

Section 2.3
**SOUTH AFRICAN QUATERNARY
CATCHMENTS DATABASE**

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Overview and Objectives

Underpinning many assessments of hydrological and agricultural responses over South Africa is the South African Quaternary Catchments Database (QDB). This QDB had its origins in the late 1980s and since then it has been revised, reconstructed and expanded upon in a series of WRC projects (e.g. Dent *et al.*, 1989; Schulze and Lynch, 1992; Schulze *et al.*, 1993; Meier, 1997; Perks *et al.*, 2000; Hallowes *et al.*, 2004; Schulze *et al.*, 2005).

The objective of developing and refining this QDB is to be able to perform spatially comparative simulations of, for example,

- stormflow,
- baseflow, or
- total runoff, as well as
- impacts of land use change on hydrological responses, or of
- climate change on hydrological responses, of
- crop yields,
- sediment yield,
- irrigation water demand, or
- hydrological risk analyses

at the spatial scale of either

- individual so-called Quaternary Catchments (QCs) or, in the case of streamflows, for
- hydrologically linked, cascading catchments, thereby facilitating cumulated flows to be compared with those from the individual QCs that make up a larger area.

These simulations are performed with the daily time step, conceptual-physical and multi-purpose *ACRU* agrohydrological modelling system (Schulze, 1995; Schulze and Smithers, 2004), with the facility to outputting results via GIS.

The inputs required for the *ACRU* model need to be written into the model's input menu prior to simulation of any catchment. Instead of storing the information pertaining to each catchment in the *ACRU* input menu in preparation for performing agrohydrological simulations in South Africa, the information required for the *ACRU* simulations has been stored in a pre-populated QDB. An interface has been developed whereby information can be selected from an *ACRU* Input Database and automatically read into the *ACRU* model's input menu for the model to run.

Briefly, an *ACRU* Input Database at the level of QCs is established, which contains information required by the *ACRU* model for agrohydrological simulations. A variety of climatic information can be used in the simulation, including present baseline climates and the options for using future climate scenarios from selected General Circulation Models (GCM) and Regional Climate Models (RCMs). Relevant catchment information stored in the database can be extracted for simulation. Selected output from the model runs can be displayed in the form of time series or maps. This process will be expanded upon in greater detail in subsequent subsections.

Four main components constitute the QDB. The first component is the *ACRU* Input Database structure developed for use with the *ACRU* model. The next component is the interface between this Input Database and the model. The third component is the simulation of agrohydrological responses using *ACRU* with this automated system, while the fourth is the extraction of output from the model for presentation of results.

What are Quaternary Catchments?

South Africa, together with the geographical enclaves of Swaziland and Lesotho, has been delineated by the South African Department of Water Affairs and Forestry (DWAF) into a hierarchical system of catchments from Primary Catchments (shown in **Figure 2.3.1** by the different colours), which in turn are disaggregated into Secondary, then Tertiary and finally,

at the fourth level, into 1946 interlinked and hydrologically cascading Quaternary Catchments (**Figure 2.3.1**). Quaternary Catchments thus constitute the lowest, i.e. most detailed, level of operational catchment in DWAF for general planning purposes (Midgley *et al.*, 1994).

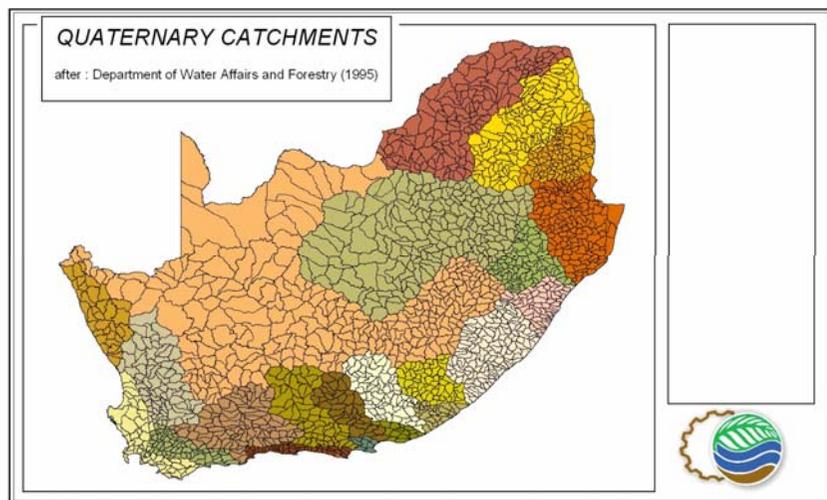


Figure 2.3.1 Delimitation of Quaternary Catchments in South Africa, Lesotho and Swaziland, with Primary Catchments distinguished by different shading (DWAF, 2000)

Quaternary Catchments are numbered in a downstream order. For example the Quaternary Catchment numbered V32E would be interpreted as follows:

- The letter 'V' denotes that the Quaternary Catchment is in Primary drainage region 'V', which is the Thukela catchment. There are 22 Primary drainage regions which cover southern Africa, numbered alphabetically from 'A' to 'X', but excluding the letters 'I' and 'O'.
- The number '3' denotes that the Quaternary Catchment is in the Secondary drainage region number 3 of the Primary drainage region 'V'. There are, at maximum 9 Secondary drainage regions (1-9) per Primary drainage region.

- The number '2' denotes that the Quaternary Catchment is located in the Tertiary drainage region number 2 of the Secondary drainage region number 3. Again, there are a maximum of 9 Tertiary drainage regions per secondary drainage region.
- 'E' denotes the Quaternary Catchment *per se*. There are at most 12 Quaternary Catchments per Tertiary drainage region, labelled 'A' to 'M', with 'I' omitted (Midgley *et al.*, 1994).

Structure of the *ACRU* Input Database

Various inputs, viz. information on soils, land use and climate for each catchment being simulated, are required for the *ACRU* model for agrohydrological simulations and are input into the model's input menu. The *ACRU* input menu is a formatted ASCII file in which the various hydrological variables required by *ACRU* are entered prior to simulation.

ACRU input information is organised into a single file, stored in a spreadsheet, thereby allowing flexible modification and manipulation of the *ACRU* input information in a familiar format. Each row in the spreadsheet refers to a catchment and each column to an *ACRU* input. The column names follow the parameter names used in the *ACRU* input menu, however, the columns need not be in the same order as they occur in the input menu. The first column is the name of the catchment, e.g. U10A. In total there are 612 *ACRU* inputs possible into this particular version of the *ACRU* input menu. However, not every input is used in a simulation, for example, if no irrigation is specified in a catchment then irrigation information is not required by the model.

Once the database has been established it is exported from the spreadsheet in comma delimited format and is subsequently converted to an array. The row containing the *ACRU* input information pertaining to the catchment selected can be extracted by matching that catchment with the catchment name recorded in the first column of the database. This allows for flexibility with the naming of the catchments using either alphabetic or numerical identity. Furthermore, high flexibility in adding new input information is achieved by giving each new *ACRU* input variable added to the database, over and above the original input information, a new input name. For example, the standard name for the *ACRU* input referring to the raingauge used to "drive" the hydrology of a particular catchment is

RAINSTA. However, the situation might arise that a station with better data is found and, therefore, this new raingauge name needs to be recorded in the database as a new option. This updated list of raingauges could be added under the header of, say, RAINSTA2.

Various additional options available in the database can be selected or de-selected depending on the information required for the simulation.

The Pre-Populated Quaternary Catchments Input Database

The QCs Input Database can be used as input to simulate agrohydrological responses of QCs in South Africa. As and when updated information is obtained for each QC it can be included in the database and become available to users of this Input Database.

1. Daily Rainfall Input per Quaternary Catchment: Background

Lynch (2004) recently compiled a comprehensive up-to-date database (1950 - 2000) of infilled rainfall station data consisting of > 300 million rainfall values from 12 153 daily rainfall stations. The daily rainfall data were checked exhaustively by Lynch (2004) for various errors and anomalies, with missing or suspect data infilled using a hierarchy of infilling techniques (cf. **Section 2.2**). From this database, a rainfall station had to be selected for each Quaternary Catchment, with that station's data considered representative of the daily rainfall of that QC. The method of selection is outlined below.

2. Method Used to Select "Driver" Rainfall Stations

The centroid was determined for each of the QCs using ArcView GIS. Using these co-ordinates, the Daily Rainfall Extraction Utility developed by Kunz (2004) was used to extract the 10 closest rainfall stations to each pair of the centroid's co-ordinates. These 10 stations are ranked by the Daily Rainfall Extraction Utility (Kunz, 2004) using the following 10 criteria:

- Distance from the rainfall station to the point of interest, with this criterion being given the highest weighting;
- Stations that are operational at the end date of the required period (i.e. the year 2000) are given a maximum score;

- If the start year of the rainfall record is earlier than the start year required by the user (in this case the year 1950), the station is given a maximum score;
- If the end year of the rainfall record is later than the end year required by the user (in this case the year 2000), the station is given a maximum score;
- Stations with relatively long rainfall records compared to other stations nearby stations are given maximum scores;
- The 1' x 1' grid value mean annual precipitation (MAP; determined by techniques described in Lynch, 2004), for the point of interest (i.e. the centroid of the QC, in this case) is compared to the grid MAP of the station's location; if the two are similar in comparison with other selected stations, a maximum score is given;
- The 1' x 1' grid MAP for the point of interest (the QC centroid) is compared to the observed MAP of the rainfall station whose suitability is being tested, and if the two are similar in comparison with other 9 selected rainfall stations, a maximum score is given;
- The higher the reliability (i.e. the higher the percentage of actual data vs. infilled values) of the rainfall station's record the higher the score given;
- The lower the fraction of infilled record (due to poor quality data or missing values), the higher the score given; and
- The lower the portion of missing record, the higher the score given.

Although the Daily Rainfall Extraction Utility's method of ranking stations is comprehensive and thorough, there are certain factors for which it does not compensate (Schulze *et al.*, 2005; Warburton and Schulze, 2005).

Therefore, it was decided that the best ranked station by the Kunz (2004) Daily Rainfall Extraction Utility would, in addition, be evaluated manually by considering the following:

- the reliability of the record;
- the ranking given by the Daily Rainfall Extraction Utility;
- the topography of the catchment, i.e. the altitude of the rainfall station compared to the average altitude of the catchment;
- prevailing weather direction;
- the hydrological knowledge/experience of a team of evaluator; and.

- In total, 1248 stations were selected, the daily rainfall values from which were to “drive” the hydrology of 1946 QCs.

3. An Analysis of the Selected “Driver” Rainfall Stations

As mentioned above, the reliability of the station’s record is an important selection criterion, as a sample error in rainfall will be amplified when the record is used in a hydrological model to generate streamflow.

The reliability of the rainfall record is the percentage of days in a required data period (in this case 1950 - 1999) for which there is a reliable observed rainfall record. The average reliability of the rainfall stations selected was 79.2 %, with the highest reliability of a chosen station being 100% and the lowest reliability of a chosen rainfall station being 23.9%. Nearly 50% of the selected rainfall stations had a reliability of 95% or higher. The breakdown of the reliability of the rainfall stations’ records is shown in **Table 2.3.1**.

Table 2.3.1 Breakdown of rainfall station reliability (Warburton and Schulze, 2005)

Reliability (%)	% of Selected Stations
100 - 95	49.7
95 - 90	8.5
90 - 80	12.1
80 - 70	12.4
70 - 60	8.7
60 - 50	5.9
50 - 30	2.3
< 30	0.4
Total	100.0

Figure 2.3.2 depicts the reliability of the chosen rainfall stations for the Quaternary Catchments in the RSA, Lesotho and Swaziland. What is immediately evident is the large portion covered by rainfall stations with reliability in excess of 90%. The cluster of QCs in the Drakensberg/Lesotho region represented by rainfall stations with a poor reliability is also clearly evident. Other clusters of low reliability are evident in the Western Cape fold mountains region, and along the northeastern border of the RSA with Mozambique. The repercussions of poor data reliability in the two specific high rainfall and runoff regions could be immense because the

Drakensberg/Lesotho region supplies water to the Lesotho Highlands Water Scheme and to South Africa’s economic heartland of Gauteng while the Western Cape region is already a highly water stressed one.

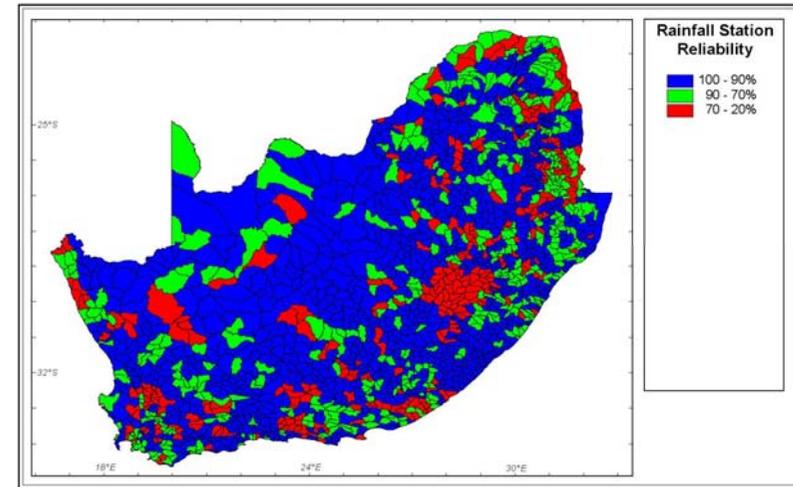


Figure 2.3.2 Reliability of daily rainfall at stations selected to represent each Quaternary Catchment in southern Africa (Warburton and Schulze, 2005)

Other factors which were considered were the ranking given to the rainfall station by the Rainfall Extraction Utility. Of the selected rainfall stations, 73.23% were ranked number 1. The entire ranking breakdown is shown in **Table 2.3.2**. The distance of the rainfall station from the centroid was also considered. However, only 20.5% of the chosen rainfall stations were the closest to the centroid. Again that breakdown is shown in **Table 2.3.2**. Furthermore, the record length of the rainfall station was also considered.

As stated before, the total number of rainfall stations selected to “drive” the 1 946 Quaternary Catchments was 1 248. In many instances one rainfall station was chosen to “drive” the hydrology of more than one QC; 486, or 25%, of the rainfall stations are used more than once. There are two stations which “drive” 7 catchments each, and a further two stations that

“drive” 6 catchments each. **Table 2.3.3** provides a breakdown of the number of rainfall stations the data from which are “driving” the hydrology of more than one Quaternary Catchment.

Table 2.3.2 Statistics of the selected rainfall stations in the South African QDB, according to the rank given by Kunz’s (2004) Daily Rainfall Extraction Utility (Warburton and Schulze, 2005)

Rank	No. of Stations	Percentage of Total	Average Reliability (%)	% Closest to Centroid
Rank 1	1425	73.23	87.6	25.75
Rank 2	261	13.41	82.4	9.58
Rank 3	56	2.88	75.5	8.93
Rank 4	23	1.18	76.9	8.70
Rank 5	4	0.20	63.9	0.00
Revisited	177	9.10	88.9	0.00
Total	1946	100	79.2	20.5

Table 2.3.3 Breakdown of rainfall stations used to “drive” the hydrology in more than one Quaternary Catchment in the southern African QDB (Warburton and Schulze, 2005)

No. of QCs a Rainfall Station Drives	No. of Rainfall Stations	Number of QCs Covered
1	762	762
2	334	668
3	110	330
4	30	120
5	8	40
6	2	12
7	2	14
Total	1248	1946

4. Concluding Remarks on the Selection of the “Driver” Rainfall Stations for the QDB

The selected rainfall stations for each QC generally have data of high quality, with adequate reliability and record length. The rainfall stations were selected based on a number of possible influences on the quality of

the record. As already highlighted, the Drakensberg area, the Cape Fold Mountain area and the northernmost parts of the RSA need to be evaluated in regard to their rainfall station networks, as in those areas the reliability of the rainfall stations is low. A considerable proportion of South Africa’s water resources have their origin in such high lying areas, and it is in these areas that the rainfall, and thus runoff, gradients are steepest and the strong curvilinear relationship between rainfall and runoff is at the highest end of the curve. The high lying mountainous areas are critical areas that are highly sensitive to climate or land use change; however, these are the areas which have the lowest rainfall network reliability.

All rainfall stations selected for the QDB receive focus in regard to the monitoring network in South Africa and should, if at all possible, be retained as high quality rainfall stations, as they are crucial in the region’s hydrological studies. This selection of the rainfall stations is likely to be used extensively for the next five to ten years. It is for that reason that great care and a large amount of time were invested in making what is believed to be the best selection possible.

5. Daily Temperature Input per Quaternary Catchment

Daily temperature values allow users to estimate, impartially or explicitly, changes in vapour pressure, solar radiation, potential evaporation, soil moisture, runoff generation or irrigation demand.

Procedures outlined in the recently completed WRC funded project by Schulze and Maharaj (2004); summarized in **Section 2.1**, facilitate the generation of a 50 year historical series of *daily* maximum and minimum temperatures at any unmeasured location in RSA, Lesotho and Swaziland at a spatial resolution of 1’ x 1’ latitude/longitude (~1.7 x 1.7 km). The underlying database was made up of daily, quality controlled, records from over 970 temperature stations, extended to a common 50 year period, 1950 - 1999. Any infilling/extension of records took account of regionalised monthly temperature lapse rates from carefully chosen target stations at which similarities in variability of daily temperature value with the control station was a key factor, as described in **Section 2.1**.

For each QC, a representative altitude was computed from a 200 m DEM and for this altitude the 50 year series of daily maximum and minimum

temperatures was generated at the centroid of the QC. This daily temperature series is then used, for example, in the generation of daily estimates of solar radiation and vapour pressure deficit, from which daily values of reference potential evaporation may be modelled.

6. Estimation of Daily Potential Evaporation per Quaternary Catchment

In the *ACRU* model there is a choice of 15 methods by which to input/estimate daily reference potential evaporation, E_r , ranging from the physically based daily version of the Penman (1948) equation to empirical temperature based equations to daily/monthly A-pan observations. With no daily A-pan or other E_r observations existing for all 1 946 QCs, but daily maximum and minimum temperature values available, a temperature-based equation had to be selected to generate E_r . Up to the year 2005 the Linacre (1991) equation was the preferred one. Since then the Linacre (1991) equation has been replaced by the Hargreaves and Samani (1985) daily equation. This equation has been found to give more realistic values in South Africa than other temperature based equations of similar level of sophistication when compared with A-pan values (Pike, 1988) and the Penman-Monteith equation (Bezuidenhout, 2005). It is a conceptually-based, temperature driven method of calculating potential evaporation in which direct account is taken of extra-terrestrial radiation and implicit account is taken of vapour pressure deficit and net radiation.

All applications in this Atlas are based on Hargreaves and Samani estimates of E_r . From 2007, however, and as a result of the completion of this Atlas, daily values of Penman-Monteith equivalent E_r , derived by the methods outlined in **Section 13.3**, are available in the QDB as an option (Penman, 1948; Monteith, 1981).

7. Hydrological Attributes of Baseline Land Cover Types

In any hydrological impact studies the hydrological attributes of baseline land cover types are required in order to simulate any changes in hydrological responses when the baseline land cover is converted to new land uses or new forms of land management. For South Africa, Lesotho and Swaziland the 70 Acocks' (1988) Veld Types are a recognised baseline land cover in hydrological impact studies (cf. **Section 3.4**).

Based on a set of working rules for determining the water use coefficient, interception per rainday, root distribution, a coefficient of infiltrability and index of suppression of soil water evaporation by a litter/mulch layer, month-by-month values of these attributes (Schulze, 2004) are now incorporated in the QDB for each of the 70 Acocks' Veld Types covering South Africa (cf. **Section 3.4**). For each QC in the database the spatially most dominant Veld Type has been selected as the baseline land cover.

8. Hydrological Attributes of Land Use Categories

For studies on present-day or anticipated future hydrological responses which are impacted by anthropogenic changes in land use and management (e.g. afforestation, land degradation, urbanisation, enhanced tillage or tillage practices), hydrological attributes of such land uses need to be input into models such as *ACRU*. Currently, in addition to the 70 Acocks baseline land covers, the QDB has options for

- undisturbed grassland, with categories into veld in good, medium and poor hydrological condition, and
- forest plantations, with categories for eucalypts, pines and wattle.

In each case, hydrological attributes, i.e. month-by-month values of the water use coefficient, leaf area index (where available), interception per rainday, root distribution, a coefficient of infiltrability and a soil loss related vegetal cover factor, were assigned to each category in a consistent manner.

9. Crop Yield Options

Information on plant dates, length of growing season and biomass indicators for maize, winter wheat, sugarcane and a generic "primary production" are contained in the Quaternary Catchments Input Database. The default plant dates and lengths of the growing seasons that are used for the Quaternary Catchments are given in **Table 2.3.4**. However, if different input information is available either for different regions or if sensitivity analyses are undertaken, this can replace the default values in the Input Database.

When simulating maize yield in *ACRU*, crop transpiration and soil water

evaporation are modelled separately according to the Ritchie (1972) method and the *ACRU* variable EVTR is manually set to 2. The winter wheat model also separates transpiration from soil water evaporation on a daily basis, but this done internally within the routine and variable EVTR is specified as equal to 1. For the sugarcane and primary production options transpiration and evaporation are modelled as a single entity (EVTR = 1). The estimation of maize yield, winter wheat yield, sugarcane yield and primary production is explained in more detail in Schulze *et al.* (1995).

Table 2.3.4 Default values of plant dates and lengths of growing seasons for various crops, yields of which can be simulated using *ACRU* at a Quaternary Catchment scale (Schulze *et al.*, 2005)

Crop	Plant Date	Length of Growing Season
Maize	15 November	150 days
Sugarcane	1 July	N/A (yields are annualised)
Winter Wheat	15 May	150 days
Primary Production	1 August	N/A (yields are annualised)

10. Irrigation Water Demand Options

ACRU contains routines which can simulate irrigation water requirements for a range of crops under a variety of soil conditions and different modes of scheduling the irrigated water, as well as routines for the supply of water from different sources.

When the default irrigation water demand option is selected for QC comparisons, a number of simplifying assumptions are, however, made for the sake of convenience. First, irrigation demand in *ACRU* is activated for each month of the year (rather than for only selected months) assuming an areal unit of irrigation (e.g. per hectare) within each QC. The mode of scheduling is specified as demand irrigation, i.e. applying irrigation water to refill the soil profile to the drained upper limit with an unlimited supply of water for irrigation once profile plant available water has been depleted to 50%. Other assumptions that are made with respect to soils, the crop and water losses when the irrigation option is selected are given in Schulze *et al.* (2005).

The *ACRU* model's irrigation output options are irrigation water demand,

and also unit stormflow from irrigated fields (for the default inputs) as well as deep percolation from irrigated fields. All default input values can be replaced by others, depending on the simulation required, as is the case in the section on irrigation in this Atlas, which contains maps not only for demand irrigation, but also for drip, deficit and fixed cycle/amount schedules.

11. Sediment Yield Analysis

Event-by-event sediment yield in *ACRU* is computed with the daily stormflow based Modified Universal Soil Loss Equation, MUSLE (Williams, 1975), which has been widely verified world-wide and also in South Africa (Kienzle *et al.*, 1997). Sediment yield at any QC outlet may be estimated from the stormflow volume for the event (m^3); peak discharge for the event (m^3/s); a soil erodibility factor (t.h/N/ha); the slope length and gradient factor (-); a cover and management factor (-); the support practice factor (-); and default values of weighting coefficients.

When the sediment yield option is selected, then the peak discharge for each QC needs to be simulated for each stormflow event. For these simulations the SCS peak discharge equation modified by Schulze and Schmidt (1995), is used. This equation requires input per QC on, *inter alia*, the:

- mean catchment slope, $S_{\%}$, which was obtained using a 1' x 1' of a degree latitude / longitude digital elevation model;
- the hydraulic length, H_i (m), of the main channel, estimated from a SCS derived default equation given in the *ACRU* User Manual (Smithers and Schulze, 1995) and using catchment area (km^2), such that

$$H_i (m) = 1738 \times A^{0.6}$$

- and
- the initial SCS Runoff Curve Number, CN_i , unadjusted for antecedent soil moisture conditions of the catchment. The Curve Number is given for various land / use treatment classes, hydrological soil groups and stormflow potentials by the SCS and in the *ACRU* User Manual (Smithers and Schulze, 1995).

12. Extreme Value Analysis

Expected magnitudes of a rainfall or flood amount at a given recurrence interval at a QC scale can be performed on the Annual Maximum Series of either

- daily rainfall (mm);
- daily simulated streamflow depth (mm); or
- daily simulated peak discharge (m³/s).

The Annual Maximum Series takes the largest event from each 'n' years of record and the extreme values are calculated for either one, or all, of the

- Gumbel,
- Log-Normal, and/or
- Log-Pearson Type III

extreme value distributions using this sample of *n* values, which represent the design magnitude in the *n* year record.

Analyses on Potential Climate Change Impacts with the Quaternary Catchments Database

A facility is available in the QDB to perform simulations directly at the Quaternary Catchment (or at smaller scale) using future projected temperature and precipitation changes as simulated by large scale atmospheric general circulation models (GCMs). Monthly perturbations for 2 x CO₂ equivalent scenarios from any one of the following five GCMs, viz.

- UKTR (1995), excluding sulphate forcing (UKTR-S);
- HadCM2 (1998), excluding sulphate forcing (HadCM2-S);
- HadCM2 (1998), including sulphate forcing (HadCM2+S);
- CSM (1998), excluding sulphate forcing; and
- Genesis (1998), excluding sulphate forcing

can be used in simulations of potential future climate conditions using this system. Detail on background and preparation of the output from those five GCMs can be obtained in Perks *et al.* (2000). The methodology of including future scenario values of precipitation and temperature in an

ACRU simulation is described by Schulze *et al.* (2005). The options of performing a sensitivity or, alternatively, a threshold analysis have also been included and the methodology, with details, is given in Schulze *et al.* (2005).

For more recent Regional Climate Models (RCMs) such as C-CAM (Engelbrecht, 2005), daily values of temperature and precipitation for both a present-day climate (1975 - 2005) and a future climate scenario (2070 - 2100) are available at spatial resolutions of 1/2°, i.e. approximately 50 km x 50 km. The RCM's daily climate file for that grid box then "drives" the hydrology of the respective QCs, be it for present or future climate scenarios.

Selections of Catchments from the Quaternary Catchments Input Database

Using the ACRU model, the hydrological responses of catchments can be generated either with the catchments operating as

- individual (i.e. non-linked) catchments, which is suited for determining where, within a region, streamflow is actually generated (details in Chapter 8.7 of Schulze *et al.*, 2005); or as
- cascading (i.e. hydrologically connected, linked) catchments, used to determine cumulative flows down a river system, and hence the total available water at any point within a large catchment (details in Ch 8.8 of Schulze *et al.*, 2005).

The user can select to model hydrological responses from a group of Quaternary Catchments which can be delimited by

- drainage region (any Primary, Secondary, Tertiary or Quaternary Catchment within southern Africa);
- a user specified list of Quaternary Catchments;
- a large catchment in southern Africa; or
- a Water Management Area.

1. Delineation of Southern Africa into Drainage Regions

If, for example, the Primary Catchment 'A' is selected then, using a

FORTRAN script, all the QCs that start with the letter 'A' are isolated in an ASCII file and the number of QCs in the selected Primary Catchment written to the screen. Each QC in that Primary Catchment can then be modelled as an individual, lumped catchment using *ACRU*. The same procedure applies for Secondary and Tertiary Catchments, using the first two and first three characters respectively of the QC numbering system. In addition, a QC or a cluster of QCs can be selected, based on the numerical identities assigned to them. The option remains to select all the QCs in South Africa for simulation.

2. A User Defined List of Quaternary Catchments

The situation may arise where a selection of Quaternary Catchments is required for simulation, however, they may be situated in scattered locations across southern Africa. In this instance, the user can enter the name of a pre-prepared list of the catchments required.

3. Option of Selecting a Large Catchment in Southern Africa

Files containing lists of the Quaternary Catchments which fall into large catchments in South Africa were created to allow the following entire catchments to be selected for simulation using *ACRU*:

- | | | | |
|-----------------|------------|---------------------|-------------|
| • Black Mbuluzi | • Limpopo | • Mzimkulu | • Sundays |
| • Breede | • Mfolozi | • Mzimvubu | • Swartkops |
| • Buffalo | • Mgeni | • Olifants (Mpumal) | • Thukela |
| • Caledon | • Mhlatuze | • Orange | • Vaal |
| • Crocodile | • Mkomazi | • Pongola | |
| • Gouritz | • Mkuze | • Sabie | |
| • Kei | • Mvoti | • Sand | |

This eliminates the need for the user to know which QCs fall into the large catchment of interest, as the names of these catchments are stored and automatically extracted.

4. Option of Selecting a Water Management Area in Southern Africa

South Africa has been delineated into 19 Water Management Areas

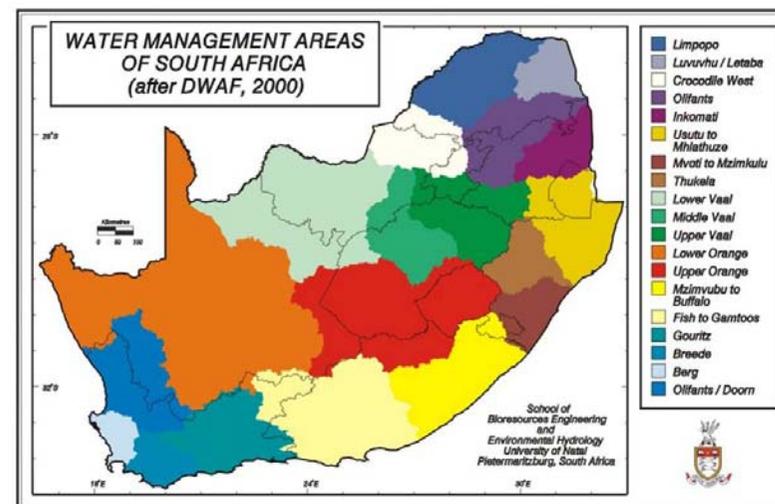


Figure 2.3.3 The Water Management Areas of South Africa (After DWAF, 2000)

(WMAs), as shown in **Figure 2.3.3**. In future each WMA is to be operated by a Catchment Management Agency (CMA) in accordance with the National Water Act of 1998 (NWA, 1998). The option of individually simulating the hydrology of those QC that are located in each Water Management Area is therefore available for decisions to be made by the future CMAs.

Simulation of Agrohydrological Responses from Individual Catchments

An *ACRU* input menu is automatically created for each catchment selected. This menu contains information (e.g. climate, soils, land cover) pertaining to that catchment, as extracted from the *ACRU* Input Database using a FORTRAN script. The file containing the daily rainfall information for the simulation period is unzipped for each selected QC using a FORTRAN program (Meier, 1997). If the option of using daily temperatures is selected, then composite files are created containing the daily rainfall and temperatures for each catchment selected for simulation.

The *ACRU* input menu established for each catchment is used for an individual *ACRU* simulation for each catchment required. The selected output from *ACRU* is written to files which can be used later for extraction of the required output for display purposes.

Simulation of Agrohydrological Responses from Cascading Catchments

1. The Need to Link Catchments

The cascading option in *ACRU* is useful to determine cumulative flows and total available water under different climate or land use scenarios. This option of simulating a cluster of catchments, such that the streamflow from one catchment flows to its immediate downstream catchment, is modelled in *distributed* mode in *ACRU* as opposed to each catchment being modelled individually, i.e. in *lumped* mode. The procedure of linking catchments to determine accumulative flows is described below.

2. Procedure of Linking Catchments

When modelling catchments in distributed mode in *ACRU* the total number of subcatchments making up the entire catchment needs to be known and used as input into the *ACRU* menu. In addition, each subcatchment has to be assigned a unique numerical identifier, with the number assigned increasing as the catchments cascades downstream, in such a way that a catchment with a smaller numerical identifier always flows into a catchment with a larger numerical identifier. This ordering, or configuration, of the subcatchments is entered into the *ACRU* input menu.

Figure 2.3.4 illustrates how a catchment might be delineated and each subcatchment assigned a numerical identifier. Subcatchment 8 in the figure would be the exiting subcatchment and if only Catchments 1 through 4 is required for simulation, then Catchment 4 would be the end catchment in the simulation.

To enable the modelling of streamflow from catchments to determine cumulative flows for a selected area, an ASCII file needs to be created listing all the catchments on the left-hand side with their respective downstream catchment listed on the right-hand side. This file is termed the Catchment Ordering File. If a catchment flows into the ocean or

another country, for example Mozambique, then that is noted on the right-hand side instead of the catchment name. An example of the format of writing the sequence of the cascading Quaternary Catchments is given in **Table 2.3.5**.

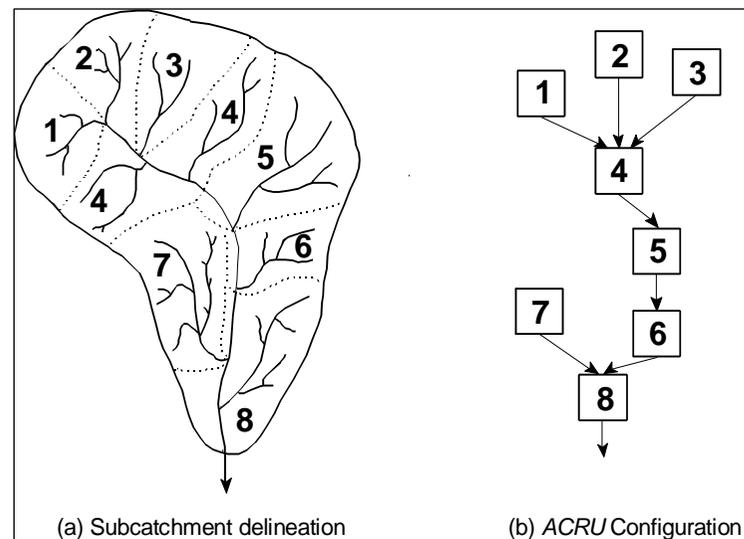


Figure 2.3.4 An example of (a) the delineation of a catchment into subcatchments and (b) the configuration of the catchment for distributed mode simulation in *ACRU* (After Schulze, Angus, Lynch and Smithers, 1995)

Table 2.3.5 Example of list showing the Quaternary Catchments on the left hand side and their downstream Quaternary Catchments or exit on the right hand side (Schulze *et al.*, 2005)

Upstream Quaternary Catchment	Downstream Quaternary Catchment or Exit
M10A	M10B
M10B	M10D
M10C	M10D
M10D	SEA

In the case of the QCs, this Catchment Ordering File has been created and is automatically accessed if the option of using the Quaternary Catchment Input Database for cascading catchments is selected. Details on more specialised options are given in Schulze *et al.* (2005).

Extraction of Output from *ACRU* for Presentation

Once the *ACRU* simulations have been performed the output that was required from any simulation needs to be extracted and imported into the ARC/INFO GIS or a spreadsheet for display purposes.

1. Graphical Display of Output from *ACRU* Using the ARC/INFO GIS

The monthly statistical output generated by *ACRU* is extracted via a FORTRAN script and is stored in a condensed ASCII file per output variable. The ASCII files are in a column format, with each column representing a statistical output for a month of the year and each row a catchment.

A FORTRAN script reads the Output Selection File. This file records which output variables were initially selected. These variables are then written to the screen and information from one of the output variables can be selected. This identifies which stored ASCII file to use to extract the relevant statistical information. Various statistical output is computed by *ACRU*, viz.

- mean;
- coefficient of variation CV (%);
- minimum value;
- maximum value;
- 10th percentile value;
- 20th percentile value;
- 20th percentile value;
- 80th percentile value; and
- 90th percentile value

and one of these statistics can be presented, in turn, for the output variable selected.

Similarly, the extreme value analysis output can be extracted for use in the GIS. Output from either the Gumbel, Log-Normal or Log-Pearson analyses can be selected. Consequently, the return period of 2, 5, 10, 20

or 50 years must be chosen. The desired column from the ASCII file for the selected output is extracted and this information can then easily be imported into the GIS using the *JOINITEM* command in ARC/INFO which joins the extracted column of information to the coverage of the catchment under investigation.

The output from a crop yield analysis, can, likewise, be extracted. The options for extraction include the same statistical options as available for the hydrological output, as well as the percentiles (10, 20, 33, 50, 66, 80 and 90%) output from the economic analysis.

2. Graphical Display of Time Series and other Statistics from *ACRU* and the QDB Using *ACRUVIEW*

ACRUVIEW a multipurpose visual graphical package which has been developed for viewing output from the *ACRU* system. Its utilities are described in detail in Schulze and Pike (2004), and that publication also contains a User Manual for *ACRUVIEW*.

Conclusions

This Section has described the development and refinements made to the Quaternary Catchments Database to the end of 2005. With these developments the agrohydrology of both Quaternary Catchments and subdivisions of QCs, viz. so-called Quinary Catchments, can be simulated as either individual or cascading catchments for both present and selected future climatic conditions. There are also a greater variety of options that can be specified for the *ACRU* simulations of the Quaternary Catchments. With these structures in place, not only is a greater versatility achieved, but also a more efficient way of obtaining results in assessments of climate change and other impacts for South Africa. Further refinements to the QDB are continually being made.

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