Hughes (1997) is confident that there is a potential for the regionalisation of the model (WRSM2000) in Southern Africa, but that further research is required to design more robust, less uncertain parameter estimation methods in order to achieve this goal.

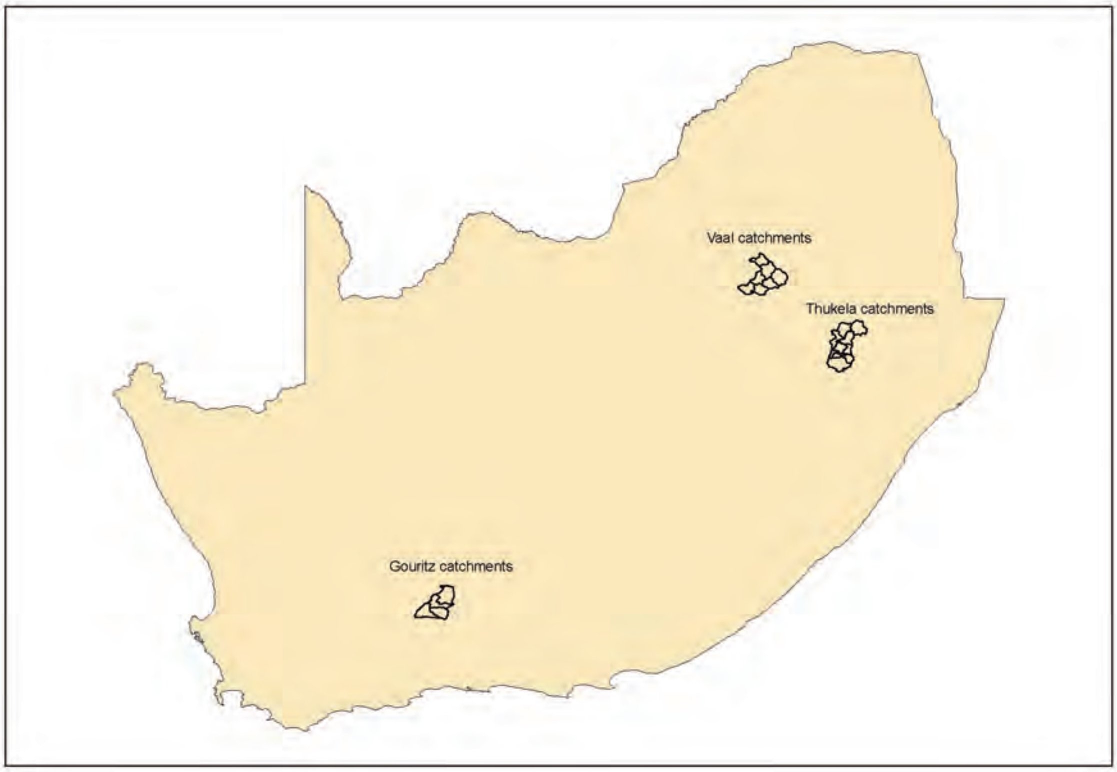

Figure 1.1: Location of the quaternary catchments used in this study

The basis on which these "fingerprints" will be derived is the physical characteristics of each quaternary catchment defined by the combinations of classification systems defining the topography, vegetation and soil properties. It was also proposed, that on derivation of these fingerprints, homogenous hydrological response zones be identified, however during the analyses undertaken in this study, it has become evident that this proposal would not be sufficient, and that an alternate proposal be established, which will be discussed in the relevant chapter.

This report provides a description on the application of the methodology in estimating the hydrological response fingerprints for the selected catchments in the different study areas as mentioned earlier, based on the physical characteristics of the quaternaries. Alternate methods to those utilised in the WRSM2000 with regards to estimating a selected number of parameters in the model, will be explored in order to represent the rainfall-runoff response of the quaternary catchments.

2 METHODOLOGY APPLICATION

The methodology discussed in the report, "Development of the Methodology to define Hydrological Fingerprints and Response Zones," as part of this study was applied to observe the applicability of catchment physical characteristics in deriving parameters for the WRSM2000 for the determination of rainfall-runoff responses for the catchments under consideration. A brief overview of this methodology will be provided but focus will be placed on the results and findings of the application of this methodology.

As stipulated in the methodology on which the study was based, a GIS analysis will be performed to obtain the hydrological "fingerprints" for every quaternary catchment within the study area. These "fingerprints" will be based on the geo-physical (soils, geology and topography), hydro-meteorological (rainfall and evaporation) and biological (vegetation) characteristics of the catchments. Information used in the derivation of these physical "fingerprints" was obtained from the SA Atlas of Agrohydrology and Climatology (Schulze, 1997); Water Resources of South Africa Study 2005 (WR2005) (WRC, 2009); Agricultural Geo-Referenced Information Systems (AGIS) landtype information (AGIS, 2007); and NASA Shuttle Radar Topographic Mission (SRTM) data (CGIAR, 2008).

The characteristics derived from the analysis to represent the physical fingerprint of each quaternary catchment, both gauged and ungauged, within the study area was compiled and is provided in **Appendix A**. Below (**Figure 2.1**) is an extract of an ungauged quaternary catchment's fingerprint (C21A) for explanatory purposes together with a brief explanation of the various fields displayed therein.

All information displayed in the database for each quaternary catchment was based on the databases previously mentioned e.g. the quaternary catchment area was predetermined in the WR90 study and verified in the GIS application of this study. The first half of the table provides the landtype distribution of the soils information as obtained from AGIS (2007). All slopes, areas and depths of the various landtype pertaining to a particular profile, i.e. Top – hilltops/crests, Middle – middle slopes, Bottom – foot/lower slopes, and Valley – valley bottoms, were included in the analysis without verification, as this dataset was assumed the best database with regards to representation of the information required for this study. The slope gradient associated with each terrain type was guided by the information provided from AGIS (2007), all slope and percentage area of each terrain type was calculated from the SRTM data, which provided 90m Digital Elevation Data (DED), in the GIS analysis.

As mentioned in the methodology report, the use of a program developed by Kapangaziwiri (2008) was undertaken in this study as it contains the framework for deriving parameters based on the physical characteristics of the catchment for input and comparison to the WR2005 study results. The program is in the initial stages of development and was limited to the inclusion of only 4 of the 5 terrain units outlined in the AGIS dataset, as well as only 5 different landtypes per unit. This was a decision by the developers, as the inclusion of all would not have been realistic in the application of the program.

	C21A - Ungauged					
	Total quat area (km²) =			707		
	Terrain 1	Terrain 3	Terrain 4	Terrain 5		
	Top	Middle	Bottom	Valley		
Area (km²)	235	75	284	113		
% Area	33	11	40	16		
Min Slope %	0	2	0	0		
Max Slope%	5	8	4	1		
Landtype 1	Bb19					
S1 % of Unit	10	21	14	23		
S1 Min Depth	300					
S1 Max Depth	750					
S1 Texture	SaCl					
Landtype 2	Dc2					
S2 % of Unit	17	21	22	11		
S2 Min Depth	250					
S2 Max Depth	450					
S2 Texture	SaClLm					
Landtype 3	Ea15					
S3 % of Unit	6	9	5	27		
S3 Min Depth	500					
S3 Max Depth	900					
S3 Texture	SaCl					
Landtype 4	Ea17					
S4 % of Unit	53	41	47	27		
S4 Min Depth	300					
S4 Max Depth	900					
S4 Texture	Cl					
Landtype 5	Ea20					
S5 % of Unit	14	7	12	12		
S5 Min Depth	300					
S5 Max Depth	600					
S5 Texture	SaCl					
Soil Vert Var	90	80	70	70		
Soil Factors	Macropore	Organics	Structure		Surface Cover	Cover Variability
Index (0 to 2)	1	1	1		0 = Well vegetated	0 = Low
Surface Cover Index	1	1	1	1	1 = Moderate	1 = Moderate
Cover variability index	1	1	1	1	2 = Crusting	2 = High
Regional GW slope %	1				Default	
Vertical Drainage %	2					
Horizontal Drainage %	98					
	GRA2	SD				
Storativity (*1000)	3	0.3				
Depth to GW (m)	25					
Fract Zone Trans (m2/d)	2.5	0.5				
Drainage Density (km/km)	0.19	0.019				
Mean monthly rain (mm)	55.5					
Max Monthly Rain (mm)	114.8					
Mean no. of raindays/month	2					
Mean Storm Duration (h)	6					
Mean Ann Evap (mm)	1600					
Mean Ann Recharge (mm)	7.1	13.2				
% Area of Dominant veg	100					
Dominant veg	Summer		Winter			
Proportions of dominant veg	Low Est	High Est	Low Est	High Est		
Dense forest	0	0	0	0		
Bush/Sparse Forest	0.1	0.2	0.1	0.2		
Dense Crop/Ground Cover	0.6	0.6	0.6	0.6		
Sparse Crop/ Ground Cover	0.3	0.2	0.3	0.2		
Bare Soil	0	0	0	0		
% Area of Secondary veg	0					
Secondary veg	Summer		Winter			
Proportions of secondary veg	Low Est	High Est	Low Est	High Est		
Dense forest						
Bush/Sparse Forest						
Dense Crop/Ground Cover						
Sparse Crop/ Ground Cover						
Bare Soil						

Figure 2.1: Physical characteristics of an ungauged quaternary catchment (C21A)

This study has adopted the use of 5 broad soil texture classes as used by Kapangaziwiri (2008), i.e. sands, loamy sand, sandy clay loams, sandy clays and clays as well as the assumed porosity assigned to each class as outlined in **Table 2.1**.

Table 2.1: Soil texture classes according to USDA (1969), based on percentage volumes of sand, silt, clay and quartz content.

Texture Class	Sand (%)	Silt (%)	Clay (%)	Quartz (%)	Assumed porosity (%)
Sand	92	5	3	92	42
Loamy sand	82	12	6	82	40
Sandy clay loam	58	15	27	60	33
Sandy clay	52	6	42	52	32
Clay	22	20	58	25	39

Additional assumptions made in the study are:

- Surface cover and variability of surface cover for each quaternary catchment within the study area were assumed to be moderate, as opposed to well vegetated or crusting;
- All the data used as input to the program is representative of the quaternary catchment under natural conditions;
- Mean storm duration was assumed as 6 hours, for each region under consideration; and
- Each quaternary catchment has one dominant vegetation present.

Focussing on the initial aim of determining the rainfall-runoff response for the natural conditions of the quaternary catchments under investigation, as outlined under the proposed methodology, it was deemed relevant to assume the above as the natural conditions for all quaternary catchments in itself is an assumption based on land use data collected from various studies over the past years, which provides an acceptable understanding of the possible occurrence of certain land use and vegetation across the country. As storm duration for various regions and storm types alike vary across the country, the average storm duration mentioned above, was included in the calculations but may be updated as more detailed rainfall analysis information and rainfall patterns are made available.

Combining the physical characteristics for each of the quaternary catchments within the study area, and the application of the parameter estimation program by Kapangaziwiri (2008), provides an array of information prior to the determination of the parameters for which rainfall-runoff per catchment is derived. This secondary basin information is based on the application of the alternate methods of deriving the various parameters used in the WRSM2000 as discussed in the methodology. Such a result is particular for the quaternary catchment for which it describes, as well as the assumed conditions placed on the catchment in order to obtain them. **Appendix B** provides the results of this application for which the parameter estimation was based. **Figure 2.2,** showing the secondary basin data used to derive the parameters for input to the WRSM2000 for C21A, is provided as an example.

C21 - VAAL

SECONDARY BASIN DATA

	C21A - Ungauged			
Property	Mean	Sdev	Skew	Dist. Type
Basin Slope (%)	9.129	2.299	0.885	1
Upper Slope (% Area)	52			
Mid Slope (% Area)	22			
Valley Bottom (% Area)	26			
Upper slope S.Depth (mm)	473	39.444	0.013	1
Mid Slope S.Depth (mm)	354	31.93	0.061	1
Valley Bottom S.Depth (mm	421	55.722	-0.027	1
Soil Porosity	0.389	0.062	-0.108	1
Vert. Variation (%)	83			
Soil K	0.665	0.099	0.189	1
Soil K var	0.013			
Soil C	212.877	45.88	-0.017	1
Soil C var	97.608			
Soil Perm. (mm/h)	100.744	89.853	0.822	1
ST Soil (mm)	139.715	23.723	0.087	1
FT soil (mm/month)	1.321	0.913	1.173	1
Regional GW slope (%)	1			
Drainage Vector slope (%)	2			
Storativity (*1000)	3	0.3		
Depth to GW(m)	25			
Fract. Zone Trans. (m2/d)	2.5	0.5		
ST Unsat (mm)	64.726	7.832	0.115	1
FT Unsat (mm/month)	0.571	0.127	0.154	1
Moisture content SD (%)	73.569	7.152	-2.359	1
Dominant LAI (Summer)	1.475	0.054	-0.041	1
Dominant LAI (Winter)	1.475	0.055	-0.061	1
Secondary LAI (Summer)	4.701	0.052	0.092	1
Secondary LAI (Winter)	4.701	0.052	0.168	1

Figure 2.2: Secondary basin data for C21A as input to the parameter estimation procedure

2.1 Parameter Estimation Procedure

This chapter aims to introduce the physically-based parameter estimation procedures undertaken in this study for use in the WRSM2000. The study of the rainfall-runoff response in the WRSM2000 was focussed on firstly, the soil moisture accounting, subsurface runoff and recharge parameters and, secondly the soil surface infiltration parameters. Kapangaziwiri (2008) attempted to identify the conceptual linkages between the model parameters and the physical basin properties and the effect these have on the hydrological processes. A program developed for that study was used to test whether this conceptualisation of physical characteristics of a catchment would provide a more accurate estimation of the parameters in the WRSM2000.

The focus of this study is on the main runoff generation parameters namely the soil moisture accounting, subsurface runoff and recharge parameters and, secondly the soil surface infiltration parameters. The remaining parameters within the model will not be studied as part of this project; however, they are just as important in calculating the rainfall-runoff response from quaternary catchments and should be studied in the future.

2.1.1 Soil moisture accounting, subsurface runoff and recharge parameters

This section will address the maximum soil storage (ST) which has been assumed, for purposes of this study, to comprise of two components (i.e. $ST = ST_{soil} + ST_{unsat}$), subsurface runoff (FT and POW), also assuming to be generated separately from these two components (i.e. $FT = FT_{soil} + FT_{unsat}$) and groundwater recharge (GW, GPOW) parameters.

<u>Maximum Soil Storage (ST)</u>

1. Estimating ST_{soil}

ST_{soil} represents the soil storage depth (mm) at saturation and is very important in hydrology as it represents the immediate soil storage of infiltrated rainfall before it is lost to either evapotranspiration or to percolation and runoff. The maximum amount of moisture of the ‘soil’ component (ST_{soil}) is assumed to be estimated by the following equation;

$$ST_{soil}\text{ (mm)} = POR\text{ (\%)} * VVAR\text{ (\%)} * \text{Soil Depth (m)} / 10 \quad \ldots\ldots\ldots\ldots (1)$$

POR represents the soil porosity and therefore a measure of the moisture holding capacity and VVAR represents a correction factor for vertical variations in porosity. The default estimate of porosity used in this study will primarily be based on the soil texture class (**Table 2.1**).

2. Estimating ST_{unsat}

The unsaturated zone between the water table and the soil zone is difficult to characterize, accepting the fact that there is a lack of knowledge and understanding of the water transfer processes that operate in this zone. The assumption made in this study is that water percolating downwards in the unsaturated zone will have two directional components; a vertical one contributing directly to recharge of the saturated groundwater zone and a lateral one that could contribute to the re-emergence of subsurface water at a spring or seep. The important issue is that these springs or seeps occur at elevations above the regional groundwater level. The lateral component could be caused by flow in horizontal fractures or through perched aquifers associated with layers of lower permeability. The vector result of these two components is referred to here as the drainage vector slope (VS in **Figure 2.3**), which is estimated in a default procedure using % values for the vertical and horizontal components. Approximate estimates for different geological conditions which also form part of the estimation procedure are;

- Horizontal bedded sedimentary rocks;
- Folded sedimentary rocks;
- Sedimentary rocks with intrusive dykes and sills;
- Fractured igneous rocks;
- Weathered igneous rocks;
- Permeable material with impermeable layers;

- Permeable material with impermeable lenses; and
- Homogeneous permeable material.

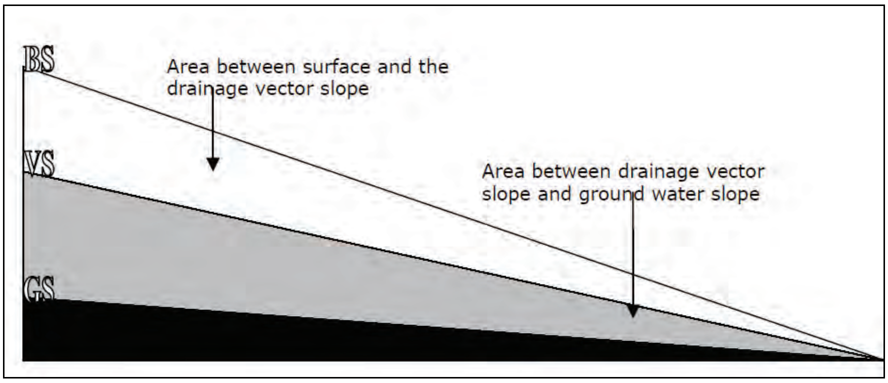

Figure 2.3: Conceptualization of the subsurface drainage that determines the interflow process from the unsaturated zone.

The ratio of the volume that lies between the basin surface slope (BS in **Figure 2.3**) and the drainage vector slope (VS) to the total unsaturated volume represents the proportion of the unsaturated zone that can contribute to the unsaturated flow from the catchment slope. The area between the drainage vector slope and the groundwater slope (GS) will not be able to contribute to unsaturated flow at the surface, but will contribute to aquifer recharge. Simple geometry from **Figure 2.3** suggests that the ratio of these two areas can be calculated from:

Ratio = [Tan(BS) – Tan(VS)] / [Tan(BS) – Tan(GS)] ....(2)

If the total unsaturated zone potential storage (mm/depth) is expressed as the product of the mean depth to groundwater (DGW/m) and the storativity (S) of the unsaturated zone material, then the final estimate of ST_{unsat} becomes:
If BS > VS then

ST_{unsat} (mm) = DGW * 1000 * S * Ratio ……………...................(3)

If BS ≤ VS then

ST_{unsat} (mm) = 0 …………………………………….(4)

With respect to the use of this estimation approach, several important issues have to be considered. The mean depth to groundwater may be available from regional borehole surveys, but it is important to recognize that any available values must be consistent with the conceptualization of the estimation approach and are not biased by preferential borehole locations. The storativity value used must represent the component of the unsaturated zone that can contribute to 'unsaturated' flow. If the drainage vector slope is close to the groundwater slope, almost all of the unsaturated zone can contribute.

The information on depth to groundwater needed for this estimation may be reasonably accurate in areas where comprehensive borehole drilling records exist. Estimations for areas without this kind of information may introduce some uncertainties. Obtaining representative values of storativity may also be a problem in some areas and may introduce a further source of uncertainty.

Subsurface runoff (FT and POW)

1. Estimating FT_{soil}

Subsurface lateral and vertical drainage are known to occur at different moisture contents. Field capacity defines the volume of moisture that a particular soil is capable of holding against the force of gravity. In a purely Darcian flow context no significant water movements occur below field capacity, while at higher moisture contents vertical drainage can occur. Significant volumes of lateral flow only occur close to saturation levels. The implication is that sub-surface lateral flow can occur within a basin over a wide range of average basin moisture contents. This is implicit in the WRSM2000 ‘soil’ moisture runoff generation component.

FT_{soil} is the maximum subsurface outflow when the basin’s soils are at full saturation and is assumed to occur through the banks of the channel. At saturation, therefore, the whole stream channel and the average soil depth gives an estimate of the depth of the channel through which water may flow into the river. The total contributing channel length is estimated from the basin drainage density. Thus, shrinkage of the drainage density should reduce the volume of subsurface flow. Since both banks are contributing to the stream, the estimation equation is thus multiplied by 2 resulting in the contributing area CA (in km/km^2) being given by the equation:

$$CA = 2 * DD\ (km/km^2) * \text{soil depth (m)} / 1000 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (5)$$

Where DD is the basin’s drainage density. The soil depth value used should be based on the soil depths in the lower topographic units of the basin. The drainage density is a measure of channel length and can be estimated from topographic maps. The calculation of drainage densities will include all potential drainage lines (identified by contour convergence) that are assumed to receive flow under conditions of basin saturation. The monthly depth of interflow from the soil (FT_{soil}, in mm/month) will be assumed to adequately explain as a function of CA, saturated hydraulic conductivity of the basin soils, K (m/d) and the mean basin slope (BS) and is expressed as follows;

$$FT_{soil} = CA * K * BS * 30 * 1000 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (6)$$

The estimation approach for K is based on area weighted soil texture classes plus some adjustments to account for macro-pore development, organic content, structural development and sand grade. Cosby et al. (1984) suggested typical means and ranges of hydraulic conductivity values for different soil types and these will be used as a guide in this study. The actual values of K will be based on the various factors that operate on a basin scale using the following relationship:

$$K\ (m/day) = e^{(PI*0.55 - 0.054)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (7)$$

Where PI is a permeability index value estimated from soil characteristics and is given by:

$$PI = M + 0.5 * (F+G+H) + K \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (8)$$

where

$$M = 0.09A + 0.05B + 0.02C + 0.015D + 0.01E \quad \ldots\ldots\ldots\ldots\ldots\ (9)$$

A to E are percentage areas of the basin covered by sandy (A), loamy sand (B), sandy clay loam (C), sandy clay (D) and clay (E) soils, while F, G and H are assumed to vary from low (0) to high (2) and represent the level of macro-pore development (F), the organic content (G) and the structural development of the soil (H). Information obtained from the fingerprint analysis will be used in equation (9). K represents the sand grade of the soil. This estimation procedure will be adopted from the methods used for the VTI model (Hughes and Sami, 1994).

2. Estimating FT_{unsat}

Estimating the outflow from the unsaturated zone (FT_{unsat}) will by far be the greater challenge. This is mainly because the physical concepts of subsurface runoff generation from this zone are not very well defined. For instance, there is no general consensus on the processes which occur in the unsaturated zone (below the root zone and above the groundwater table). There is also limited documentation of the typical hydraulic conductivities of fracture zones. **Figure 2.3** represents a conceptual diagram that is independent of the actual processes occurring. The lateral component contributing to the drainage vector may be the result of water flowing in horizontal, or near horizontal, fractures. It may also be a result of a series of overlapping layers of material with low permeability creating perched water tables and allowing lateral saturated flow to develop. The estimation approach to be adopted assumes either saturated flow in the fracture zones or a perched water table and is based on defining a representative transmissivity (T in m^2/d):

$$FT_{unsat}(mm) = 2 * DD * T * VS * 30 / 100 \quad \text{.................................} \quad (10)$$

The quantification of a representative value for the transmissivity is the major source of uncertainty. While transmissivity values in fractures can be very high (Razack and Lasm, 2006), the fractures represent a variable but generally small proportion of the total volume of the unsaturated zone. This will depend on the degree of fracturing and the connectivity of individual fractures. In a perched aquifer situation, estimation of FT_{unsat} will depend on the transmissivity of the more permeable layers as well as on the number and geometric arrangement of the impermeable layers. It should be further emphasized that the transmissivity value used must represent the sub-basin as a whole, which accounts for variability in the geology. The drainage density used in the default estimation equation will be the same as that used for the calculation of the parameter FT_{soil}. However, it is also possible that the length of the channel that receives flow from the unsaturated zone could be less than the length receiving flow from near surface soil saturated flow. It is difficult to offer generic guidelines as individual basins may experience different conditions.

3. Estimating POW

The power (POW) of the relationship between subsurface outflow and the volume of moisture in a basin is assumed to be made up of the two components associated with the soil water and the unsaturated zone runoff. POW represents the shape of the relationship that determines reduced runoff (relative to the maximum) as the moisture contents of the soil and unsaturated zones decrease. This reduced runoff may be caused by reduced areas of saturation and therefore reduced contributing area, or it may be caused by reduced rates of runoff. In the soil zone the relationship is likely to be mainly influenced by patterns of moisture redistribution following rainfall events and how these patterns affect the distribution of saturated zones. The redistribution will be influenced by such processes as evapotranspiration, and vertical and lateral drainage. Geology, topography, vegetation cover, soil type and texture will all influence patterns of moisture redistribution within a basin. It is therefore reasonable to suggest that, for any given mean basin moisture content (S), the spatial variation could be represented by a frequency distribution. At the extreme ends of the moisture content spectrum, i.e. when the basin is either very dry or close to saturation, this variability must be low. The variability would be highest at moderate moisture contents. Given detailed field observations the spatial variation of moisture content could be adequately defined for a range of basin mean moisture contents. However, in the absence of detailed field data, a simpler approach will be adopted based on the probability distributed principle of Moore (1985) and similar to the procedures used within the VTI model (Hughes and Sami, 1994), illustrated in **Figure 2.4**

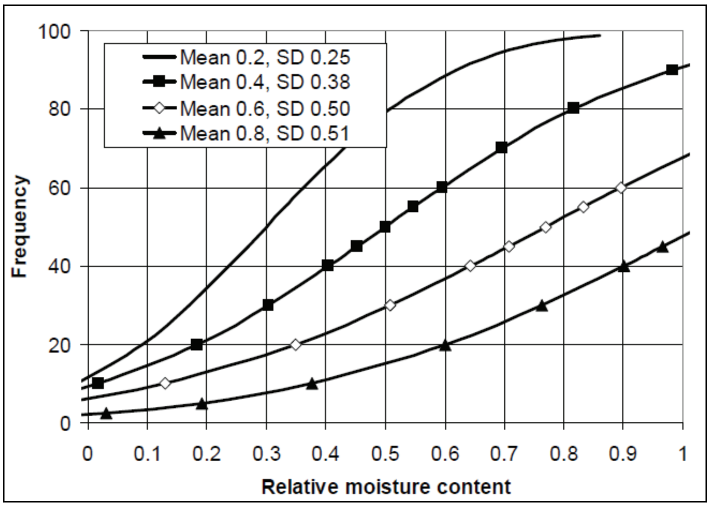

Figure 2.4: Illustration of the concept of using a frequency distribution to describe the spatial distribution of soil moisture for different mean moisture contents.

The four lines represent cumulative Normal distribution frequency curves for mean basin moisture contents of 0.2 to 0.8, each having a different standard deviation. If a relative moisture content of 0.9 is assumed to represent the threshold for lateral flow, **Figure 2.4** indicates that the percentage of the basin area contributing to runoff would vary from 0% (at mean of 0.2) to 60% at a mean of 0.8.

The contribution of the unsaturated zone and this component of the relationship is more difficult to assess. It is assumed to be related to a decrease in the number of saturated fractures as well as a reduction in the drainage density of channels receiving spring flow as the moisture content (S_{unsat}) reduces.

The full estimation approach is to generate two curves separately (soil and unsaturated zones) and then adjust both to ensure that the ordinates range from 0 to 1. The adjustment will be based on the relative contributions to the total runoff of the two zones (i.e. FT_{soil} and FT_{unsat}).

<u>Groundwater Recharge parameters (GW and GPOW)</u>

1. Estimating GW and GPOW

Estimating the value of GW is difficult as it involves the complexities of vertical drainage through the total unsaturated zone. The approach to estimating GW and GPOW could follow similar principles to those used for FT_{soil} and POW. There are, however, existing estimates of mean annual recharge available for some southern African basins, such as the Groundwater Resource Assessment study (DWAF, 2005), which can be used to guide the calibration of GW. These approaches are considered to be adequate for this study.

2.1.2 Soil Surface Infiltration Parameters

These parameters control the absorption rate at the surface, the volume of water entering the moisture store reservoir and the depth of infiltration excess flow generated within a particular basin. Ponding occurs when the rainfall rate is greater than the infiltration capacity of the soil and is an important aid to the process of infiltration at the basin scale. However infiltration rates tend to decrease with time under ponded conditions and will approach the saturated hydraulic conductivity (K_{sat}) of the soil due to the weakening of the energy gradient in Darcy's law as the soil gets wetter. Under non-ponded conditions infiltration rates will vary with the rates of the rainfall input. An array of factors influences the process of infiltration, most important among them being soil properties (both physical and hydraulic) and antecedent moisture conditions and these factors will be used in developing a new physically-based estimation procedure for the soil surface infiltration parameters.

The approach required for the design of a physically-based procedure needs to make use of both basin surface and hydro-meteorological factors. The basic rule of this approach is to use soil properties to define the parameters of a modified form of the Kostiakov equation (Hughes and Sami, 1994), basin hydro-meteorological characteristics to disaggregate monthly rainfall and to apply the infiltration equation to estimate surface runoff for a range of monthly rainfalls. The parameters ZMIN, ZAVE and ZMAX of the surface runoff model algorithm will then be manually fitted to match the infiltration equation based estimates of runoff for different monthly rainfalls.

This procedure was based on the use of a variation of the Kostiakov equation (Kostiakov, 1932) to estimate surface infiltration rate as follows:

$$\text{Infiltration rate (mm/h)} = k * C * T^{k-1} \qquad (11)$$

where k and C are parameters and T is cumulative time in minutes from the start of the storm.

The mean values of the parameters and their assumed spatial variability (expressed as the standard deviation of a log-normal distribution) will be estimated from soil texture properties and surface cover. The approach incorporates the principle of spatial variability in infiltration rates over the sub-basin and allows for this variability in estimating the surface runoff at any specific rainfall rate. In order to apply the infiltration function to monthly rainfall totals it will be necessary to first disaggregate the monthly rainfall. Within the WRSM2000, monthly rainfalls are disaggregated into four periods, this study will utilize the same equations but disaggregating the monthly rainfall into 30 periods (i.e. approximately 1 day per period).

This disaggregation process generates rainfall on every day of the month, which is not a very realistic distribution to use with the infiltration function. A parameter representing the mean number of rain days expected in the basin is used to aggregate some of the initial daily rainfall estimates and leave some days with zero rainfall. The assumption is that any daily rainfall must be greater than the square root of the ratio of monthly rainfall total divided by the mean number of rain days. This is loosely based on the probability of occurrence of a rain day (De Groen, 2002) which n this study is taken as a day with rain above a certain threshold (as opposed to a day with recorded rain). This threshold is defined by the total monthly rainfall and the mean number of rain days. Such an approach is deemed adequate for the disaggregation of monthly rain.

3 RESULTS AND DISCUSSION

Applying the equations discussed above, the results of the estimation of the input parameters for the WRSM2000 in most cases, showed similar trends to those estimated in the WR2005 study. For comparative purposes, both parameter estimations derived for the two studies, i.e. for WR2005 study as well as for this study (abbreviated as *Hydz* in the tables) are provided in **Appendix C**. From the results achieved, it is noted that the parameter values for the two studies are similar for the majority of parameters. The subsequent sub sections will focus on the results attained, comparison and discussion of the findings of this study.

3.1 Comparison to observed catchment runoff

An analysis was undertaken to compare the calibrated simulation results obtained from the WR2005 study to the results of this study, which would provide insight into whether the outcome of inputting the parameters determined through this physical-based approach, could be justified in gauged catchments. For this purpose the system setups as published in the WR2005 study were amended to include these physically-based parameters and results for each system were noted and tabulated in the respective tables to follow. The system diagrams as obtained from WR2005 study may be viewed in **Appendix D**.

3.1.1 Upper Vaal System

The portion of the Upper Vaal River System analysed in this study comprises the C21 quaternary catchments, i.e. C21A to C21G, totalling 7 quaternary catchments (**Figure 3.1**).

Figure 3.1: Geographical layout of the quaternary catchments within the Vaal study area

Two gauging stations exist on this river network, and both are located in C21G, which is the outlet of the network i.e. C2H070 and C2H004 on the Suikerbosrand River. The

Suikerbosrand River flows from C21A and through C21B and C21C until the confluence with Blesbokspruit River in C21G. The Blesbokspruit River flows from C21D to C21F. The flow gauge C2H070 was the only gauge used in the calibration of this network in WR2005 study; it has a record period from 1977 to 1995. This was the period used for the calibration of this gauge in the WR2005 study. There exists little missing data or gaps in the record, but a few months were highlighted as being unreliable.

Statistical results obtained from the WR2005 study for gauge C2H070 are provided in **Table 3.1**, which shows a satisfactory calibration achieved. Also in **Table 3.1** are the results from this study, without performing any calibration of the parameters. Highlighted in the WR2005 study was that the flow gauge C2H070 over simulated low flows and that the use of C2H004 was more reliable for measuring low flows accurately and the calibration of the low flows was based on this gauge.

Table 3.1: Comparison of Statistical results for C2H070

	1977 - 1994		
C2H070	**Observed**	**WR2005**	**Hydz**
MAR (Mm^3/a)	86.78	89.52	76.98
Mean(Log)	1.81	1.82	1.79
Std Dev	81.04	78.79	58.17
Log Std Dev	0.34	0.33	0.29
Seasonal Index	29.82	30.8	34.22

Graphical representation of the mean monthly and annual flows for all flow gauges analysed in the study are provided in **Appendix E**.

3.1.2 Gouritz (Gamka River) System

The portion of the Gamka River System analysed in this study comprises the J21 quaternary catchments, i.e. J21A to J21D, totalling 4 quaternary catchments (**Figure 3.2**).

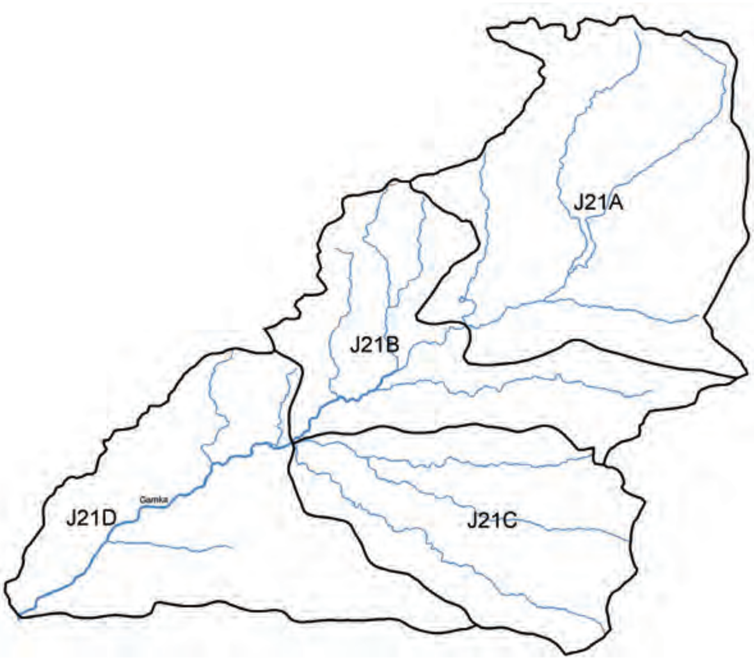

Figure 3.2: Geographical layout of the quaternary catchments within the Gouritz study area

One gauge stations exists on this river network, located in J21A at the inlet to the Gamka Dam, J2R004. The flow gauge J2R004 is the only gauge in this network used in the calibration in the WR2005 study; it has a record period 1958 to 1988. This was the period used for the calibration of this gauge in the WR2005 study. There exists little missing data or gaps in the record, but a few months were highlighted as being unreliable.

Statistical results obtained from the WR2005 study for gauge J2R004 are provided in **Table 3.2**, which shows a satisfactory calibration achieved. Also in **Table 3.2** are the results from this study, without performing any calibration of the parameters.

Table 3.2: Comparison of Statistical results for J2R004

	1958 - 1988		
J2R004	**Observed**	**WR2005**	**Hydz**
MAR (Mm^3/a)	3.55	3.24	0.51
Mean(Log)	0.23	0.38	-0.5
Std Dev	4.77	2.66	0.63
Log Std Dev	0.57	0.34	0.40
Seasonal Index	17.12	22.25	28.46

3.1.3 Thukela River System

Due to the size of the river system, within the WR2005 study, it was modelled in smaller river systems. The same river systems were dealt with in a similar fashion in this study to maintain a consistent platform for comparison.

Four river systems make up the study area in the Thukela River System, namely, Buffels, Ngagane, Horn and Ncandu River systems. **Figure 3.3** provides the geographical layout of the study area. Each system will be dealt with individually as for the WR2005 study, however maintaining the interlinking flow between the systems.

Figure 3.3: Geographical layout of the quaternary catchments within the Thukela study area

(a) Buffels River

The quaternary catchments included in the system are V31A to V31C, with the outlet at V31C. The first flow gauge in the system is upstream from Zaaihoek Dam in V31A, V3R003. The record period used in the calibration of this gauge was 1992 to 2004. A comparison of the statistical results for both the WR2005 and this current study are provided in **Table 3.3**.

Table 3.3: Comparison of Statistical results for V3R003

	1992 - 2004		
V3R003	**Observed**	**WR2005**	**Hydz**
MAR (Mm^3/a)	86.76	93.70	64.43
Mean(Log)	1.82	1.78	1.53
Std Dev	67.56	93.06	85.11
Log Std Dev	0.34	0.47	0.54
Seasonal Index	38.49	40.41	49.92

The second flow gauge in the system downstream from Zaaihoek Dam in V31B, V3H005. Only 11% of the quaternaries runoff is measured at this gauge which has a record period from 1947 to 1991 and few highlighted unreliable data exist in the record. A comparison of the statistical results for both the WR2005 and this current study are provided in **Table 3.4**.

Table 3.4: Comparison of Statistical results for V3H005

	1947 - 1991		
V3H005	**Observed**	**WR2005**	**Hydz**
MAR (Mm^3/a)	96.51	103.47	65.90
Mean(Log)	1.87	1.95	1.72
Std Dev	56.64	52.31	43.11
Log Std Dev	0.39	0.27	0.33
Seasonal Index	38.05	35.45	43.06

The last flow gauge in the system downstream in V31C used in the calibration process was V3H002. Due to unrepresentative calibration in the WR2005 study, the record period used in the final calibration was 1953 to 1974. A comparison of the statistical results for both the WR2005 and this current study are provided in **Table 3.5**.

Table 3.5: Comparison of Statistical results for V3H002

	1953 - 1974		
V3H002	**Observed**	**WR2005**	**Hydz**
MAR (Mm^3/a)	201.22	213.58	144.88
Mean(Log)	2.25	2.27	2.08
Std Dev	116.50	112.36	93.18
Log Std Dev	0.22	0.22	0.27
Seasonal Index	31.84	32.92	39.78

(b) Ngagane River

The quaternary catchments included in the system are V31E and V31G. The first flow gauge analysed in the system is upstream from Ntshinwayo Dam at the outlet of V31E, V3R001. The record period used in the calibration of this gauge was 1962 to 2004. A comparison of the statistical results for both the WR2005 and this current study are provided in **Table 3.6**.

Table 3.6: Comparison of Statistical results for V3R001

	1962 - 2004		
V3R001	**Observed**	**WR2005**	**Hydz**
MAR (Mm^3/a)	87.85	84.94	84.41
Mean(Log)	1.74	1.81	1.82
Std Dev	65.09	71.24	69.26
Log Std Dev	0.69	0.33	0.32
Seasonal Index	41.87	39.67	46.83

The second flow gauge in the system downstream from Ntshinwayo Dam in V31G is V3H003. This gauge has a record period from 1934 to 1949. A comparison of the statistical results for both the WR2005 and this current study are provided in **Table 3.7**.

Table 3.7: Comparison of Statistical results for V3H003

	1934 - 1949		
V3H003	**Observed**	**WR2005**	**Hydz**
MAR (Mm^3/a)	93.20	102.11	97.14
Mean(Log)	1.93	1.97	1.94
Std Dev	39.99	52.08	49.17
Log Std Dev	0.21	0.19	0.19
Seasonal Index	30.86	38.41	44.78

(c) Horn River

The single quaternary catchment included in the system is V31F. The only flow gauge analysed in the system is V3H009. The record period used in the calibration of this gauge was 1962 to 2004. A comparison of the statistical results for both the WR2005 and this current study are provided in **Table 3.8**.

Table 3.8: Comparison of Statistical results for V3H009

	1962 - 2004		
V3H009	**Observed**	**WR2005**	**Hydz**
MAR (Mm^3/a)	19.70	20.70	21.44
Mean(Log)	1.12	1.19	1.24
Std Dev	16.61	16.43	15.56
Log Std Dev	0.46	0.35	0.28
Seasonal Index	40.84	40.64	43.98

(d) Ncandu River

The single quaternary catchment included in the system is V31H. The only flow gauge analysed in the system is V3H007. The record period used in the calibration of this gauge was 1977 to 2004. A comparison of the statistical results for both the WR2005 and this current study are provided in **Table 3.9**.

Table 3.9: Comparison of Statistical results for V3H007

	1977 - 2004		
V3H007	**Observed**	**WR2005**	**Hydz**
MAR (Mm^3/a)	32.03	31.35	18.97
Mean(Log)	1.39	1.43	1.17
Std Dev	23.40	17.27	14.90
Log Std Dev	0.33	0.26	0.32
Seasonal Index	41.30	39.59	45.61

3.2 Discussion of Results

From the results achieved it may be seen that the correlation between the use of physically-based parameters and those used in the WR2005 study, for most flow gauges, yielded similar results. Although room for improvement of the calibration exists, it provides evidence that the use of the physically-based parameters do provide a good representation of the recorded flow in the river at that flow gauge, without any calibration.

The necessity to calibrate in a few instances e.g. in the Gamka study area shows the parameters derived in this study do not represent this portion of the catchment above the Gamka Dam when comparing to the WR2005 study. Possible reasons are the differences in soil characteristics used, for instance, the *Hydz* study made use of the physical soil characteristics for the various soil forms located in the entire quaternary catchment revealing a generally deep, permeable soil, with potentially large storage capacity. Incorporating these into the parameter estimation procedures resulted in a lower runoff response from the catchment due to the high absorption rate associated to the deep and permeable soils. The occurrence of these soils was identified throughout the Gouritz study area, which pre-empted a low runoff yield from this study area.

A few additional aspects were identified, a) the results obtained for calibration gauge J2R004, was based on 11% of the catchments runoff; and b) the parameters used for this quaternary were different to the other catchments, in particular the low figure used to represent the maximum soil moisture absorption rate of the soils in J21A. Considering the landtype characteristics obtained from the analysis in the *Hydz* study, there was insufficient evidence to justify this. To elaborate, the soils in all the quaternary catchments in this area are relatively deep well drained soils as mentioned previously, meaning the absorption rate would be fairly high, thus reducing the runoff from the quaternary, which is notable in the natural runoff obtained to be discussed in the subsequent chapter. The parameters used for the calibration point in the WR2005 study produced satisfactory comparable results to the observed data, but only represents approximately 26% of the total quaternary catchment, which when adopting these parameters for the entire quaternary catchment for naturalisation, will produce a natural runoff for the entire catchment based on the parameters used for the calibration of the gauge recording 26% of the catchments runoff. Discussion of the effect on natural runoff is discussed in the following chapter.

Except for the Gouritz study area results, which would require an in-depth analysis of parameters, all other results obtained provide and support that the use of the physical characteristics of the quaternary catchments in the study does provide a reasonable representation of the expected runoff from that catchment. The above comparison also proves that the parameters used in the WR2005 study provide a reasonable estimate of the catchments' rainfall-runoff response.

3.3 Comparison of natural runoff

The final comparison undertaken in this study was the comparison of the natural runoff generated by the WR2005 and the current study. The difference between the two is; the natural runoff for all quaternary catchments above the calibration point in the WR2005 study were derived from a single set of parameters which were finalised after achieving a good simulation in comparison to the observed runoff. The natural runoff per quaternary catchment in this study were based on the physical characteristics of that particular catchment, which accounted for all physical aspects of the quaternary such as landtype, vegetation cover, slope and drainage density. Results of this comparison are provided below.

In order to test whether the parameters produced in this study provide a reasonable representation of the expected natural runoff, the WRSM2000 setups as used previously in the WR2005 study for the selected study areas, was executed and the natural MAR (nMAR) was compared to that obtained from the WR2005 study.
Table 3.10 provides the comparison between the results of this study and that estimated in the WR2005 study.

Table 3.10: Comparison of the natural MAR obtained between the two studies

	natural MAR (million m^3/a)			
	Quaternary	**HYDZ**	**WR2005**	**Diff (%)**
Vaal	**C21A**	14.6	16.7	-13
	C21B	6.4	11.5	-44
	C21C	8.9	10.0	-11
	C21D	11.3	12.3	-8
	C21E	14.6	16.4	-11
	C21F	8.7	12.0	-28
	C21G	8.7	10.9	-20
Gouritz	**J21A**	4.2	32.1	-87
	J21B	3.4	2.3	46
	J21C	0.8	2.2	-62
	J21D	3.3	2.2	49
Thukela	**V31A**	80.0	115.7	-31
	V31B	46.9	68.4	-32
	V31C	39.5	49.4	-20
	V31D	26.3	32.7	-20
	V31E	93.5	95.8	-2
	V31F	22.7	22.5	1
	V31G	10.2	23.4	-56
	V31H	20.6	32.4	-36
	V31J	45.3	34.4	32
	V31K	10.6	13.6	-22

Application of the derived parameters in the WRSM2000 setup pertaining to the quaternary catchments identified for this study as that used in the WR2005 study, shows considerable differences between the two studies. Percentage differences range from as high as 87% to as low as 1%. The high percentage difference occurs in the Gouritz study area which raises concern but also motivated the discussions on possible reasons for this occurrence. Taking the observations noted in the previous chapter into account, and simply comparing the natural runoff result of the WR2005 study for J21A and J21B, it is apparent that a discrepancy lies in the parameters used in these quaternary catchments to derive the natural runoff. In comparison to WR90, WR2005 produced approximately 120% more natural runoff for this quaternary, which also should raise concerns as to the data used to generate it in both studies given that there was no gauge at the outlet of the quaternary catchment to compare modelled results to.

These differences are concerning but considering the quaternary catchment sample size in this study does not provide substantial evidence that either method is incorrect. What is apparent is that both studies produced results which are within acceptable thresholds, with the exception of a few quaternary catchments, namely J21A. Where large differences occur and also applicable for quaternary results that are similar, is the question along the uncertainty of the data utilised in the formulation of the physically-based parameters. The current WRC funded project undertaken by Prof Denis Hughes called "Identification, estimation, quantification and incorporation of risk and uncertainty in water resources management tools in South Africa, K5/1838", attempts to tackle this issue. At the project K5/1838 workshop held in November 2008, it was highlighted that this study K8/684/1, was an overlapping study and could run in parallel to obtain the objective of determining regional constraints of hydrological behaviour. As the deliverables for the K8/684/1 study were already accepted, the aim was to assist Prof Denis Hughes in the compilation of these constraints which was presented in Deliverable 5 of that project.

Parameter estimation in rainfall-runoff models is affected by uncertainties in the observed historical data (e.g. rainfall, evapotranspiration) and/or runoff response data and model inconsistencies. Due to the high variability of rainfall in both space and time it is likely that input errors are likely to persist into the near future. The errors in the observed data collected usually impact the calibration of the WRSM2000 and other rainfall-runoff models. The calibration of the models relies entirely on the accuracy of the observed data, whose accuracy in many cases is difficult to guarantee. This influences the resulting parameters, which will be compounded in any other process dependant on these parameters within the model and ultimately the model results. The reality that uncertainty in the accuracy of data is more sensitive in ungauged catchments where there are no referenced historical observations to guide the parameter estimation process. The derivation of parameters within this study was solely dependent on the accuracy of the data used to formulate these parameters. It however, shows that it is possible to include and quantify the physical characteristics of a catchment in order to produce such parameters for use in the WRSM2000.

4 CONCLUSION

The aim of this analysis was to provide a comparison between the simulated runoff generated for two different parameter derivation procedures. The first of which resulted from the WR2005 study which was based on parameters derived from a regionalisation approach per quaternary catchment in the selected study area, where calibration of these parameters were performed to derive a representative simulated runoff in comparison to the observed runoff. The second, being the focus of this study, was an attempt to include the actual physical catchment characteristics in the process of deriving the parameters as used in the WRSM2000, with an intention of either limiting or avoiding the process of calibration completely. However, as observed from the results above, in most cases, calibration of these parameters was still required in order to replicate the behaviour of the observed runoff measured at the particular flow gauges. Taking all assumptions made during the study along with the uncertainty of data accuracy, it is felt that the aim has been achieved. From the study results it is evident that the inclusion of physical catchment characteristics in the parameter estimation procedure does provide a more accurate sense of catchment layout and an understanding of contributing factors. It highlights the importance of understanding the physical attributes of the catchments under investigation in any study, as this will allow for a higher confidence in the results obtained from the analysis.

The aim of this study was to develop a scientific method to define hydrological response zones, which will provide provisional response zone characteristics for every quaternary catchment within the study areas of Southern Africa. Based on the outcome of the study, this has been highlighted as a possible move to advancement of rainfall-runoff parameter estimation procedures. From the study it is evident that from the utilisation of all available data, i.e. catchment vegetation, slope, soils and geology, formulation of individual quaternary catchment fingerprints throughout the country is achievable and with little effort. The idea behind this statement links back to the proposal made at the onset of this project, which stated that, "on derivation of these fingerprints, homogenous hydrological response zones will be identified". Homogeneity of quaternary catchments with detailed content pertaining to various soils information and slopes alone is an insurmountable task. The idea behind the proposal was to advance on the hydrological zones highlighted in the WR90 study and recently WR2005 study, which was simply based on zones of similar runoff. The advancement was focussed on updating these hydrological zones by including the use of physical catchment characteristics as those mentioned previously. The results obtained from the study supersedes this idea of homogeneity as each quaternary catchment within the country, upon derivation of a "hydrological fingerprint map" will possess its own physical fingerprint necessary for inclusion in any parameter estimation procedures. This then excludes the use of any process of grouping homogenous catchments, and provides the ability to obtain physical characteristics of a more confined study area within a quaternary catchment, and derive the parameters necessary for inclusion in the WRSM2000.

This exploratory pilot study aimed at ascertaining whether the concept of hydrological response fingerprinting is feasible and from the results obtained in the study, it is evident that it is feasible. It is expected that scope will exist in future for more detailed studies to improve the equations and procedures used to define hydrological response "fingerprints". Current studies like the K5/1838 study aims to quantify the compounding effect of data uncertainty but also to assist in providing an extent this uncertainty has on modelled results for informed decisions in water resources planning. Future studies focussing on refining the hydro-meteorological information (rainfall, evaporation and temperature), and biological (vegetation) characteristics, the local geo-physical characteristics (soils, geography, topography) etc would assist such projects in decreasing the uncertainty of results obtained from water resources planning models.

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APPENDICES

APPENDIX A:

Hydrological Fingerprints

C21D - Gauged

	Total quat area (km^2) =			**446**	**Flow gauge**	**Use in WR2005**
	Terrain 1	**Terrain 3**	**Terrain 4**	**Terrain 5**	C2H102	No
	Top	**Middle**	**Bottom**	**Valley**	C2H134	No
Area (km^2)	83	6	162	195	C2H150	No
% Area	19	1	36	44	C2H177	No
Min Slope %	0	3	0	0	C2H187	No
Max Slope%	5	8	5	1	C2H188	No
					C2H189	No
Landtype 1	**Ba1**				C2H190	No
S1 % of Unit	51	83	54	35	C2H191	No
S1 Min Depth	600				C2H192	No
S1 Max Depth	1200+				C2H193	No
S1 Texture	SaClLm				C2H194	No
Landtype 2	**Ba2**				C2H195	No
S2 % of Unit	6	0	30	60	C2H196	No
S2 Min Depth	450				C2H197	No
S2 Max Depth	600				C2H198	No
S2 Texture	SaCl				C2H199	No
Landtype 3	**Ba35**				C2H200	No
S3 % of Unit	5	0	1	0	C2H201	No
S3 Min Depth	300				C2H202	No
S3 Max Depth	1050				C2H203	No
S3 Texture	LmSa				C2H204	No
Landtype 4	**Ba36**				C2H205	No
S4 % of Unit	1	0	1	1	C2H208	No
S4 Min Depth	300					
S4 Max Depth	1050					
S4 Texture	LmSa					
Landtype 5	**Bb3**					
S5 % of Unit	37	17	14	4		
S5 Min Depth	700					
S5 Max Depth	1200					
S5 Texture	SaClLm					
Soil Vert Var	90	80	70	70		
Soil Factors	Macropore	Organics	Structure		Surface Cover	Cover Variability
Index (0 to 2)	1	1	1		0 = Well vegetated	0 = Low
Surface Cover Index	1	1	1	1	1 = Moderate	1 = Moderate
Cover variability index	1	1	1	1	2 = Crusting	2 = High
Regional GW slope %	1				Default	
Vertical Drainage %	4					
Horizontal Drainage %	96					
	GRA2	SD				
Storativity (*1000)	3	0.3				
Depth to GW (m)	25					
Fract Zone Trans (m2/d)	2.5	0.5				
Drainage Density (km/km)	0.13	0.013				
Mean monthly rain (mm)	57.5					
Max Monthly Rain (mm)	118.9					
Mean no. of raindays/month	2					
Mean Storm Duration (h)	6					
Mean Ann Evap (mm)	1625					
Mean Ann Recharge (mm)	4.8	20.6				
% Area of Dominant veg	100					
Dominant veg	Summer		Winter			
Proportions of dominant veg	Low Est	High Est	Low Est	High Est		
Dense forest	0	0	0	0		
Bush/Sparse Forest	0.1	0.2	0.1	0.2		
Dense Crop/Ground Cover	0.6	0.6	0.6	0.6		
Sparse Crop/ Ground Cover	0.3	0.2	0.3	0.2		
Bare Soil	0	0	0	0		
% Area of Secondary veg	0					
Secondary veg	Summer		Winter			
Proportions of secondary veg	Low Est	High Est	Low Est	High Est		
Dense forest						
Bush/Sparse Forest						
Dense Crop/Ground Cover						
Sparse Crop/ Ground Cover						
Bare Soil						

	C21E - Gauged					
	Total quat area (km^2) =			**629**	**Flow gauge**	**Use in WR2005**
	Terrain 1	**Terrain 3**	**Terrain 4**	**Terrain 5**	C2H142	No
	Top	**Middle**	**Bottom**	**Valley**	C2H143	No
Area (km^2)	47	18	185	379	C2H144	No
% Area	7	3	29	60	C2H145	No
Min Slope %	0	7	0	0	C2H146	No
Max Slope%	3	15	2	1	C2H147	No
					C2H148	No
Landtype 1	**Ba1**				C2H149	No
S1 % of Unit	34	28	34	13	C2H178	No
S1 Min Depth	600				C2H179	No
S1 Max Depth	1200+				C2H180	No
S1 Texture	SaClLm				C2H181	No
Landtype 2	**Bb19**				C2H182	No
S2 % of Unit	13	0	17	22	C2H183	No
S2 Min Depth	300				C2H184	No
S2 Max Depth	750				C2H206	No
S2 Texture	SaCl				C2H207	No
Landtype 3	**Bb3**				C2H209	No
S3 % of Unit	53	22	49	53	C2H210	No
S3 Min Depth	700				C2H211	No
S3 Max Depth	1200+				C2H212	No
S3 Texture	SaClLm					
Landtype 4	**Ea15**					
S4 % of Unit	0	6	0	12		
S4 Min Depth	500					
S4 Max Depth	900					
S4 Texture	SaCl					
Landtype 5	**Ib41**					
S5 % of Unit	0	44	0	0		
S5 Min Depth	100					
S5 Max Depth	250					
S5 Texture	LmSa					
Soil Vert Var	90	80	70	70		
Soil Factors	Macropore	Organics	Structure		Surface Cover	Cover Variability
Index (0 to 2)	1	1	1		0 = Well vegetated	0 = Low
Surface Cover Index	1	1	1	1	1 = Moderate	1 = Moderate
Cover variability index	1	1	1	1	2 = Crusting	2 = High
Regional GW slope %	1				Default	
Vertical Drainage %	4					
Horizontal Drainage %	96					
	GRA2	SD				
Storativity (*1000)	3	0.3				
Depth to GW (m)	25					
Fract Zone Trans (m2/d)	2.5	0.5				
Drainage Density (km/km)	0.09	0.009				
Mean monthly rain (mm)	56.9					
Max Monthly Rain (mm)	117.7					
Mean no. of raindays/month	2					
Mean Storm Duration (h)	6					
Mean Ann Evap (mm)	1625					
Mean Ann Recharge (mm)	6.8	14.1				
% Area of Dominant veg	100					
Dominant veg	Summer		Winter			
Proportions of dominant veg	Low Est	High Est	Low Est	High Est		
Dense forest	0	0	0	0		
Bush/Sparse Forest	0.1	0.2	0.1	0.2		
Dense Crop/Ground Cover	0.6	0.6	0.6	0.6		
Sparse Crop/ Ground Cover	0.3	0.2	0.3	0.2		
Bare Soil	0	0	0	0		
% Area of Secondary veg	0					
Secondary veg	Summer		Winter			
Proportions of secondary veg	Low Est	High Est	Low Est	High Est		
Dense forest						
Bush/Sparse Forest						
Dense Crop/Ground Cover						
Sparse Crop/ Ground Cover						
Bare Soil						

	C21F - Gauged					
	Total quat area (km^2) =			**427**	**Flow gauge**	**Use in WR2005**
	Terrain 1	**Terrain 3**	**Terrain 4**	**Terrain 5**	C2H133	No
	Top	**Middle**	**Bottom**	**Valley**	C2H185	No
Area (km^2)	12	16	78	321	C2H186	No
% Area	3	4	18	75	C2H213	No
Min Slope %	0	7	5	0	C2H214	No
Max Slope%	8	50	9	1	C2H216	No
					C2H217	No
Landtype 1	**Ba1**					
S1 % of Unit	8	0	9	34		
S1 Min Depth	450					
S1 Max Depth	700					
S1 Texture	SaClLm					
Landtype 2	**Ba27**					
S2 % of Unit	0	0	6	11		
S2 Min Depth	600					
S2 Max Depth	900					
S2 Texture	SaCl					
Landtype 3	**Ba29**					
S3 % of Unit	0	0	8	46		
S3 Min Depth	450					
S3 Max Depth	1200+					
S3 Texture	LmSa					
Landtype 4	**Ib42**					
S4 % of Unit	58	56	62	10		
S4 Min Depth	100					
S4 Max Depth	250					
S4 Texture	LmSa					
Landtype 5	**Ib43**					
S5 % of Unit	33	44	15	0		
S5 Min Depth	200					
S5 Max Depth	500					
S5 Texture	SaCl					
Soil Vert Var	90	80	70	70		
Soil Factors	Macropore	Organics	Structure		Surface Cover	Cover Variability
Index (0 to 2)	1	1	1		0 = Well vegetated	0 = Low
Surface Cover Index	1	1	1	1	1 = Moderate	1 = Moderate
Cover variability index	1	1	1	1	2 = Crusting	2 = High
Regional GW slope %	1				Default	
Vertical Drainage %	2					
Horizontal Drainage %	98					
	GRA2	SD				
Storativity (*1000)	3	0.3				
Depth to GW (m)	25					
Fract Zone Trans (m2/d)	2.5	0.5				
Drainage Density (km/km)	0.13	0.013				
Mean monthly rain (mm)	58					
Max Monthly Rain (mm)	119.9					
Mean no. of raindays/month	2					
Mean Storm Duration (h)	6					
Mean Ann Evap (mm)	1625					
Mean Ann Recharge (mm)	6.8	13.4				
% Area of Dominant veg	100					
Dominant veg	Summer		Winter			
Proportions of dominant veg	Low Est	High Est	Low Est	High Est		
Dense forest	0	0	0	0		
Bush/Sparse Forest	0.1	0.2	0.1	0.2		
Dense Crop/Ground Cover	0.6	0.6	0.6	0.6		
Sparse Crop/ Ground Cover	0.3	0.2	0.3	0.2		
Bare Soil	0	0	0	0		
% Area of Secondary veg	0					
Secondary veg	Summer		Winter			
Proportions of secondary veg	Low Est	High Est	Low Est	High Est		
Dense forest						
Bush/Sparse Forest						
Dense Crop/Ground Cover						
Sparse Crop/ Ground Cover						
Bare Soil						

	C21G - Gauged					
	Total quat area (km^2) =			**463**	**Flow gauge**	**Use in WR2005**
	Terrain 1	**Terrain 3**	**Terrain 4**	**Terrain 5**	C2H004	No
	Top	**Middle**	**Bottom**	**Valley**	C2H070	Yes
Area (km^2)	13	19	106	325	C2H234	No
% Area	3	4	23	70		
Min Slope %	0	12	0	0		
Max Slope%	8	50	12	1		
Landtype 1	**Ba28**					
S1 % of Unit	0	0	6	14		
S1 Min Depth	600					
S1 Max Depth	900					
S1 Texture	SaCl					
Landtype 2	**Ba29**					
S2 % of Unit	46	0	42	62		
S2 Min Depth	450					
S2 Max Depth	1200+					
S2 Texture	LmSa					
Landtype 3	**Ba31**					
S3 % of Unit	0	0	0	24		
S3 Min Depth	400					
S3 Max Depth	600					
S3 Texture	SaClLm					
Landtype 4	**Ib42**					
S4 % of Unit	23	32	25	0		
S4 Min Depth	100					
S4 Max Depth	250					
S4 Texture	LmSa					
Landtype 5	**Ib44**					
S5 % of Unit	31	68	28	0		
S5 Min Depth	200					
S5 Max Depth	500					
S5 Texture	SaCl					
Soil Vert Var	90	80	70	70		
Soil Factors	Macropore	Organics	Structure		Surface Cover	Cover Variability
Index (0 to 2)	1	1	1		0 = Well vegetated	0 = Low
Surface Cover Index	1	1	1	1	1 = Moderate	1 = Moderate
Cover variability index	1	1	1	1	2 = Crusting	2 = High
Regional GW slope %	1				Default	
Vertical Drainage %	2					
Horizontal Drainage %	98					
	GRA2	SD				
Storativity (*1000)	3	0.3				
Depth to GW (m)	25					
Fract Zone Trans (m2/d)	2.5	0.5				
Drainage Density (km/km)	0.14	0.014				
Mean monthly rain (mm)	54.9					
Max Monthly Rain (mm)	113.6					
Mean no. of raindays/month	2					
Mean Storm Duration (h)	6					
Mean Ann Evap (mm)	1625					
Mean Ann Recharge (mm)	5.4	13.6				
% Area of Dominant veg	100					
Dominant veg	Summer		Winter			
Proportions of dominant veg	Low Est	High Est	Low Est	High Est		
Dense forest	0	0	0	0		
Bush/Sparse Forest	0.1	0.2	0.1	0.2		
Dense Crop/Ground Cover	0.6	0.6	0.6	0.6		
Sparse Crop/ Ground Cover	0.3	0.2	0.3	0.2		
Bare Soil	0	0	0	0		
% Area of Secondary veg	0					
Secondary veg	Summer		Winter			
Proportions of secondary veg	Low Est	High Est	Low Est	High Est		
Dense forest						
Bush/Sparse Forest						
Dense Crop/Ground Cover						
Sparse Crop/ Ground Cover						
Bare Soil						

	C21A - Ungauged					
	Total quat area (km^2) =			707		
	Terrain 1	Terrain 3	Terrain 4	Terrain 5		
	Top	Middle	Bottom	Valley		
Area (km^2)	235	75	284	113		
% Area	33	11	40	16		
Min Slope %	0	2	0	0		
Max Slope%	5	8	4	1		
Landtype 1	Bb19					
S1 % of Unit	10	21	14	23		
S1 Min Depth	300					
S1 Max Depth	750					
S1 Texture	SaCl					
Landtype 2	Dc2					
S2 % of Unit	17	21	22	11		
S2 Min Depth	250					
S2 Max Depth	450					
S2 Texture	SaClLm					
Landtype 3	Ea15					
S3 % of Unit	6	9	5	27		
S3 Min Depth	500					
S3 Max Depth	900					
S3 Texture	SaCl					
Landtype 4	Ea17					
S4 % of Unit	53	41	47	27		
S4 Min Depth	300					
S4 Max Depth	900					
S4 Texture	Cl					
Landtype 5	Ea20					
S5 % of Unit	14	7	12	12		
S5 Min Depth	300					
S5 Max Depth	600					
S5 Texture	SaCl					
Soil Vert Var	90	80	70	70		
Soil Factors	Macropore	Organics	Structure		Surface Cover	Cover Variability
Index (0 to 2)	1	1	1		0 = Well vegetated	0 = Low
Surface Cover Index	1	1	1	1	1 = Moderate	1 = Moderate
Cover variability index	1	1	1	1	2 = Crusting	2 = High
Regional GW slope %	1				Default	
Vertical Drainage %	2					
Horizontal Drainage %	98					
	GRA2	SD				
Storativity (*1000)	3	0.3				
Depth to GW (m)	25					
Fract Zone Trans (m2/d)	2.5	0.5				
Drainage Density (km/km)	0.19	0.019				
Mean monthly rain (mm)	55.5					
Max Monthly Rain (mm)	114.8					
Mean no. of raindays/month	2					
Mean Storm Duration (h)	6					
Mean Ann Evap (mm)	1600					
Mean Ann Recharge (mm)	7.1	13.2				
% Area of Dominant veg	100					
Dominant veg	Summer		Winter			
Proportions of dominant veg	Low Est	High Est	Low Est	High Est		
Dense forest	0	0	0	0		
Bush/Sparse Forest	0.1	0.2	0.1	0.2		
Dense Crop/Ground Cover	0.6	0.6	0.6	0.6		
Sparse Crop/ Ground Cover	0.3	0.2	0.3	0.2		
Bare Soil	0	0	0	0		
% Area of Secondary veg	0					
Secondary veg	Summer		Winter			
Proportions of secondary veg	Low Est	High Est	Low Est	High Est		
Dense forest						
Bush/Sparse Forest						
Dense Crop/Ground Cover						
Sparse Crop/ Ground Cover						
Bare Soil						

	C21B - Ungauged					
	Total quat area (km^2) =			**431**		
	Terrain 1	**Terrain 3**	**Terrain 4**	**Terrain 5**		
	Top	**Middle**	**Bottom**	**Valley**		
Area (km^2)	48	41	146	196		
% Area	11	10	34	45		
Min Slope %	0	12	0	0		
Max Slope%	8	50	5	2		
Landtype 1	**Ba1**					
S1 % of Unit	60	0	34	33		
S1 Min Depth	600					
S1 Max Depth	1200+					
S1 Texture	SaClLm					
Landtype 2	**Ba2**					
S2 % of Unit	23	0	34	30		
S2 Min Depth	900					
S2 Max Depth	1200+					
S2 Texture	SaClLm					
Landtype 3	**Ba27**					
S3 % of Unit	10	27	25	0		
S3 Min Depth	600					
S3 Max Depth	900					
S3 Texture	SaCl					
Landtype 4	**Bb19**					
S4 % of Unit	6	0	8	37		
S4 Min Depth	300					
S4 Max Depth	750					
S4 Texture	SaCl					
Landtype 5	**Ib44**					
S5 % of Unit	0	73	0	0		
S5 Min Depth	200					
S5 Max Depth	500					
S5 Texture	SaCl					
Soil Vert Var	90	80	70	70		
Soil Factors	Macropore	Organics	Structure		Surface Cover	Cover Variability
Index (0 to 2)	1	1	1		0 = Well vegetated	0 = Low
Surface Cover Index	1	1	1	1	1 = Moderate	1 = Moderate
Cover variability index	1	1	1	1	2 = Crusting	2 = High
Regional GW slope %	1				Default	
Vertical Drainage %	2					
Horizontal Drainage %	98					
	GRA2	SD				
Storativity (*1000)	3	0.3				
Depth to GW (m)	25					
Fract Zone Trans (m2/d)	2.5	0.5				
Drainage Density (km/km)	0.14	0.014				
Mean monthly rain (mm)	57.4					
Max Monthly Rain (mm)	118.7					
Mean no. of raindays/month	2					
Mean Storm Duration (h)	6					
Mean Ann Evap (mm)	1600					
Mean Ann Recharge (mm)	6.9	11.3				
% Area of Dominant veg	100					
Dominant veg	Summer		Winter			
Proportions of dominant veg	Low Est	High Est	Low Est	High Est		
Dense forest	0	0	0	0		
Bush/Sparse Forest	0.1	0.2	0.1	0.2		
Dense Crop/Ground Cover	0.6	0.6	0.6	0.6		
Sparse Crop/ Ground Cover	0.3	0.2	0.3	0.2		
Bare Soil	0	0	0	0		
% Area of Secondary veg	0					
Secondary veg	Summer		Winter			
Proportions of secondary veg	Low Est	High Est	Low Est	High Est		
Dense forest						
Bush/Sparse Forest						
Dense Crop/Ground Cover						
Sparse Crop/ Ground Cover						
Bare Soil						

	C21C - Ungauged					
	Total quat area (km^2) =			438		
	Terrain 1	Terrain 3	Terrain 4	Terrain 5		
	Top	Middle	Bottom	Valley		
Area (km^2)	12	26	91	309		
% Area	3	6	21	71		
Min Slope %	0	7	0	0		
Max Slope%	8	15	5	1		
Landtype 1	Ba1					
S1 % of Unit	42	4	22	15		
S1 Min Depth	600					
S1 Max Depth	1200+					
S1 Texture	SaClLm					
Landtype 2	Ba29					
S2 % of Unit	8	0	24	21		
S2 Min Depth	600					
S2 Max Depth	1200+					
S2 Texture	LmSa					
Landtype 3	Ba30					
S3 % of Unit	0	0	8	64		
S3 Min Depth	450					
S3 Max Depth	600					
S3 Texture	SaClLm					
Landtype 4	Ib42					
S4 % of Unit	33	58	29	0		
S4 Min Depth	100					
S4 Max Depth	250					
S4 Texture	LmSa					
Landtype 5	Ib44					
S5 % of Unit	17	38	18	0		
S5 Min Depth	200					
S5 Max Depth	500					
S5 Texture	SaCl					
Soil Vert Var	90	80	70	70		
Soil Factors	Macropore	Organics	Structure		Surface Cover	Cover Variability
Index (0 to 2)	1	1	1		0 = Well vegetated	0 = Low
Surface Cover Index	1	1	1	1	1 = Moderate	1 = Moderate
Cover variability index	1	1	1	1	2 = Crusting	2 = High
Regional GW slope %	1				Default	
Vertical Drainage %	2					
Horizontal Drainage %	98					
	GRA2	SD				
Storativity (*1000)	3	0.3				
Depth to GW (m)	25					
Fract Zone Trans (m2/d)	2.5	0.5				
Drainage Density (km/km)	0.20	0.020				
Mean monthly rain (mm)	55.5					
Max Monthly Rain (mm)	114.8					
Mean no. of raindays/month	2					
Mean Storm Duration (h)	6					
Mean Ann Evap (mm)	1600					
Mean Ann Recharge (mm)	7.8	10.7				
% Area of Dominant veg	100					
Dominant veg	Summer		Winter			
Proportions of dominant veg	Low Est	High Est	Low Est	High Est		
Dense forest	0	0	0	0		
Bush/Sparse Forest	0.1	0.2	0.1	0.2		
Dense Crop/Ground Cover	0.6	0.6	0.6	0.6		
Sparse Crop/ Ground Cover	0.3	0.2	0.3	0.2		
Bare Soil	0	0	0	0		
% Area of Secondary veg	0					
Secondary veg	Summer		Winter			
Proportions of secondary veg	Low Est	High Est	Low Est	High Est		
Dense forest						
Bush/Sparse Forest						
Dense Crop/Ground Cover						
Sparse Crop/ Ground Cover						
Bare Soil						

	J21A - Gauged					
	Total quat area (km^2) =			**854**	**Flow gauge**	**Use in WR2005**
	Terrain 1	**Terrain 3**	**Terrain 4**	**Terrain 5**	J2H017	No
	Top	**Middle**	**Bottom**	**Valley**	J2H018	No
Area (km^2)	68	64	122	600	J2H019	No
% Area	8	7	14	70	J2H020	No
Min Slope %	0	10	2	0	J2H022	No
Max Slope%	4	40	4	3	J2H023	No
					J2H025	No
Landtype 1	**Fc160**				J2H026	No
S1 % of Unit	0	0	7	47		
S1 Min Depth	500					
S1 Max Depth	1200+					
S1 Texture	Sa					
Landtype 2	**Fc385**					
S2 % of Unit	1	3	14	32		
S2 Min Depth	500					
S2 Max Depth	1200+					
S2 Texture	LmSa					
Landtype 3	**Fc389**					
S3 % of Unit	0	0	0	21		
S3 Min Depth	500					
S3 Max Depth	1200+					
S3 Texture	LmSa					
Landtype 4	**Ib255**					
S4 % of Unit	10	77	35	0		
S4 Min Depth	50					
S4 Max Depth	200					
S4 Texture	Sa					
Landtype 5	**Ib257**					
S5 % of Unit	88	20	44	0		
S5 Min Depth	150					
S5 Max Depth	300					
S5 Texture	LmSa					
Soil Vert Var	90	80	70	70		
Soil Factors	Macropore	Organics	Structure		Surface Cover	Cover Variability
Index (0 to 2)	1	1	1		0 = Well vegetated	0 = Low
Surface Cover Index	1	1	1	1	1 = Moderate	1 = Moderate
Cover variability index	1	1	1	1	2 = Crusting	2 = High
Regional GW slope %	1				Default	
Vertical Drainage %	2					
Horizontal Drainage %	98					
	GRA2	SD				
Storativity (*1000)	3	0.3				
Depth to GW (m)	25					
Fract Zone Trans (m2/d)	2.5	0.5				
Drainage Density (km/km)	0.14	0.014				
Mean monthly rain (mm)	19.8					
Max Monthly Rain (mm)	39.3					
Mean no. of raindays/month	1					
Mean Storm Duration (h)	6					
Mean Ann Evap (mm)	2300					
Mean Ann Recharge (mm)	0.1	3.0				
% Area of Dominant veg	100					
Dominant veg	Summer		Winter			
Proportions of dominant veg	Low Est	High Est	Low Est	High Est		
Dense forest	0	0	0	0		
Bush/Sparse Forest	0.1	0.1	0.1	0.1		
Dense Crop/Ground Cover	0.15	0.2	0.15	0.2		
Sparse Crop/ Ground Cover	0.55	0.6	0.55	0.6		
Bare Soil	0.2	0.1	0.2	0.1		
% Area of secondary veg	0					
Secondary veg	Summer		Winter			
Proportions of secondary veg	Low Est	High Est	Low Est	High Est		
Dense forest						
Bush/Sparse Forest						
Dense Crop/Ground Cover						
Sparse Crop/ Ground Cover						
Bare Soil						

J21B - Ungauged

	Total quat area (km^2) =			530		
	Terrain 1	Terrain 3	Terrain 4	Terrain 5		
	Top	Middle	Bottom	Valley		
Area (km^2)	17	18	97	398		
% Area	3	3	18	75		
Min Slope %	1	6	2	1		
Max Slope%	5	25	4	3		
Landtype 1		Fc160				
S1 % of Unit	41	39	43	47		
S1 Min Depth	50					
S1 Max Depth	200					
S1 Texture	Sa					
Landtype 2		Fc179				
S2 % of Unit	0	0	9	26		
S2 Min Depth	400					
S2 Max Depth	600					
S2 Texture	Sa					
Landtype 3		Fc181				
S3 % of Unit	6	17	12	0		
S3 Min Depth	50					
S3 Max Depth	300					
S3 Texture	Sa					
Landtype 4		Fc384				
S4 % of Unit	0	0	0	26		
S4 Min Depth	500					
S4 Max Depth	1200+					
S4 Texture	Sa					
Landtype 5		Ib254				
S5 % of Unit	53	44	35	0		
S5 Min Depth	50					
S5 Max Depth	100					
S5 Texture	Sa					
Soil Vert Var	90	80	70	70		
Soil Factors	Macropore	Organics	Structure		Surface Cover	Cover Variability
Index (0 to 2)	1	1	1		0 = Well vegetated	0 = Low
Surface Cover Index	1	1	1	1	1 = Moderate	1 = Moderate
Cover variability index	1	1	1	1	2 = Crusting	2 = High
Regional GW slope %	1				Default	
Vertical Drainage %	2					
Horizontal Drainage %	98					
	GRA2	SD				
Storativity (*1000)	3	0.3				
Depth to GW (m)	25					
Fract Zone Trans (m2/d)	2.5	0.5				
Drainage Density (km/km)	0.21	0.021				
Mean monthly rain (mm)	16.2					
Max Monthly Rain (mm)	32.1					
Mean no. of raindays/month	1					
Mean Storm Duration (h)	6					
Mean Ann Evap (mm)	2305					
Mean Ann Recharge (mm)	0.0	0.7				
% Area of Dominant veg	100					
Dominant veg	Summer		Winter			
Proportions of dominant veg	Low Est	High Est	Low Est	High Est		
Dense forest	0	0	0	0		
Bush/Sparse Forest	0.1	0.1	0.1	0.1		
Dense Crop/Ground Cover	0.15	0.2	0.15	0.2		
Sparse Crop/ Ground Cover	0.55	0.6	0.55	0.6		
Bare Soil	0.2	0.1	0.2	0.1		
% Area of secondary veg	0					
Secondary veg	Summer		Winter			
Proportions of secondary veg	Low Est	High Est	Low Est	High Est		
Dense forest						
Bush/Sparse Forest						
Dense Crop/Ground Cover						
Sparse Crop/ Ground Cover						
Bare Soil						

	J21C - Ungauged					
	Total quat area (km^2) =			526		
	Terrain 1	Terrain 3	Terrain 4	Terrain 5		
	Top	Middle	Bottom	Valley		
Area (km^2)	46	30	192	258		
% Area	9	6	37	49		
Min Slope %	1	6	2	1		
Max Slope%	3	15	4	3		
Landtype 1	Fc160					
S1 % of Unit	98	97	95	91		
S1 Min Depth	500					
S1 Max Depth	1200+					
S1 Texture	Sa					
Landtype 2	Fc183					
S2 % of Unit	2	3	4	6		
S2 Min Depth	50					
S2 Max Depth	300					
S2 Texture	Sa					
Landtype 3	Fc383					
S3 % of Unit	0	0	2	3		
S3 Min Depth	50					
S3 Max Depth	200					
S3 Texture	LmSa					
Landtype 4						
S4 % of Unit						
S4 Min Depth						
S4 Max Depth						
S4 Texture						
Landtype 5						
S5 % of Unit						
S5 Min Depth						
S5 Max Depth						
S5 Texture						
Soil Vert Var	90	80	70	70		
Soil Factors	Macropore	Organics	Structure		Surface Cover	Cover Variability
Index (0 to 2)	1	1	1		0 = Well vegetated	0 = Low
Surface Cover Index	1	1	1	1	1 = Moderate	1 = Moderate
Cover variability index	1	1	1	1	2 = Crusting	2 = High
Regional GW slope %	1				Default	
Vertical Drainage %	2					
Horizontal Drainage %	98					
	GRA2	SD				
Storativity (*1000)	3	0.3				
Depth to GW (m)	25					
Fract Zone Trans (m2/d)	2.5	0.5				
Drainage Density (km/km)	0.20	0.020				
Mean monthly rain (mm)	14.2					
Max Monthly Rain (mm)	30.5					
Mean no. of raindays/month	0					
Mean Storm Duration (h)	6					
Mean Ann Evap (mm)	2350					
Mean Ann Recharge (mm)	0.0	0.1				
% Area of Dominant veg	100					
Dominant veg	Summer		Winter			
Proportions of dominant veg	Low Est	High Est	Low Est	High Est		
Dense forest	0	0	0	0		
Bush/Sparse Forest	0.1	0.1	0.1	0.1		
Dense Crop/Ground Cover	0.15	0.2	0.15	0.2		
Sparse Crop/ Ground Cover	0.55	0.6	0.55	0.6		
Bare Soil	0.2	0.1	0.2	0.1		
% Area of secondary veg	0					
Secondary veg	Summer		Winter			
Proportions of secondary veg	Low Est	High Est	Low Est	High Est		
Dense forest						
Bush/Sparse Forest						
Dense Crop/Ground Cover						
Sparse Crop/ Ground Cover						
Bare Soil						

	J21D - Ungauged					
	Total quat area (km^2) =			**650**		
	Terrain 1	**Terrain 3**	**Terrain 4**	**Terrain 5**		
	Top	**Middle**	**Bottom**	**Valley**		
Area (km^2)	108	32	253	257		
% Area	17	5	39	40		
Min Slope %	1	6	2	1		
Max Slope%	3	25	4	3		
Landtype 1	**Fc160**					
S1 % of Unit	51	47	36	14		
S1 Min Depth	50					
S1 Max Depth	200					
S1 Texture	Sa					
Landtype 2	**Fc179**					
S2 % of Unit	48	47	60	76		
S2 Min Depth	400					
S2 Max Depth	600					
S2 Texture	Sa					
Landtype 3	**Fc183**					
S3 % of Unit	1	3	3	5		
S3 Min Depth	100					
S3 Max Depth	300					
S3 Texture	Sa					
Landtype 4	**Ia45**					
S4 % of Unit	0	3	1	4		
S4 Min Depth	600					
S4 Max Depth	1200+					
S4 Texture	LmSa					
Landtype 5						
S5 % of Unit						
S5 Min Depth						
S5 Max Depth						
S5 Texture						
Soil Vert Var	90	80	70	70		
Soil Factors	Macropore	Organics	Structure		Surface Cover	Cover Variability
Index (0 to 2)	1	1	1		0 = Well vegetated	0 = Low
Surface Cover Index	1	1	1	1	1 = Moderate	1 = Moderate
Cover variability index	1	1	1	1	2 = Crusting	2 = High
Regional GW slope %	1				Default	
Vertical Drainage %	2					
Horizontal Drainage %	98					
	GRA2	SD				
Storativity (*1000)	3	0.3				
Depth to GW (m)	25					
Fract Zone Trans (m2/d)	2.5	0.5				
Drainage Density (km/km)	0.12	0.012				
Mean monthly rain (mm)	13.2					
Max Monthly Rain (mm)	28.5					
Mean no. of raindays/month	0					
Mean Storm Duration (h)	6					
Mean Ann Evap (mm)	2305					
Mean Ann Recharge (mm)	0.0	0.1				
% Area of Dominant veg	100					
Dominant veg	Summer		Winter			
Proportions of dominant veg	Low Est	High Est	Low Est	High Est		
Dense forest	0	0	0	0		
Bush/Sparse Forest	0.1	0.1	0.1	0.1		
Dense Crop/Ground Cover	0.15	0.2	0.15	0.2		
Sparse Crop/ Ground Cover	0.55	0.6	0.55	0.6		
Bare Soil	0.2	0.1	0.2	0.1		
% Area of secondary veg	0					
Secondary veg	Summer		Winter			
Proportions of secondary veg	Low Est	High Est	Low Est	High Est		
Dense forest						
Bush/Sparse Forest						
Dense Crop/Ground Cover						
Sparse Crop/ Ground Cover						
Bare Soil						

	V31A - Gauged					
	Total quat area (km^2) =			622	Flow gauge	Use in WR2005
	Terrain 1	Terrain 3	Terrain 4	Terrain 5	V3H028	Yes
	Top	Middle	Bottom	Valley	V3H029	Yes
Area (km^2)	326	137	0	159		
% Area	52	22	0	26		
Min Slope %	2	12		0		
Max Slope%	8	60		2		
Landtype 1	Ab63					
S1 % of Unit	4	0	0	0		
S1 Min Depth	600					
S1 Max Depth	900					
S1 Texture	SaClLm					
Landtype 2	Ac99					
S2 % of Unit	41	9	0	0		
S2 Min Depth	600					
S2 Max Depth	1000					
S2 Texture	SaClLm					
Landtype 3	Ca17					
S3 % of Unit	2	41	0	88		
S3 Min Depth	300					
S3 Max Depth	600					
S3 Texture	LmSa					
Landtype 4	Fa360					
S4 % of Unit	39	36	0	8		
S4 Min Depth	100					
S4 Max Depth	300					
S4 Texture	LmSa					
Landtype 5	Fa361					
S5 % of Unit	14	15	0	4		
S5 Min Depth	100					
S5 Max Depth	300					
S5 Texture	LmSa					
Soil Vert Var	90	80	70	70		
Soil Factors	Macropore	Organics	Structure		Surface Cover	Cover Variability
Index (0 to 2)	1	1	1		0 = Well vegetated	0 = Low
Surface Cover Index	1	1	1	1	1 = Moderate	1 = Moderate
Cover variability index	1	1	1	1	2 = Crusting	2 = High
Regional GW slope %	1				Default	
Vertical Drainage %	2					
Horizontal Drainage %	98					
	GRA2	SD				
Storativity (*1000)	3	0.3				
Depth to GW (m)	25					
Fract Zone Trans (m2/d)	2.5	0.5				
Drainage Density (km/km)	0.22	0.022				
Mean monthly rain (mm)	76.2					
Max Monthly Rain (mm)	152.8					
Mean no. of raindays/month	2					
Mean Storm Duration (h)	6					
Mean Ann Evap (mm)	1400					
Mean Ann Recharge (mm)	15.9	28.8				
% Area of Dominant veg	100					
Dominant veg	Summer		Winter			
Proportions of dominant veg	Low Est	High Est	Low Est	High Est		
Dense forest	0	0	0	0		
Bush/Sparse Forest	0	0	0	0		
Dense Crop/Ground Cover	0.5	0.6	0.5	0.6		
Sparse Crop/ Ground Cover	0.3	0.3	0.3	0.3		
Bare Soil	0.2	0.1	0.2	0.1		
% Area of secondary veg	0					
Secondary veg	Summer		Winter			
Proportions of secondary veg	Low Est	High Est	Low Est	High Est		
Dense forest						
Bush/Sparse Forest						
Dense Crop/Ground Cover						
Sparse Crop/ Ground Cover						
Bare Soil						

	V31B - Gauged					
	Total quat area (km^2) =			505	Flow gauge	Use in WR2005
	Terrain 1	Terrain 3	Terrain 4	Terrain 5	V3H005	Yes
	Top	Middle	Bottom	Valley		
Area (km^2)	47	149	0	309		
% Area	9	30	0	61		
Min Slope %	5	8		1		
Max Slope%	15	30		2		
Landtype 1	Ac3					
S1 % of Unit	23	0	0	0		
S1 Min Depth	100					
S1 Max Depth	200					
S1 Texture	LmSa					
Landtype 2	Ca17					
S2 % of Unit	19	0	0	7		
S2 Min Depth	600					
S2 Max Depth	1200+					
S2 Texture	LmSa					
Landtype 3	Ca2					
S3 % of Unit	0	18	0	93		
S3 Min Depth	300					
S3 Max Depth	600					
S3 Texture	LmSa					
Landtype 4	Fa24					
S4 % of Unit	57	52	0	0		
S4 Min Depth	300					
S4 Max Depth	600					
S4 Texture	SaClLm					
Landtype 5	Ib50					
S5 % of Unit	0	30	0	0		
S5 Min Depth	400					
S5 Max Depth	600					
S5 Texture	SaCl					
Soil Vert Var	90	80	70	70		
Soil Factors	Macropore	Organics	Structure		Surface Cover	Cover Variability
Index (0 to 2)	1	1	1		0 = Well vegetated	0 = Low
Surface Cover Index	1	1	1	1	1 = Moderate	1 = Moderate
Cover variability index	1	1	1	1	2 = Crusting	2 = High
Regional GW slope %	1				Default	
Vertical Drainage %	2					
Horizontal Drainage %	98					
	GRA2	SD				
Storativity (*1000)	3	0.3				
Depth to GW (m)	25					
Fract Zone Trans (m2/d)	2.5	0.5				
Drainage Density (km/km)	0.16	0.016				
Mean monthly rain (mm)	71.2					
Max Monthly Rain (mm)	142.8					
Mean no. of raindays/month	2					
Mean Storm Duration (h)	6					
Mean Ann Evap (mm)	1400					
Mean Ann Recharge (mm)	8.7	17.6				
% Area of Dominant veg	100					
Dominant veg	Summer		Winter			
Proportions of dominant veg	Low Est	High Est	Low Est	High Est		
Dense forest	0	0	0	0		
Bush/Sparse Forest	0	0	0	0		
Dense Crop/Ground Cover	0.5	0.6	0.5	0.6		
Sparse Crop/ Ground Cover	0.3	0.3	0.3	0.3		
Bare Soil	0.2	0.1	0.2	0.1		
% Area of secondary veg	0					
Secondary veg	Summer		Winter			
Proportions of secondary veg	Low Est	High Est	Low Est	High Est		
Dense forest						
Bush/Sparse Forest						
Dense Crop/Ground Cover						
Sparse Crop/ Ground Cover						
Bare Soil						

	V31C - Gauged					
	Total quat area (km^2) =			**396**	**Flow gauge**	**Use in WR2005**
	Terrain 1	**Terrain 3**	**Terrain 4**	**Terrain 5**	V3H002	Yes
	Top	**Middle**	**Bottom**	**Valley**	V3H030	No
Area (km^2)	113	79	61	143	V3H031	Yes
% Area	29	20	15	36	V3H032	Yes
Min Slope %	4	12	12	3	V3H033	Yes
Max Slope%	8	30	30	6		
Landtype 1	**Bb31**					
S1 % of Unit	85	0	25	7		
S1 Min Depth	100					
S1 Max Depth	200					
S1 Texture	LmSa					
Landtype 2	**Bd26**					
S2 % of Unit	0	0	0	32		
S2 Min Depth	300					
S2 Max Depth	800					
S2 Texture	SaClLm					
Landtype 3	**Ca20**					
S3 % of Unit	0	0	0	31		
S3 Min Depth	300					
S3 Max Depth	500					
S3 Texture	SaCl					
Landtype 4	**Ea34**					
S4 % of Unit	0	32	39	28		
S4 Min Depth	300					
S4 Max Depth	1200					
S4 Texture	SaCl					
Landtype 5	**Fa29**					
S5 % of Unit	15	68	36	2		
S5 Min Depth	100					
S5 Max Depth	200					
S5 Texture	LmSa					
Soil Vert Var	90	80	70	70		
Soil Factors	Macropore	Organics	Structure		Surface Cover	Cover Variability
Index (0 to 2)	1	1	1		0 = Well vegetated	0 = Low
Surface Cover Index	1	1	1	1	1 = Moderate	1 = Moderate
Cover variability index	1	1	1	1	2 = Crusting	2 = High
Regional GW slope %	1				Default	
Vertical Drainage %	2					
Horizontal Drainage %	98					
	GRA2	SD				
Storativity (*1000)	3	0.3				
Depth to GW (m)	25					
Fract Zone Trans (m2/d)	2.5	0.5				
Drainage Density (km/km)	0.21	0.021				
Mean monthly rain (mm)	67.4					
Max Monthly Rain (mm)	135.1					
Mean no. of raindays/month	2					
Mean Storm Duration (h)	6					
Mean Ann Evap (mm)	1400					
Mean Ann Recharge (mm)	4.6	13.0				
% Area of Dominant veg	100					
Dominant veg	Summer		Winter			
Proportions of dominant veg	Low Est	High Est	Low Est	High Est		
Dense forest	0.4	0.5	0.4	0.5		
Bush/Sparse Forest	0.1	0.2	0.1	0.2		
Dense Crop/Ground Cover	0.5	0.3	0.5	0.3		
Sparse Crop/ Ground Cover	0	0	0	0		
Bare Soil	0	0	0	0		
% Area of secondary veg	0					
Secondary veg	Summer		Winter			
Proportions of secondary veg	Low Est	High Est	Low Est	High Est		
Dense forest						
Bush/Sparse Forest						
Dense Crop/Ground Cover						
Sparse Crop/ Ground Cover						
Bare Soil						

V31D - Gauged

	Total quat area (km^2) =			**467**	**Flow gauge**	**Use in WR2005**
	Terrain 1	**Terrain 3**	**Terrain 4**	**Terrain 5**	V3H022	No
	Top	**Middle**	**Bottom**	**Valley**	V3H023	No
Area (km^2)	34	24	59	350		
% Area	7	5	13	75		
Min Slope %	4	12	2	1		
Max Slope%	5	60	6	6		
Landtype 1	**Ac110**					
S1 % of Unit	59	0	0	0		
S1 Min Depth	600					
S1 Max Depth	900					
S1 Texture	SaCl					
Landtype 2	**Bb54**					
S2 % of Unit	0	0	37	62		
S2 Min Depth	400					
S2 Max Depth	600					
S2 Texture	LmSa					
Landtype 3	**Ea34**					
S3 % of Unit	29	17	15	38		
S3 Min Depth	200					
S3 Max Depth	900					
S3 Texture	SaCl					
Landtype 4	**Fa28**					
S4 % of Unit	0	25	36	0		
S4 Min Depth	400					
S4 Max Depth	600					
S4 Texture	Cl					
Landtype 5	**Fa360**					
S5 % of Unit	12	58	12	0		
S5 Min Depth	100					
S5 Max Depth	300					
S5 Texture	LmSa					
Soil Vert Var	90	80	70	70		
Soil Factors	Macropore	Organics	Structure			Cover Variability
Index (0 to 2)	1	1	1			0 = Low
Surface Cover Index	1	1	1	1		1 = Moderate
Cover variability index	1	1	1	1		2 = High
Regional GW slope %	1					
Vertical Drainage %	2					
Horizontal Drainage %	98					
	GRA2	SD				
Storativity (*1000)	3	0.3				
Depth to GW (m)	25					
Fract Zone Trans (m2/d)	2.5	0.5				
Drainage Density (km/km)	0.11	0.011				
Mean monthly rain (mm)	65.7					
Max Monthly Rain (mm)	131.8					
Mean no. of raindays/month	2					
Mean Storm Duration (h)	6					
Mean Ann Evap (mm)	1450					
Mean Ann Recharge (mm)	7.7	13.4				
% Area of Dominant veg	100					
Dominant veg	Summer		Winter			
Proportions of dominant veg	Low Est	High Est	Low Est	High Est		
Dense forest	0	0	0	0		
Bush/Sparse Forest	0	0	0	0		
Dense Crop/Ground Cover	0.5	0.6	0.5	0.6		
Sparse Crop/ Ground Cover	0.3	0.3	0.3	0.3		
Bare Soil	0.2	0.1	0.2	0.1		
% Area of secondary veg	0					
Secondary veg	Summer		Winter			
Proportions of secondary veg	Low Est	High Est	Low Est	High Est		
Dense forest						
Bush/Sparse Forest						
Dense Crop/Ground Cover						
Sparse Crop/ Ground Cover						
Bare Soil						

	V31E - Gauged					
	Total quat area (km^2) =			834	Flow gauge	Use in WR2005
	Terrain 1	Terrain 3	Terrain 4	Terrain 5	V3H012	No
	Top	Middle	Bottom	Valley	V3H013	No
Area (km^2)	39	103	149	543	V3H014	No
% Area	5	12	18	65	V3H016	No
Min Slope %	1	20	3	1	V3H017	No
Max Slope%	2	100	10	4	V3H019	No
					V3H020	No
Landtype 1	Bb32				V3H025	Yes
S1 % of Unit	18	8	38	0	V3H026	Yes
S1 Min Depth	300				V3H027	Yes
S1 Max Depth	450					
S1 Texture	SaClLm					
Landtype 2	Ac438					
S2 % of Unit	82	0	0	0		
S2 Min Depth	700					
S2 Max Depth	1200					
S2 Texture	SaClLm					
Landtype 3	Bb53					
S3 % of Unit	0	0	0	100		
S3 Min Depth	300					
S3 Max Depth	500					
S3 Texture	SaCl					
Landtype 4	Fa28					
S4 % of Unit	0	43	28	0		
S4 Min Depth	400					
S4 Max Depth	600					
S4 Texture	Cl					
Landtype 5	Fa804					
S5 % of Unit	0	50	34	0		
S5 Min Depth	300					
S5 Max Depth	400					
S5 Texture	Cl					
Soil Vert Var	90	80	70	70		
Soil Factors	Macropore	Organics	Structure		Surface Cover	Cover Variability
Index (0 to 2)	1	1	1		0 = Well vegetated	0 = Low
Surface Cover Index	1	1	1	1	1 = Moderate	1 = Moderate
Cover variability index	1	1	1	1	2 = Crusting	2 = High
Regional GW slope %	1				Default	
Vertical Drainage %	2					
Horizontal Drainage %	98					
	GRA2	SD				
Storativity (*1000)	3	0.3				
Depth to GW (m)	25					
Fract Zone Trans (m2/d)	2.5	0.5				
Drainage Density (km/km)	0.24	0.024				
Mean monthly rain (mm)	71					
Max Monthly Rain (mm)	150.1					
Mean no. of raindays/month	2					
Mean Storm Duration (h)	6					
Mean Ann Evap (mm)	1450					
Mean Ann Recharge (mm)	15.1	29.5				
% Area of Dominant veg	100					
Dominant veg	Summer		Winter			
Proportions of dominant veg	Low Est	High Est	Low Est	High Est		
Dense forest	0.4	0.5	0.4	0.5		
Bush/Sparse Forest	0.1	0.2	0.1	0.2		
Dense Crop/Ground Cover	0.5	0.3	0.5	0.3		
Sparse Crop/ Ground Cover	0	0	0	0		
Bare Soil	0	0	0	0		
% Area of secondary veg	0					
Secondary veg	Summer		Winter			
Proportions of secondary veg	Low Est	High Est	Low Est	High Est		
Dense forest						
Bush/Sparse Forest						
Dense Crop/Ground Cover						
Sparse Crop/ Ground Cover						
Bare Soil						

	V31F - Gauged					
	Total quat area (km^2) =			156	Flow gauge	Use in WR2005
	Terrain 1	Terrain 3	Terrain 4	Terrain 5	V3H004	No
	Top	Middle	Bottom	Valley	V3H009	Yes
Area (km^2)	4	18	0	134		
% Area	3	12	0	86		
Min Slope %	1	20		1		
Max Slope%	4	100		4		
Landtype 1	Ac5					
S1 % of Unit	0	17	0	31		
S1 Min Depth	300					
S1 Max Depth	600					
S1 Texture	SaCl					
Landtype 2	Bb53					
S2 % of Unit	0	6	0	65		
S2 Min Depth	300					
S2 Max Depth	500					
S2 Texture	SaCl					
Landtype 3	Bb54					
S3 % of Unit	0	0	0	2		
S3 Min Depth	400					
S3 Max Depth	600					
S3 Texture	LmSa					
Landtype 4	Fa28					
S4 % of Unit	100	78	0	2		
S4 Min Depth	400					
S4 Max Depth	600					
S4 Texture	Cl					
Landtype 5						
S5 % of Unit						
S5 Min Depth						
S5 Max Depth						
S5 Texture						
Soil Vert Var	90	80	70	70		
Soil Factors	Macropore	Organics	Structure		Surface Cover	Cover Variability
Index (0 to 2)	1	1	1		0 = Well vegetated	0 = Low
Surface Cover Index	1	1	1	1	1 = Moderate	1 = Moderate
Cover variability index	1	1	1	1	2 = Crusting	2 = High
Regional GW slope %	1				Default	
Vertical Drainage %	2					
Horizontal Drainage %	98					
	GRA2	SD				
Storativity (*1000)	3	0.3				
Depth to GW (m)	25					
Fract Zone Trans (m2/d)	2.5	0.5				
Drainage Density (km/km)	0.23	0.023				
Mean monthly rain (mm)	76.4					
Max Monthly Rain (mm)	161.5					
Mean no. of raindays/month	2					
Mean Storm Duration (h)	6					
Mean Ann Evap (mm)	1450					
Mean Ann Recharge (mm)	3.8	5.3				
% Area of Dominant veg	100					
Dominant veg	Summer		Winter			
Proportions of dominant veg	Low Est	High Est	Low Est	High Est		
Dense forest	0.4	0.5	0.4	0.5		
Bush/Sparse Forest	0.1	0.2	0.1	0.2		
Dense Crop/Ground Cover	0.5	0.3	0.5	0.3		
Sparse Crop/ Ground Cover	0	0	0	0		
Bare Soil	0	0	0	0		
% Area of secondary veg	0					
Secondary veg	Summer		Winter			
Proportions of secondary veg	Low Est	High Est	Low Est	High Est		
Dense forest						
Bush/Sparse Forest						
Dense Crop/Ground Cover						
Sparse Crop/ Ground Cover						
Bare Soil						

	V31G - Gauged					
	Total quat area (km^2) =			255	Flow gauge	Use in WR2005
	Terrain 1	Terrain 3	Terrain 4	Terrain 5	V3H003	Yes
	Top	Middle	Bottom	Valley	V3H018	No
Area (km^2)	4	50	0	201		
% Area	2	20	0	79		
Min Slope %	2	3		1		
Max Slope%	4	12		6		
Landtype 1	Bb53					
S1 % of Unit	0	16	0	23		
S1 Min Depth	300					
S1 Max Depth	500					
S1 Texture	SaCl					
Landtype 2	Bb54					
S2 % of Unit	0	20	0	42		
S2 Min Depth	400					
S2 Max Depth	600					
S2 Texture	LmSa					
Landtype 3	Ea86					
S3 % of Unit	75	56	0	0		
S3 Min Depth	200					
S3 Max Depth	400					
S3 Texture	SaCl					
Landtype 4	Ib134					
S4 % of Unit	25	8	0	0		
S4 Min Depth	300					
S4 Max Depth	500					
S4 Texture	LmSa					
Landtype 5	Ca12					
S5 % of Unit	0	0	0	35		
S5 Min Depth	450					
S5 Max Depth	700					
S5 Texture	LmSa					
Soil Vert Var	90	80	70	70		
Soil Factors	Macropore	Organics	Structure		Surface Cover	Cover Variability
Index (0 to 2)	1	1	1		0 = Well vegetated	0 = Low
Surface Cover Index	1	1	1	1	1 = Moderate	1 = Moderate
Cover variability index	1	1	1	1	2 = Crusting	2 = High
Regional GW slope %	1				Default	
Vertical Drainage %	2					
Horizontal Drainage %	98					
	GRA2	SD				
Storativity (*1000)	3	0.3				
Depth to GW (m)	25					
Fract Zone Trans (m2/d)	2.5	0.5				
Drainage Density (km/km)	0.05	0.005				
Mean monthly rain (mm)	63.3					
Max Monthly Rain (mm)	133.8					
Mean no. of raindays/month	2					
Mean Storm Duration (h)	6					
Mean Ann Evap (mm)	1500					
Mean Ann Recharge (mm)	3.3	5.5				
% Area of Dominant veg	100					
Dominant veg	Summer		Winter			
Proportions of dominant veg	Low Est	High Est	Low Est	High Est		
Dense forest	0	0	0	0		
Bush/Sparse Forest	0	0	0	0		
Dense Crop/Ground Cover	0.5	0.6	0.5	0.6		
Sparse Crop/ Ground Cover	0.3	0.3	0.3	0.3		
Bare Soil	0.2	0.1	0.2	0.1		
% Area of secondary veg	0					
Secondary veg	Summer		Winter			
Proportions of secondary veg	Low Est	High Est	Low Est	High Est		
Dense forest						
Bush/Sparse Forest						
Dense Crop/Ground Cover						
Sparse Crop/ Ground Cover						
Bare Soil						

V31H - Gauged

	Total quat area (km^2) =			129	Flow gauge	Use in WR2005
	Terrain 1	Terrain 3	Terrain 4	Terrain 5	V3H007	Yes
	Top	Middle	Bottom	Valley		
Area (km^2)	40	38	0	51		
% Area	31	29	0	40		
Min Slope %	1	20		2		
Max Slope%	4	100		15		
Landtype 1	Ac5					
S1 % of Unit	3	3	0	82		
S1 Min Depth	300					
S1 Max Depth	600					
S1 Texture	SaCl					
Landtype 2	Ad2					
S2 % of Unit	23	8	0	0		
S2 Min Depth	100					
S2 Max Depth	200					
S2 Texture	LmSa					
Landtype 3	Ad3					
S3 % of Unit	20	3	0	0		
S3 Min Depth	300					
S3 Max Depth	900					
S3 Texture	Sa					
Landtype 4	Ca18					
S4 % of Unit	13	3	0	0		
S4 Min Depth	100					
S4 Max Depth	450					
S4 Texture	LmSa					
Landtype 5	Fa28					
S5 % of Unit	43	84	0	18		
S5 Min Depth	400					
S5 Max Depth	600					
S5 Texture	Cl					
Soil Vert Var	90	80	70	70		
Soil Factors	Macropore	Organics	Structure		Surface Cover	Cover Variability
Index (0 to 2)	1	1	1		0 = Well vegetated	0 = Low
Surface Cover Index	1	1	1	1	1 = Moderate	1 = Moderate
Cover variability index	1	1	1	1	2 = Crusting	2 = High
Regional GW slope %	1				Default	
Vertical Drainage %	2					
Horizontal Drainage %	98					
	GRA2	SD				
Storativity (*1000)	3	0.3				
Depth to GW (m)	25					
Fract Zone Trans (m2/d)	2.5	0.5				
Drainage Density (km/km)	0.19	0.019				
Mean monthly rain (mm)	80.2					
Max Monthly Rain (mm)	169.6					
Mean no. of raindays/month	2					
Mean Storm Duration (h)	6					
Mean Ann Evap (mm)	1400					
Mean Ann Recharge (mm)	3.6	5.4				
% Area of Dominant veg	100					
Dominant veg	Summer		Winter			
Proportions of dominant veg	Low Est	High Est	Low Est	High Est		
Dense forest	0.4	0.5	0.4	0.5		
Bush/Sparse Forest	0.1	0.2	0.1	0.2		
Dense Crop/Ground Cover	0.5	0.3	0.5	0.3		
Sparse Crop/ Ground Cover	0	0	0	0		
Bare Soil	0	0	0	0		
% Area of secondary veg	0					
Secondary veg	Summer		Winter			
Proportions of secondary veg	Low Est	High Est	Low Est	High Est		
Dense forest						
Bush/Sparse Forest						
Dense Crop/Ground Cover						
Sparse Crop/ Ground Cover						
Bare Soil						

V31K - Gauged

	Total quat area (km^2) =			227	Flow gauge	Use in WR2005
	Terrain 1	Terrain 3	Terrain 4	Terrain 5	V3H021	No
	Top	Middle	Bottom	Valley	V3H024	No
Area (km^2)	13	24	0	190		
% Area	6	11	0	84		
Min Slope %	2	6		2		
Max Slope%	4	15		15		
Landtype 1	Ac5					
S1 % of Unit	69	4	0	0		
S1 Min Depth	900					
S1 Max Depth	1200					
S1 Texture	SaCl					
Landtype 2	Bb54					
S2 % of Unit	8	25	0	86		
S2 Min Depth	400					
S2 Max Depth	600					
S2 Texture	LmSa					
Landtype 3	Dc40					
S3 % of Unit	0	17	0	12		
S3 Min Depth	400					
S3 Max Depth	500					
S3 Texture	LmSa					
Landtype 4	Ea34					
S4 % of Unit	15	38	0	0		
S4 Min Depth	300					
S4 Max Depth	1200					
S4 Texture	SaCl					
Landtype 5	Ib134					
S5 % of Unit	8	17	0	2		
S5 Min Depth	300					
S5 Max Depth	500					
S5 Texture	LmSa					
Soil Vert Var	90	80	70	70		
Soil Factors	Macropore	Organics	Structure		Surface Cover	Cover Variability
Index (0 to 2)	1	1	1		0 = Well vegetated	0 = Low
Surface Cover Index	1	1	1	1	1 = Moderate	1 = Moderate
Cover variability index	1	1	1	1	2 = Crusting	2 = High
Regional GW slope %	1				Default	
Vertical Drainage %	2					
Horizontal Drainage %	98					
	GRA2	SD				
Storativity (*1000)	3	0.3				
Depth to GW (m)	25					
Fract Zone Trans (m2/d)	2.5	0.5				
Drainage Density (km/km)	0.19	0.019				
Mean monthly rain (mm)	66.1					
Max Monthly Rain (mm)	139.7					
Mean no. of raindays/month	2					
Mean Storm Duration (h)	6					
Mean Ann Evap (mm)	1500					
Mean Ann Recharge (mm)	3.5	5.2				
% Area of Dominant veg	100					
Dominant veg	Summer		Winter			
Proportions of dominant veg	Low Est	High Est	Low Est	High Est		
Dense forest	0	0	0	0		
Bush/Sparse Forest	0	0	0	0		
Dense Crop/Ground Cover	0.5	0.6	0.5	0.6		
Sparse Crop/ Ground Cover	0.3	0.3	0.3	0.3		
Bare Soil	0.2	0.1	0.2	0.1		
% Area of secondary veg	0					
Secondary veg	Summer		Winter			
Proportions of secondary veg	Low Est	High Est	Low Est	High Est		
Dense forest						
Bush/Sparse Forest						
Dense Crop/Ground Cover						
Sparse Crop/ Ground Cover						
Bare Soil						

V31J - Ungauged

	Total quat area (km^2) =			**358**		
	Terrain 1	**Terrain 3**	**Terrain 4**	**Terrain 5**		
	Top	**Middle**	**Bottom**	**Valley**		
Area (km^2)	8	35	0	315		
% Area	2	10	0	88		
Min Slope %	2	20		2		
Max Slope%	4	100		15		
Landtype 1	**Ac5**					
S1 % of Unit	0	3	0	70		
S1 Min Depth	300					
S1 Max Depth	600					
S1 Texture	SaCl					
Landtype 2	**Ad2**					
S2 % of Unit	38	3	0	0		
S2 Min Depth	100					
S2 Max Depth	200					
S2 Texture	LmSa					
Landtype 3	**Bb56**					
S3 % of Unit	0	0	0	30		
S3 Min Depth	300					
S3 Max Depth	600					
S3 Texture	LmSa					
Landtype 4	**Fa28**					
S4 % of Unit	38	91	0	0		
S4 Min Depth	400					
S4 Max Depth	600					
S4 Texture	Cl					
Landtype 5	**Fa48**					
S5 % of Unit	25	3	0	0		
S5 Min Depth	200					
S5 Max Depth	400					
S5 Texture	Sa					
Soil Factors	90	80	70	70		
Index (0 to 2)	Macropore	Organics	Structure		Surface Cover	Cover Variability
Surface Cover Index	1	1	1		0 = Well vegetated	0 = Low
Cover variability index	1	1	1	1	1 = Moderate	1 = Moderate
Regional GW slope %	1	1	1	1	2 = Crusting	2 = High
Vertical Drainage %	1				Default	
Horizontal Drainage %	2					
	98					
Storativity (*1000)	GRA2	SD				
Depth to GW (m)	3	0.3				
Fract Zone Trans (m2/d)	25					
Drainage Density (km/km)	2.5	0.5				
Mean monthly rain (mm)	0.08	0.008				
Max Monthly Rain (mm)	72.6					
Mean no. of raindays/month	153.4					
Mean Storm Duration (h)	2					
Mean Ann Evap (mm)	6					
Mean Ann Recharge (mm)	1450					
	7.5	12.3				
% Area of Dominant veg						
Dominant veg	100					
Proportions of dominant veg	Summer		Winter			
Dense forest	Low Est	High Est	Low Est	High Est		
Bush/Sparse Forest	0.4	0.5	0.4	0.5		
Dense Crop/Ground Cover	0.1	0.2	0.1	0.2		
Sparse Crop/ Ground Cover	0.5	0.3	0.5	0.3		
Bare Soil	0	0	0	0		
	0	0	0	0		
% Area of secondary veg						
Secondary veg	0					
Proportions of secondary veg	Summer		Winter			
Dense forest	Low Est	High Est	Low Est	High Est		
Bush/Sparse Forest						
Dense Crop/Ground Cover						
Sparse Crop/ Ground Cover						
Bare Soil						

APPENDIX B:

Secondary Basin Data

C21 - VAAL

SECONDARY BASIN DATA

	C21A - Ungauged			
Property	Mean	Sdev	Skew	Dist. Type
Basin Slope (%)	9.129	2.299	0.885	1
Upper Slope (% Area)	52			
Mid Slope (% Area)	22			
Valley Bottom (% Area)	26			
Upper slope S.Depth (mm)	473	39.444	0.013	1
Mid Slope S.Depth (mm)	354	31.93	0.061	1
Valley Bottom S.Depth (mm	421	55.722	-0.027	1
Soil Porosity	0.389	0.062	-0.108	1
Vert. Variation (%)	83			
Soil K	0.665	0.099	0.189	1
Soil K var	0.013			
Soil C	212.877	45.88	-0.017	1
Soil C var	97.608			
Soil Perm. (mm/h)	100.744	89.853	0.822	1
ST Soil (mm)	139.715	23.723	0.087	1
FT soil (mm/month)	1.321	0.913	1.173	1
Regional GW slope (%)	1			
Drainage Vector slope (%)	2			
Storativity (*1000)	3	0.3		
Depth to GW(m)	25			
Fract. Zone Trans. (m2/d)	2.5	0.5		
ST Unsat (mm)	64.726	7.832	0.115	1
FT Unsat (mm/month)	0.571	0.127	0.154	1
Moisture content SD (%)	73.569	7.152	-2.359	1
Dominant LAI (Summer)	1.475	0.054	-0.041	1
Dominant LAI (Winter)	1.475	0.055	-0.061	1
Secondary LAI (Summer)	4.701	0.052	0.092	1
Secondary LAI (Winter)	4.701	0.052	0.168	1

	C21B - Ungauged			
Property	Mean	Sdev	Skew	Dist. Type
Basin Slope (%)	4.355	0.893	0.678	1
Upper Slope (% Area)	11			
Mid Slope (% Area)	10			
Valley Bottom (% Area)	79			
Upper slope S.Depth (mm)	898	78.705	-0.018	1
Mid Slope S.Depth (mm)	459	49.763	0.02	1
Valley Bottom S.Depth (mm	845	52.124	-0.051	1
Soil Porosity	0.327	0.05	-0.02	1
Vert. Variation (%)	73			
Soil K	0.532	0.028	0.028	1
Soil K var	0.013			
Soil C	138.304	16.219	-0.21	1
Soil C var	108.213			
Soil Perm. (mm/h)	9.984	0.818	-0.09	1
ST Soil (mm)	194.343	31.801	0.101	1
FT soil (mm/month)	0.071	0.021	0.173	1
Regional GW slope (%)	1			
Drainage Vector slope (%)	2			
Storativity (*1000)	3	0.3		
Depth to GW(m)	25			
Fract. Zone Trans. (m2/d)	2.5	0.5		
ST Unsat (mm)	50.516	9.87	0.217	1
FT Unsat (mm/month)	0.42	0.094	0.249	1
Moisture content SD (%)	43.822	8.547	-0.66	1
Dominant LAI (Summer)	1.475	0.055	-0.042	1
Dominant LAI (Winter)	1.475	0.055	-0.082	1
Secondary LAI (Summer)	4.702	0.052	0.182	1
Secondary LAI (Winter)	4.702	0.053	0.18	1

	C21C - Ungauged			
Property	Mean	Sdev	Skew	Dist. Type
Basin Slope (%)	1.711	0.281	0.043	1
Upper Slope (% Area)	3			
Mid Slope (% Area)	6			
Valley Bottom (% Area)	91			
Upper slope S.Depth (mm)	565	57.727	0.047	1
Mid Slope S.Depth (mm)	270	31.229	-0.003	1
Valley Bottom S.Depth (mm	613	39.642	0.024	1
Soil Porosity	0.355	0.061	0.091	1
Vert. Variation (%)	71			
Soil K	0.58	0.062	0.436	1
Soil K var	0.014			
Soil C	169.57	34.124	0.275	1
Soil C var	105.254			
Soil Perm. (mm/h)	21.585	13.73	0.517	1
ST Soil (mm)	149.678	27.163	0.117	1
FT soil (mm/month)	0.067	0.04	0.819	1
Regional GW slope (%)	1			
Drainage Vector slope (%)	2			
Storativity (*1000)	3	0.3		
Depth to GW(m)	25			
Fract. Zone Trans. (m2/d)	2.5	0.5		
ST Unsat (mm)	0.001	0	0	0
FT Unsat (mm/month)	0	0	0	1
Moisture content SD (%)	44.524	10.784	-1.284	1
Dominant LAI (Summer)	1.475	0.055	-0.032	1
Dominant LAI (Winter)	1.474	0.055	-0.11	1
Secondary LAI (Summer)	4.701	0.053	0.133	1
Secondary LAI (Winter)	4.702	0.052	0.121	1

C21 - VAAL

SECONDARY BASIN DATA

Property	C21D - Gauged				C21E - Gauged				C21F - Gauged			
	Mean	Sdev	Skew	Dist. Type	Mean	Sdev	Skew	Dist. Type	Mean	Sdev	Skew	Dist. Type
Basin Slope (%)	1.71	0.422	0.074	1	1.081	0.176	0.058	1	2.61	0.414	0.797	1
Upper Slope (% Area)	19				7				3			
Mid Slope (% Area)	1				3				4			
Valley Bottom (% Area)	80				90				93			
Upper slope S.Depth (mm)	884	78.194	-0.033	1	879	71.598	-0.042	1	266	28.307	-0.092	1
Mid Slope S.Depth (mm)	909	108.52	-0.06	1	579	44.039	-0.118	1	252	32.596	-0.069	1
Valley Bottom S.Depth (mm	732	60.64	-0.001	1	841	64.188	-0.066	1	497	47.118	-0.068	1
Soil Porosity	0.329	0.051	0.073	1	0.329	0.051	0.053	1	0.372	0.061	-0.121	1
Vert. Variation (%)	74				72				71			
Soil K	0.535	0.033	0.934	1	0.536	0.032	0.689	1	0.605	0.065	-0.252	1
Soil K var	0.013				0.014				0.014			
Soil C	140.253	19.297	0.831	1	143.577	16.444	0.266	1	182.299	38.407	-0.577	1
Soil C var	108.156				112.392				96.041			
Soil Perm. (mm/h)	10.694	1.266	5.523	2	10.844	1.212	6.705	2	28.139	14.107	-0.439	1
ST Soil (mm)	186.162	31.37	0.214	1	199.165	33.7	0.238	1	127.204	24.213	0.209	1
FT soil (mm/month)	0.026	0	0	0	0.013	0	0	0	0.068	0.037	0.685	1
Regional GW slope (%)	1				1				1			
Drainage Vector slope (%)	4.2				4.2				2			
Storativity (*1000)	3	0.3			3	0.3			3	0.3		
Depth to GW(m)	25				25				25			
Fract. Zone Trans. (m2/d)	2.5	0.5			2.5	0.5			2.5	0.5		
ST Unsat (mm)	0	0	0	1	0	0	0	1	25.862	8.786	0.11	1
FT Unsat (mm/month)	0	0	0	1	0	0	0	1	0.387	0.092	-0.185	1
Moisture content SD (%)	32	0	0	0	32	0	0	0	47.998	9.417	-1.127	1
Dominant LAI (Summer)	1.475	0.054	-0.031	1	1.475	0.056	-0.065	1	1.475	0.055	-0.043	1
Dominant LAI (Winter)	1.475	0.055	-0.051	1	1.474	0.055	-0.067	1	1.475	0.055	-0.082	1
Secondary LAI (Summer)	4.701	0.052	0.138	1	4.701	0.052	0.166	1	4.702	0.052	0.179	1
Secondary LAI (Winter)	4.702	0.053	0.176	1	4.7	0.052	0.148	1	4.702	0.053	0.174	1

C21 - VAAL

SECONDARY BASIN DATA

	C21G - Gauged			
Property	Mean	Sdev	Skew	Dist. Type
Basin Slope (%)	2.935	0.675	0.135	1
Upper Slope (% Area)	3			
Mid Slope (% Area)	4			
Valley Bottom (% Area)	93			
Upper slope S.Depth (mm)	529	76.282	-0.031	1
Mid Slope S.Depth (mm)	295	43.858	-0.043	1
Valley Bottom S.Depth (mm	632	82.525	0.053	1
Soil Porosity	0.372	0.062	-0.106	1
Vert. Variation (%)	71			
Soil K	0.604	0.067	-0.285	1
Soil K var	0.014			
Soil C	180.247	41.281	-0.55	1
Soil C var	93.331			
Soil Perm. (mm/h)	28.183	14.294	-0.468	1
ST Soil (mm)	163.191	34.512	0.277	1
FT soil (mm/month)	0.106	0.061	0.895	1
Regional GW slope (%)	1			
Drainage Vector slope (%)	2			
Storativity (*1000)	3	0.3		
Depth to GW(m)	25			
Fract. Zone Trans. (m2/d)	2.5	0.5		
ST Unsat (mm)	32.111	10.926	0.106	1
FT Unsat (mm/month)	0.418	0.097	-0.084	1
Moisture content SD (%)	48.692	9.926	-0.989	1
Dominant LAI (Summer)	1.474	0.055	-0.062	1
Dominant LAI (Winter)	1.474	0.055	-0.059	1
Secondary LAI (Summer)	4.701	0.052	0.19	1
Secondary LAI (Winter)	4.701	0.053	0.124	1

J21 - GOURITZ

SECONDARY BASIN DATA

	J21A - Gauged			
Property	Mean	Sdev	Skew	Dist. Type
Basin Slope (%)	3.322	0.626	0.074	1
Upper Slope (% Area)	8			
Mid Slope (% Area)	7			
Valley Bottom (% Area)	81			
Upper slope S.Depth (mm)	221	28.73	-0.091	1
Mid Slope S.Depth (mm)	167	25.346	-0.046	1
Valley Bottom S.Depth (mm	586	56.357	-0.022	1
Soil Porosity	0.409	0.051	-0.002	1
Vert. Variation (%)	70			
Soil K	0.711	0.079	0.257	1
Soil K var	0.012			
Soil C	236.54	32.539	0.285	1
Soil C var	86.4			
Soil Perm. (mm/h)	159.158	68.194	0.4	1
ST Soil (mm)	144.446	22.442	0.239	1
FT soil (mm/month)	0.567	0.322	0.657	1
Regional GW slope (%)	1			
Drainage Vector slope (%)	2			
Storativity (*1000)	3	0.3		
Depth to GW(m)	25			
Fract. Zone Trans. (m2/d)	2.5	0.5		
ST Unsat (mm)	39.802	11.863	0.126	1
FT Unsat (mm/month)	0.42	0.095	0.132	1
Moisture content SD (%)	67.93	5.122	-4.781	1
Dominant LAI (Summer)	0.851	0.028	0.169	1
Dominant LAI (Winter)	0.851	0.028	0.117	1
Secondary LAI (Summer)	4.702	0.053	0.189	1
Secondary LAI (Winter)	4.702	0.053	0.13	1

	J21B - Ungauged			
Property	Mean	Sdev	Skew	Dist. Type
Basin Slope (%)	2.615	0.36	-0.02	1
Upper Slope (% Area)	3			
Mid Slope (% Area)	3			
Valley Bottom (% Area)	94			
Upper slope S.Depth (mm)	102	14.761	-0.005	1
Mid Slope S.Depth (mm)	111	15.763	0.037	1
Valley Bottom S.Depth (mm	281	25.407	-0.069	1
Soil Porosity	0.42	0.05	0.015	1
Vert. Variation (%)	71			
Soil K	0.789	0.04	0.006	1
Soil K var	0.01			
Soil C	270.047	13.356	-0.02	1
Soil C var	90			
Soil Perm. (mm/h)	232.139	23.08	0.063	1
ST Soil (mm)	81.05	12.053	0.276	1
FT soil (mm/month)	0.497	0.134	-0.203	1
Regional GW slope (%)	1			
Drainage Vector slope (%)	2			
Storativity (*1000)	3	0.3		
Depth to GW(m)	25			
Fract. Zone Trans. (m2/d)	2.5	0.5		
ST Unsat (mm)	26.523	9.117	0.186	1
FT Unsat (mm/month)	0.627	0.148	-0.206	1
Moisture content SD (%)	68	0	0	0
Dominant LAI (Summer)	0.851	0.028	0.163	1
Dominant LAI (Winter)	0.851	0.028	0.087	1
Secondary LAI (Summer)	4.701	0.052	0.119	1
Secondary LAI (Winter)	4.701	0.052	0.109	1

	J21C - Ungauged			
Property	Mean	Sdev	Skew	Dist. Type
Basin Slope (%)	2.88	0.289	0	1
Upper Slope (% Area)	9			
Mid Slope (% Area)	6			
Valley Bottom (% Area)	85			
Upper slope S.Depth (mm)	837	147.563	-0.023	1
Mid Slope S.Depth (mm)	830	144.352	-0.043	1
Valley Bottom S.Depth (mm	798	137.07	-0.007	1
Soil Porosity	0.419	0.05	0.013	1
Vert. Variation (%)	72			
Soil K	0.788	0.044	-0.513	1
Soil K var	0.01			
Soil C	268.61	16.044	-1.001	1
Soil C var	90			
Soil Perm. (mm/h)	229.891	35.509	-2.139	1
ST Soil (mm)	243.577	46.166	0.243	1
FT soil (mm/month)	1.531	0.42	0.597	1
Regional GW slope (%)	1			
Drainage Vector slope (%)	2			
Storativity (*1000)	3	0.3		
Depth to GW(m)	25			
Fract. Zone Trans. (m2/d)	2.5	0.5		
ST Unsat (mm)	34.132	7.441	0.105	1
FT Unsat (mm/month)	0.598	0.134	0.202	1
Moisture content SD (%)	68	0	0	0
Dominant LAI (Summer)	0.85	0.028	0.114	1
Dominant LAI (Winter)	0.85	0.028	0.168	1
Secondary LAI (Summer)	4.701	0.052	0.131	1
Secondary LAI (Winter)	4.701	0.053	0.099	1

J21 - GOURITZ

SECONDARY BASIN DATA

Property	J21D - Ungauged			
	Mean	Sdev	Skew	Dist. Type
Basin Slope (%)	3.064	0.321	-0.018	1
Upper Slope (% Area)	17			
Mid Slope (% Area)	5			
Valley Bottom (% Area)	78			
Upper slope S.Depth (mm)	307	25.495	0.031	1
Mid Slope S.Depth (mm)	327	24.785	-0.057	1
Valley Bottom S.Depth (mm	404	31.121	-0.014	1
Soil Porosity	0.42	0.05	0.009	1
Vert. Variation (%)	74			
Soil K	0.786	0.045	-0.586	1
Soil K var	0.01			
Soil C	268.795	15.896	-1.043	1
Soil C var	90			
Soil Perm. (mm/h)	229.876	35.592	-2.057	1
ST Soil (mm)	119.752	16.068	0.208	1
FT soil (mm/month)	0.467	0.116	0.455	1
Regional GW slope (%)	1			
Drainage Vector slope (%)	2			
Storativity (*1000)	3	0.3		
Depth to GW(m)	25			
Fract. Zone Trans. (m2/d)	2.5	0.5		
ST Unsat (mm)	37.694	7.323	0.235	1
FT Unsat (mm/month)	0.36	0.08	0.222	1
Moisture content SD (%)	68.015	1.004	19.533	2
Dominant LAI (Summer)	0.85	0.028	0.153	1
Dominant LAI (Winter)	0.85	0.028	0.175	1
Secondary LAI (Summer)	4.701	0.052	0.118	1
Secondary LAI (Winter)	4.701	0.052	0.108	1

V31 - THUKELA

SECONDARY BASIN DATA

	V31A - Gauged				V31B - Gauged				V31C - Gauged			
Property	Mean	Sdev	Skew	Dist. Type	Mean	Sdev	Skew	Dist. Type	Mean	Sdev	Skew	Dist. Type
Basin Slope (%)	9.115	2.304	0.947	1	7.503	1.421	0.016	1	10.705	1.021	-0.007	1
Upper Slope (% Area)	52				9				29			
Mid Slope (% Area)	22				30				20			
Valley Bottom (% Area)	26				61				51			
Upper slope S.Depth (mm)	474	38.343	0.011	1	468	44.103	-0.096	1	150	18.424	-0.019	1
Mid Slope S.Depth (mm)	355	31.756	-0.022	1	457	41.292	-0.072	1	342	62.653	0.026	1
Valley Bottom S.Depth (mm	421	55.321	-0.042	1	482	60.669	0.05	1	454	67.362	-0.006	1
Soil Porosity	0.383	0.058	-0.128	1	0.388	0.057	-0.234	1	0.37	0.062	-0.134	1
Vert. Variation (%)	83				75				78			
Soil K	0.622	0.058	-0.574	1	0.63	0.054	-0.804	1	0.6	0.068	-0.219	1
Soil K var	0.015				0.015				0.013			
Soil C	194.766	27.78	-0.842	1	197.976	28.206	-1.466	1	176.849	42.689	-0.424	1
Soil C var	97.608				93.895				92.448			
Soil Perm. (mm/h)	33.311	9.851	-0.926	1	33.987	11.025	-1.507	1	27.305	14.52	-0.362	1
ST Soil (mm)	138.266	22.478	0.167	1	137.674	23.042	0.109	1	99.09	19.755	0.329	1
FT soil (mm/month)	0.417	0.181	0.828	1	0.28	0.117	0.722	1	0.315	0.213	0.99	1
Regional GW slope (%)	1				1				1			
Drainage Vector slope (%)	2				2				2			
Storativity (*1000)	3	0.3			3	0.3			3	0.3		
Depth to GW(m)	25				25				25			
Fract. Zone Trans. (m2/d)	2.5	0.5			2.5	0.5			2.5	0.5		
ST Unsat (mm)	64.614	8.089	0.191	1	62.837	7.006	0.005	1	67.208	6.69	-0.081	1
FT Unsat (mm/month)	0.662	0.147	0.242	1	0.477	0.107	0.284	1	0.628	0.142	0.28	1
Moisture content SD (%)	66.116	6.65	0.001	1	62.665	4.768	0.125	1	70.083	7.001	-1.598	1
Dominant LAI (Summer)	1.474	0.055	-0.083	1	1.475	0.055	-0.034	1	3.304	0.122	0.267	1
Dominant LAI (Winter)	1.474	0.055	-0.06	1	1.474	0.055	-0.046	1	3.306	0.123	0.358	1
Secondary LAI (Summer)	4.701	0.052	0.131	1	4.702	0.052	0.139	1	4.702	0.053	0.174	1
Secondary LAI (Winter)	4.701	0.053	0.098	1	4.702	0.052	0.189	1	4.701	0.053	0.164	1

V31 - THUKELA

SECONDARY BASIN DATA

	V31D - Gauged				V31E - Gauged				V31F - Gauged			
Property	Mean	Sdev	Skew	Dist. Type	Mean	Sdev	Skew	Dist. Type	Mean	Sdev	Skew	Dist. Type
Basin Slope (%)	4.881	0.954	0.151	1	8.543	2.061	0.975	1	7.873	2.071	0.956	1
Upper Slope (% Area)	7				5				3			
Mid Slope (% Area)	5				12				12			
Valley Bottom (% Area)	88				83				85			
Upper slope S.Depth (mm)	628	56.107	0.032	1	850	86.113	0.015	1	500	43.024	-0.024	1
Mid Slope S.Depth (mm)	335	36.836	0.018	1	416	20.819	-0.093	1	486	34.753	-0.017	1
Valley Bottom S.Depth (mm	495	46.189	-0.017	1	401	23.056	-0.013	1	420	33.934	0.024	1
Soil Porosity	0.375	0.062	-0.145	1	0.349	0.059	0.077	1	0.332	0.057	0.212	1
Vert. Variation (%)	72				72				72			
Soil K	0.585	0.076	-0.014	1	0.517	0.03	0.124	1	0.52	0.032	1.249	1
Soil K var	0.013				0.011				0.01			
Soil C	157.166	59.787	-0.4	1	104.41	36.06	-0.176	1	113.039	24.987	-0.295	1
Soil C var	84.873				85.482				85.81			
Soil Perm. (mm/h)	24.265	15.636	-0.055	1	8.388	1.455	0.421	1	8.491	1.261	6.937	2
ST Soil (mm)	134.351	25.137	0.176	1	106.957	18.759	0.133	1	102.773	18.774	0.047	1
FT soil (mm/month)	0.101	0.061	0.894	1	0.106	0.043	1.899	1	0.095	0.032	0.538	1
Regional GW slope (%)	1				1				1			
Drainage Vector slope (%)	2				2				2			
Storativity (*1000)	3	0.3			3	0.3			3	0.3		
Depth to GW(m)	25				25				25			
Fract. Zone Trans. (m2/d)	2.5	0.5			2.5	0.5			2.5	0.5		
ST Unsat (mm)	54.063	8.593	0.217	1	64.052	7.834	0.103	1	62.617	8.541	0.075	1
FT Unsat (mm/month)	0.33	0.074	0.24	1	0.718	0.162	0.288	1	0.686	0.154	0.284	1
Moisture content SD (%)	56.857	9.674	-1.343	1	53.922	8.227	0.763	1	52.15	7.456	0.802	1
Dominant LAI (Summer)	1.474	0.055	-0.061	1	3.304	0.12	0.274	1	3.303	0.12	0.225	1
Dominant LAI (Winter)	1.474	0.055	-0.044	1	3.303	0.121	0.29	1	3.303	0.121	0.306	1
Secondary LAI (Summer)	4.701	0.052	0.178	1	4.703	0.053	0.192	1	4.702	0.052	0.188	1
Secondary LAI (Winter)	4.701	0.052	0.127	1	4.701	0.053	0.154	1	4.702	0.053	0.189	1

V31 - THUKELA

SECONDARY BASIN DATA

	V31G - Gauged				V31H - Gauged				V31J - Ungauged			
Property	Mean	Sdev	Skew	Dist. Type	Mean	Sdev	Skew	Dist. Type	Mean	Sdev	Skew	Dist. Type
Basin Slope (%)	4.29	0.917	0.008	1	17.889	4.953	0.999	1	12.278	2.96	0.174	1
Upper Slope (% Area)	2				31				2			
Mid Slope (% Area)	20				29				10			
Valley Bottom (% Area)	78				40				88			
Upper slope S.Depth (mm)	326	33.485	-0.007	1	411	31.992	0.001	1	319	20.304	-0.023	1
Mid Slope S.Depth (mm)	364	26.138	-0.048	1	468	35.107	-0.068	1	483	39.008	-0.048	1
Valley Bottom S.Depth (mm	503	28.642	-0.069	1	461	53.645	-0.053	1	450	50.035	-0.038	1
Soil Porosity	0.374	0.063	-0.161	1	0.37	0.062	-0.082	1	0.351	0.062	0.107	1
Vert. Variation (%)	72				79				71			
Soil K	0.606	0.068	-0.389	1	0.548	0.088	1.723	1	0.556	0.069	0.939	1
Soil K var	0.013				0.011				0.011			
Soil C	179.554	43.655	-0.583	1	116.41	65.81	1.045	1	140.055	49.403	0.523	1
Soil C var	90				76.684				87.044			
Soil Perm. (mm/h)	28.901	14.302	-0.601	1	12.834	2.906	3.009	2	14.525	2.493	3.437	2
ST Soil (mm)	127.099	22.352	0.149	1	131.101	23.185	0.17	1	112.379	22.789	0.291	1
FT soil (mm/month)	0.043	0.024	0.775	1	0.253	0.09	0.368	1	0.093	0.032	0.537	1
Regional GW slope (%)	1				1				1			
Drainage Vector slope (%)	2				2				2			
Storativity (*1000)	3	0.3			3	0.3			3	0.3		
Depth to GW(m)	25				25				25			
Fract. Zone Trans. (m2/d)	2.5	0.5			2.5	0.5			2.5	0.5		
ST Unsat (mm)	49.863	10.44	0.191	1	69.922	7.486	0.078	1	67.796	7.268	0.015	1
FT Unsat (mm/month)	0.15	0.034	0.28	1	0.573	0.129	0.242	1	0.239	0.054	0.289	1
Moisture content SD (%)	56.3	9.65	-1.118	1	68.319	5.028	-2.861	1	67.113	7.594	-1.379	1
Dominant LAI (Summer)	1.474	0.056	-0.03	1	3.304	0.121	0.272	1	3.304	0.122	0.265	1
Dominant LAI (Winter)	1.474	0.055	-0.092	1	3.303	0.121	0.34	1	3.305	0.123	0.346	1
Secondary LAI (Summer)	4.701	0.052	0.195	1	4.702	0.053	0.205	1	4.701	0.052	0.15	1
Secondary LAI (Winter)	4.701	0.052	0.152	1	4.701	0.052	0.092	1	4.701	0.052	0.079	1

V31 - THUKELA

SECONDARY BASIN DATA

	V31K - Gauged			
Property	Mean	Sdev	Skew	Dist. Type
Basin Slope (%)	8.399	2.328	0.016	1
Upper Slope (% Area)	6			
Mid Slope (% Area)	11			
Valley Bottom (% Area)	83			
Upper slope S.Depth (mm)	909	53.815	-0.02	1
Mid Slope S.Depth (mm)	591	74.068	-0.007	1
Valley Bottom S.Depth (mm	493	36.057	-0.044	1
Soil Porosity	0.393	0.055	-0.211	1
Vert. Variation (%)	72			
Soil K	0.638	0.05	-1.157	1
Soil K var	0.015			
Soil C	201.345	28.25	-2.162	1
Soil C var	90			
Soil Perm. (mm/h)	36.011	9.161	-2.309	1
ST Soil (mm)	149.938	22.678	0.195	1
FT soil (mm/month)	0.437	0.199	1.223	1
Regional GW slope (%)	1			
Drainage Vector slope (%)	2			
Storativity (*1000)	3	0.3		
Depth to GW(m)	25			
Fract. Zone Trans. (m2/d)	2.5	0.5		
ST Unsat (mm)	63.144	9	0.177	1
FT Unsat (mm/month)	0.572	0.127	0.242	1
Moisture content SD (%)	65.198	6.379	0.35	1
Dominant LAI (Summer)	1.474	0.055	-0.081	1
Dominant LAI (Winter)	1.474	0.055	-0.06	1
Secondary LAI (Summer)	4.701	0.052	0.133	1
Secondary LAI (Winter)	4.701	0.053	0.098	1

APPENDIX C:

Parameter Estimation Results

RESULTS FROM THE APPLICATION OF THE PARAMETER ESTIMATION METHODS

C21 - VAAL

	C21A - Ungauged		C21B - Ungauged		C21C - Ungauged		C21D - Gauged		C21E - Gauged		C21F - Gauged		C21G - Gauged	
	WR2005	HYDZ	WR2005	HYDZ	WR2005	HYDZ	WR2005	HYDZ	WR2005	HYDZ	WR2005	HYDZ	WR2005	HYDZ
POW	3	2	3	2	3	3	3	4	3	4	3	2	3	2
SL	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ST	130	205	130	245	130	151	130	187	130	199	130	153	130	195
FT	6	2	5	0	5	0	5	1	5	1	5	0	5	1
ZMIN	999	29	999	13	999	39	999	14	999	12	999	31	999	34
ZMAX	999	934	999	1121	999	823	999	879	999	901	999	1126	999	951
PI	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
TL	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
R	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

J21 - GOURITZ

	J21A - Gauged		J21B - Ungauged		J21C - Ungauged		J21D - Ungauged	
	WR2005	HYDZ	WR2005	HYDZ	WR2005	HYDZ	WR2005	HYDZ
POW	1	2	1	2	1	2	1	2
SL	0	0	0	0	0	0	0	0
ST	100	184	100	108	100	278	100	158
FT	10	1	0	1	0	2	0	1
ZMIN	5	35	10	30	10	35	10	30
ZMAX	200	398	390	240	390	900	390	220
PI	1.5	1.7	1.5	1.8	1.5	1.9	1.5	2.0
TL	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
R	0.0	0.5	0.0	0.5	0.0	0.5	0.0	0.5

V31 - THUKELA

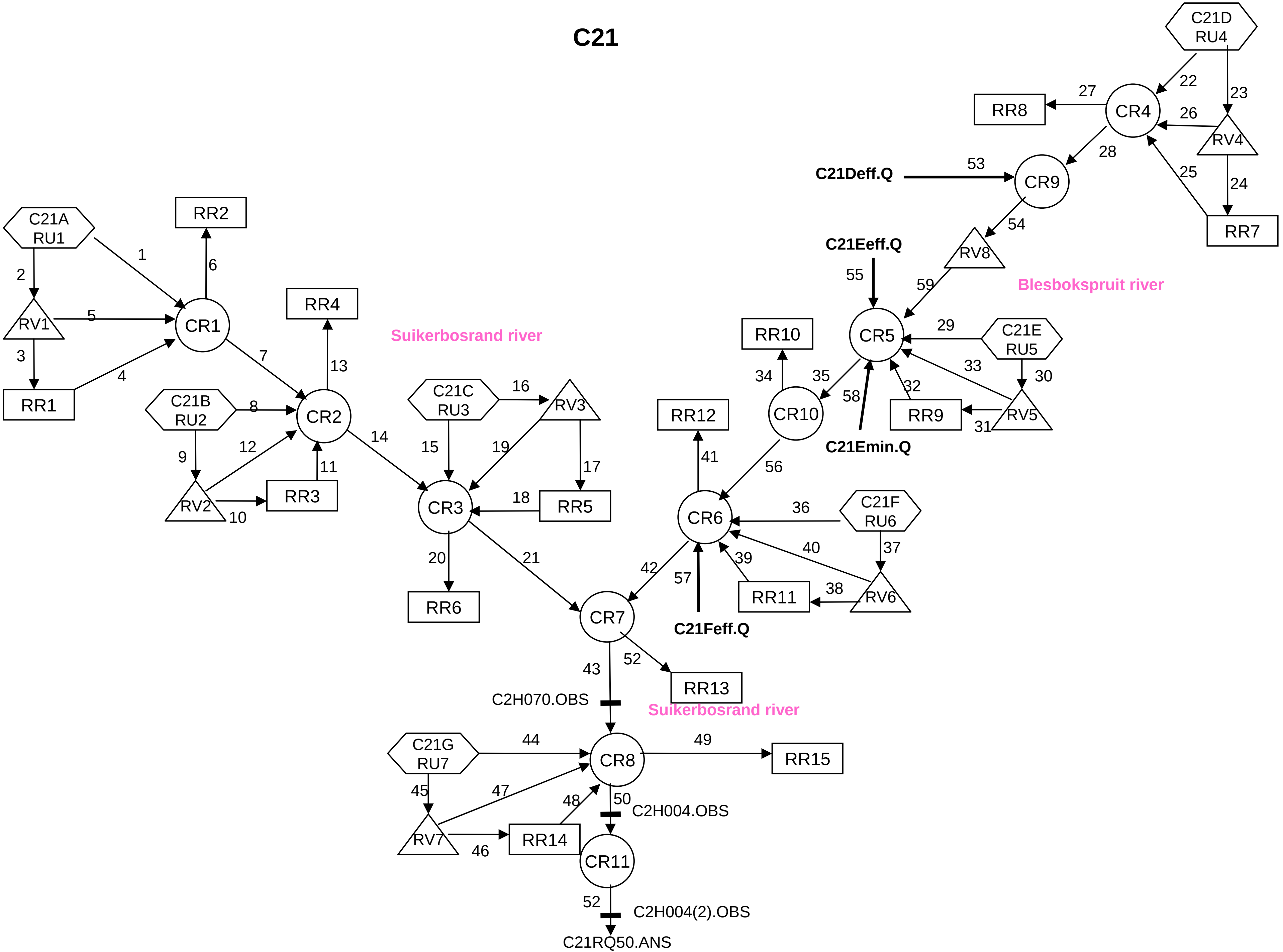
	V31A - Gauged		V31B - Gauged		V31C - Gauged		V31D - Gauged		V31E - Gauged		V31F - Gauged		V31G - Gauged		V31H - Gauged		V31J - Ungauged		V31K - Gauged	
	WR2005	HYDZ	WR2005	HYDZ	WR2005	HYDZ	WR2005	HYDZ	WR2005	HYDZ	WR2005	HYDZ	WR2005	HYDZ	WR2005	HYDZ	WR2005	HYDZ	WR2005	HYDZ
POW	3	2	3	2	3	2	3	2	3	2	3	2	3	2	3	2	3	2	3	2
SL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0
ST	120	203	120	201	100	166	175	188	150	171	120	165	100	177	55	201	175	180	175	213
FT	25	1	15	1	15	1	10	0	20	1	10	1	20	0	25	1	10	0	10	1
ZMIN	999	24	999	30	999	19	999	24	999	12	999	13	999	28	999	17	999	19	999	30
ZMAX	999	593	999	663	999	515	999	1000	999	521	999	513	999	1016	999	521	999	477	999	828
PI	1.5	1.3	1.5	1.3	1.5	1.4	1.5	1.4	1.5	1.3	1.5	1.3	1.5	1.4	1.5	1.3	1.5	1.3	1.5	1.4
TL	0.25	0.25	0.25	0.25	0.25	0.25	0.50	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.50	0.25	0.50	0.25	0.50	0.25
R	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

- Represents the parameter for which the estimation procedures calculated higher than the input constraint for the WRSM2000 i.e. 4
- Represents the parameter for which the estimation procedures calculated lower than the input constraint for the WRSM2000 i.e. 0

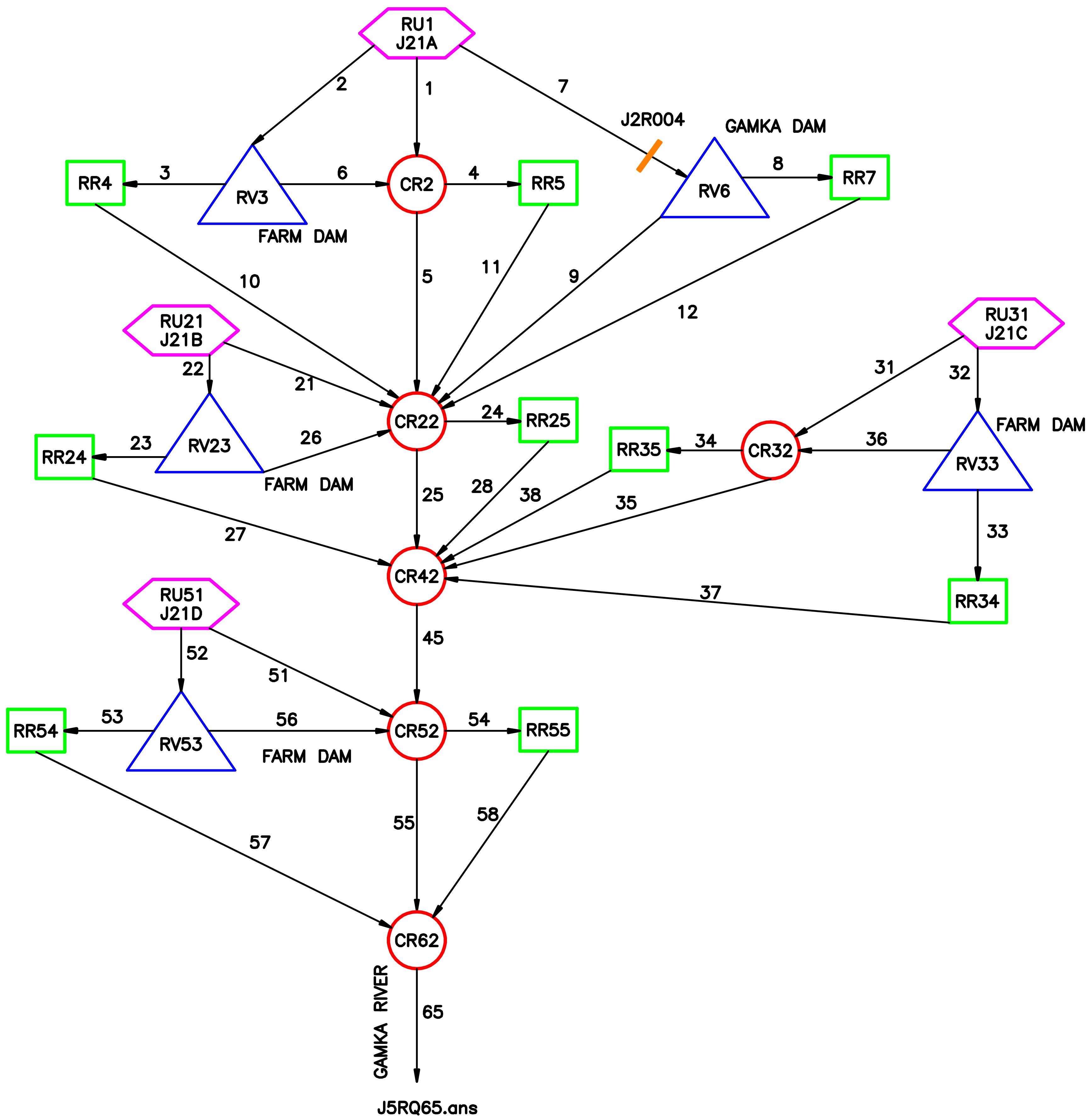
APPENDIX D:

System Diagrams

C21



C21D
RU4
RR8
CR4
RV4
C21Deff.Q
CR9
RR7
C21Eeff.Q
RV8
Blesbokspruit river
C21A
RU1
RR2
RR4
RV1
CR1
RR10
CR5
C21E
RU5
Suikerbosrand river
RR1
C21B
RU2
CR2
C21C
RU3
RV3
CR10
RR9
RV5
RR12
C21Emin.Q
RV2
RR3
CR3
RR5
CR6
C21F
RU6
RR11
RV6
RR6
CR7
C21Feff.Q
RR13
C2H070.OBS
Suikerbosrand river
C21G
RU7
CR8
RR15
RV7
RR14
C2H004.OBS
CR11
C2H004(2).OBS
C21RQ50.ANS



LEGEND:

- RU1 G10A — PARENT RUNOFF MODULE
- RU11 — CHILD: ALIEN VEGETATION
- RU111 — CHILD: FORESTRY
- 102 — RESERVOIR
- 103 — CHANNEL REACH
- 44 — IRRIGATION BLOCK
- 42 — ROUTE
- A1A001 — CALIBRATION/OBSERVATION POINT

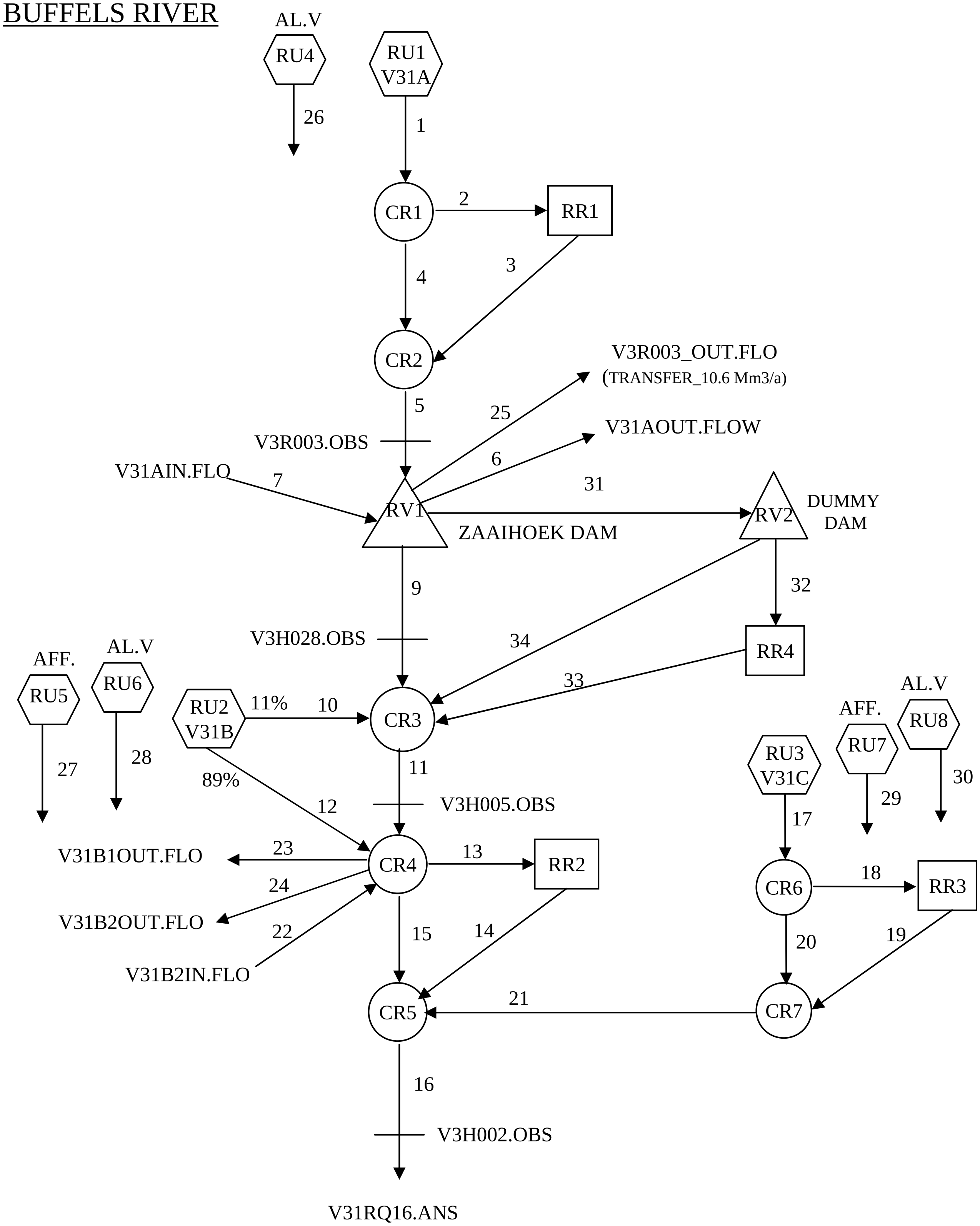
WR 2005:

WATER MANAGEMENT AREA: J
NETWORK CONFIGURATION: J5

MAY 2007

I:\HYDRO\400682 WR2005\Graphics & CAD\Network Diagrams\J\J05.dwg, 24/05/2007 10:54:25 AM

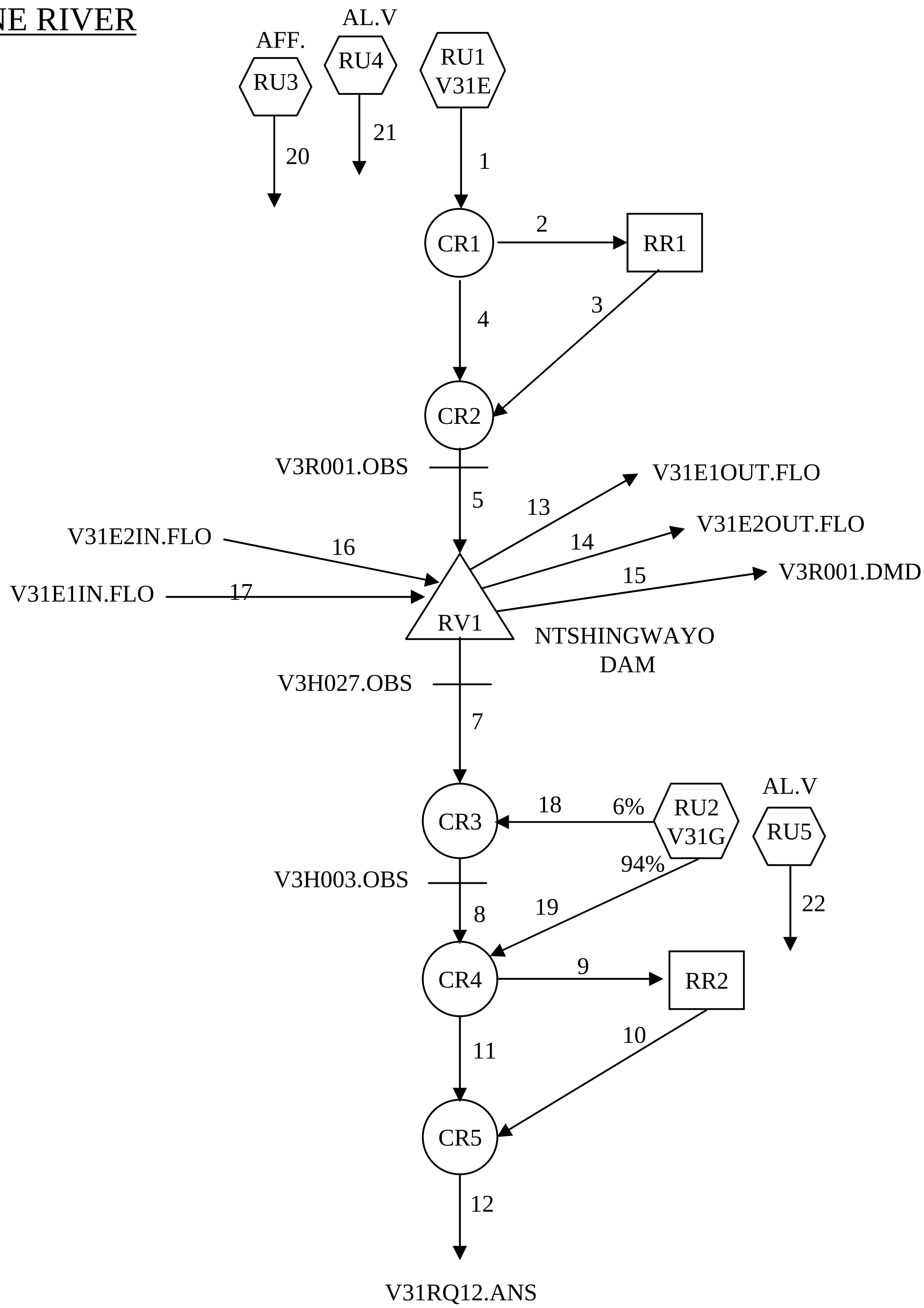
BUFFELS RIVER



WR 2005

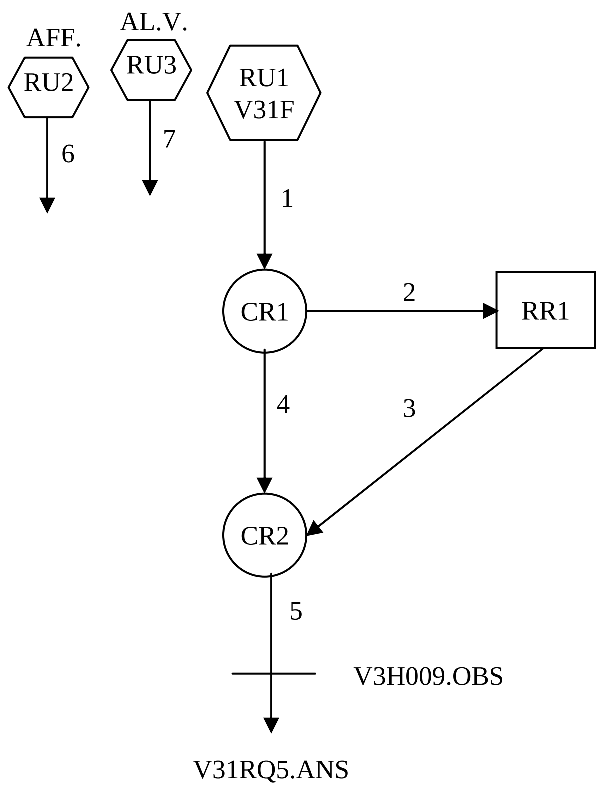
V312

NGAGANE RIVER

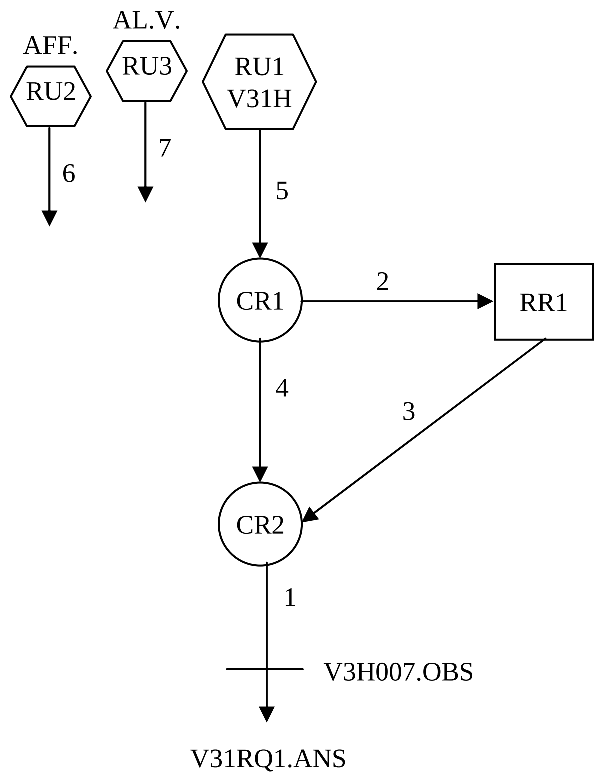


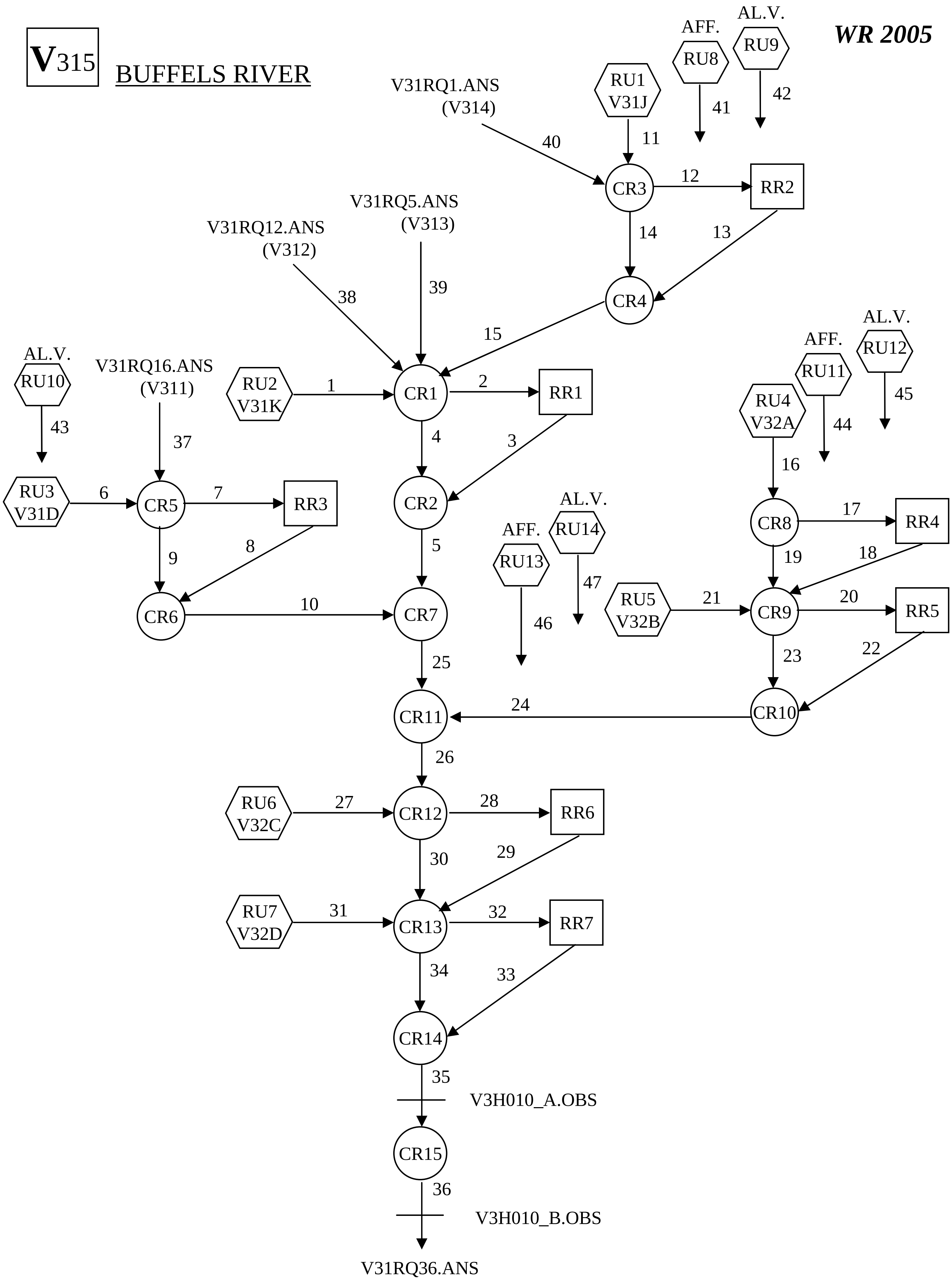
V313

HORN RIVER



V314 NCANDU RIVER




V315
BUFFELS RIVER
WR 2005
V31RQ1.ANS (V314)
RU1 V31J
AFF. RU8
AL.V. RU9
CR3
RR2
CR4
V31RQ5.ANS (V313)
V31RQ12.ANS (V312)
CR1
RR1
RU2 V31K
CR2
AL.V. RU10
V31RQ16.ANS (V311)
RU3 V31D
CR5
RR3
CR6
CR7
AFF. RU13
AL.V. RU14
AL.V. RU12
AFF. RU11
RU4 V32A
CR8
RR4
RU5 V32B
CR9
RR5
CR10
CR11
RU6 V32C
CR12
RR6
RU7 V32D
CR13
RR7
CR14
V3H010_A.OBS
CR15
V3H010_B.OBS
V31RQ36.ANS

APPENDIX E:

Mean monthly and Annual Flows Diagrams

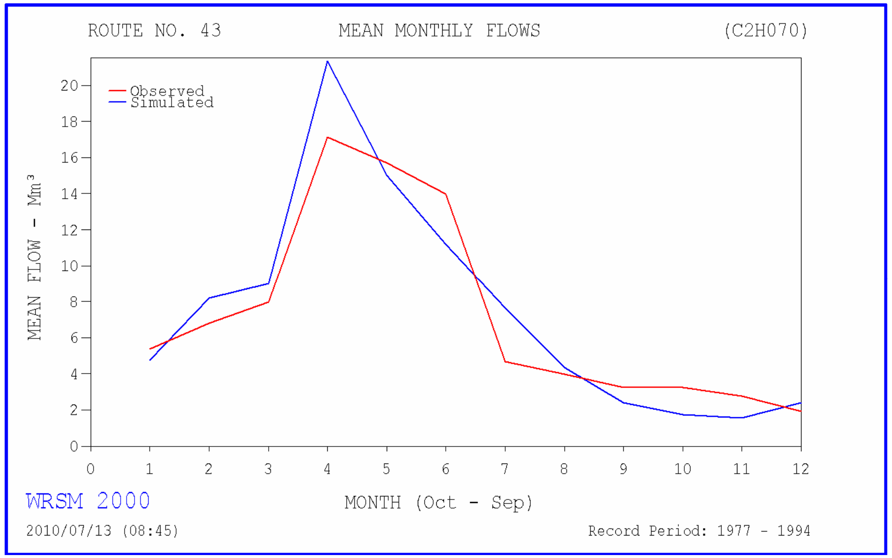
Upper Vaal River System – C21

Statistical Results

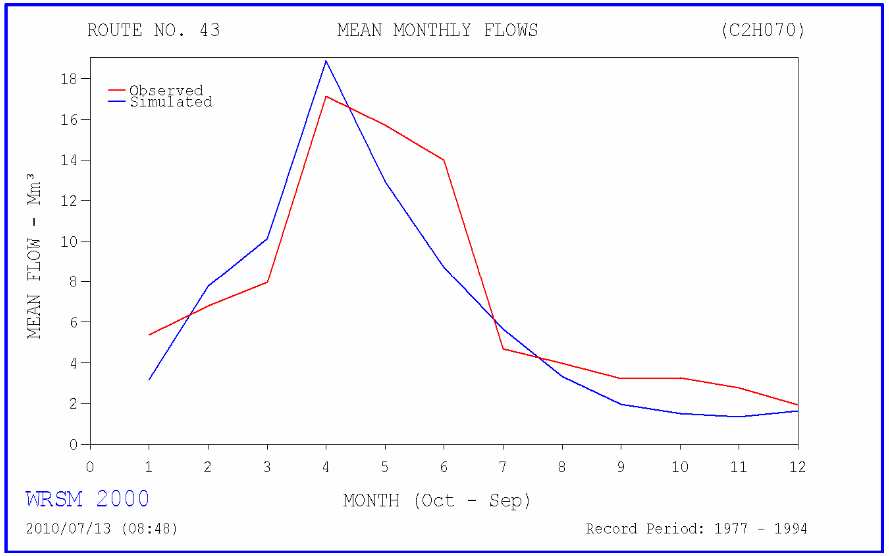
	1977 - 1994		
C2H070	**Observed**	**WR2005**	**Hydz**
MAR (Mm^3/a)	86.78	89.52	76.98
Mean(Log)	1.81	1.82	1.79
Std Dev	81.04	78.79	58.17
Log Std Dev	0.34	0.33	0.29
Seasonal Index	29.82	30.8	34.22

C2H070 - Mean Monthly Flows

WR2005

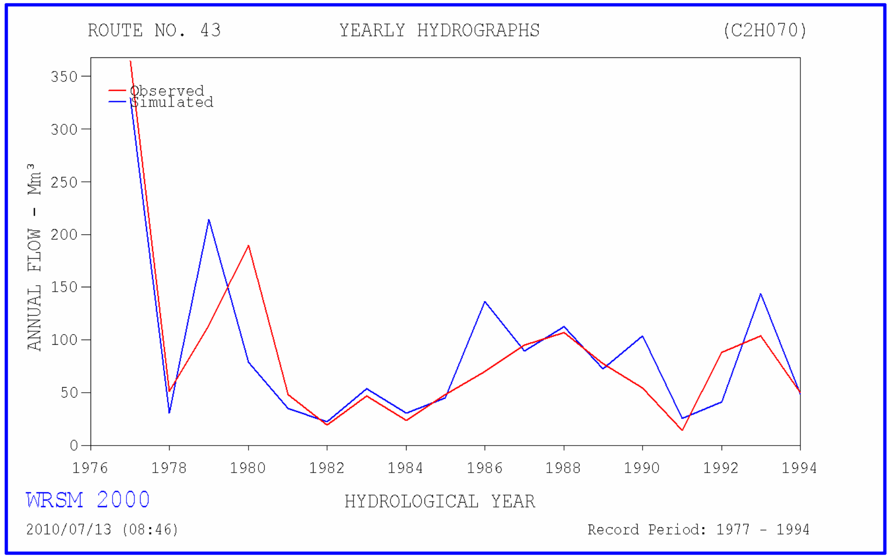


HYDZ

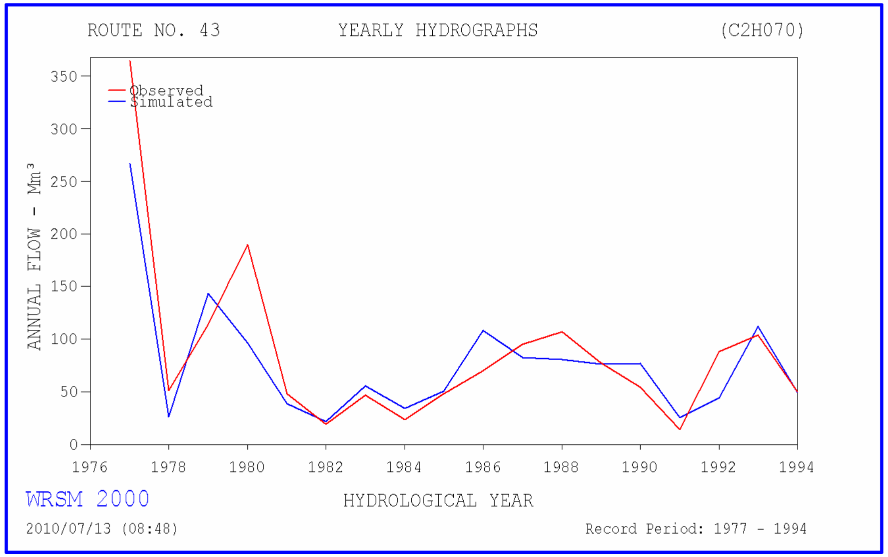


C2H070 - Yearly Hydrographs

WR2005



HYDZ



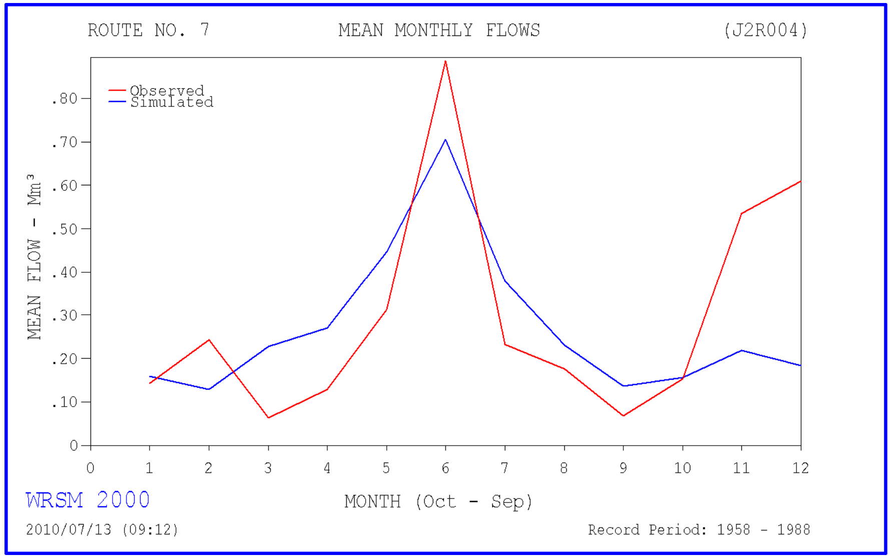
(Gouritz) Gamka River System – J21

Statistical Results

	1958 - 1988		
J2R004	**Observed**	**WR2005**	**Hydz**
MAR (Mm^3/a)			
Mean(Log)			
Std Dev			
Log Std Dev			
Seasonal Index			

J2R004 - Mean Monthly Flows

WR2005



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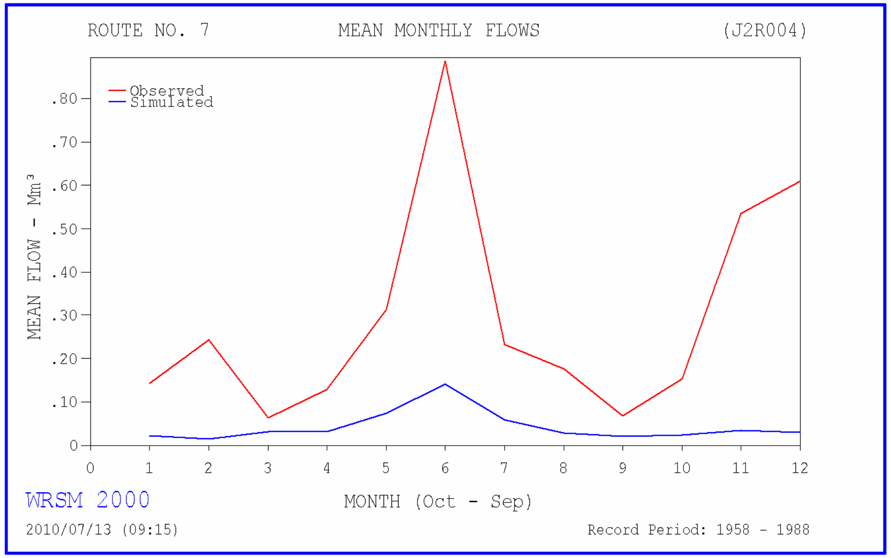
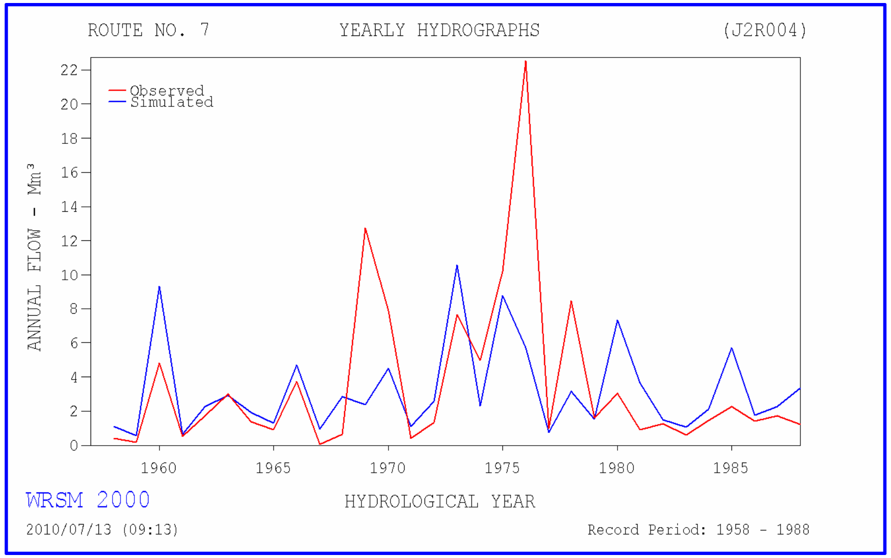


J2R004 - Yearly Hydrographs

WR2005



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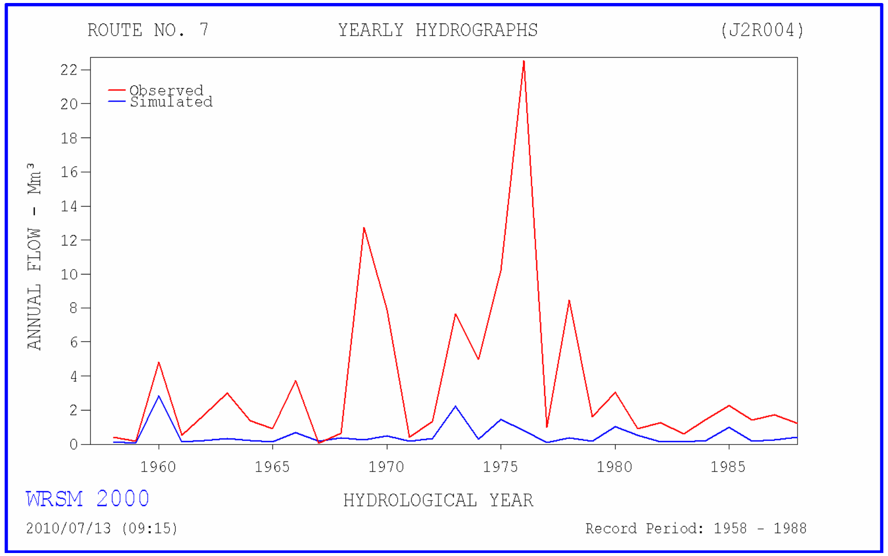


Thukela River System – V31

Buffels River System Calibration – V3R003

Statistical Results

	1992 - 2004		
V3R003	**Observed**	**WR2005**	**Hydz**
MAR (Mm^3/a)	86.76	93.70	64.43
Mean(Log)	1.82	1.78	1.53
Std Dev	67.56	93.06	85.11
Log Std Dev	0.34	0.47	0.54
Seasonal Index	38.49	40.41	49.92

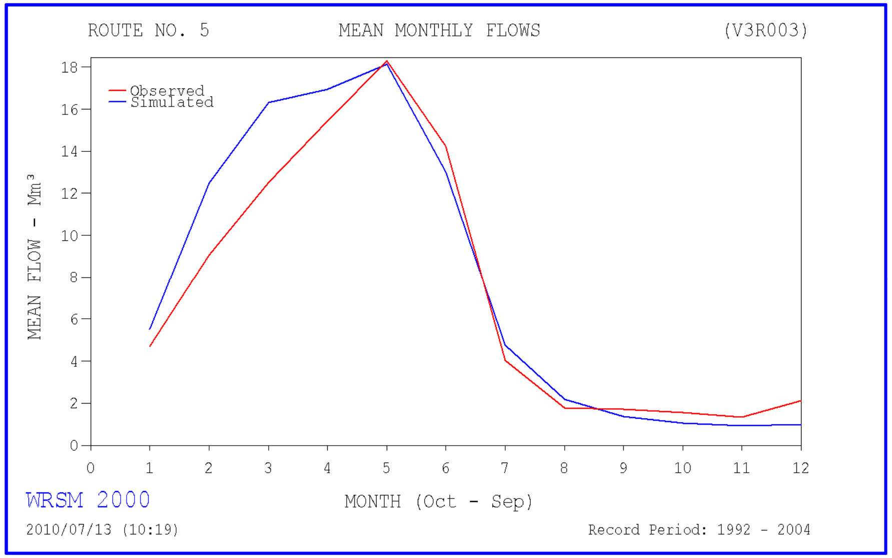
Buffels River System Calibration – V3H005

Statistical Results

	1947 - 1991		
V3H005	**Observed**	**WR2005**	**Hydz**
MAR (Mm^3/a)			
Mean(Log)			
Std Dev			
Log Std Dev			
Seasonal Index			

V3R003 - Mean Monthly Flows

WR2005



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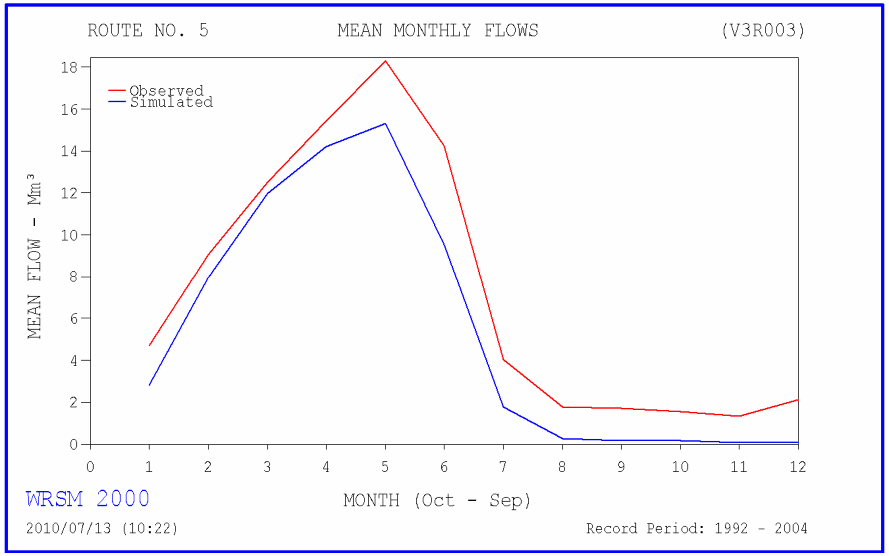
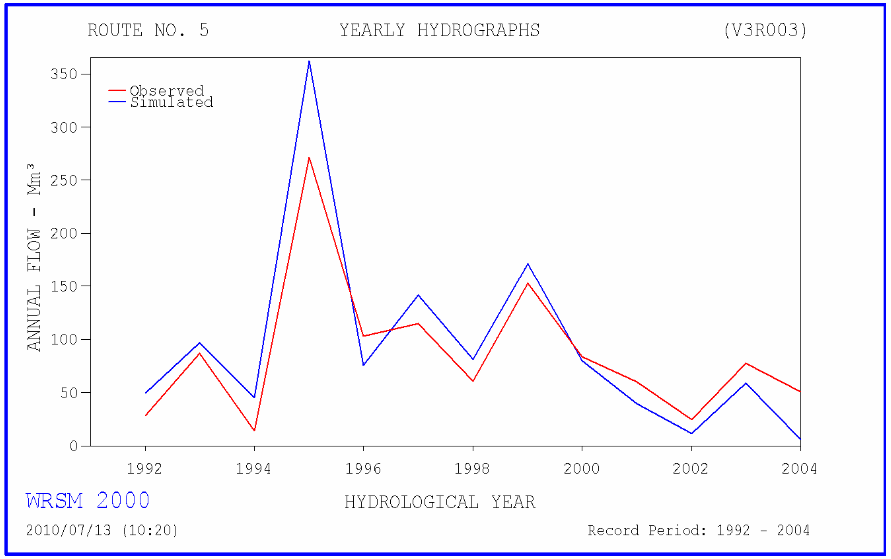


V3R003 - Yearly Hydrographs

WR2005



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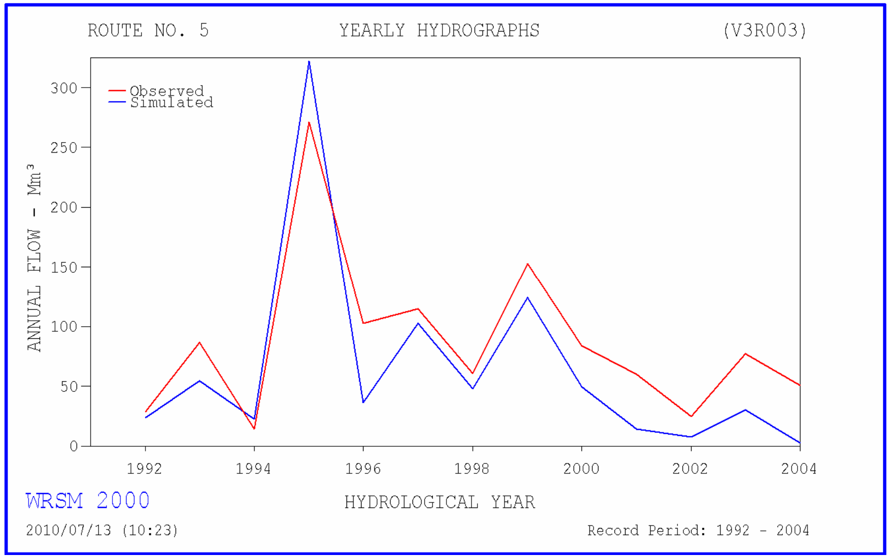
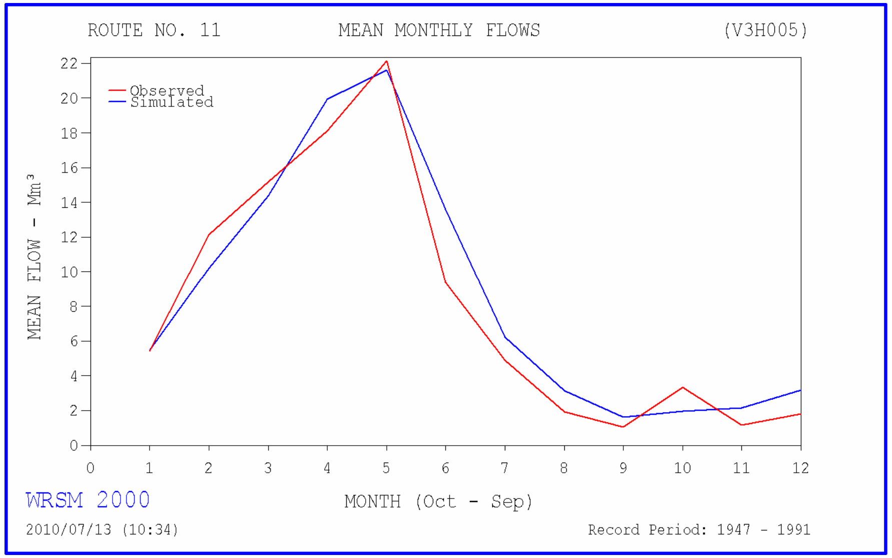


V3H005 - Mean Monthly Flows

WR2005



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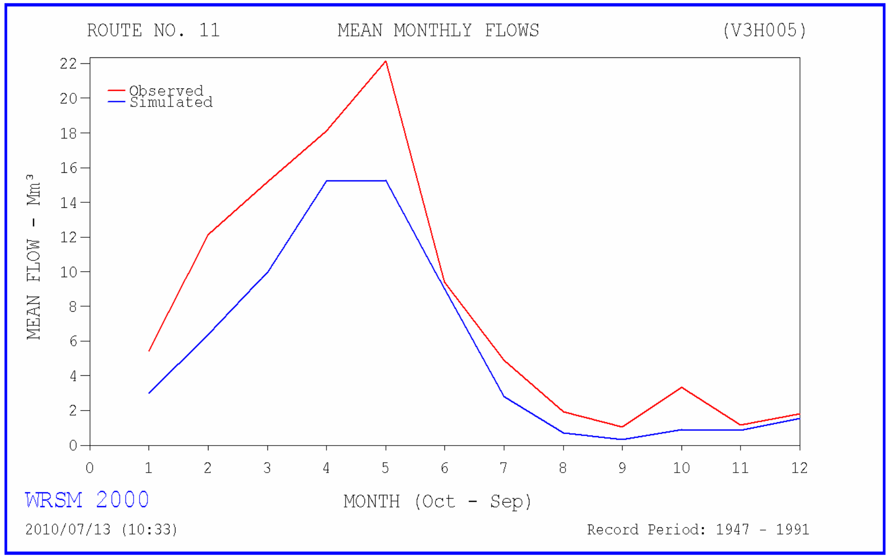
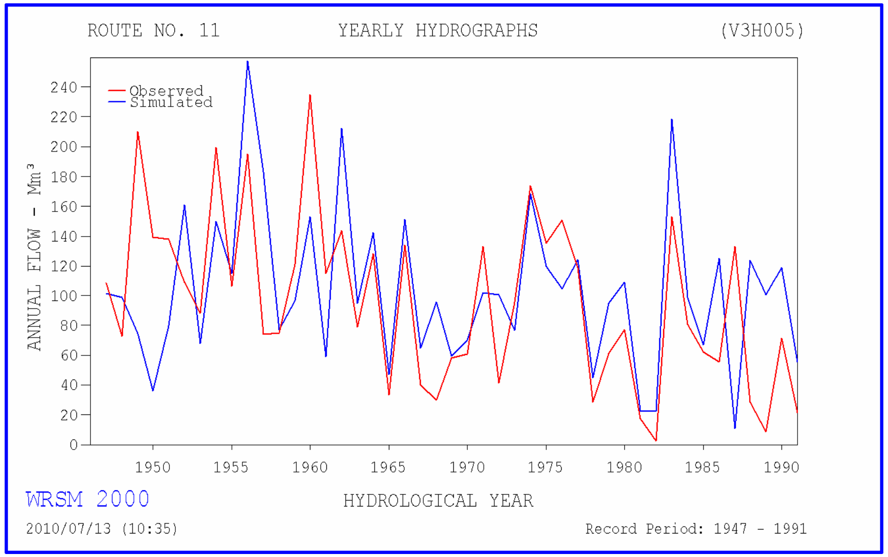


V3H005 - Yearly Hydrographs

WR2005



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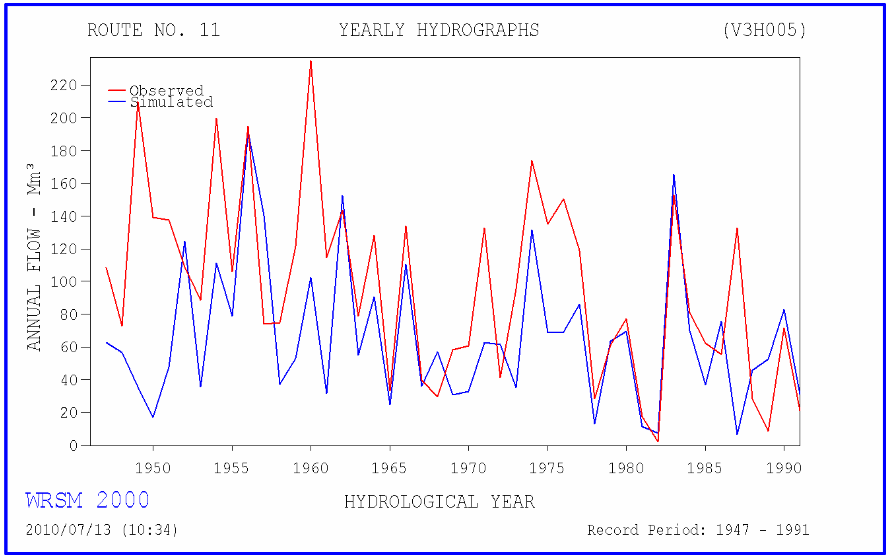
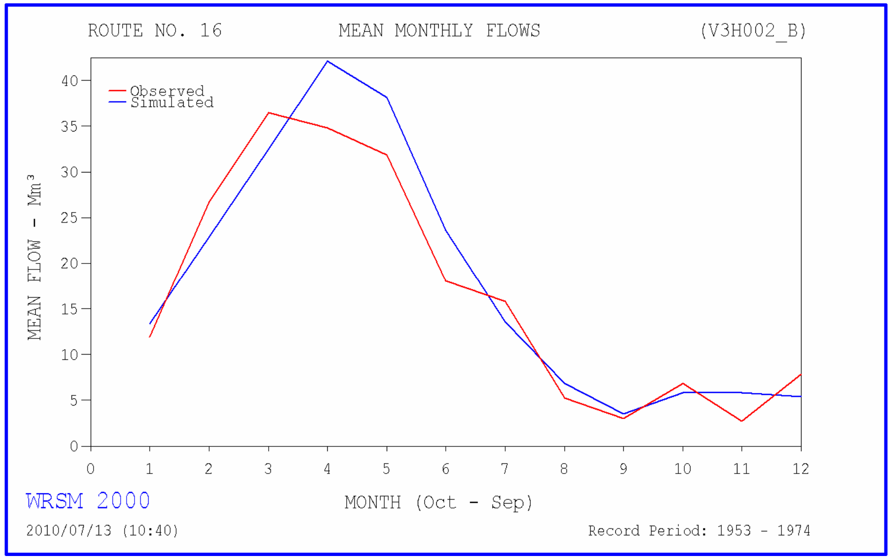


V3H002 - Mean Monthly Flows

WR2005



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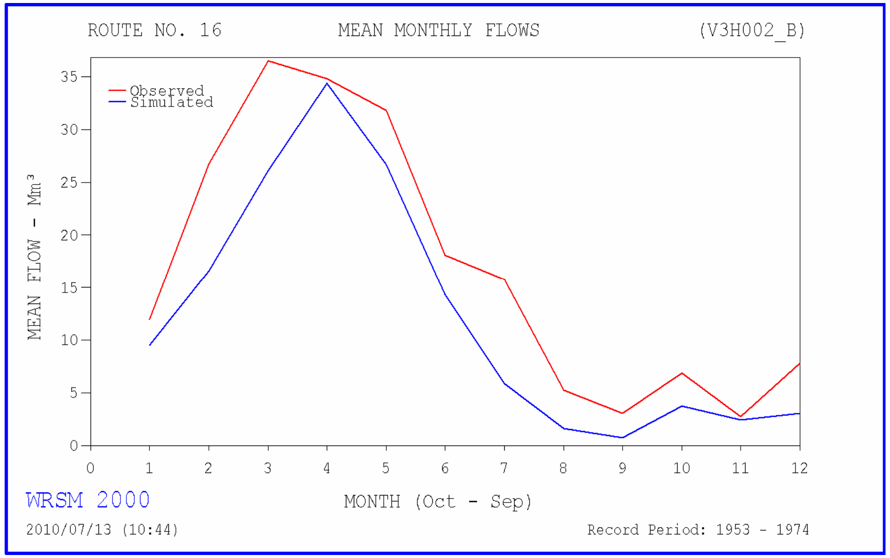
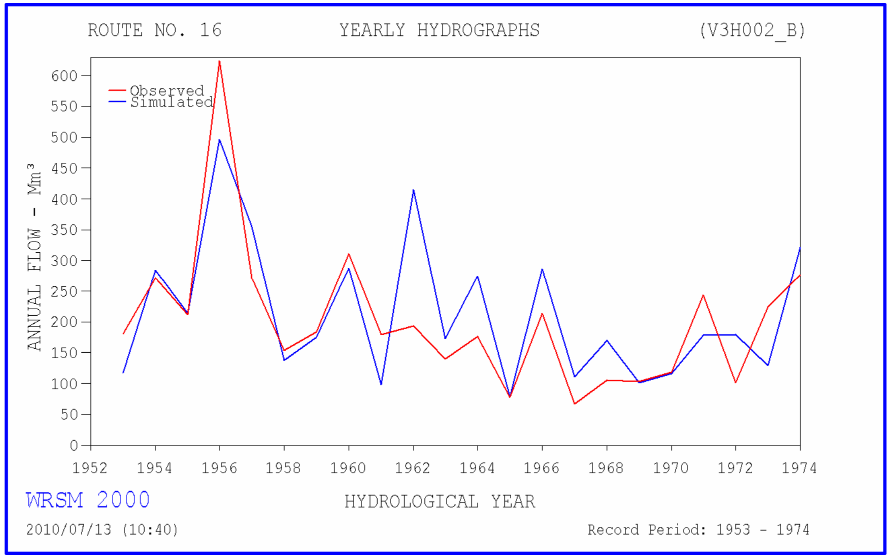


V3H002 - Yearly Hydrographs

WR2005



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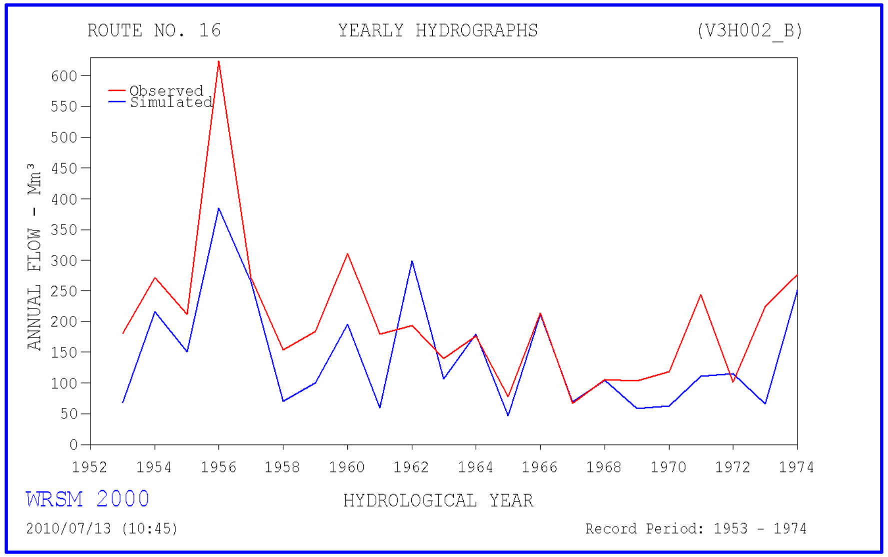
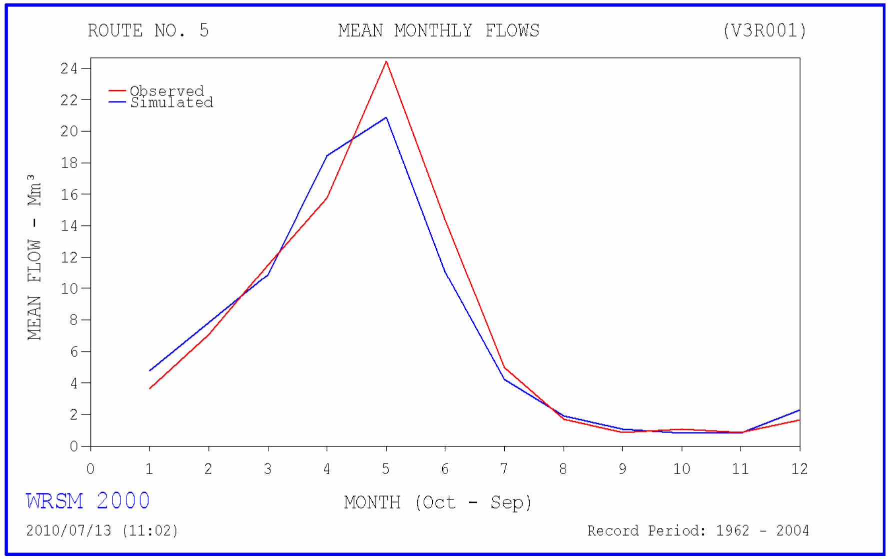


V3R001 - Mean Monthly Flows

WR2005



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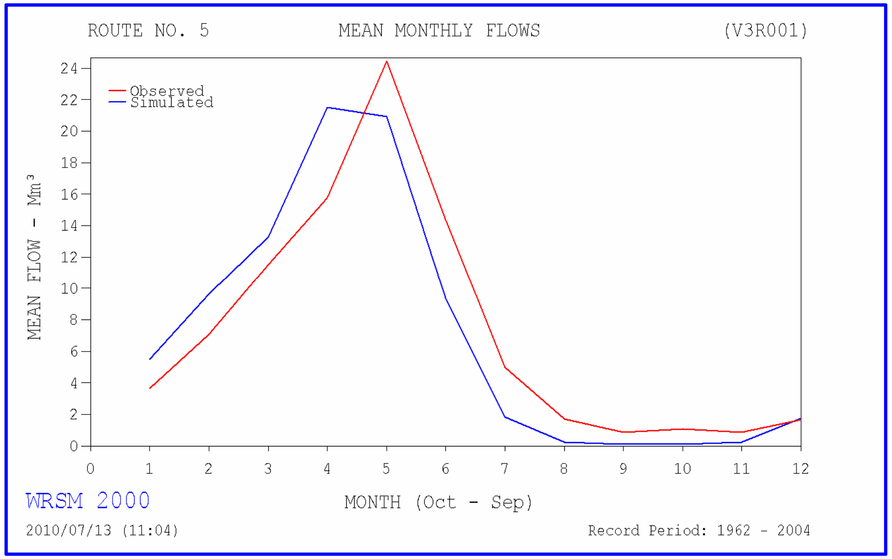
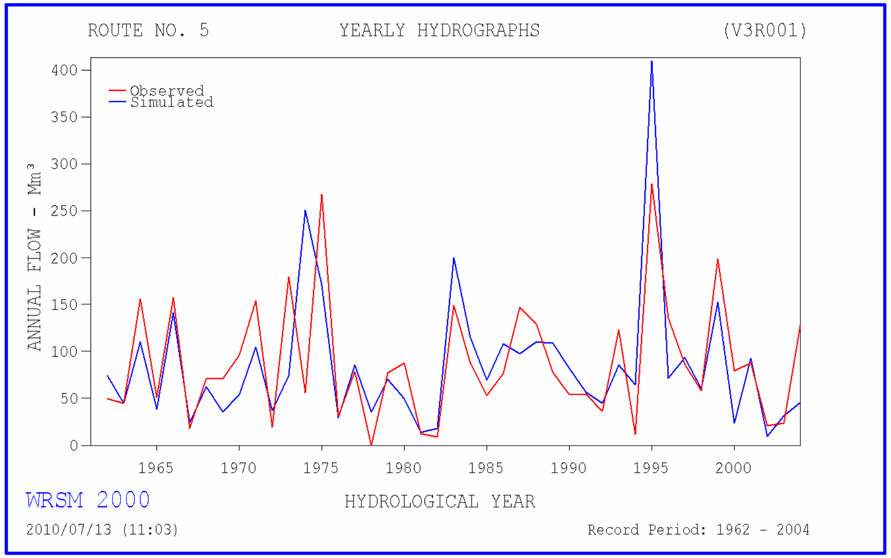


V3R001 - Yearly Hydrographs

WR2005



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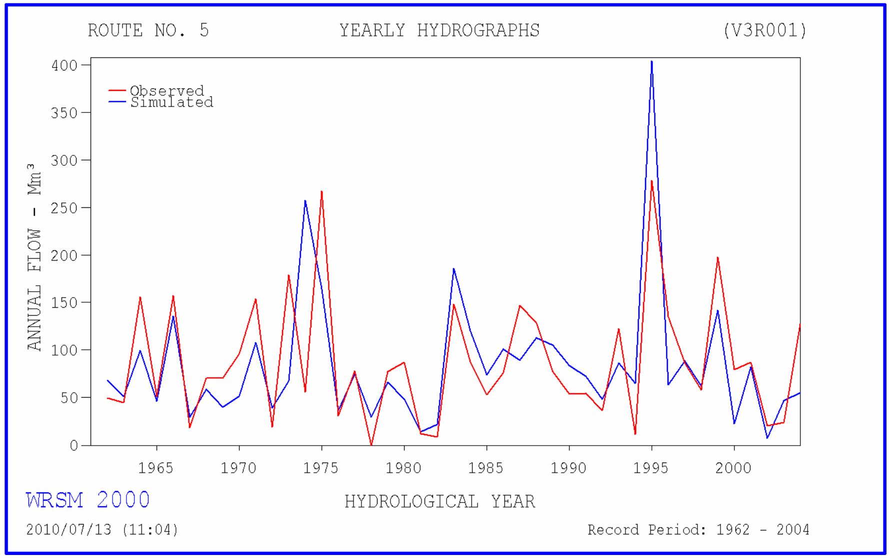
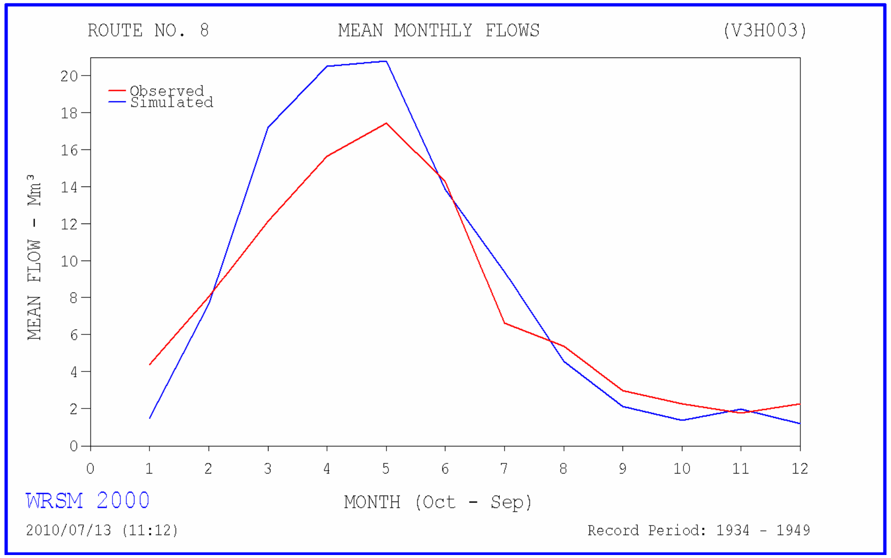


V3H003 - Mean Monthly Flows

WR2005



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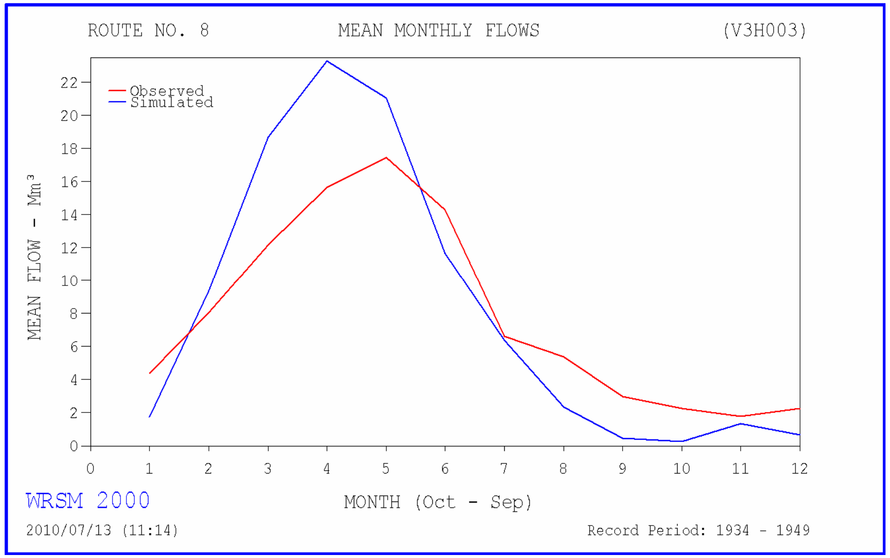
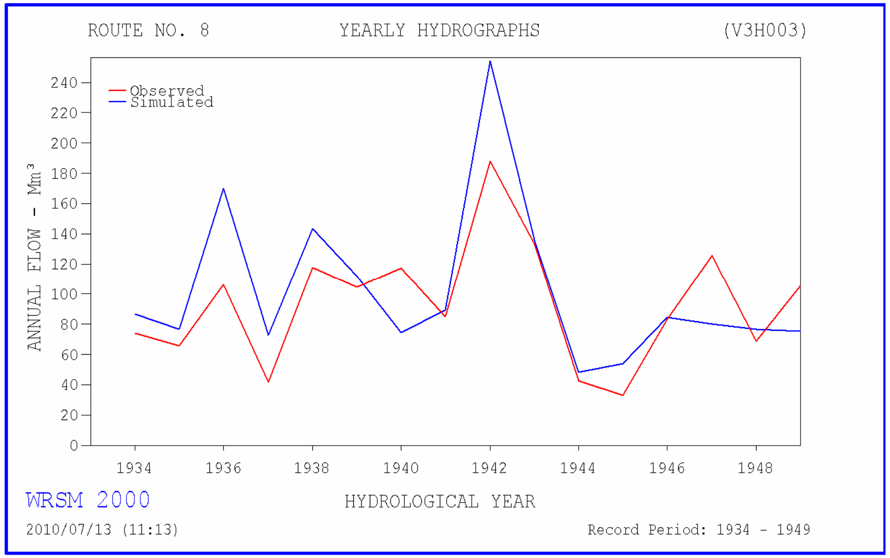


V3H003 - Yearly Hydrographs

WR2005



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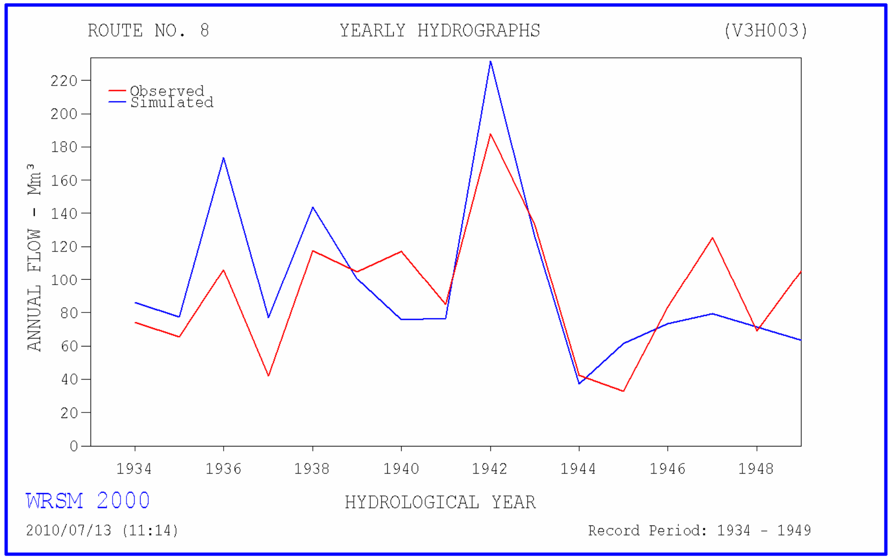
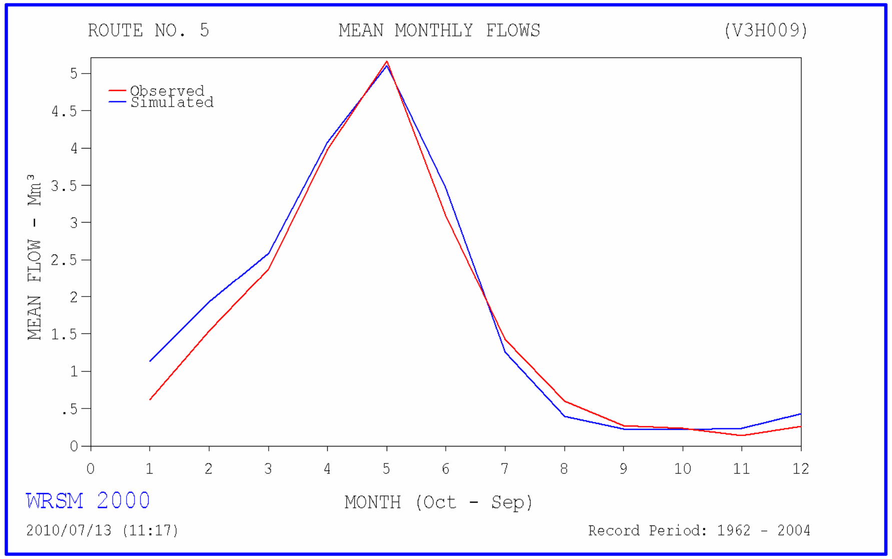


V3H009 - Mean Monthly Flows

WR2005



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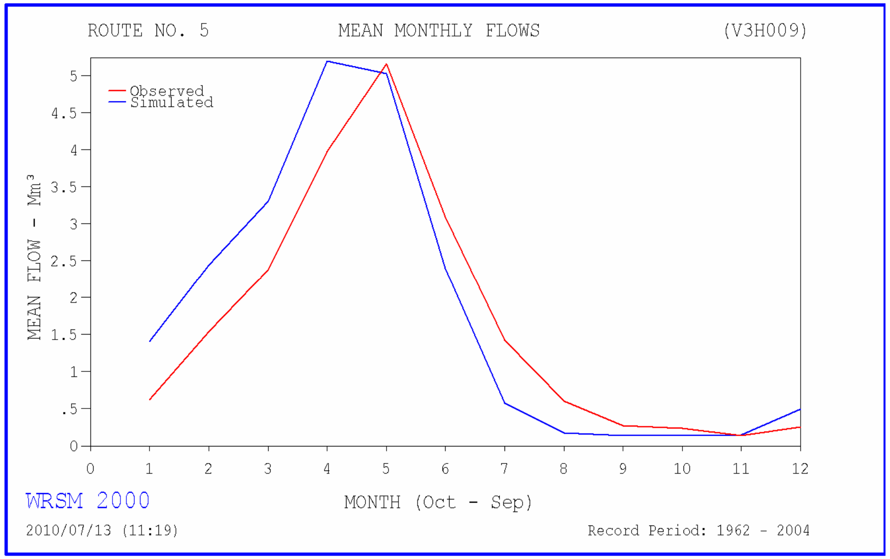
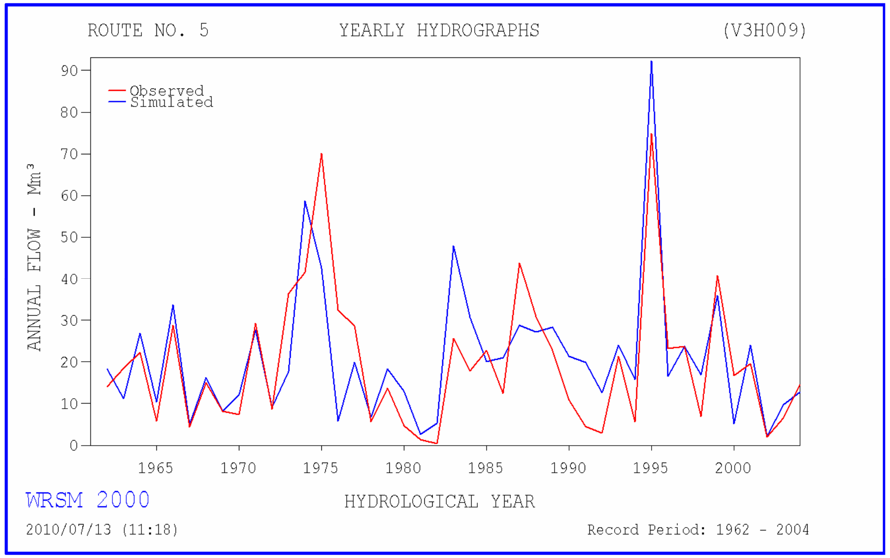


V3H009 - Yearly Hydrographs

WR2005



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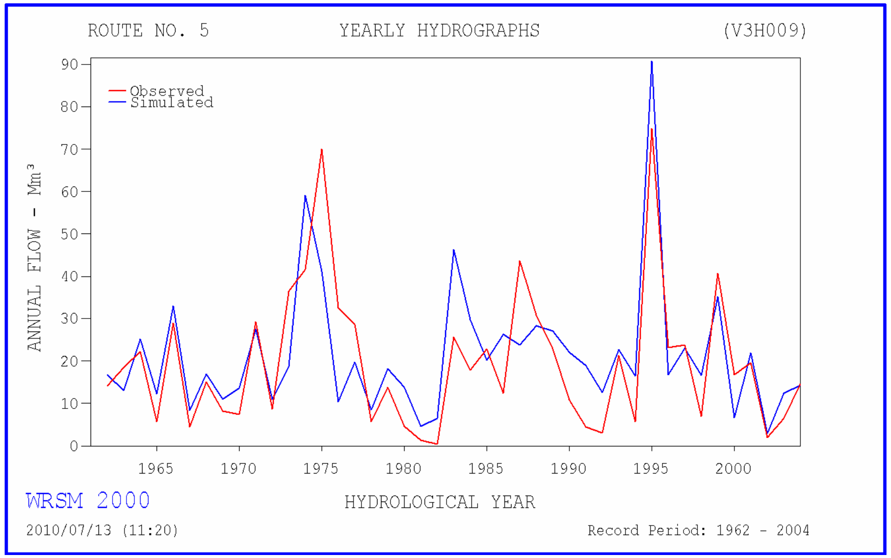
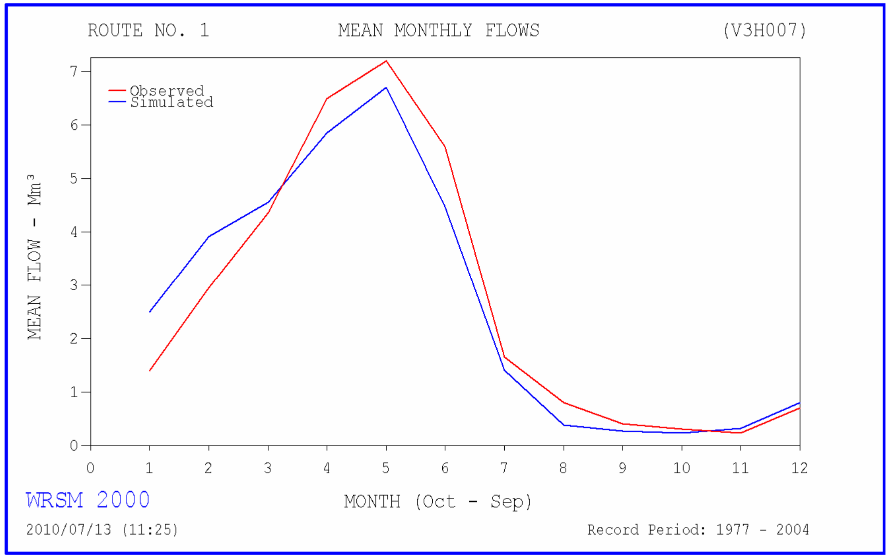


V3H007 - Mean Monthly Flows

WR2005



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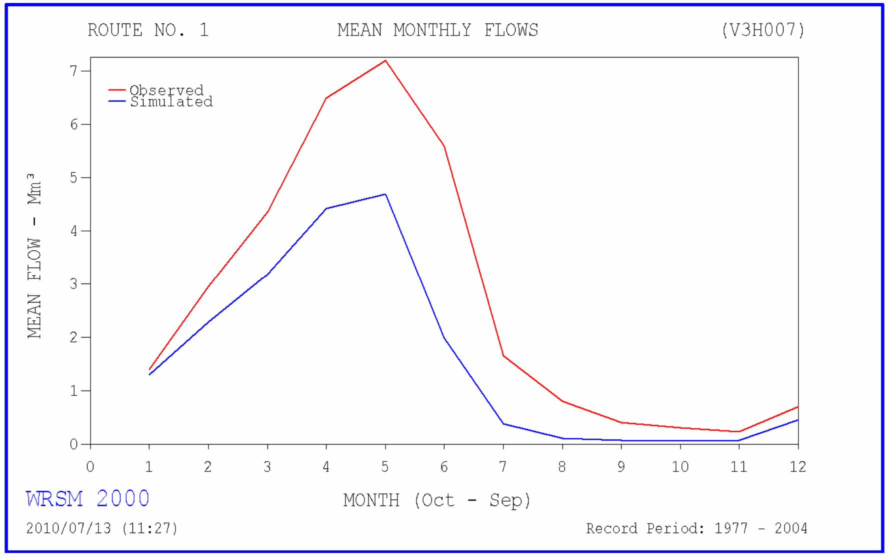
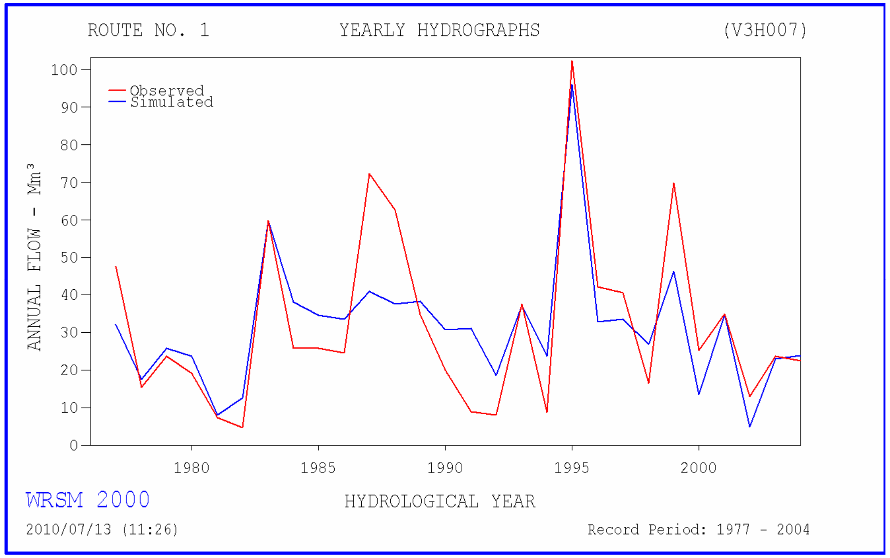


V3H007 - Yearly Hydrographs

WR2005



HYDZ