MODELING THE OLIFANTS BASIN

Report for

International Water Management Institute

by

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Summary

This report describes the application of the SLURP hydrological model to the Olifants River basin in South Africa.

The Olifants River is a tributary of the Limpopo. The basin has an area of 54,600 km^2 and is located to the north-east of Pretoria. The basin has been identified by the International Water Management Institute (IWMI) as a reference basin for the long-term study of institutional and management aspects of water resources. The basin is well developed for mining, hydropower, irrigation, dryland farming and cattle grazing. The north-eastern section of the river flows through the Kruger National Park to the Mozambique border. Water is exported from the basin to supply nearby cities and imported to the basin for use in mines and coal-fired power stations. The river is therefore important for water supply for the riparian peoples, for the South African economy, as an internationally-renowned wildlife refuge and as part of a major international river system with obligations to downstream states.

Problems identified in the basin include the availability of water in relation to demand, the quality of water, the impact of land use on the water resources, the availability of management information and the coordination of basin management practices

Applying a hydrological model to the basin will allow simulation of the existing water resources management practices and the investigation of alternative scenarios of management as well as alternative climate and water supply scenarios.

The model applied, SLURP, has been used in many other basins in North America, South America, Africa and Asia to study the interaction of natural water resources and human modifications to river basins. Previous applications by IWMI include the Gediz Basin in Turkey and the Mekong Basin in S.E. Asia. The topographic, land use and climate data required by the model were supplied by CPH Water under separate contract with IWMI. Other data such as leaf area index were derived from satellite images.

Two versions of the Olifants model have been prepared. One contains detailed analysis of the Steelpoorts basin with a simplified representation of the rest of the basin; the second models the entire basin in detail. Details of nineteen dams and reservoirs have been included for the Steelpoorts Basin. For some of the reservoirs level-area-volume tables were available; for others, straight-line relationships have been assumed. Simple operating rules have been assumed as no actual rules are yet available. Similarly, reservoir starting levels have been assumed. When actual data become available, it is a simple matter to substitute these.

The two models may be used by IWMI to investigate the distribution of water resources across the basin and the effects of alternative water supplies and reservoir operations.

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1. INTRODUCTION

The Olifants River is a tributary of the Limpopo. The basin has an area of 54,600 km^2 and is located to the north-east of Pretoria. The basin has been identified by the International Water Management Institute (IWMI) as a reference basin for the long-term study of institutional and water resource management. The basin is well developed for mining, hydropower, irrigation, dryland farming and cattle grazing. The north-eastern section of the river flows through the Kruger National Park to the Mozambique border. Water is exported from the basin to supply nearby cities and imported to the basin for use in mines and coal-fired power stations. The river is therefore important for water supply for the riparian peoples, for the South African economy, as an internationally-renowned wildlife refuge and as part of a major international river system with obligations to downstream states.

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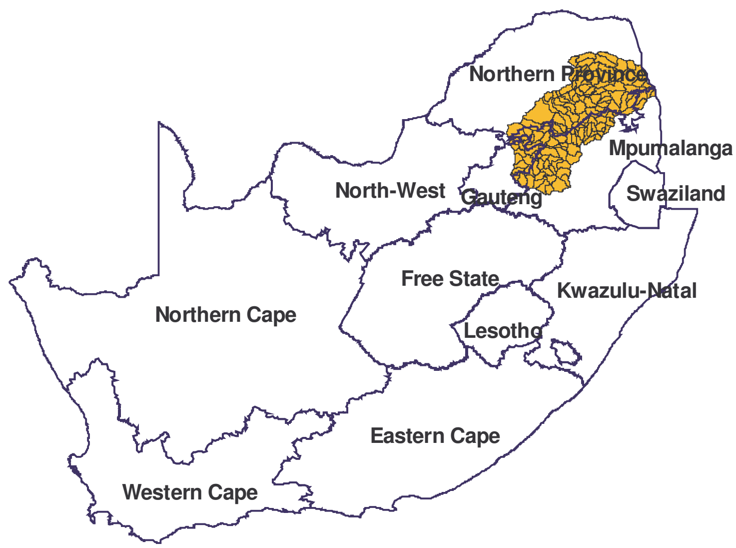
Two versions of the Olifants model have been prepared. One contains detailed analysis of the Steelpoorts basin with a simplified representation of the rest of the basin; the second models the entire basin in detail. At this stage, the models simulate the natural hydrology of the basin. No man-made impacts such as dams, reservoirs or diversions have been included as these data have not yet been made available. In their present form the models may be used by IWMI to investigate the natural distribution of water resources across the basin.

2. THE OLIFANTS RIVER BASIN

The Olifants river basin covers an area of 54,600 km^2 and is located within three provinces of north-eastern South Africa, reaching the border with Mozambique (see figure below). The basin is used for irrigated and dryland agriculture, grazing, for hydropower and mining and for a major national park. The following description is based on IWMI Working Paper 17 (Stimie at al., 2001).



The basin can be divided into five regions:

- the Highveld region, above the Loskop dam
- the irrigated region, between Loskop dam and Arabie dam
- the underdeveloped or rural poor region from the Arabie dam to the confluence of the Steelpoort and the Olifants rivers
- the Steelpoort sub-catchment
- the Lowveld region, which ends at the confluence of the Steelpoort and Letaba rivers with the Olifants river.

The Highveld region is the most developed region of the basin in terms of infrastructure. It has eight power stations for which water is imported from the Vaal river basin. Mining and industry are major sources of pollution with the Witbank reservoir being the most affected. This region is characterized by natural inundations and small farm ponds for stock watering.

The region between the Loskop and Arabie dams uses about 90 percent of its water for irrigation. In recent years, commercial farmers have shown a tendency to move to high-value crops like citrus and grapes under precision irrigation systems. The Loskop reservoir with a capacity of 348 million m^3 is by far the largest reservoir in the basin and supplies irrigation to farmers through a canal and releases in the river.

The underdeveloped or rural poor region below the Arabie dam has little industry or infrastructure.The irrigation schemes are either underutilized or nonoperational. It is the region with the highest population and the highest population growth rate in the basin. Stock densities are approximately three times the recommended stocking rates. This is one of the major contributions to denuded rangeland, soil erosion and a heavy sediment yield in the rivers of the basin.

The Steelpoort Sub-basin covers 13 percent of the entire Olifants Basin and is characterized by competition and potential conflict between irrigation and mining uses of water. The sub-basin lies on an escarpment between 1500 and 2400 m high and there is good potential for dam sites for water supply to mines, irrigation and domestic water users. At present about 5% of the available water supply in the sub-basin is regulated.

The Lowveld section also has significant commercial irrigation but its unique feature is the Kruger National Park at the lowest end of the section. There seems to be increasing support for water to serve the ecological demand of the park. This demand is not only for quantity but also for quality in terms of physical and chemical impurities. This lower end of the catchment experiences all the effects of the water users upstream. Fortunately, the unpolluted rivers like the Blyde dilute the contaminated water of the Olifants River to keep it thus far at acceptable quality levels.

Rainfall occurs predominantly in the summer months between October and March, with January generally experiencing the heaviest rain. The mean annual rainfall for the area is in the range 630–1,000 mm. Thunderstorms, with the associated low infiltration of the soil and high erosion in mountainous areas, are common in the basin.

The average daily temperature varies between 13 and 22 °C. Early morning frost occurs in low-lying areas. There is very high potential evapotranspiration and actual evapotranspiration is limited by water supply.

The basin has 2,500 reservoirs, of which 90 percent have capacities smaller than 20,000 m^3. There are 30 large reservoirs whose capacities are larger than 2 million m^3 and a total storage of 1,100 million m^3. The estimated usage in the basin in 1987 was 1,060 million m^3 per year, including evaporation. The mean annual runoff is 1,235 million m^3 per year.

Irrigation farming used about 500 million m^3 of water per year in the late 1980s. This figure has gradually declined over the last decade although irrigation is still the major water user in the basin. Ecological needs were estimated to be 200 million m^3 per year in the 1990s. There are about 200 mines in the basin, which use about 90 million m^3 per year. A relatively small amount of water is also exported from the basin, e.g., water is sent downstream from the Arabie dam to Pietersburg for domestic use.

Water use by power stations is about 208 million m^3 per year. Ecological use was estimated as 200 million m^3 per year.

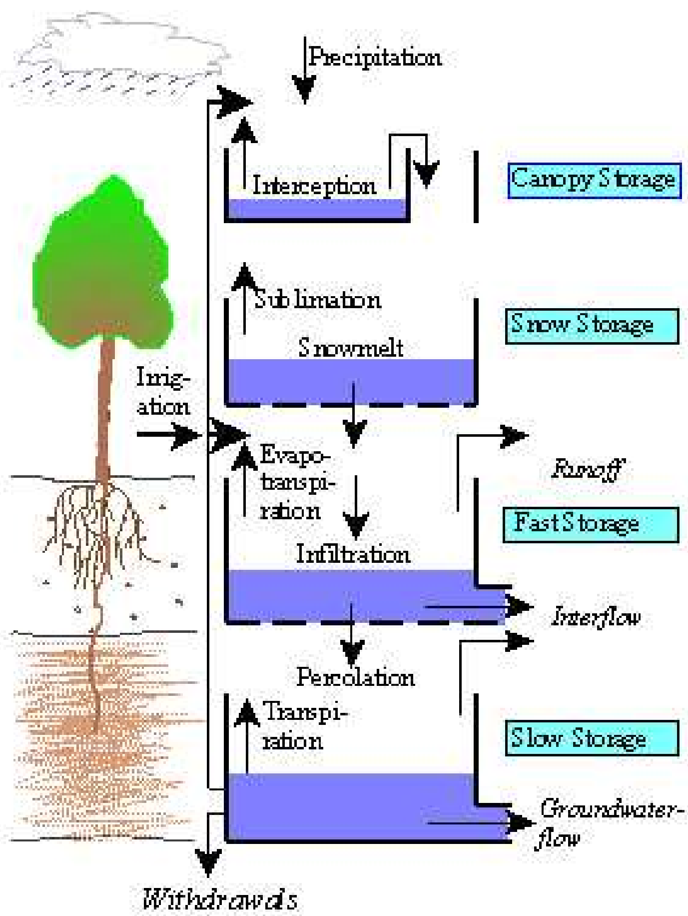
The main issues identified in the Olifants River basin are:

- availability of water in relation to demand
- quality of water
- impact of land use on the water resources
- availability of management information

3. THE SLURP HYDROLOGICAL MODEL

SLURP (Kite, 1995) is a basin model that simulates the hydrological cycle from precipitation to runoff including the effects of reservoirs, regulators and water extractions. It first divides a basin into sub-basins using topography from a digital elevation map. These sub-basins are further divided into areas of different land covers using data from a digital land cover classification. Each land cover classe has a distint set of parameters in the model.

The hydrological model simulates the vertical water balance for each land cover within each sub-basin each day. That is, the model approximates the physical processes controlling the transformation of precipitation into evapotranspiration and runoff separately for each land cover within each sub-basin. Each element of the sub-basin/land cover matrix is represented by four nonlinear reservoirs or tanks representing canopy interception, snowpack, fast storage and slow storage. The outputs of each vertical water balance include evaporation, transpiration, runoff, groundwater flow and changes in canopy storage, snowpack, soil moisture and ground water.



The model has previously been applied in many countries for basins ranging in size from prairie sloughs measuring only a few hectares (Su et al. 1997) to large basins such as the Mackenzie with an area of 1.8 million square kilometers (Kite et al., 1994) and has been designed to make maximum use of remotely sensed data. Applications of the model have included studies of climate change (Kite, G.W., 1993), hydropower (Kite et al., 1998), water productivity (Droogers et al., 2000), irrigation (Kite and Droogers, 1999) and wildlife refuges (de Voogt et al., 2000).

The evapotranspirative demand for each land cover in each sub-basin is usually calculated using the Food and Agriculture Organization's (FAO) version of the Penman-Monteith method (Verhoef and Feddes, 1991):

$$\lambda \cdot ET = \frac{s(Q^* - G)}{s + \gamma(1 + \frac{r_s}{r_a})} + \frac{\rho_a c_p \frac{e_s - e_a}{r_a}}{s + \gamma(1 + \frac{r_s}{r_a})} \quad (1)$$

where λ is the latent heat of vaporisation, ET is the potential evapotranspiration rate (mm) , s is the slope of the vapour pressure curve, Q^* is the net radiation, G is the soil heat flux , γ is the psychrometric constant, r_a is the aerodynamic resistance, r_c is the crop resistance, e_s is the saturated vapour pressure, e_a is the actual vapour pressure, ρ_a is the air density, and c_p is the heat capacity of moist air .

For the Olifants Basin there are only very limited radiation and humidity data and so the Linacre (1977) method of deriving pan equivalent potential evaporation is used in the form described by Schultze (1989):

$$ET = \frac{700T_m/(100-\phi) + u(T_a - T_d)}{80 - T_a} \quad (2)$$

where $T_m = T_a + 0.006 A_m$,and T_a is the mean air temperature, A_m is the elevation (m) , Φ is the latitude in degrees, u is a wind factor (often defaulted to 15) and $T_a - T_d$ is the difference between air and dewpoint temperatures approximated by:

$$T_a - T_d = 0.0023\,A_m + 0.37\,T_a + 0.53\,R_m + 0.35\,R_{hc} - 10.9 \quad (3)$$

with R_m as the mean daily or monthly range in temperature and R_{hc} as the difference between the mean temperatures of the hottest and coldest months of the year.

Dent et al. (1988) adjusted equation 2 by adding a correction for the length of daylight to:

$$E = \frac{D.700T_m/(100-\phi) + u(T_a - T_d)}{80 - T_a} \quad (4)$$

where D is the number of daylight hours divided by 12.

The resulting evapotranspirative demand is met by evaporation from intercepted precipitation stored on the canopy, from soil evaporation and from crop transpiration.

The canopy capacity is computed by multiplying a specified maximum leaf capacity by the leaf area index (LAI) for a particular crop and date. The LAI data are derived from NDVI (Normalized Difference Vegetation Index) data obtained from NOAA AVHRR (National Oceanic and Atmospheric Administration, Advanced Very High Resolution Radiometer) satellite images from the internet. Precipitation is intercepted by the canopy and any excess falls to the ground or to a snowpack depending on the air temperature.

If a snowpack exists and the temperature exceeds a critical value, snowmelt will be computed using either a simple degree-day method or a modified energy balance approach.

Excess precipitation and any snowmelt will infiltrate into a fast groundwater store at a rate computed by Equation 2. The fast store represents that soil water storage which provides the rapid-response part of the streamflow hydrograph.

$$Inf = \left(1 - \frac{S_1}{S_{1,\max}}\right) \cdot Inf_{\max} \qquad (2)$$

Here, S_1 is the current contents of the fast store (mm), $S_{1,max}$ is the maximum possible contents of the fast store (mm), *Inf* is the current infiltration rate (mm day^{-1}) and Inf_{max} is the maximum possible infiltration rate (mm day^{-1}) specified for the particular land cover. If the current infiltration rate is not sufficient to transmit all the excess precipitation, then the surplus will be spilt as surface runoff.

The fast store generates outflow, $Q_{1,out,}$ using equation (3):

$$Q_{1,out} = \frac{1}{k_1} \cdot S_1 \qquad (3)$$

where k_1 is the retention constant for the fast store. The outflow $Q_{1,out}$ is then separated into deep percolation, RP, flowing to a lower (slow) store and to interflow, RI, using equations (4) and (5):

$$RP = \frac{Q_{1,out}}{1 + \frac{S_2}{S_{\max}}} \qquad (4)$$

$$RI = Q_{1,out} - RP \qquad (5)$$

where S_2 is the current contents of the slow store (mm) and S_{max} is the maximum possible contents of the slow store (mm). The slow store contains groundwater that contributes to the baseflow of the stream hydrograph.

Finally, the slow store generates groundwater flow, RG, using equation (6). If the slow store overflows, the surplus water will be added to the interflow (RI):

$$RG = \frac{1}{k_2} * S_2 \qquad (6)$$

where k_2 is the retention constant for the slow store.

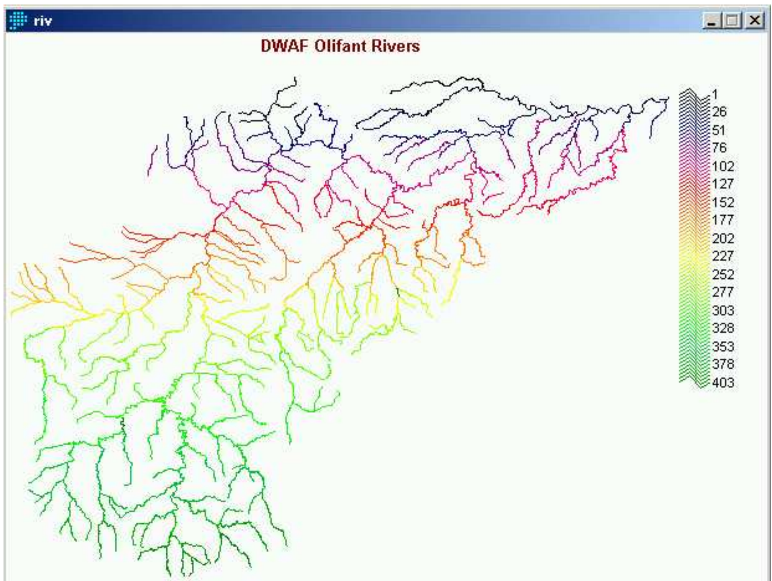
From each land cover in a sub-basin the surface runoff, interflow and groundwater runoff are accumulated using a time/contributing area relationship for each land cover and the combined runoff is converted to streamflow and routed between each sub-basin. For first order sub-basins (those which directly discharge to the river) the streamflow is routed by simply accumulating the flows down the basin with no delay or attenuation. For second order or higher sub-basins, either the Muskingum or Muskingum/Cunge routing method is used to describe the relationship between inflow, outflow and storage of the channel reach. The Muskingum weight function, x, is set to a default value of 0.25 and the time of travel, K, is computed from the change in elevation along the stream channel.

The effects of dams and reservoirs are incorporated into the model by including stage-storage, stage-area and stage-discharge relationships together with the operating rules for the structures.

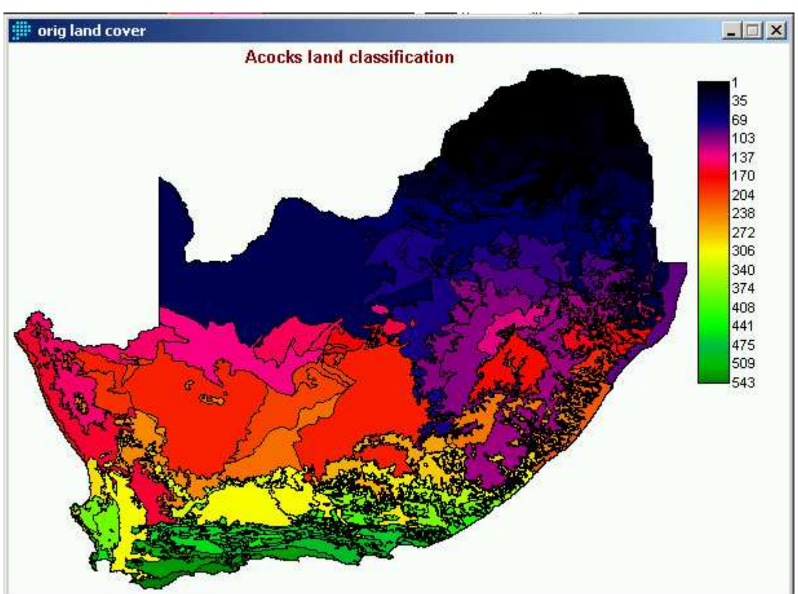
4. APPLYING THE MODEL

4.1 Topographic and land cover data

During a visit to South Africa, 1:250,000 topographic maps of the basin were obtained as well as more general basin maps from the Department of Water Affairs and Forestry and publications from the Water Research Commission such as Surface Water Resources of Sout Africa (Midgley, et al., 1994).



In addition, various maps of land use such as the Acocks veldt classification system were obtained.



Topographic data were supplied as digital elevation models by DEM data were supplied by CPH Water in 2 different projections; a) degree decimal (lat, long), b) UTM (northing, easting). Unfortunately, the Olifants river catchment falls on the boundary between two different zones for the UTM projection (zone 35S ranges from 24-30˚ and zone 36S goes from 30-36˚).

For each projection, data were supplied in 3 formats; i) IDRISI raster format in binary, ii) IDRISI raster format in ASCI and iii) a straight file conversion export from the Arc/Info GIS format for checking purposes.

The list below gives the original file names as supplied and a simplified file name for future operations (in brackets).

a) The degree decimal lat/long files are:

i) olidem200ddrdc.rdc & olidem200ddrst.rst (dem-ll.rdc & dem-ll.rst)
DEM information in IDRISI binary raster format. Olidem200ddrdc stands for Olifants (oli); digital elevation model, 0.002083 degrees resolution - nominally 200m – (dem200), degree decimal (dd). The olidem200rst is the raster in binary format for IDRISI. The data type is real.

ii) olidem200ddtxt.txt (dem-ll.txt)
DEM in IDRISI ASCII raster format as single column. Properties are the same as those in olidem200ddrdc.rdc.

iii) olidem200ddasc.asc (dem-ll.asc)
A two dimensional grid converted to ASCI format to check the data conversions.

b) The UTM files are:

i) olidemutmi.rdc & olidemutmi.rst (dem-utm.rdc & dem-utm.rst)
DEM information in IDRISI binary raster format for UTM zone 36S. This information is from the surveyor general and is probably the most accurate DEM available for this region. The projection properties are:

ii) olidemutm200.txt (dem-utm.txt)
DEM in IDRISI ASCII raster format as single column for the DEM 200 false UTM grid. Properties are the same as those in olidemutmi.rdc.

Land use data were also supplied by CPH Water in two different projections; a) degree decimal (lat, long), and b) UTM zone 36S.

The land use data are also available in three formats; i) IDRISI raster format in binary, ii) IDRISI raster format in ASCI and iii) a straight file conversion export from the other GIS format for checking purposes.

a) The degree decimal lat/long files are:

i) oliluddrdc.rdc & oliluddrst.rst (lu-ll.rdc & lu-ll.rst)

Land use data in IDRISI binary raster format. Olifants (oli), landuse (lu), degree decimal (dd), record description (rdc) and raster binary (rst) files.

ii) oliddidrtxt.txt (lu-ll.txt)
Land use in IDRISI ASCII raster format with all the values in one column. This has the same properties as the binary RST file and is essentially a checking file.

iii) oliddidrasc.asc (lu-ll.asc)
Land use as an ASCI grid (rows and columns) for checking purposes.

b) The UTM files are:

i) oliluutmi.rdc & oliluutmi.rst (lu-utm.rdc & lu-utm.rst)
Land use data in IDRISI binary raster format for the UTM zone 36S projection.

ii) oliluutmtxt.txt (lu-utm.txt)
Land use in IDRISI ASCII raster format with all the values in one column. This has the same properties as the binary RST file and is essentially a checking file.

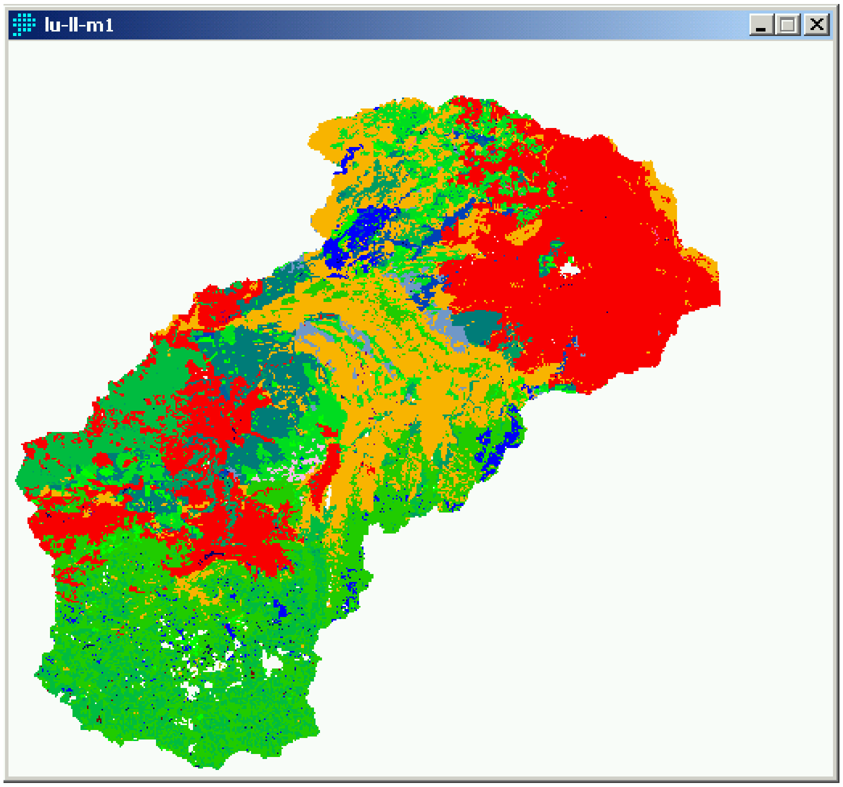
iii) oliluutmasc.asc (lu-utm.asc)
Land use as an ASCI grid (rows and columns) for checking purposes.

Landuse classification.doc
In addition an MS Word document was supplied to provide descriptions of the 31 land use classifications.

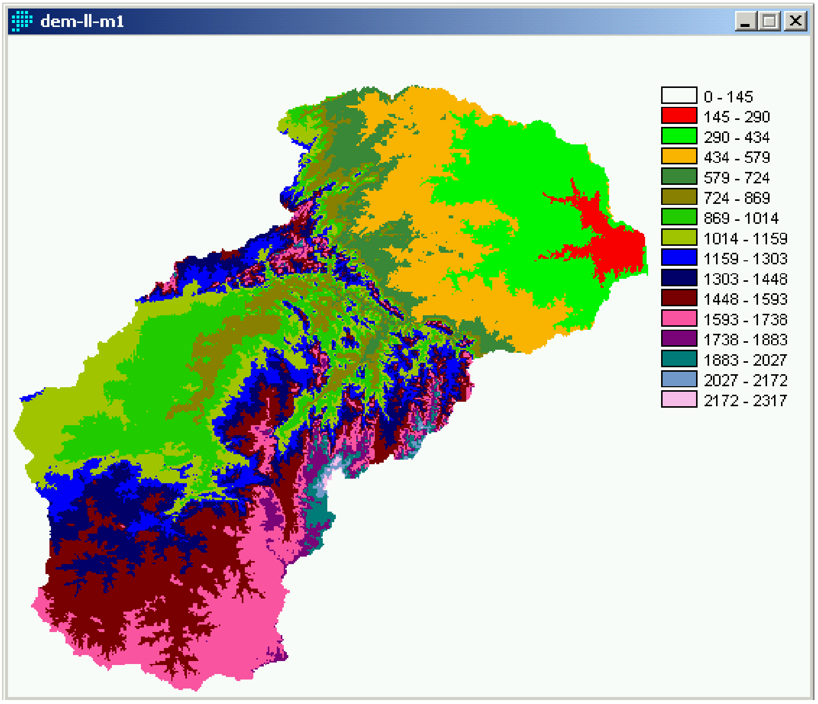
The DEM and land use data files were all checked and renamed. The agreement between geodetic and UTM images was checked and the possibility of using both UTM Zone 35S and 36S was checked. No real difference was apparent and so it was decided to use Zone 36S

The UTM DEM and land use images were imported to IDRISI and reclassified to get rid of –ve values. The land use image was reformatted to integer from byte (DEM-UTM-M1 and LU-DEM-M1 files). Note that the 200m image resolution lat/long projection changes to 231m when reprojected to UTM. Note also that the DEM and land use images supplied by CPH Water include the Letaba Basin (top-right of images).

The figures below show the first land cover and DEM images for the Olifants Basin.



Olifants Land cover

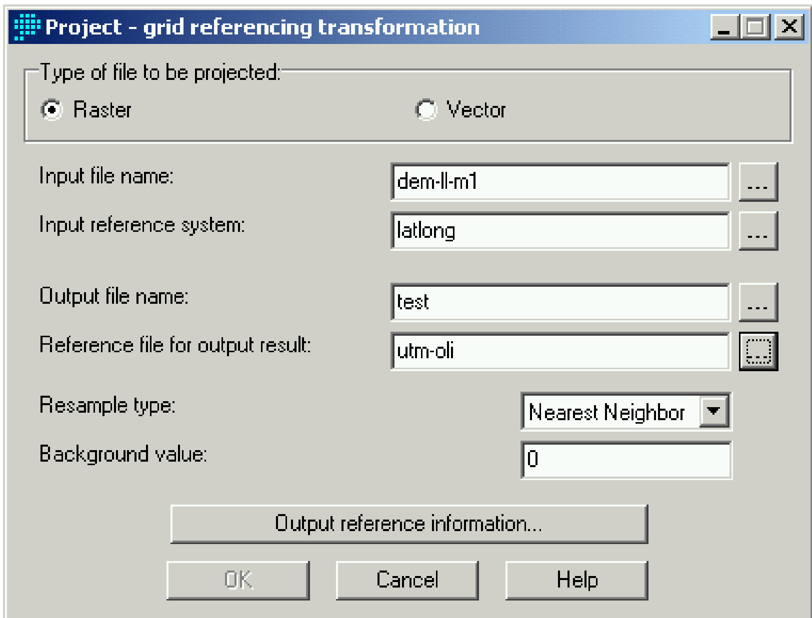


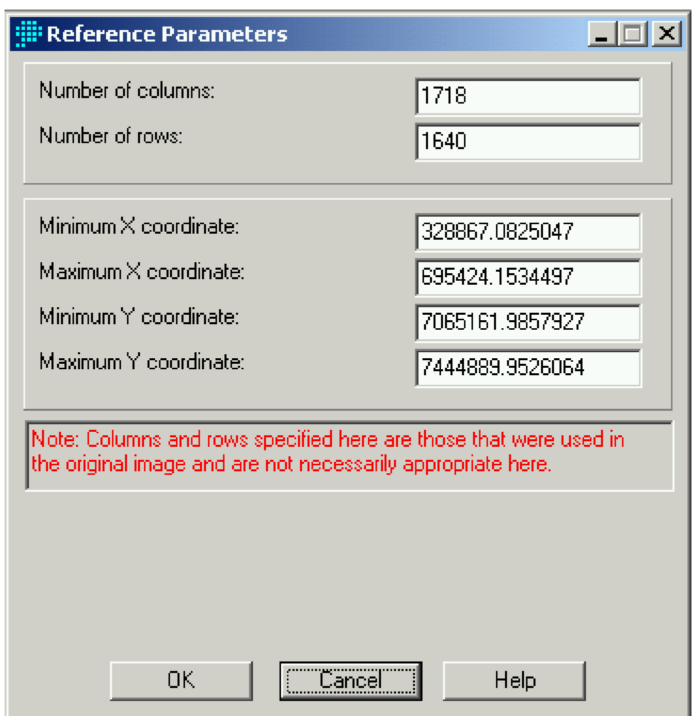
Olifants DEM

A further test was made of using a false UTM zone in order to minimise DEM and land cover image distortion. The lat/long image for the DEM was converted to UTM in IDRISI using:

\REFORMAT\Project

to a false UTM centred at meridian 30˚east.





using a new reference file UTM-Oli.REF containing the following records:

ref. system : False UTM zone for Olifants Basin
projection : Transverse Mercator
datum : WGS84
delta WGS84 : 0 0 0
ellipsoid : WGS 84
major s-ax : 6378137.000
minor s-ax : 6356752.314
origin long : 30
origin lat : 0
origin X : 500000
origin Y : 10000000
scale fac : 0.9996
units : m
parameters : 0

The resulting image had a resolution of 231.54m, no different than using the standard UTM Zone 36S and so it was decided to continue to use the Zone 36S images.

Before starting the DEM analysis using the TOPAZ software within SLURP, IDRISI was used to find the river outlet at the bottom of the basin as Row 409, Column 1572, elevation 145 m. by zooming in on the DEM image (see below):

While within IDRISI, both DEM and land use images were exported as bitmaps for later use in SLURP (DEM-UTM.BMP and LU-UTM.BMP).

The land cover image was modified to reduce the number of land covers by:

1) preparing a histogram of the number of pixels in each land use category:

Analysis\Database query\HISTO

Histogram of lu-utm-m1

Class	Lower Limit	Upper Limit	Frequency	Prop.	Cum. Freq.	Cum. Prop.
0	0.0000	0.9999	1390156	0.5219	1390156	0.5219
1	1.0000	1.9999	365203	0.1371	1755359	0.6590
2	2.0000	2.9999	5301	0.0020	1760660	0.6610
3	3.0000	3.9999	236536	0.0888	1997196	0.7498
4	4.0000	4.9999	0	0.0000	1997196	0.7498
5	5.0000	5.9999	2	0.0000	1997198	0.7498
6	6.0000	6.9999	227695	0.0855	2224893	0.8352
7	7.0000	7.9999	460	0.0002	2225353	0.8354
8	8.0000	8.9999	25815	0.0097	2251168	0.8451
9	9.0000	9.9999	3493	0.0013	2254661	0.8464
10	10.0000	10.9999	621	0.0002	2255282	0.8466
11	11.0000	11.9999	562	0.0002	2255844	0.8469
12	12.0000	12.9999	852	0.0003	2256696	0.8472
13	13.0000	13.9999	77183	0.0290	2333879	0.8761
14	14.0000	14.9999	15026	0.0056	2348905	0.8818
15	15.0000	15.9999	2931	0.0011	2351836	0.8829
16	16.0000	16.9999	5	0.0000	2351841	0.8829
17	17.0000	17.9999	0	0.0000	2351841	0.8829
18	18.0000	18.9999	10680	0.0040	2362521	0.8869
19	19.0000	19.9999	4284	0.0016	2366805	0.8885
20	20.0000	20.9999	0	0.0000	2366805	0.8885
21	21.0000	21.9999	25508	0.0096	2392313	0.8981
22	22.0000	22.9999	154834	0.0581	2547147	0.9562
23	23.0000	23.9999	80789	0.0303	2627936	0.9865
24	24.0000	24.9999	25191	0.0095	2653127	0.9960
25	25.0000	25.9999	12	0.0000	2653139	0.9960
26	26.0000	26.9999	0	0.0000	2653139	0.9960
27	27.0000	27.9999	0	0.0000	2653139	0.9960
28	28.0000	28.9999	787	0.0003	2653926	0.9963
29	29.0000	29.9999	96	0.0000	2654022	0.9963
30	30.0000	30.9999	878	0.0003	2654900	0.9967
31	31.0000	31.9999	8896	0.0033	2663796	1.0000

```
Class width      =       1.0000
Display minimum  =       0.0000
Display maximum  =      31.0000
Actual minimum   =       0.0000
Actual maximum   =      31.0000
Mean             =       4.1215
Stand. Deviation =       7.3220
df               =      2663795
```

The names of the land classes are as follows:

Landuse Code	Description
1	Forest and Woodland
2	Forest
3	Thicket and bushland etc
4	Shrubland and low fynbos
5	Herbland
6	Unimproved grassland
7	Improved grassland
8	Forest plantations
9	Waterbodies
10	Wetlands
11	Barren rock
12	Dongas and sheet erosion scars
13	Degraded forest and woodland
14	Degraded thicket and bushland etc
15	Degraded unimproved grassland
16	Degraded shrubland and low fynbos
17	Degraded herbland
18	Cultivated permanent commercial irrigated
19	Cultivated permanent commercial dryland
20	Cultivated permanent commercial sugarcane
21	Cultivated temporary commercial irrigated
22	Cultivated temporary commercial dryland
23	Cultivated temporary semi-commercial/subsistence dryland
24	Urban/built up residential
25	Urban/built up land residential (small holding: woodland)
26	Urban/built up land residential (small holding: bushland)
27	Urban/built up land residential (small holding: shrubland)
28	Urban/built up land residential (small holding: grassland)
29	Urban/land built up commercial
30	Urban/built up land/industrial/transport
31	Mines and quarries

2) The histogram shows that the following land uses are important (ignoring 0 as this signifies land outside the basin). Other minor land uses were grouped with the important classes to give 10 categories. These were then related to SiB numbers for later use in SLURP.

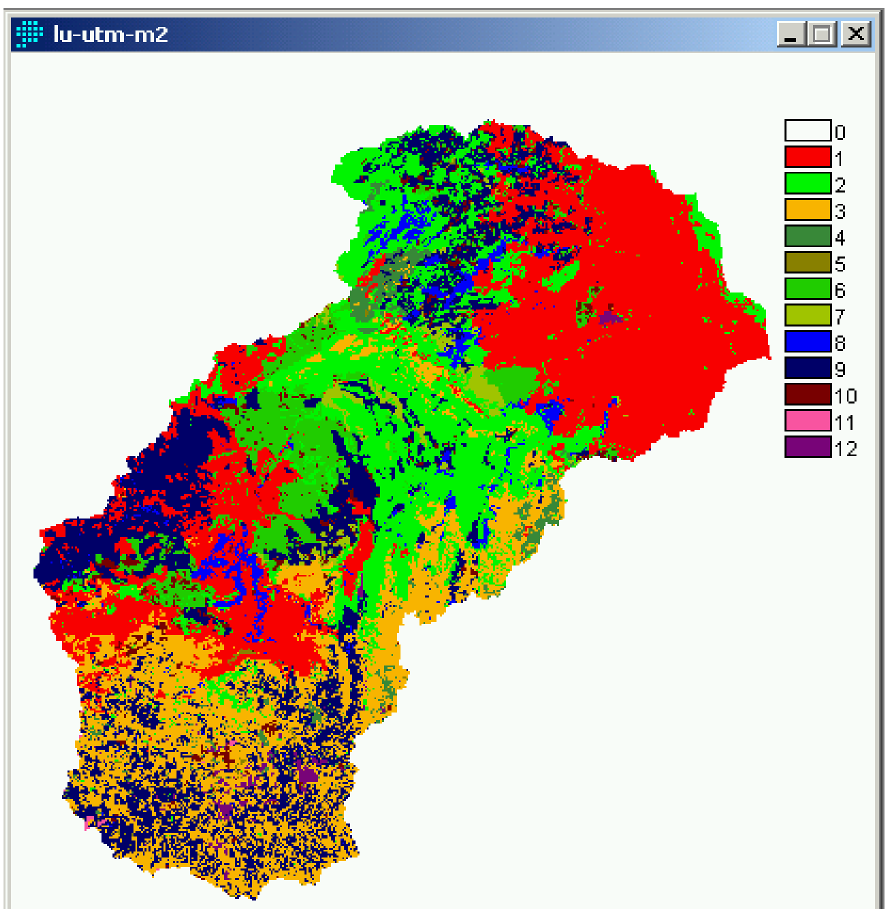
Land class number	Land class description	Additional land covers incorporated	SLURP number	SiB number
	Outside basin		0	
1	Forest and woodland	2	1	5

3	Thicket and bushland etc	4, 5	2	8
6	Unimproved grassland	7	3	7
8	Forest plantations		4	1
9	Waterbodies	10	5	0
13	Degraded forest and woodland	11, 12	6	6
14	Degraded thicket and bushland etc	15, 16, 17	7	9
18	Cultivated permanent commercial irrigated	20, 21	8	16
19	Cultivated permanent commercial dryland	22, 23	9	12
24	Urban/built up residential	29,30	10	17
25	Urban/built up land residential (small holdings)	26, 27, 28	11	14
31	Mines and quarries		12	11

3) The land use image was reclassified to the SLURP land cover numbers using:

Analysis\Database query\RECLASS

with the reclassification file LU-UTM.RCL. The result is files LU-UTM-M2.RST and .RDC.

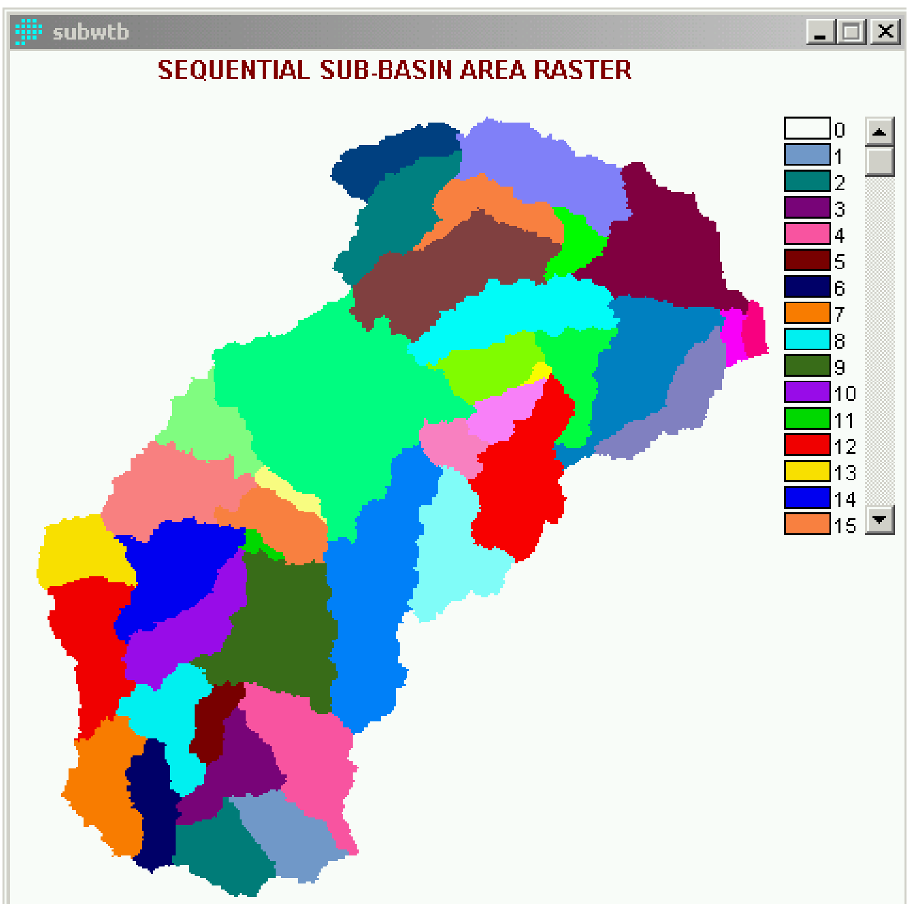


Both DEM and land use images were converted to ASCII integer files and the resulting .RST files were renamed as DEDNM.INP LCLASS.INP for later use in SLURP/TOPAZ.

After preparing the land use and the digital elevation data files, the next step was to run SLURP option:

\Tools\Topographic and land cover analysis

This procedure divides the basin into sub-basins, derives the river network and associates the land covers with the sub-basins. The resulting image of sub-basins was:



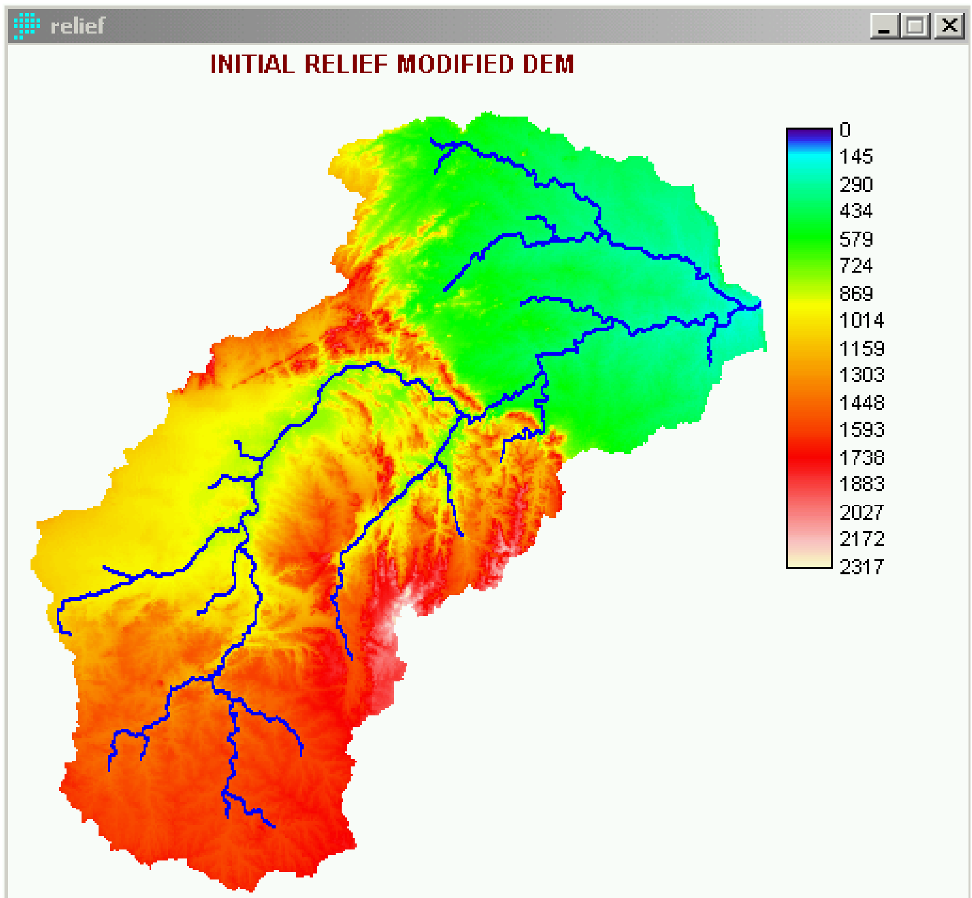
The river network produced can be seen by converting the raster image NETW to vector using:

\Reformat\Raster/vector conversion\POINTVEC

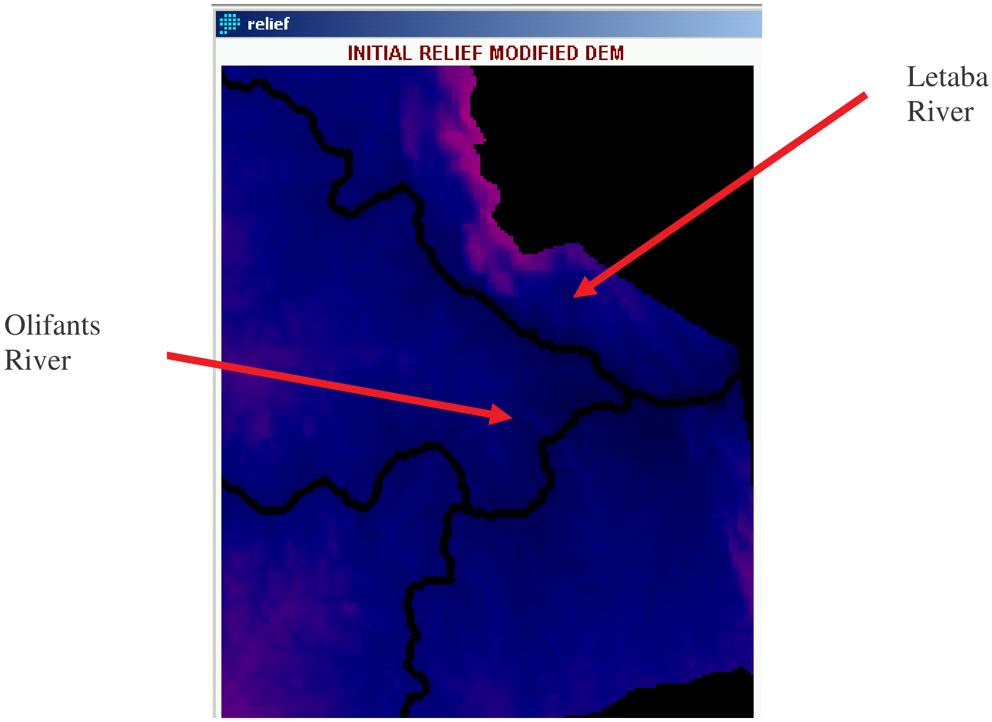
and overlaying the resulting vector file on top of RELIEF.RST using

\Composer\Add layer

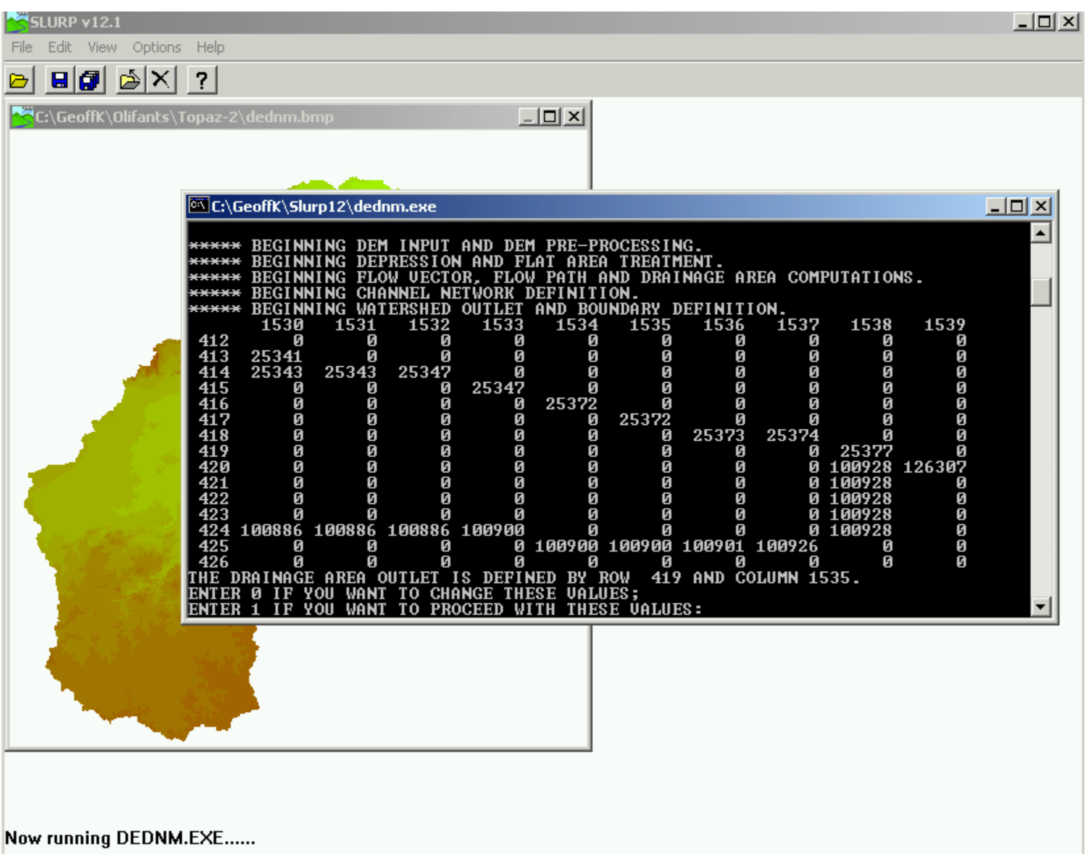
The result is shown below:



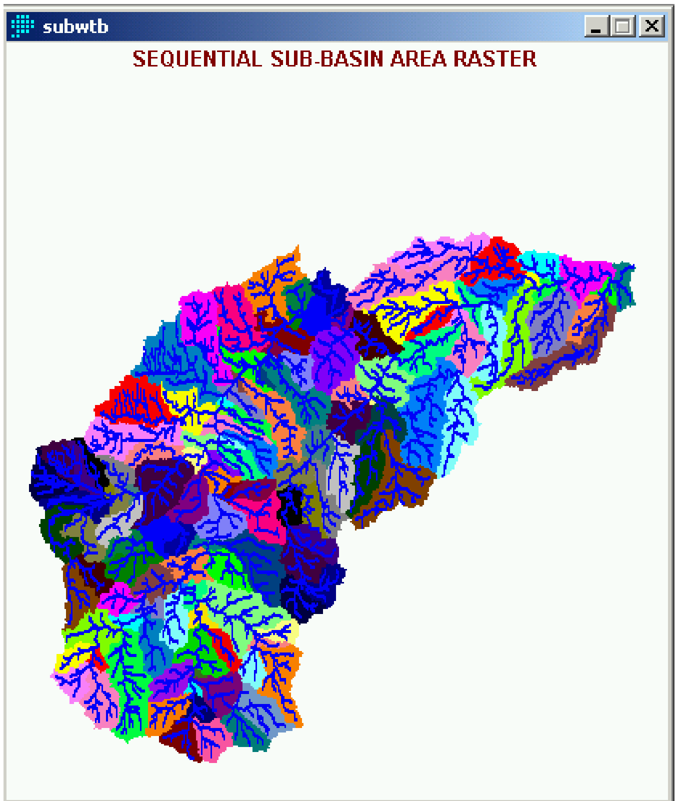
These sub-basins and river network still include the Letaba Basin which must be removed by relocating the basin outlet. This is done by selecting a new row and column above the Olifants/Letaba junction in IDRISI:

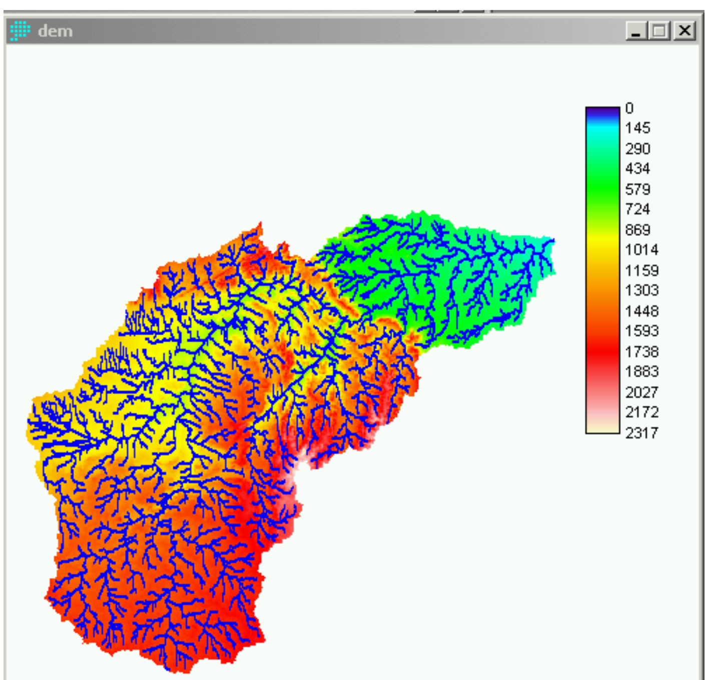


and changing the starting row and column in TOPAZ

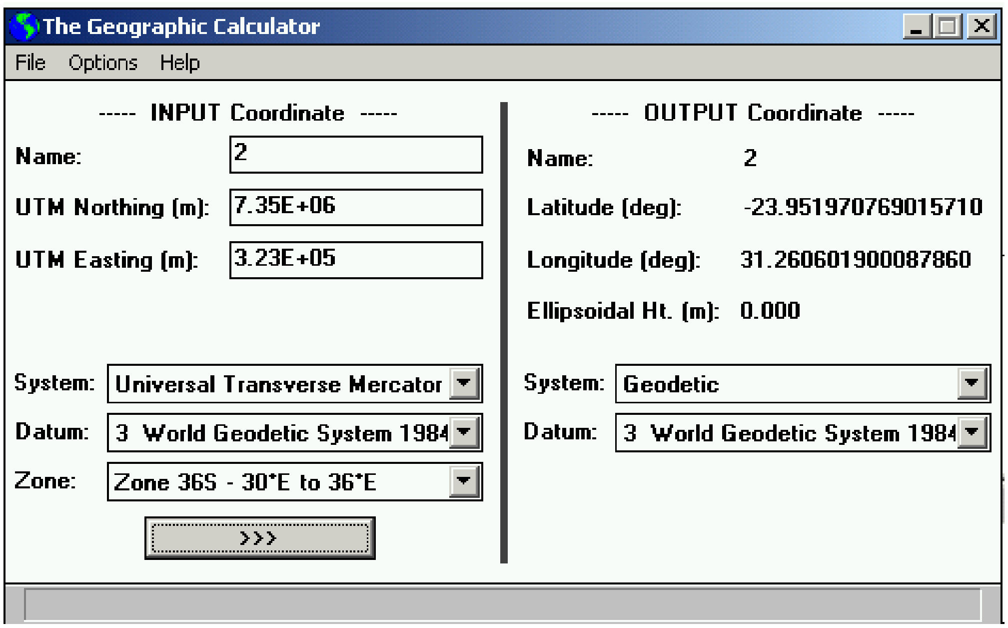


The resulting 137 sub-basins and river network correspond to the Olifants Basin.





The \OPTIONS\Topographic and land cover analyses in SLURP12 does all the analysis of the DEM and land cover images automatically and produces the files necessary to run the model. One of the parameters computed in this option is the mean latitude of each sub-basin which is used in some of the methods of computing potential evapotranspiration. This option will only compute latitudes from recognised UTM zones. If you are using a false UTM zone, then a more sophisticated program such as Geographic Calculator (Blue Marble Geographics, 1993) or a GIS such as IDRISI will have to be used. SLURPAZ generates two data files to help in this. File ASA-UTM.PTS file can be used as a coordinate file with the Geographic Calculator.



Alternatively, take the SLURPAZ output file ASA-UTM.INP and run program INP2VXP.EXE off the SLURP12 CD to produce an IDRISI vector export file. Import this to IDRISI, re-project from UTM to lat/long and export the result as another .VXP file.

The correct latitudes computed by Geographic Calculator or by IDRISI can then be put into the .CMD file from the .PTS or .VXP file using program LAT2CMD.EXE (see the SLURP manual for details).

To check the sub-basins derived by TOPAZ, the quaternary sub-basin information from Midgley, D.C., et al. (1994) were used. This reference includes information on land cover percents, mean annual precipitation, evaporation and runoff.

Sub-basin	Area km**2	Net area km**2	Forest area km**2	Irrigated area km**2	MAE	MAP mm	MAR mm	Dams	River
B11A	945	945		1.7	1550	699	39		Olifants
B11B	435	435		2.4	1550	687	36		
B11C	385	385		1.9	1550	673	33		
B11D	551	551		6.3	1600	671	30		
B11E	467	467		7.4	1600	682	32		
B11F	428	428		0.7	1600	692	34		
B11G	368	368			1600	693	36	Witbank	
B11H	246	246	1.0	0.6	1600	695	36		
B11J	269	269		9.3	1650	682	49		
B11K	378	378	6.0	2.3	1700	684	46		
B11L	242	242	1.0		1700	692	48		
B11	**4714**	**4714**	**8.0**	**32.6**	**1597**	**687**	**37**		
B12A	405	405			1500	672	26		Klein Olifants
B12B	659	659		2.8	1550	697	28		
B12C	529	529	4.0	6.4	1550	707	30	Middleburg	
B12D	362	362	17.0	5.7	1600	703	38		
B12E	436	436	17.0	1.2	1650	697	53		
B12	**2391**	**2391**	**38.0**	**16.1**	**1567**	**696**	**34**		
B20A	574	574		3.1	1650	661	38		Wilge
B20B	322	322		3.1	1700	667	37		
B20C	364	364		2.7	1700	675	38	Bronkhorstspruit	
B20D	480	480		7.7	1750	677	36		
B20E	620	620		9.0	1650	657	34		
B20F	504	504		8.0	1700	667	33		
B20G	522	522		4.6	1700	669	44		
B20H	563	563	1.0	5.3	1750	671	42		
B20J	407	407		12.7	1800	696	44		
B20	**4356**	**4356**	**1.0**	**56.2**	**1708**	**670**	**38**		
B31A	387	387		4.8	1750	677	35		Elands
B31B	385	385		5.7	1800	640	26		
B31C	373	373		1.0	1800	607	21		
B31D	558	558			1800	599	20	Rust der Winter	
B31E	1382	1104			1800	588	7.8		
B31F	638	589			1850	568	6.7	Rhenosterkop	
B31G	433	433			1850	604	20		
B31H	612	612			1900	575	15		
B31J	1380	459		13.5	1900	552	5.9		
B31	**6148**	**4900**		**25.0**	**1838**	**589**	**12**		
B32A	801	801		4.5	1700	691	52	Loskop	Olifants
B32B	614	614	2.0	2.5	1600	698	51		
B32C	303	303		7.8	1700	664	36		
B32D	521	521			1800	626	23		
B32E	203	203			1650	668	34		
B32F	667	667		1.7	1750	659	29		
B32G	968	968		3.1	1850	639	26		
B32H	694	694		11.9	1900	610	20		
B32J	323	323			1900	589	14		
B32	**5094**	**5094**		**31.5**	**1771**	**651**	**32**		
B41A	765	765	54.0		1500	714	65	Belfast	Steelpoort

B41B	778	778	4.0	23.0	1500	705	62		
B41C	302	302		3.0	1500	694	59	Vlugkraal	
B41D	403	403		5.0	1600	652	41	Mapoch	
B41E	237	237		1.1	1650	616	18		
B41F	380	380		2.0	1500	676	74		
B41G	442	442	6.0	11.4	1500	650	66		
B41H	410	410		8.0	1600	621	18	Dr. Eiselen	
B41J	691	691		8.9	1550	598	22		
B41K	635	635		2.2	1500	626	27		
B41	**5043**	**5043**	**64.0**	**64.6**	**1530**	**659**	**46**		
B42A	319	319	4.0	5.4	1400	773	110		Spekboom
B42B	214	214	16.0		1400	879	156		
B42C	164	164	1.0		1400	729	50		
B42D	155	155		11.3	1400	1002	223		
B42E	222	222		7.6	1450	645	26		
B42F	279	279		7.6	1450	733	101	Buffelkloof	
B42G	327	327	1.0	14.7	1450	676	32		
B42H	413	413		10.0	1450	591	22		
B42	**2093**	**2093**	**22.0**	**56.6**	**1430**	**727**	**79**		
B51A	311	311		1.1	1800	616	17	Lola Montes	Olifants
B51B	591	591			1900	578	13		
B51C	638	638		12.0	1900	529	9.7		
B51E	2927	673			1900	542	6.8		
B51F	395	395			1850	573	16	Nkumpidamme	
B51G	591	591		6.6	1900	528	12		
B51H	717	717		9.0	1800	568	13	Piet Gouws	
B51	**6170**	**3916**		**28.7**	**1880**	**551**	**7.5**		
B52A	566	566		10.7	1900	475	8		Olifants
B52B	633	633		3.5	1750	553	14		
B52C	200	200			1850	539	16		
B52D	341	341			1900	498	9.5		
B52E	451	451		1.3	1800	535	12		
B52F	118	118			1850	557	18		
B52G	291	291			1900	518	14		
B52H	563	563	11.0		1700	660	36		
B52J	395	395		2.5	1800	570	20		
B52	**3558**	**3558**		**18.0**	**1813**	**548**	**17**		
B60A	210	210	127.0		1400	1193	441		Blyde
B60B	302	302	99.0	1.6	1400	1026	349		
B60C	94	94	23.0		1400	1352	539		
B60D	244	244	33.0		1400	1004	218	Blyderivierspoort	
B60E	83	83	17.0		1400	1027	201	Ohrigstadt	
B60F	400	400	9.0	16.5	1400	766	46		
B60G	448	448	4.0	21.6	1400	681	30	Vyehoek	
B60H	385	385		16.5	1400	778	48		
B60J	676	676	11.0	33.0	1482	607	50		
B60	**2842**	**2842**	**323.0**	**89.2**	**1420**	**823**	**142**		
B71A	298	298	5.0	1.5	1650	674	46		Olifants
B71B	274	274		4.8	1650	577	27		
B71C	263	263	21.0		1500	858	153		
B71D	227	227			1550	686	66		
B71E	782	782		0.8	1650	591	29		
B71F	541	541	2.0	3.9	1500	800	101		
B71G	245	245			1450	845	142		
B71H	330	330	10.0	6.6	1450	615	39		

B71J	78	78			1550	459	9.8		
B71	**3038**	**3038**	**38.0**	**17.6**	**1562**	**685**	**67**		
B72A	534	534	21.0	6.1	1500	713	79		Selati
B72B	332	332			1550	512	16		
B72C	335	335			1500	485	13		
B72D	923	923			1600	468	6.4		
B72E	320	320	4.0	10.4	1500	770	98		
B72F	81	81	10.0		1500	934	168		
B72G	48	48		10.1	1500	630	42		
B72H	386	386		17.9	1550	614	35		
B72J	538	538			1600	594	21		
B72K	967	967		11.8	1650	495	8.1		
B72	**4464**	**4464**	**35.0**	**56.3**	**1573**	**567**	**31**		
B73A	165	165	75.0	1.0	1450	957	213	Klaserie	Olifants
B73B	688	688		7.5	1650	491	7.1		
B73C	881	881			1750	511	8.1		
B73D	688	688			1750	502	7.5		
B73E	431	431			1600	617	22		Timbavati
B73F	508	508			1800	569	13		
B73G	734	734			1850	533	9.5		
B73H	302	302			1900	469	5.1		
B73J	255	255			1900	510	7.7		
B73	**4652**	**4652**	**75.0**	**8.5**	**1750**	**539**	**17**		
Areas	54563	51061	604	500.9					
Sub-basins	114								

It was found that the basin area given in this reference is 54,563 km^2 while that computed in IDRISI and SLURP is 54,144 km^2, a difference of less than 1%. The first runs of TOPAZ were attempts to define sub-basins which correspond roughly to the quaternary catchments defined in Midgley et al. (1994). The agreement can never be exact because the quaternary catchments do not always correspond to river toplogy. For example, quaternary catchment B11A in the southwestern corner of the Olifants Basin divides the Olifants River well below the point at which a topographic analysis program would produce separate sub-basins.

The number of sub-basins produced by the TOPAZ programs depends on two factors:

- the critical source area (csa) in hectares, and
- the minimum source channel length (mscl) in meters.

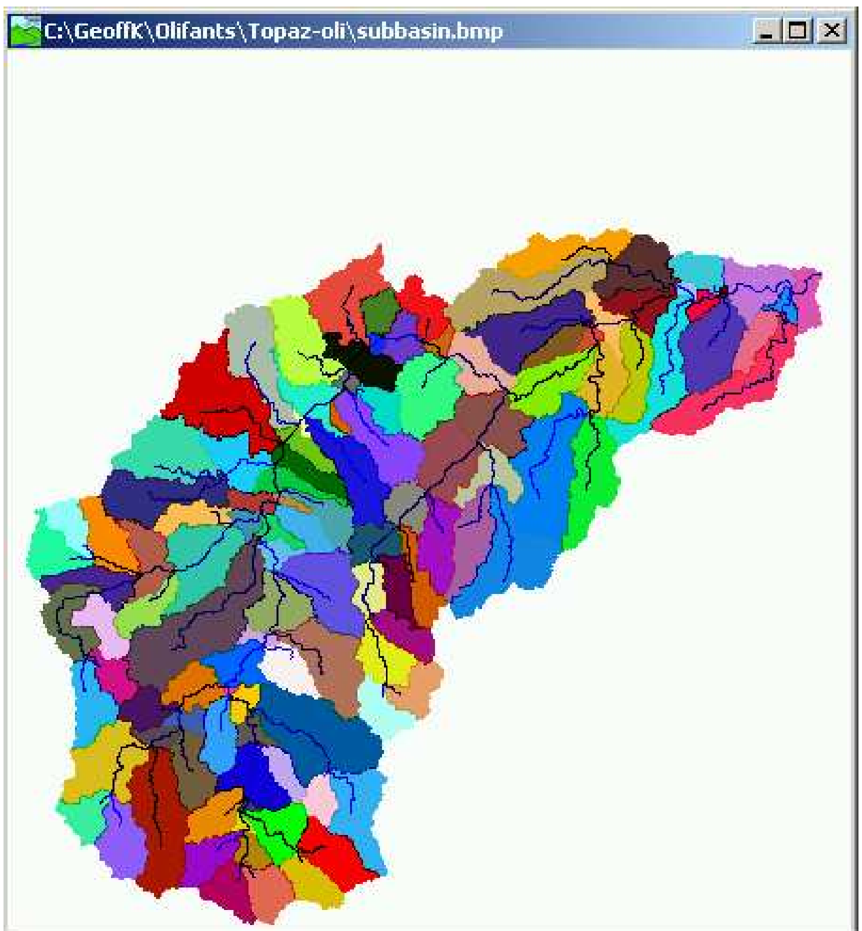
the critical source area is the threshold (minimum) upstream drainage area below which a source channel is initiated and maintained while the minimum source channel length is the minimum acceptable length for source channels to exist.

These were varied as follows for the entire Olifants Basin:

CSA	MSCL	No of Sub-basins
100	2,000	6,557
1,000	2,000	1,588
10,000	2,000	187
20,000	2,000	137
22,000	2,000	129
24,000	2,000	119

For this study, the values of CSA and MSCL corresponding to 119 sub-basins were selected and a comparison was made between the TOPAZ sub-basins and the WRC quaternary catchments.

The resulting map of sub-basins and rivers is shown below:



A direct comparison between the WRC Quaternary Catchments and the SLURP/TOPAZ sub-basins may be made as follows:

Comparison of WRC Quaternary Catchments and TOPAZ Sub-Basins

WRC Catchment	Area km**2	Net area km**2	TOPAZ Sub-basins for Olifants	Area km**2	TOPAZ Sub-basins for Spekboom	Area km**2	River
B11A	945	945	1,2	920			Olifants
B11B	435	435	3	463			
B11C	385	385	4	402			
B11D	551	551	5,6	534			
B11E	467	467	7,8	402			
B11F	428	428	9,10	428			
B11G	368	368	11	489			
B11H	246	246	12	248			
B11J	269	269	13	156			
B11K	378	378	18	425			
B11L	242	242	17,19	190			
B11	**4714**	**4714**		**4657**			
B12A	405	405	14,15	972			Kl. Olifants
B12B	659	659	see B12A				
B12C	529	529	16	1414			
B12D	362	362	see B12C				
B12E	436	436	see B12C				
B12	**2391**	**2391**		**2386**			
B20A	574	574	20	561			Wilge
B20B	322	322	21	320			
B20C	364	364	22	845			
B20D	480	480	see B20C				
B20E	620	620	23	1133			
B20F	504	504	see B20E				
B20G	522	522	25	474			
B20H	563	563	24,26,27	611			
B20J	407	407	28	395			
B20	**4356**	**4356**		**4340**			
B31A	387	387	39	483			Elands
B31B	385	385	38	284			
B31C	373	373	40,41	894			
B31D	558	558	see B31D				
B31E	1382	1104	42,43,44,45	1612			
B31F	638	589	46	443			
B31G	433	433	47	377			
B31H	612	612	48,50,51	1198			
B31J	1380	459	49,56	1136			
B31	**6148**	**4900**		**6425**			

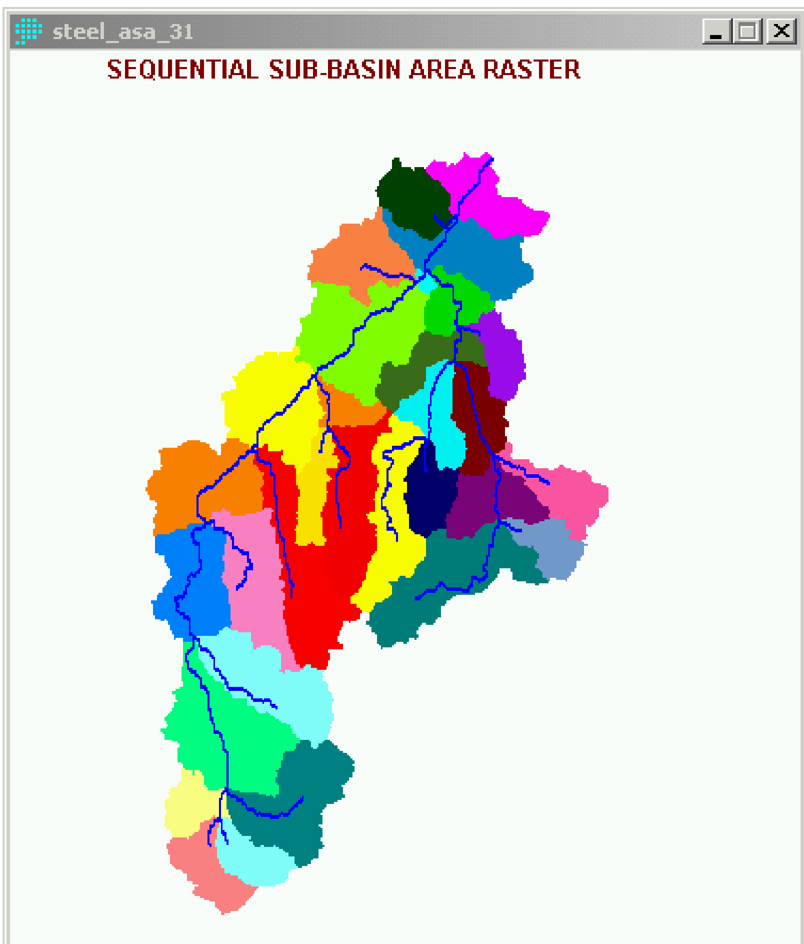
B32A	801	801	29,30	795			
B32B	614	614	31,32	951			
B32C	303	303	see B32C				
B32D	521	521	33	523			
B32E	203	203	34	862			
B32F	667	667	see B32E				
B32G	968	968	36	1668			
B32H	694	694	see B32G				
B32J	323	323	35,37	317			
B32	**5094**	**5094**		**5116**			
B41A	765	765	83,84	764			Steelpoort
B41B	778	778	85,86	786			
B41C	302	302	88	316			
B41D	403	403	87	292			
B41E	237	237	89	332			
B41F	380	380	90	375			
B41G	442	442	92	530			
B41H	410	410	91	346			
B41J	691	691	93	687			
B41K	635	635	94	643			
B41	**5043**	**5043**		**5070**			
B42A	319	319	80	1068	S2	396	Spekboom
B42B	214	214	see B42A		S1	119	
B42C	164	164	see B42A		S3	192	
B42D	155	155	see B42A		S4	178	
B42E	222	222	see B42A		S5	184	
B42F	279	279	81	599	S7	295	
B42G	327	327	see B42F		S6,S8	304	
B42H	413	413	82	410	S9,S10,S11	425	
B42	**2093**	**2093**		**2077**		**2093**	
B51A	311	311	55	256			
B51B	591	591	52,53,54	724			
B51C	638	638	59,61,63	566			
B51E	2927	673	57,58,60,65	3062			
B51F	395	395	62	861			
B51G	591	591	see B51G				
B51H	717	717	64	712			
B51	**6170**	**3916**		**6180**			
B52A	566	566	67,68	335			
B52B	633	633	66	721			
B52C	200	200	70	822			
B52D	341	341	see B52C				
B52E	451	451	69,73	128			
B52F	118	118	see B52C				
B52G	291	291	71	417			
B52H	563	563	72	807			

B52J	395	395	see B52H			
B52	**3558**	**3558**		**3229**		
B60A	210	210	96	845		Blyde
B60B	302	302	see B60A			
B60C	94	94	see B60A			
B60D	244	244	see B60A			
B60E	83	83	97	1319		
B60F	400	400	see B60E			
B60G	448	448	see B60E			
B60H	385	385	see B60E			
B60J	676	676	98	467		
B60	**2842**	**2842**		**2631**		
B71A	298	298	74	255		
B71B	274	274	75	295		
B71C	263	263	76	348		
B71D	227	227	77	106		
B71E	782	782	78	811		
B71F	541	541	79	515		
B71G	245	245	95	658		
B71H	330	330	see B71G			
B71J	78	78	see B71G			
B71	**3038**	**3038**		**2989**		
B72A	534	534	101	865		
B72B	332	332	see B72A			
B72C	335	335	99,100	332		
B72D	923	923	102,103,104,105	1131		
B72E	320	320	106	1110		
B72F	81	81	see B72E			
B72G	48	48	see B72E			
B72H	386	386	see B72E			
B72J	538	538	107	607		
B72K	967	967	108	603		Selati
B72	**4464**	**4464**		**4648**		
B73A	165	165	110	840		Olifants
B73B	688	688	see B73A			
B73C	881	881	109,111,112,113	504		
B73D	688	688	114	800		
B73E	431	431	116	979		
B73F	508	508	see B73E			
B73G	734	734	117	299		
B73H	302	302	115,118	650		
B73J	255	255	119	270		
B73	**4652**	**4652**		**4342**		
Areas	54563	51061		54090	54106	
Sub-basins	114			119	127	

Comparing the quaternary catchment areas and the sub-basin areas for the Steelpoorts Basin (B41 and B42) the agreement is very good (7,136 vs. 7,147 km^2). The main differences are that, within the Spekboom Basin, the quaternary catchments B42A, B, C, D and E are all lumped into TOPAZ sub-basin 80 and the quaternary catchments B42F and G are lumped into TOPAZ sub-basin 81.

To rectify this, TOPAZ was run again for just the Steelpoorts Basin to create a larger number of sub-basins.

	WRC Quaternary Catchments	TOPAZ Sub-basins
Entire Olifants	114	119
Steelpoorts (original)	18	15
Steelpoorts (modified)	18	31



Those sub-basins corresponding to the quaternary catchments in the Spekboom Basin were combined with the remaining sub-basins in the main Steelpoorts and Olifants data files. The table of correspondences between quaternary catchments and sub-basins was modified accordingly (last two columns).

A combined basin command file,COMBI.CMD, for SLURP was then prepared by combining the Olifants sub-basins and the revised Spekboom sub-basins, giving a total of 127 sub-basins for the entire Olifants.

Boundary vectors for the Olifants and Steelpoorts basins were prepared using:

\Reformat\Rastor/Vector conversion\POLYVEC

excluding the background polygon. These files are named OLI_BOUND and STEEL_BOUND respectively.

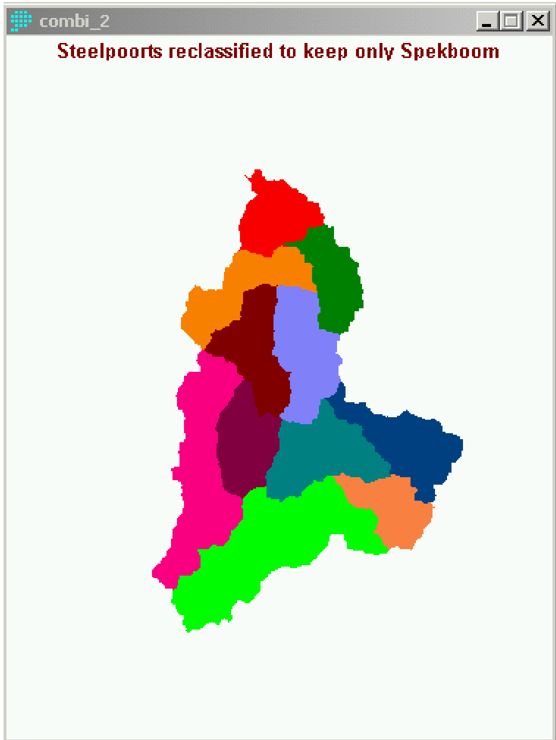
A combined image containing the original Olifants sub-basins and the new Spekboom sub-basins was prepared by:

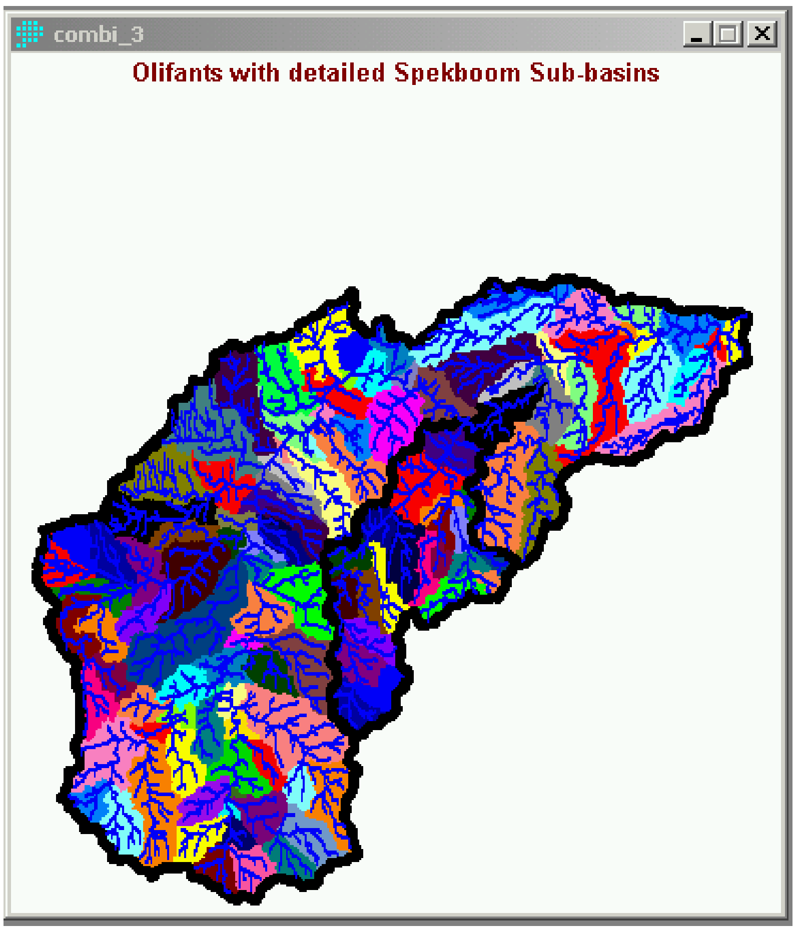
i) In the Olifants raster OLI_ASA_119, reclassify sub-basins 83-119 to numbers 91-127 using OLI2COMBI.RCL to raster COMBI_1 (sub-basins 80-82 will be overlaid).

ii) In the Steelpoorts raster STEEL_ASA_31, reclassify sub-basins 1-11 to numbers 80-90 and all sub-basins 12-31 to 0 using STEEL2COMBI.RCL to raster COMBI_2.

iii) The two reclassified images are now combined by overlaying COMBI_2 over COMBI_1 except where zero. The result (with boundaries added) is shown below:

The sub-basin and the LCASA2 images are also saved as bitmaps for later use in SLURP. In the command file OLI_ASA_127.CMD and the Morton evapotranspiration file OLI_ASA_127.MOR, the sub-basin names should be changed to correspond to the new sequence of numbering and the final image of sub-basins is renamed OLI_ASA_127.


combi_2
Steelpoorts reclassified to keep only Spekboom


combi_3
Olifants with detailed Spekboom Sub-basins

SLURP uses an image with classes specific to every combination of sub-basin and land cover to prepare basin-wide distribution maps of components of the vertical water balance. This image is prepared by first cutting the land cover image to include only the Olifants Basin:

\Analysis\Mathematical Operators\Image Calculator

as

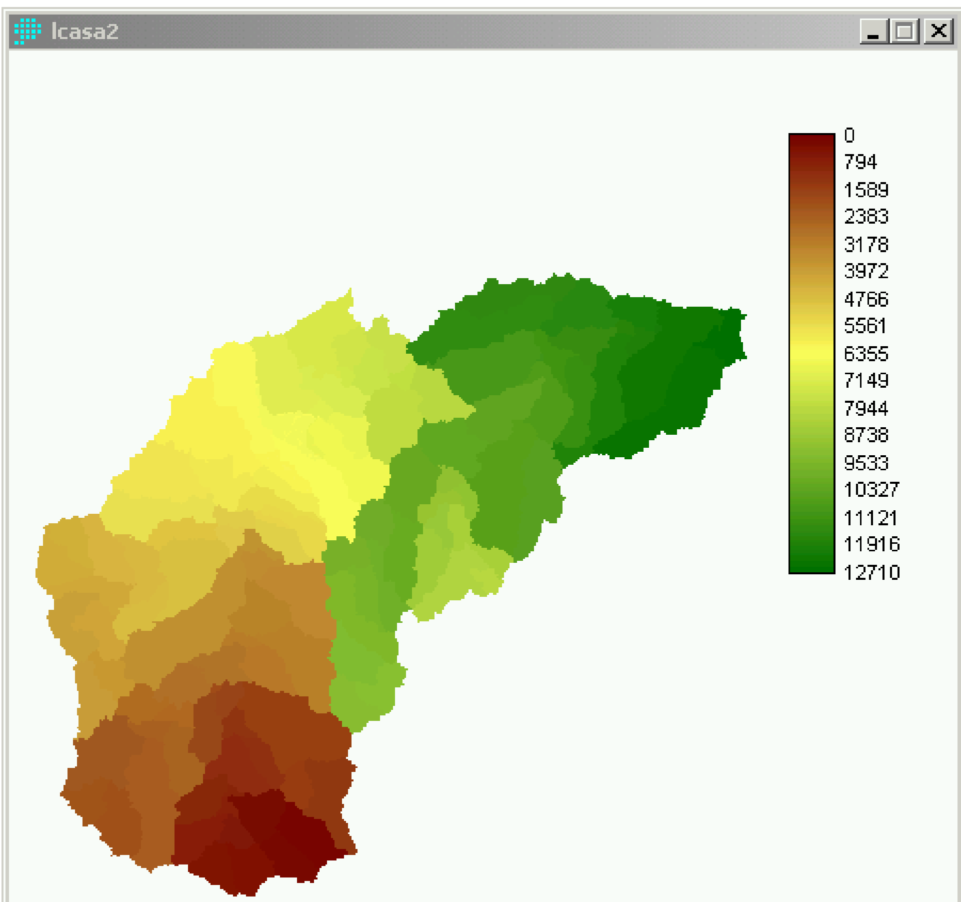
LCLASS_2 = LCLASS * BOUND

The revised land class image should then be combined with the sub-basin image using the procedure:

\Analysis\Mathematical Operators\Image Calculator

as

LCASA2 = COMBI_3 * 100 +LCLASS_2



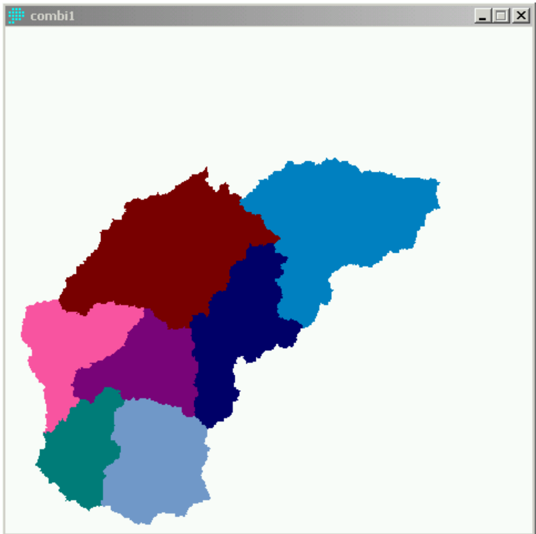
So far we have prepared SLURP input files for a detailed Olifants and Steelpoort Basin. This version of the model will give detailed results for the entire Olifants Basin. However, on many occasions modelling will concentrate on the Steelpoorts Basin and a detailed model of the rest of the Olifants will not be necessary.

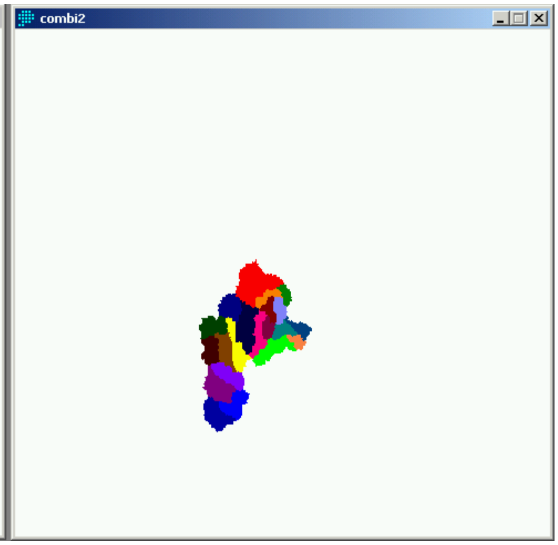
a) To accommodate this, a TOPAZ run was made to produce a few large sub-basins for the Olifants, OLI_ASA_7:

b) Next it was necessary to add the detailed Steelpoort and Spekboom sub-basins to this image by:

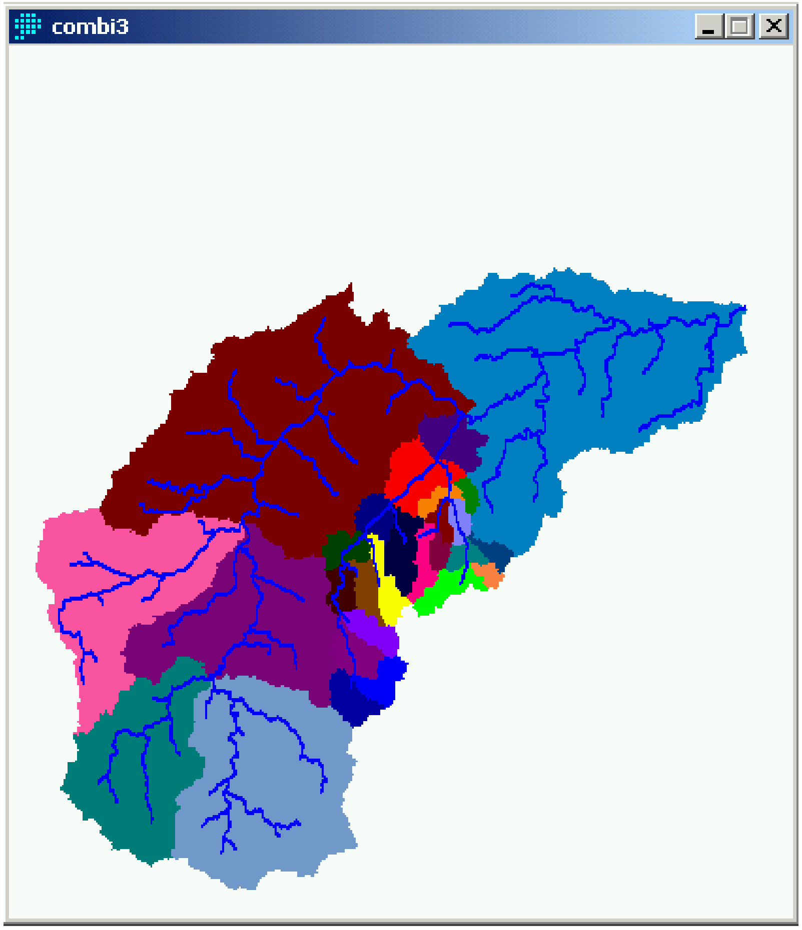
i) In the detailed Olifants raster OLI_ASA_127, reclassify sub-basins 1-79 and 103-127 to 0 (leaving only the Steelpoorts and Spekboom basins 80-102) to raster COMBI_1.

ii) In the simple Olifants raster OLI_ASA_7, reclassify sub-basin 7 to 29 to COMBI_2.



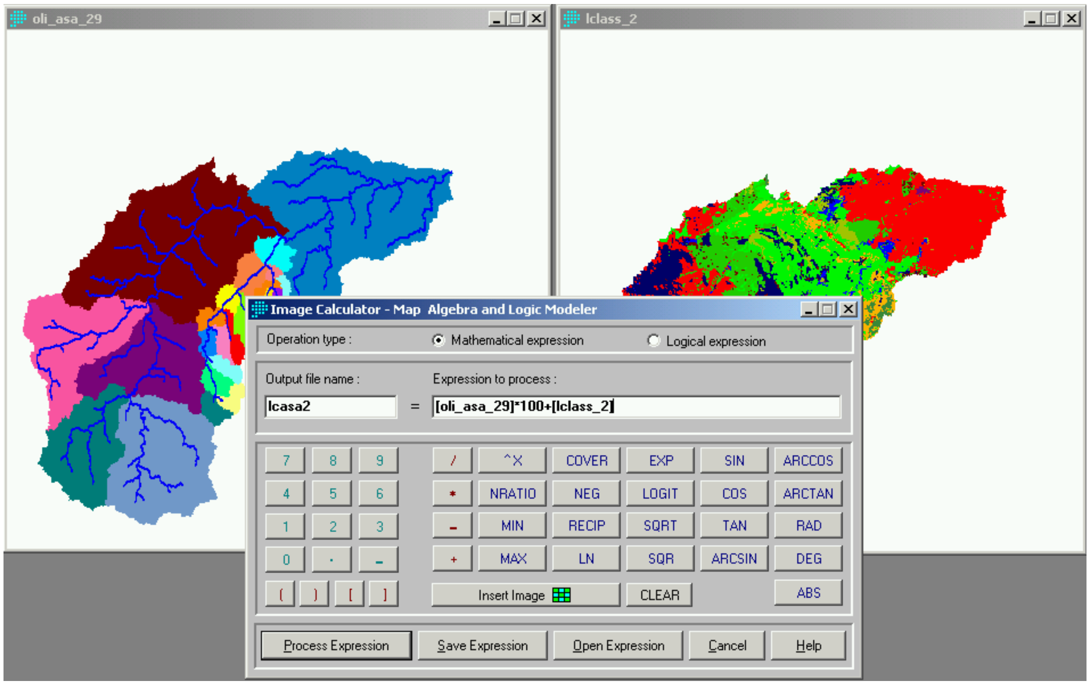


iii) The two reclassified images are now combined by overlaying COMBI_2 over COMBI_1 except where zero. The result (COMBI_3) is shown below:



iv) image COMBI_3 is then reclassified using OLI2COMBI.RCL to give consecutive sub-basin numbers 1-29 in image OLI_ASA_29.

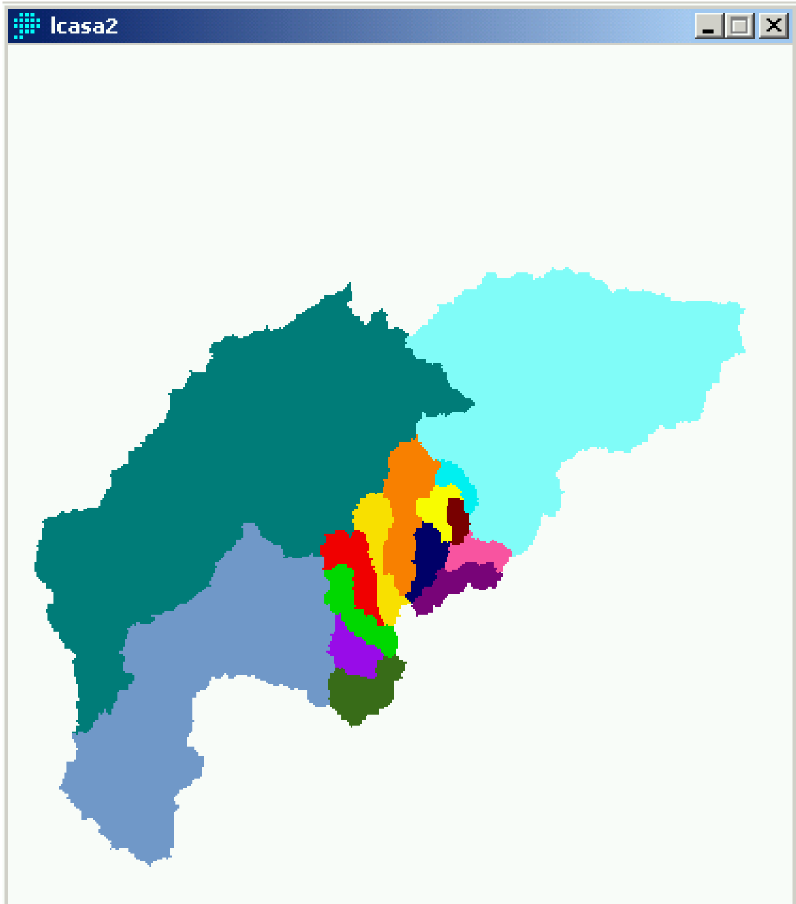
Just as with the detailed Olifants images, SLURP will use an image with classes specific to every combination of sub-basin and land cover to prepare basin-wide distribution maps of components of the vertical water balance. This image is prepared by combining the Olifants land class image with the sub-basin image using the procedure:



\Analysis\Mathematical Operators\Image Calculator

as

LCASA2 = OLI_ASA_29 * 100 +LCLASS_2



The sub-basin and the LCASA2 images are saved as bitmaps for use in SLURP. In the command file OLI_ASA_29.CMD and the Morton evapotranspiration file OLI_ASA_29.MOR, the sub-basin names are changed to correspond to the new sequence of numbering.

4.2 Leaf Area Index

Leaf Area Index (LAI) is a measure of the density of vegetation expressed as the ratio of the area of vegetation divided by the area of ground beneath the vegetation and varies from 0 to over 5. The SLURP hydrological model uses LAI to control interception (how much of the precipitation is intercepted by the canopy) and to divide evapotranspiration between evaporation from soil and leaf surface and transpiration from vegetation.

Leaf area index has traditionally been calculated using species-specific allometric equations relating stem diameter and foliage biomass. These equations are generally of the form:

$$\ln(y) = a + b\ln(x)$$

where, y is the foliage biomass and x is the diameter breast height. Biomass is converted to leaf area using surface area to mass conversion factors and LAI is calculated by summing individual leaf areas and dividing by ground surface area.

Direct estimates of LAI are often very laborious and can also be imprecise. Differences in light conditions cause large variations even within a single species and leaf area biomass changes with age. Separate regression equations to account for different light conditions and age are possible but also tedious. There are inconsistencies in the reporting of data. Most reported LAI of broadleaf species represent only a single surface of the leaf but, as exchange can occur on more than one leaf surface, total surface area is the most desirable context in which to express LAI.

These problems become even more cumbersome when investigations take place at the landscape or regional scale. With increasing demand for an understanding of regional and global scale exchanges between the land and atmosphere, a more efficient method of determining evapotranspiration and interception should be found. Running et al. (1986) suggest the only feasible method to estimate LAI at the regional scale is from satellite.

Normalized Difference Vegetation Index

There are significant correlations between LAI, as an index of canopy properties, and reflectance measured by satellites. Chlorophyll pigments in green leaves absorb radiation in the red wavelengths and so reflectances are inversely proportional to the quantity of chlorophyll present in the canopy vegetation. On the other hand, near infrared radiation is scattered by internal leaf structure and is then either reflected or transmitted. The spectral reflectance of vegetation is more than three times greater in the infrared than in the visible. The difference between the values of the infrared and the red is an indicator of the amount of green vegetation.

Suitable spectral bands of reflectance data are measured by sensors on the NOAA series of meteorological satellites and on the Landsat and SPOT satellites. The Advanced Very High Resolution Radiometer (AVHRR) sensor on the NOAA satellites measures reflectances in the visible and infrared channels at a resolution of 1.1 km with a twicedaily repeat cycle. A particular advantage of using AVHRR for regional analysis is that it integrates over a large area such that variations caused by canopy closure, understory vegetation and background reflectance at local scales may be eliminated in favour of large scale variations caused by regional climatic patterns.

The most commonly used indicator of vegetation activity is the normalized difference vegetation index (NDVI), which is generally computed from the AVHRR sensor as:

$$NDVI = \frac{(IR - R)}{(IR + R)}$$

where IR is the pixel value from band 2 (infrared: 0.73 - 1.0μm) and R is the pixel value from band 1 (visible; 0.58 - 0.68 μm). Using a normalized index partially compensates for changing illumination conditions, surface slope and viewing aspect. NDVI is strongly related to the amount of chlorophyll in the vegetation cover and to the amount of absorbed photosynthetically active radiation (APAR) absorbed by the plant canopy. As such, the NDVI could be used directly in a hydrological model as an indicator of canopy evaporation and of transpiration but, to correspond to the more detailed ecosystem models available, it is more usually converted to LAI. The relationships between LAI and NDVI vary according to seasonal changes based on phenological changes in LAI, proportions of surface cover types contributing to overall reflectance and effects resulting from large variations in solar zenith angle.

There are three easily accessible sources of NDVI data:

1. The Global Change Data Base CD Volume 2 contains an experimental normalized difference vegetation index (NDVI) developed and produced during 1988 through 1990, from weekly visible and near-infrared AVHRR channel data available from NOAA's Global Vegetation Index product. NOAA's Mercator-projected product was utilized. The data are produced for the region between 75 degrees North latitude and 55 degrees South latitude. Data resolution in the Mercator projection varies from 19.6 km pixel size at the equator to 15 km at 40 degrees (North or South) (10” x 10”). The reflectance values of the visible and near-IR data were computed from pre-launch calibration coefficients (Gallo, 1994).

2. The ISLSCP CD contains monthly composite NDVI, FPAR and LAI on a 1º x 1º grid. FPAR is Fraction of Photosynthetic Active Radiation absorbed by the green part of vegetation. All data sets cover the period 1987-1988. The temporal frequency for most of the data sets is monthly.

3. For this study we needed higher resolution than available on the GCDB CD and for a more recent period than available on the ISLSCP CD and so we extracted monthly NDVI composites from the USGS/NOAA website for the three 10-day periods of each month for the period February 1-10, 1995 to January 21-30 1996 (there are no January 1995 images). Note that as of August 2000, production of the Global AVHRR composites has been temporarily suspended while funding and new processing techniques are under consideration.

On the website http://edcdaac.usgs.gov/1km/comp10d.html specify the date and location coordinates required (see figure below). Specify "BAND 6 NDVI", specify "GZIP" compression and specify "MOST SIG BYTE FIRST" byte order. Click the left mouse button over the button "Retrieve data". For the Olifants Basin, the coordinates requested are:

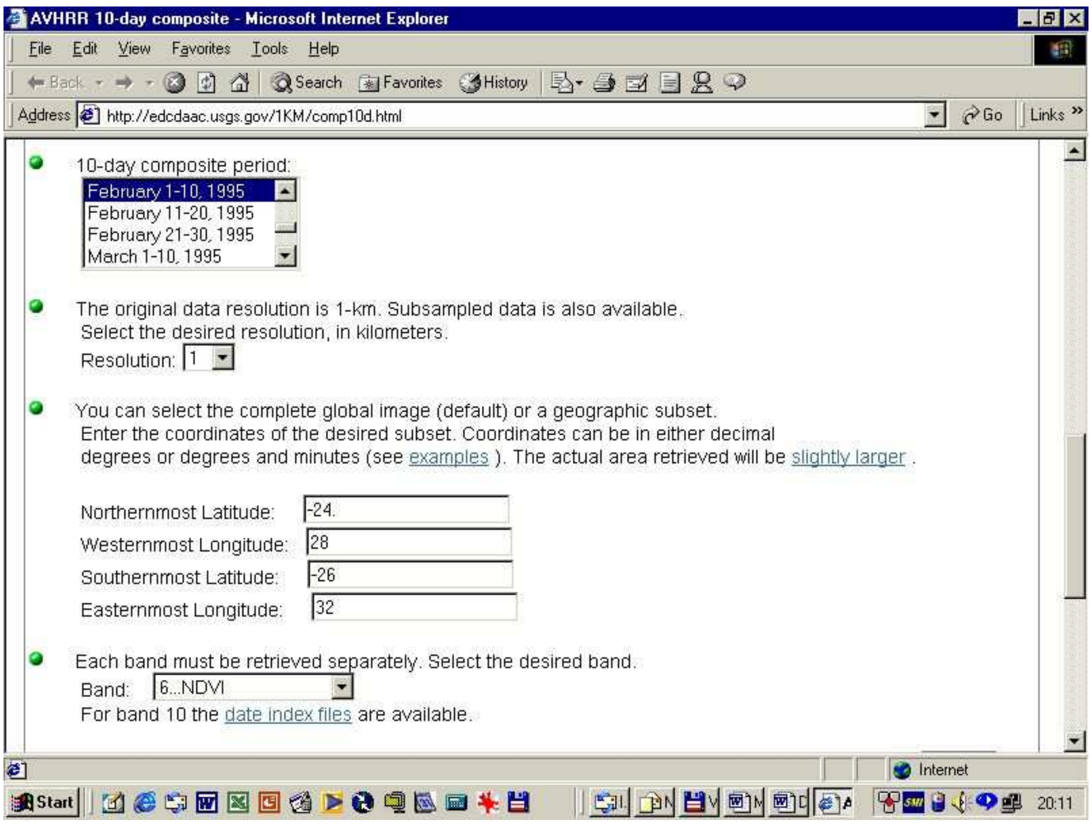
Requested Coordinates:

Northernmost Latitude: -24.000000

Westernmost Longitude: 28.000000

Southernmost Latitude: -26.000000

Easternmost Longitude: 32.000000



The USGS website will respond with the size, number of lines (rows) and samples (columns) and the actual coordinates of the image available (see figure below). Position the mouse over the phrase "Retrieve the data" and press the right mouse button and select "Save Target As" to start the download process. The compression method selected does not seem to matter; the image is downloaded in uncompressed format anyway. Note that the NDVI images are specified as 1 km resolution and are also specified in latitude/longitude coordinates. The two are incompatible and the correct specification is latitude/longitude. The actual coordinates supplied for the Olifants were:

Actual Coordinates:

Northernmost Latitude: -23.30143, line 11265

Westernmost Longitude: 26.6590939, sample 22913

Southernmost Latitude: -26.745837, line 11648

Easternmost Longitude: 33.213744, sample 23552

number of lines (rows) is 384
number of samples (columns)is 640

This process is repeated for each image.

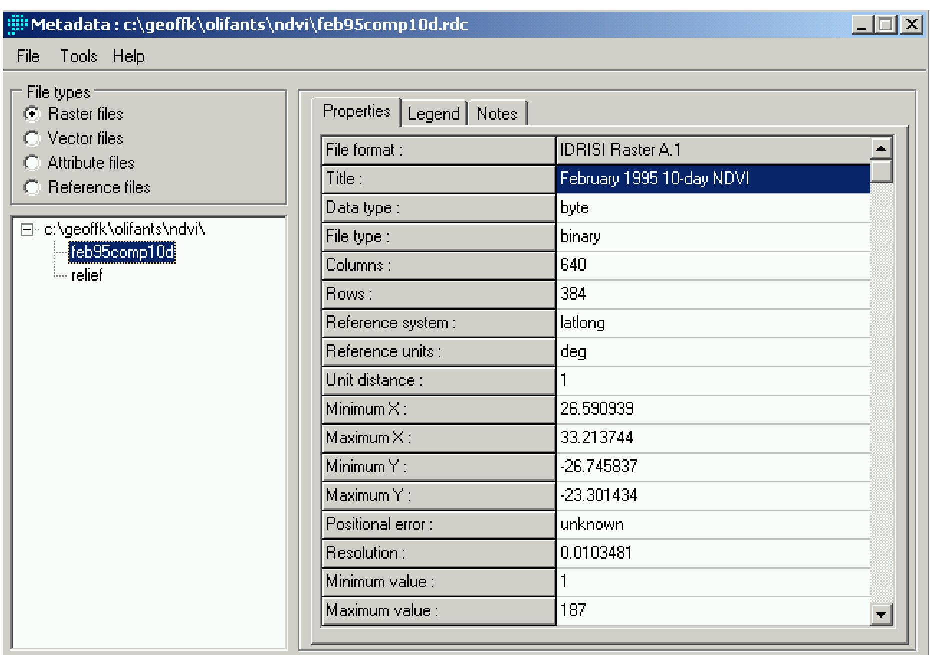
Now that a basin boundary and DEM have been established in IDRISI, the NDVI images downloaded from the USGS website can be processed.

First, rename all the .TXT files to raster .RST files.

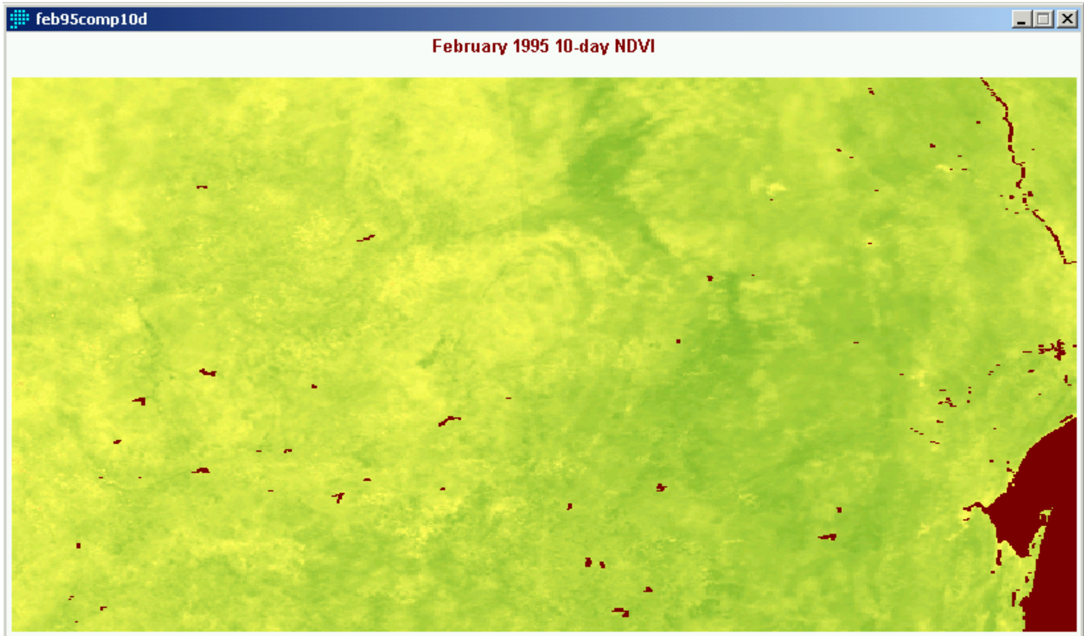
Then prepare corresponding .RDC files using:

\File\Metadata

Set 'Raster files' and click on \File\New. Fill in the fields specifying a byte binary image with latlong projection and using the actual coordinates given above. Use \Tools to compute the resolution and the maximum and minimum values and save the file to <name>.RDC. Display using the IDRIS256 palette.

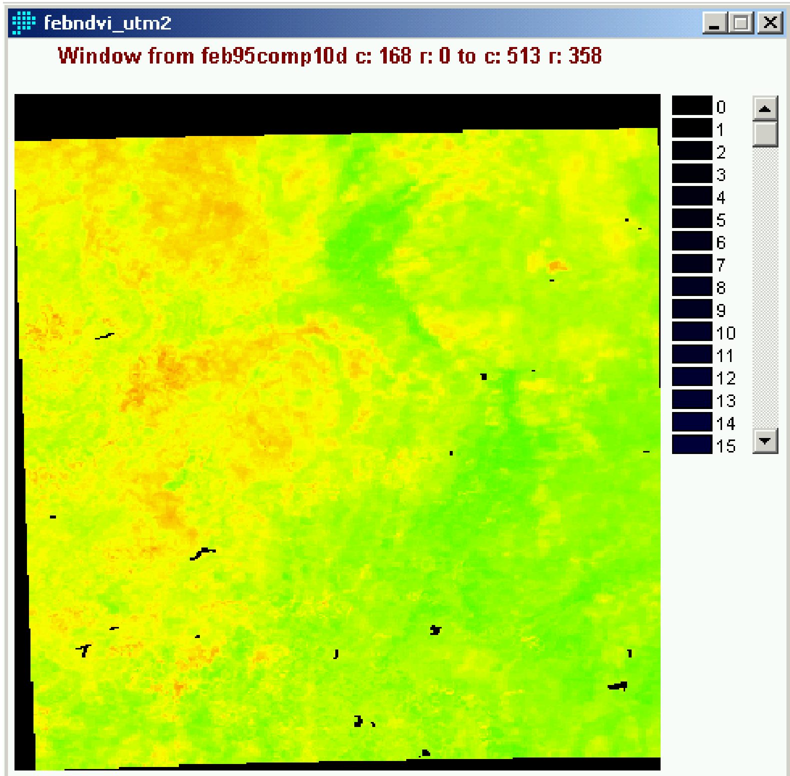


At this stage we have a series of NDVI images which must be converted to LAI.



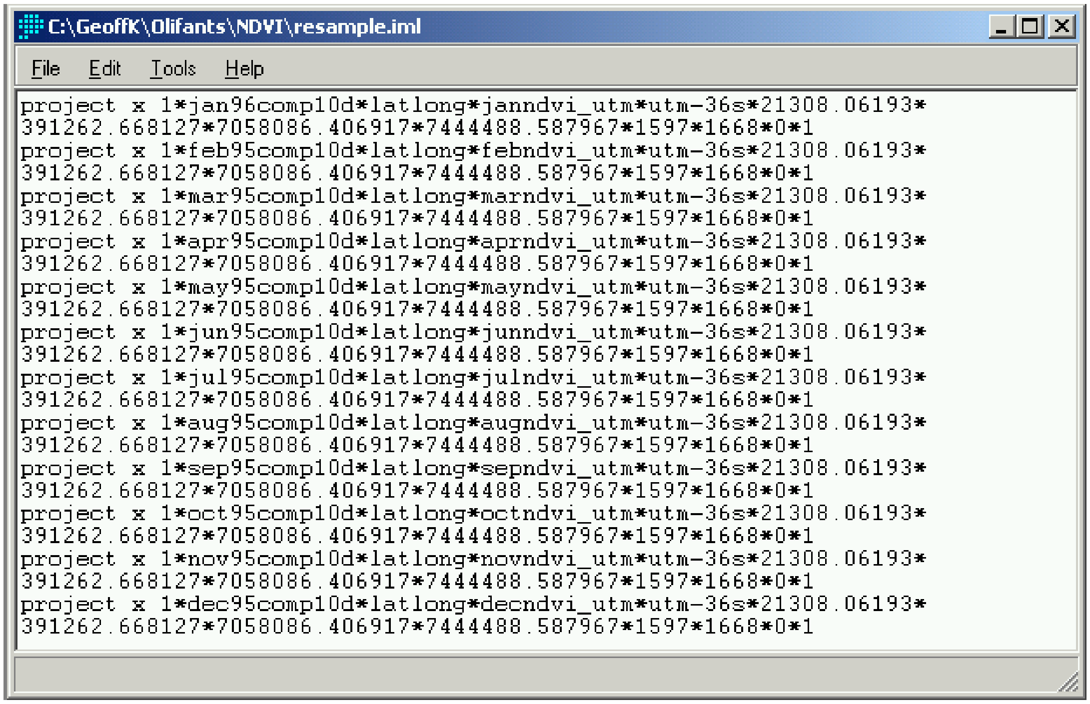
The NDVI images downloaded from the USGS website are first converted to the UTM projection and cut to the basin boundaries.

1. First cut the downloaded image to the same latitude and longitude as the original lat/long DEM file DEM_LL_M1. Call this image FEBNDVI_LL_WINDOW.



2. Next, convert the windowed lat/long NDVI to the UTM projection using the same MIN and MAX X and Y as the basin boundary image, BOUND. Note that the number of columns and rows of the NDVI are smaller than those of BOUND. This is because the NDVI have a nominal 1km resolution while the boundary image is derived from the nominal 200m. DEM.

In practice, because we have 12 monthly NDVI images to process, this is done using an IDRISI macro as:

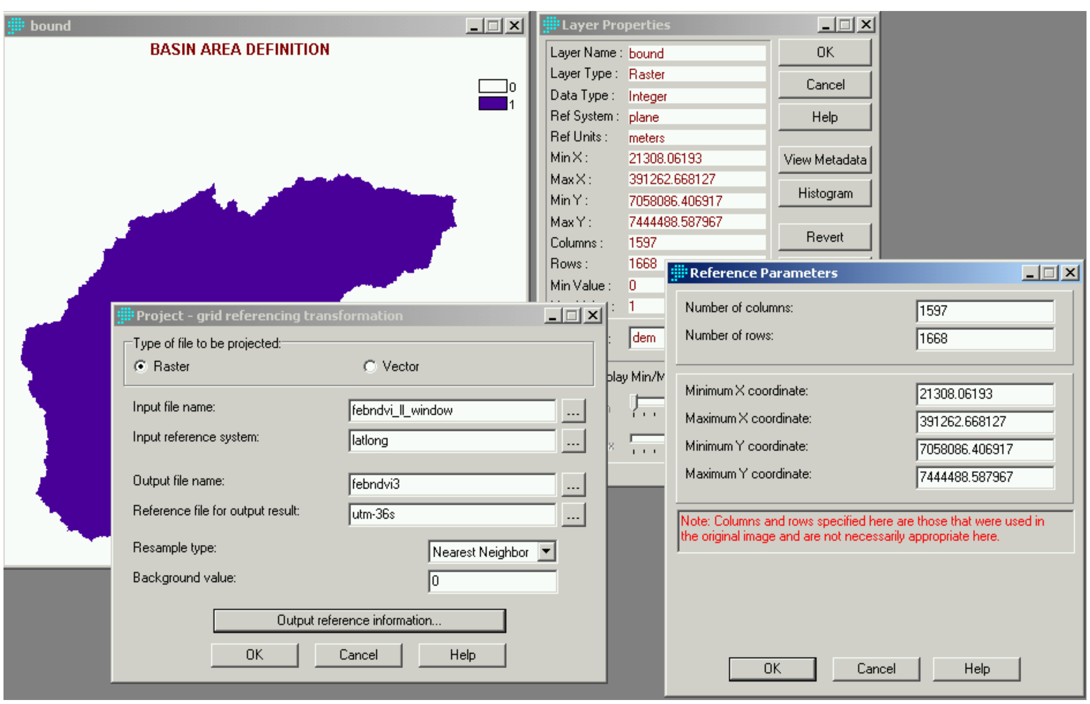



```
project x 1*jan96comp10d*latlong*janndvi_utm*utm-36s*21308.06193*
391262.668127*7058086.406917*7444488.587967*1597*1668*0*1
project x 1*feb95comp10d*latlong*febndvi_utm*utm-36s*21308.06193*
391262.668127*7058086.406917*7444488.587967*1597*1668*0*1
project x 1*mar95comp10d*latlong*marndvi_utm*utm-36s*21308.06193*
391262.668127*7058086.406917*7444488.587967*1597*1668*0*1
project x 1*apr95comp10d*latlong*aprndvi_utm*utm-36s*21308.06193*
391262.668127*7058086.406917*7444488.587967*1597*1668*0*1
project x 1*may95comp10d*latlong*mayndvi_utm*utm-36s*21308.06193*
391262.668127*7058086.406917*7444488.587967*1597*1668*0*1
project x 1*jun95comp10d*latlong*junndvi_utm*utm-36s*21308.06193*
391262.668127*7058086.406917*7444488.587967*1597*1668*0*1
project x 1*jul95comp10d*latlong*julndvi_utm*utm-36s*21308.06193*
391262.668127*7058086.406917*7444488.587967*1597*1668*0*1
project x 1*aug95comp10d*latlong*augndvi_utm*utm-36s*21308.06193*
391262.668127*7058086.406917*7444488.587967*1597*1668*0*1
project x 1*sep95comp10d*latlong*sepndvi_utm*utm-36s*21308.06193*
391262.668127*7058086.406917*7444488.587967*1597*1668*0*1
project x 1*oct95comp10d*latlong*octndvi_utm*utm-36s*21308.06193*
391262.668127*7058086.406917*7444488.587967*1597*1668*0*1
project x 1*nov95comp10d*latlong*novndvi_utm*utm-36s*21308.06193*
391262.668127*7058086.406917*7444488.587967*1597*1668*0*1
project x 1*dec95comp10d*latlong*decndvi_utm*utm-36s*21308.06193*
391262.668127*7058086.406917*7444488.587967*1597*1668*0*1
```

The ASCII .IML file is prepared in an editor and is run using:

\File\Run Macro

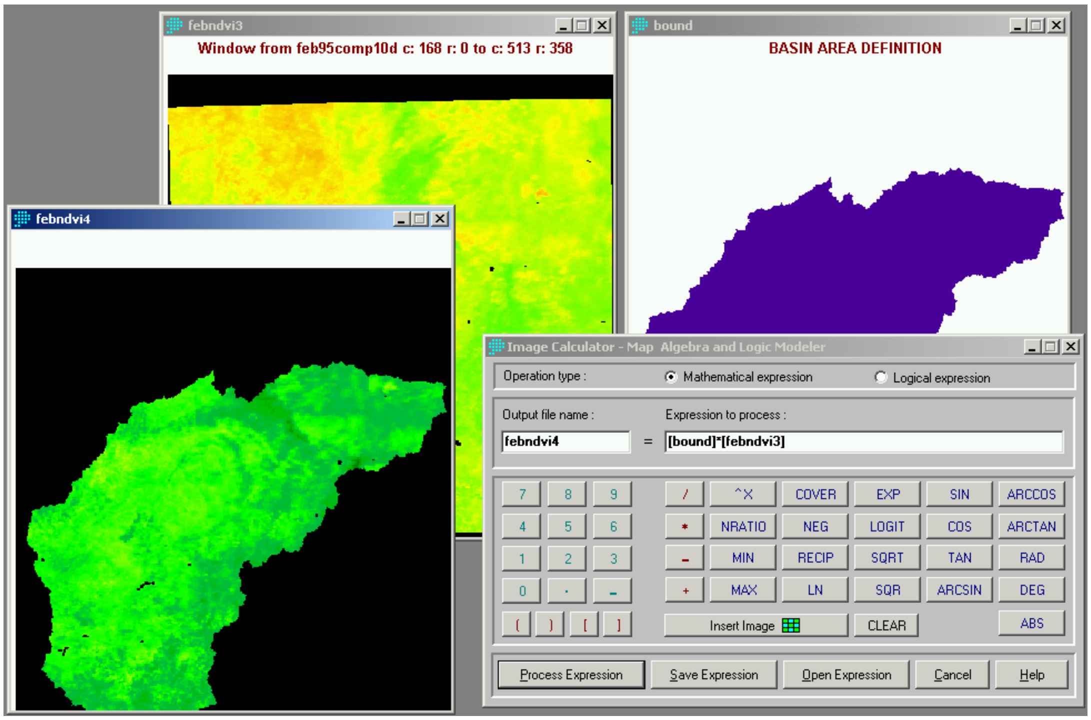
The resulting files are named JANNDVI_UTM, etc.

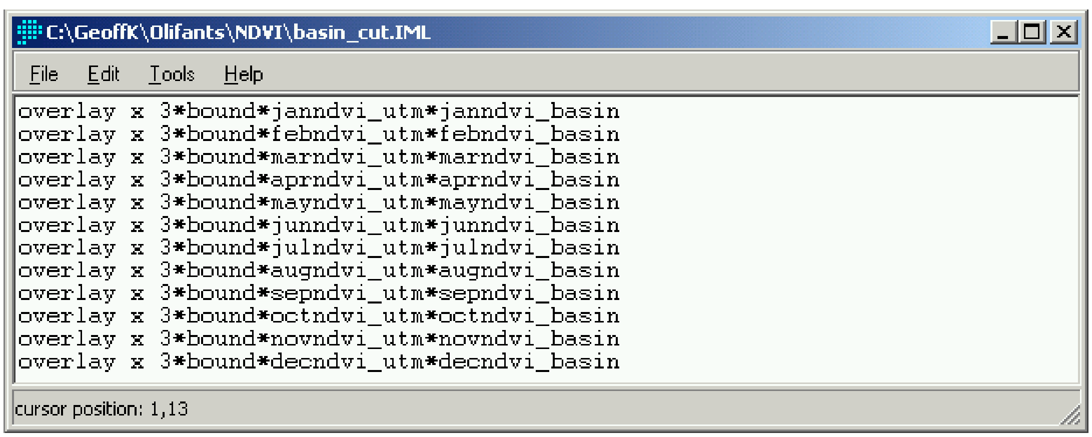


3. The UTM NDVI image can now be cut to the basin boundary using:

\Analysis\Mathematical operators\Image calculator

multiplying the NDVI by BOUND, which is 1 inside the basin and 0 outside the basin. No macro is available for this command and so the OVERLAY module is used in a macro instead.





The output files are named JANNDVI_BASIN, etc.

4. Next, the NDVI values are extracted for each of the land covers using:

\Analysis\Database Query\EXTRACT

with the basin-cut land class image, LCLASS-2 as the feature definition image. The macro file below was used and the outputs are a series of .AVL attribute files such as JANNDVI.AVL and .ADC.

C:\GeoffK\Olifants\NDVI\extract_ndvi.IML

File Edit Tools Help

```
extract x lclass_2*janndvi_basin*1*4*janndvi
extract x lclass_2*febndvi_basin*1*4*febndvi
extract x lclass_2*marndvi_basin*1*4*marndvi
extract x lclass_2*aprndvi_basin*1*4*aprndvi
extract x lclass_2*mayndvi_basin*1*4*mayndvi
extract x lclass_2*junndvi_basin*1*4*junndvi
extract x lclass_2*julndvi_basin*1*4*julndvi
extract x lclass_2*augndvi_basin*1*4*augndvi
extract x lclass_2*sepndvi_basin*1*4*sepndvi
extract x lclass_2*octndvi_basin*1*4*octndvi
extract x lclass_2*novndvi_basin*1*4*novndvi
extract x lclass_2*decndvi_basin*1*4*decndvi
```

A moving image of NDVI across the basin can be created from the .BMP files using a video editor such as Ulead Systems MorphStudio Video Editor. Insert each of the series of bitmaps on the timeline using:

\Insert\Image file

and preview the timing using:

\View\Preview

When the file is correct, create a .AVI video file using:

\Create\Video File.

If required, text (such as the month) can be added to the bitmaps prior to using Video Editor by using an editor such as Ulead Systems MorphStudio Image Editor. The completed .AVI can then be inserted into the Powerpoint presentation using:

\Insert\Movies and Sounds\Movie from file

To view the NDVI movie, double-click the left mouse button within the basin area.

5. The NDVI values contained in the .AVL files created by the .IML macro can now be put into the SLURP command files using SLURP menu option

\Tools\Add NDVI to command file

on the SLURP menu. For compact storage, the 10-day composite NDVI data downloaded from the NOAA website are in a byte format and so this menu option also converts the NDVI back to the original range (-1.0 to +1.0) using the following conversion:

NDVI = (byte NDVI – 100)/100.

Thus, a byte NDVI value of 151 in the byte format is equivalent to a real NDVI value of 0.51.

Once the NDVI have been added to the command file, they can be converted to leaf area index (LAI) using the SLURP menu option:

\Tools\Convert NDVI to LAI

This is done via the FPAR (Fraction of Photosynthetic Active Radiation absorbed by the green part of vegetation). FPAR is calculated from NDVI and land cover classification as

$$FPAR = 0.95-0.001(SR - SR02)/(SR98 - SR02) + 0.001$$

truncated such that $0.001 \le FPAR \le 0.950$ where

SR = (1+NDVI)/(1-NDVI)   (known as the Simple Ratio)

and

SR98 = 98 % SR of a particular land cover class for overhead sun

SR02 = 2 % SR of desert (bare soil) for overhead sun

as given in the following table :

vegetation parameters

IV	NDVI98	NDVI02
1	0.618	0.034
2	0.686	0.034
3	0.686	0.034
4	0.686	0.034
5	0.686	0.034
6	0.618	0.034
7	0.630	0.034
8	0.618	0.034
9	0.630	0.034
10	0.686	0.034
11	0.630	0.034
12	0.630	0.034

where IV refers to the land cover classes given below:

SiB and ISLSCP LAND_COVER_CLASSIFICATIONS

Value		Land Cover class
0	0	water
1	1	broadleaf evergreen forest
2	2	broadleaf deciduous forest and woodland
3	3	mixed coniferous and broad-leaf deciduous forest and woodland
4	4	coniferous forest and woodland
5	5	high latitude deciduous forest and woodland
6	6	broadleaf trees with groundcover
7	6	c4 grassland
8	6	broadleaf shrubs with groundcover
9	7	shrubs and bare ground
10	8	tundra
11	6	desert, bare ground
12	9	cultivation
13		ice
14	9	c3 wooded grassland
15	9	c3 grassland
16		irrigated agriculture

The data values in the first column are consistent with SiB vegetation classes. For the purpose of producing the NDVI related data sets on the ISLSCP CD-ROM, this classification was simplified to the right-hand column, where most tropical seasonal biomes were assigned C4 grassland properties and temperate biomes with c3 ground cover were assigned cultivation properties. The last category was added by the present author to aid in modelling irrigation schemes.

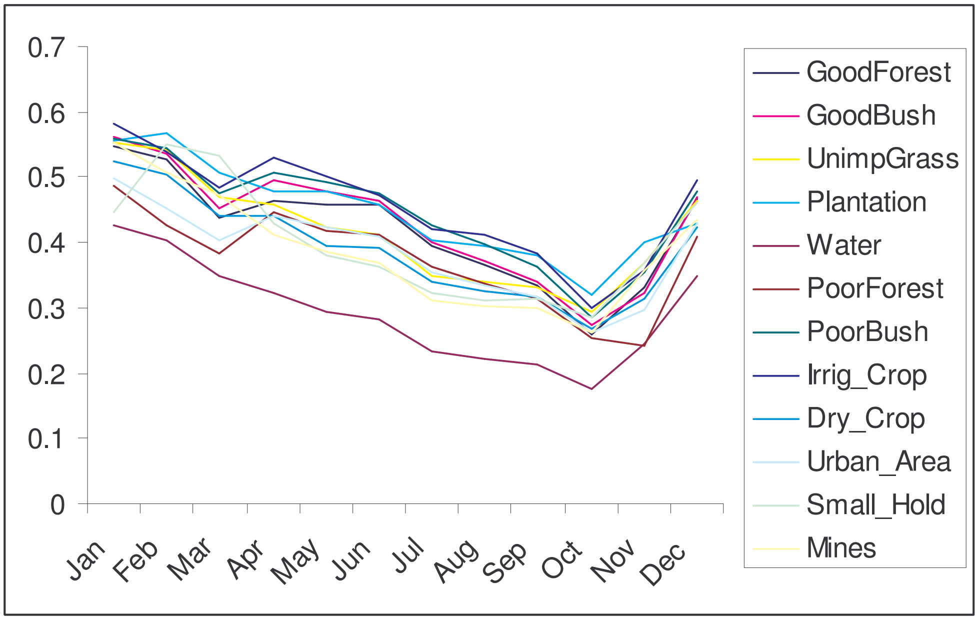
The FPAR - LAI relationship is assumed exponential for vegetation evenly distributed over a surface (Monteith, 1973) and linear for vegetation concentrated in clusters (Huemmrich and Goward, 1992), likely to occur in classes 4, 5, and 9. An FPAR of 0.95 is equivalent to the maximum LAI for a particular class; an FPAR of 0.001 is equivalent to a minimum LAI. Data in each file are ordered from North to South and from West to East beginning at the international dateline. Point (1,1) represents the grid cell centered at 89.5 N and 179.5 W. The ISLSCP CD-ROM file format is ASCII, and consists of numerical fields of varying length, which are space delimited and arranged in columns and rows. Each column contains 180 numerical values and each row contains 360 numerical values.

SLURP computes LAI from FPAR using the variables BARKD and STEMSD obtained from the lookup table below:

vegetation parameters

IV	**LAIMAX**	**STEM**
1	7.0	0.08
2	7.0	0.08
3	7.5	0.08
4	8.0	0.08
5	8.0	0.08
6	5.0	0.20
7	5.0	0.20
8	5.0	0.20
9	5.0	0.20
10	5.0	0.20
11	5.0	0.20
12	6.0	0.20

The resulting LAI values for each land cover can be plotted for each month of the year as:

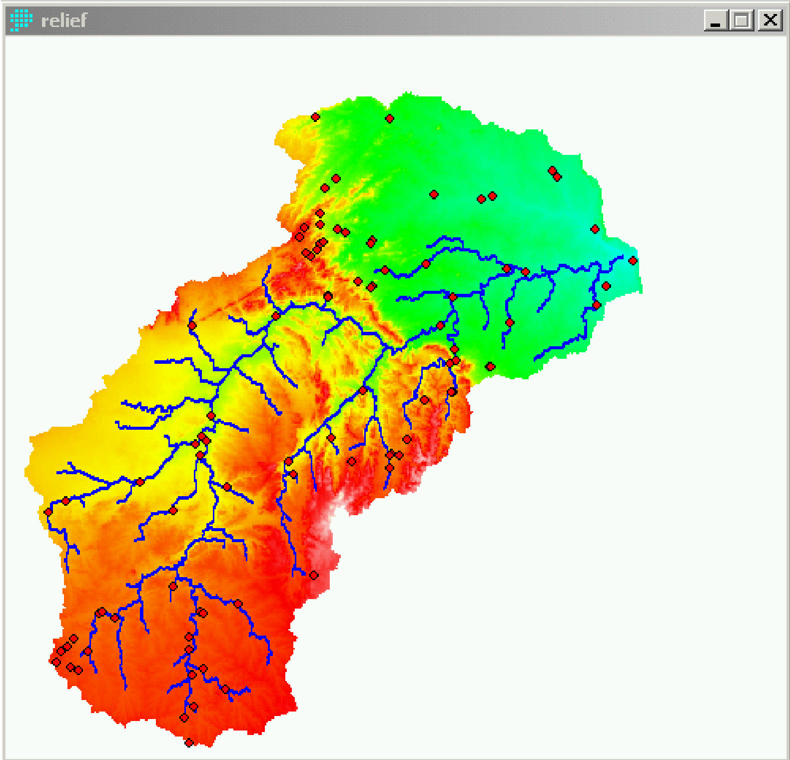


The following table (Table 2.6.1, ACRU) shows Leaf Area Index for various crops and may be used as a check on the values computed in SLURP from NDVI.

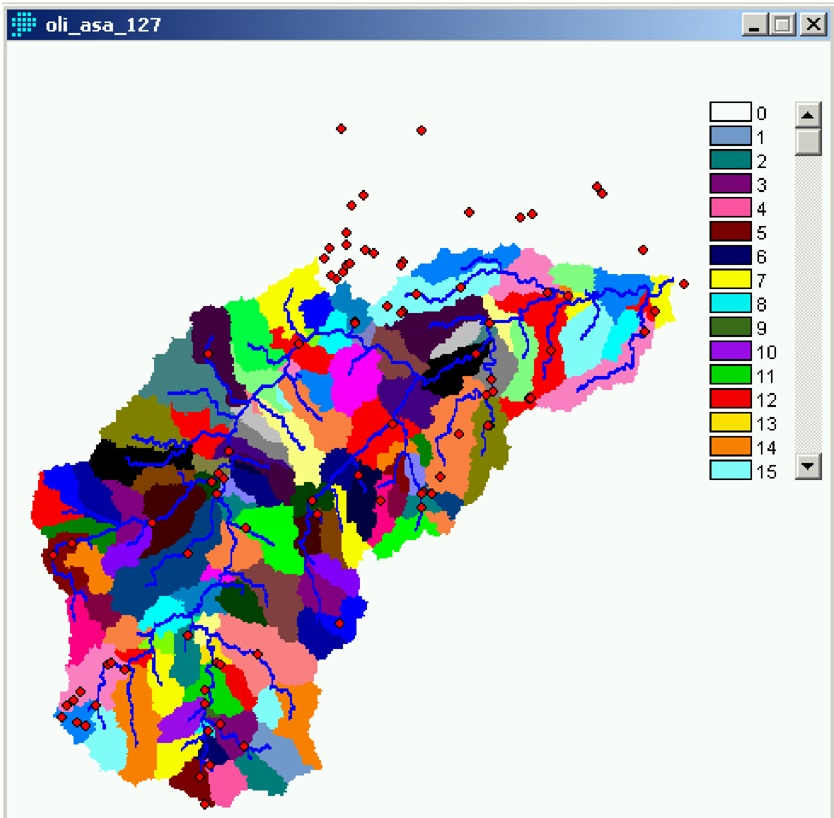
Land use Number	Description	J	F	M	A	M	J	J	A	S	O	N	D
2	Maize, growing season 140 days	3.50	5.10	1.8	0	0	0	0	0	0	0	0.20	0.70
4	Maize, growing season 120 days	3.00	5.25	2.50	0.10	0	0	0	0	0	0	0	0.25
6	Wheat, E. Transvaal, Pongola, growing season 110 days	0	0	0	0	0.35	1.70	2.90	4.80	0.15	0	0	0
7	Wheat, Transvaal, Middleveld, growing season 140 days	0	0	0	0	0	1.00	1.80	2.90	5.70	1.20	0	0
23	Cotton, marginal areas, growing season 160 days	1.89	2.91	2.96	2.10	0.46	0	0	0	0	0	0.12	0.44
38	Poplar plantation	4.00	4.00	4.00	4.00	3.50	3.00	3.00	3.00	3.00	3.50	4.00	4.00

4.3 Streamflow Data

The file of streamflow gauging stations OLIWEIRDD.XLS was exported from the spreadsheet to a .INP file, converted to a .VXP file using \Tools\Convert .INP to .VXP on the SLURP menu and imported to IDRISI as a vector file. In IDRISI, the weir data were converted to UTM zone 36S projection and displayed on the digital elevation model and river network.



Next the streamflow stations were displayed in IDRISI on top of the sub-basin image and stations were selected close to the outlets of as many sub-basins as possible. Note that stations are also displayed for the Letaba which is outside the Olifants Basin. This process ended up with a list of 19 streamgauging stations to use to verify SLURP. The drainage areas above the gauging stations and for the closest SLURP sub-basin were compared and found to be in good agreement. Any differences in area will be taken into account when using the recorded streamflow to verify the model performance. The streamflow files were copied to the correct directories using batch files COPY_FLO_MAX.BAT and COPY_FLO_MIN.BAT



oli_asa_127
0
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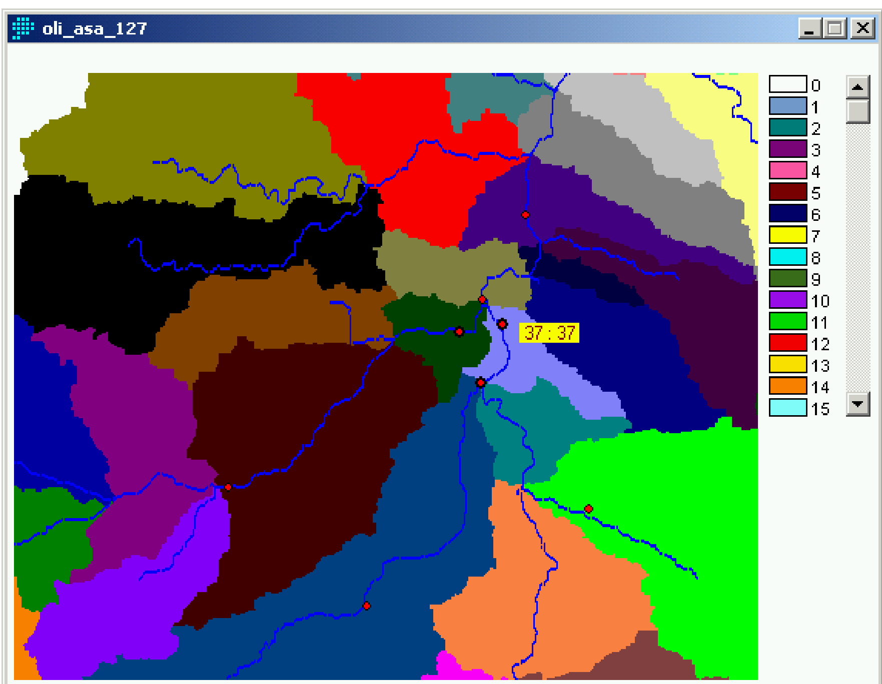

oli_asa_127
37 : 37
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ASA	IDRIS	GAUGE	AREA	FYEAR	FMNTH	FDAY	LYEAR	LMNTH	LDAY	RIVER	DESCR	LATITUDE	LONGITUDE
11	2	B1H001	3904	1904	8	16	1951	9	30	OLIFANTS RIVER	GAUGING WEIR	-25.8093	29.3197
3	12	B1H020	1330	1990	3	8	9999	99	99	KORINGSPRUIT	GAUGING WEIR	-26.1065	29.3308
8	13	B1H021	1356	1990	10	12	9999	99	99	STEENKOOLSPRUIT	GAUGING WEIR	-26.1368	29.2700
21	21	B2H007	317	1985	8	23	9999	99	99	KOFFIESPRUIT	GAUGING WEIR	-25.9954	28.6628
22	25	B2H014	1086	1990	11	7	9999	99	99	WILGE RIVER	GAUGING WEIR	-25.8273	28.8303
37	26	B3H001	16553	1966	9	1	9999	99	99	OLIFANTS RIVER	GAUGING WEIR	-24.9173	29.3842
50	29	B3H004	6133	1966	9	6	9999	99	99	ELANDS RIVER	GAUGING WEIR	-24.8853	29.3575
97	37	B4H003	2240	1955	10	1	9999	99	99	STEELPOORT RIVER	GAUGING WEIR	-25.0295	29.8567
82	38	B4H004	701	1960	9	5	9999	99	99	DORPS RIVER	DIVERSION WEIR	-25.0095	30.4450
100	42	B4H009	448	1966	9	5	9999	99	99	DWARS RIVER	GAUGING WEIR	-24.9131	30.1033
71	46	B5H002	31416	1948	9	1	1988	7	1	OLIFANTS RIVER	GAUGE PLATES	-24.2673	29.8008
106	50	B6H004	2241	1950	11	1	9999	99	99	BLYDE RIVER	GAUGING WEIR	-24.4592	30.8275
110	62	B7H007	46583	1955	6	23	9999	99	99	OLIFANTS RIVER	GAUGING WEIR	-24.1839	30.8222
114	63	B7H008	832	1956	4	24	9999	99	99	SELATI RIVER	STORAGE WEIR	-24.0098	30.6728
103	64	B7H009	42472	1960	9	1	9999	99	99	OLIFANTS RIVER	GAUGING WEIR	-24.3312	30.7408
76	68	B7H013	263	1970	8	11	9999	99	99	MOHLAPITSE RIVER	GAUGING WEIR	-24.1731	30.1031
117	70	B7H015	49826	1983	10	18	9999	99	99	OLIFANTS RIVER	GAUGING WEIR	-24.0595	31.2372
116	71	B7H019	2268	1961	9	7	9999	99	99	GA-SELATI RIVER	GAUGING WEIR	-24.0362	31.1289

Similarly, the procedure of determining appropriate streamflow stations was continued for the model which combined the detailed Steelpoort sub-basins with a simple 6 sub-basin system for the remainder of the Olifants Basin.

SLURP uses recorded streamflow data to verify the streamflows computed by the model. Because many of the streamflow stations are not located at the outlets of sub-basins, the recorded streamflows have to be adjusted to take into account the differences between the drainage areas upstream of the stations and those upstream of the sub-basins. This is accomplished in two stages:

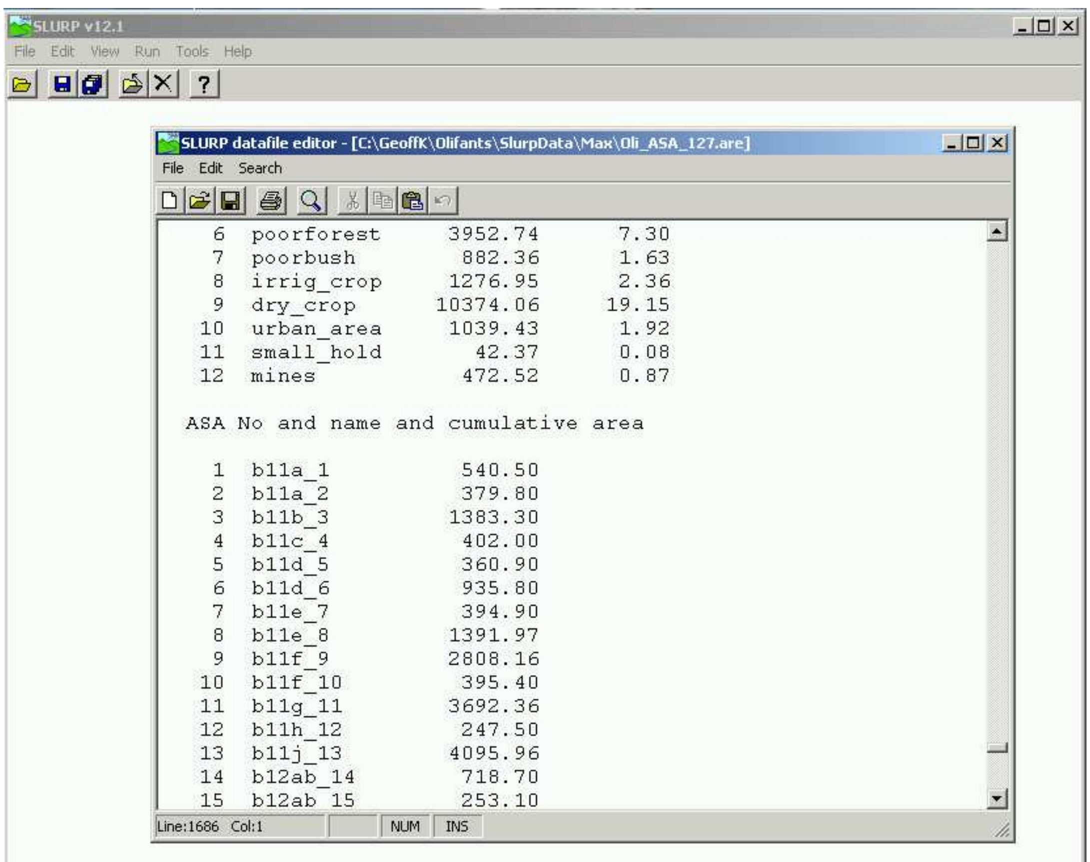
First, the SLURP option

\Tools\Compute basin areas

is run. This program reads the basin command file <basin_name.CMD> and produces an output file <basin_name.ARE> containing the cumulative areas for each sub-basin.

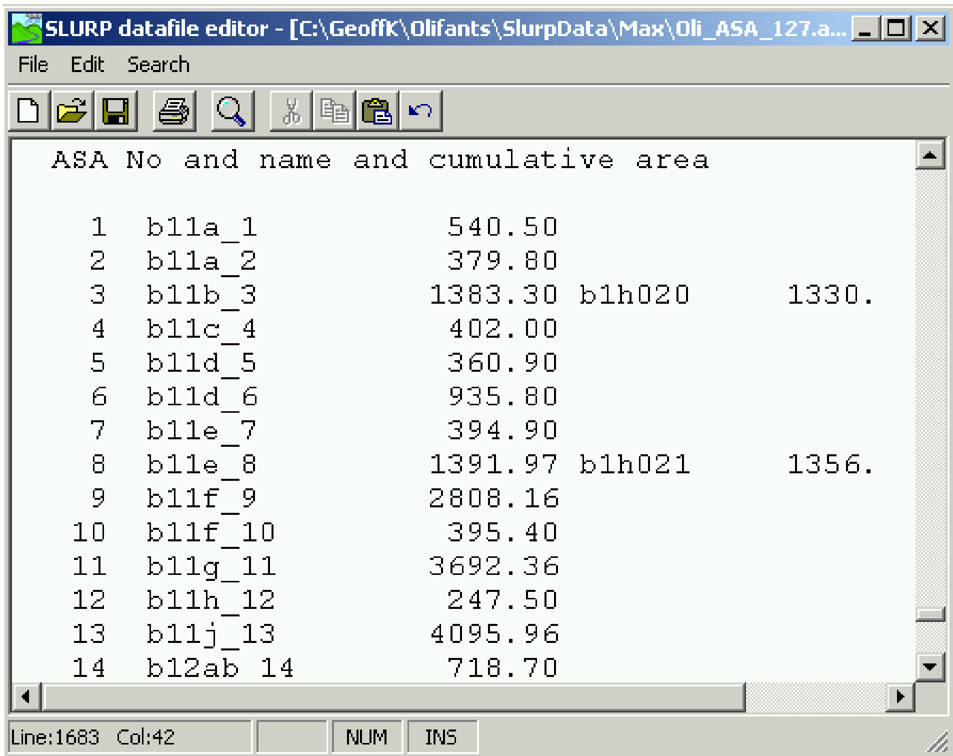
The user should then edit this file using option

\Edit\Data file



by finding the part of the file below the title "ASA No. and name and cumulative area" and adding station names and cumulative areas to the records corresponding to those sub-basins containing flow data. The figure below shows part of the original file OLI_ASA_127.ARE

Leave a space between the existing cumulative ASA area and the new station name and between the station name and the station area. The streamflow station name can contain up to 10 characters. If the name is less than 10 characters, add blanks to pad it out to 10. For example, the following table shows part of the modified OLI_ASA_127.ARE file.



The streamflow records were checked and the option

\Tools\Adjust flow data

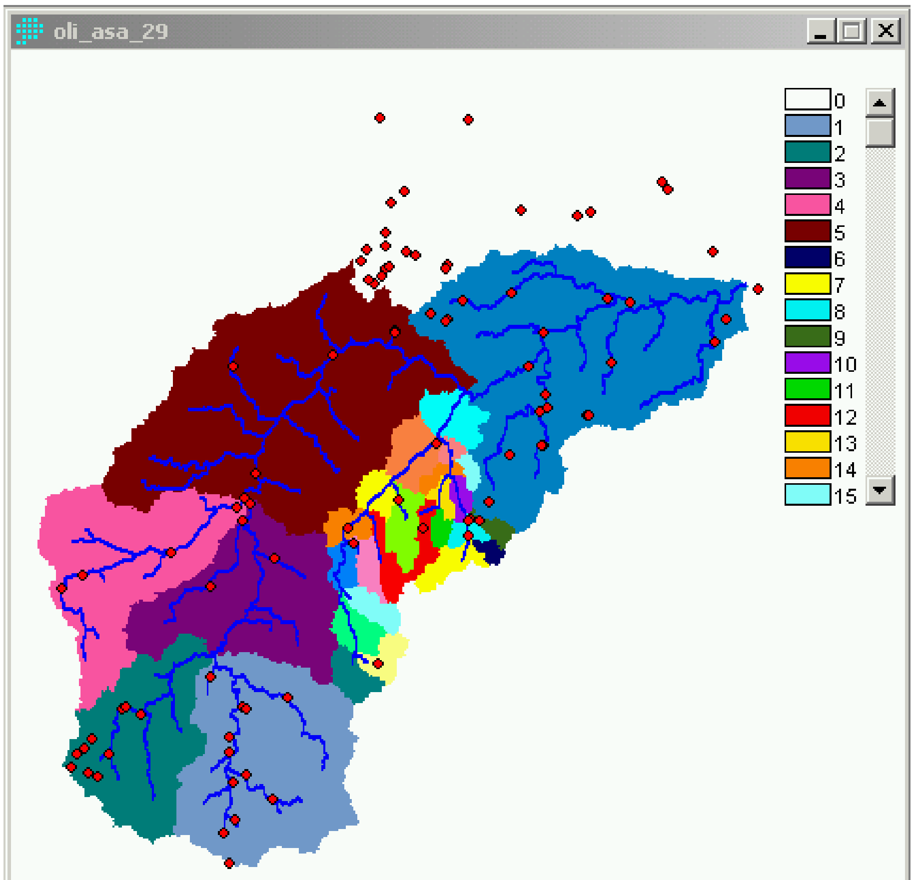
was used to convert the station flow files to sub-basin flow files. Missing flows were found and were filled in as follows:

Station	Sub-basin (in full basin and then in partial basin)	Period	Filled by
B3H001	b32j_37	10-17/12/1987	interpolation
	b32_3	7-21/4/1988	interpolation
		8/7/1988 – 1/9/1988	as missing data (-9999.99)
		12-17/11/1988	interpolation
		17-22/2/1989	interpolation
		10/2-5/3 1990	as missing data
		27/11-2/12 1990	interpolation
		17/12 1990 – 21/2 1991	as missing data
		10-18/9 1991	as missing data
		15/11-11/12 1991	as missing data
		25/10-6/11 1991	as missing data
B4H009	b41g_100	20-22/3/1987	interpolation
	b41g_26	4-6/3/1988	interpolation
B3H004	b31h_50	17-25/10/1985	interpolation
		30/6 – 2/7/1986	interpolation
B7H013	b71c_76	13-31/12/1985	interpolation
		14-19/3/1988	interpolation
		18/4 – 7/5/1988	interpolation
		16/10 – 24/12/1988	interpolation
		8/1/1989 – 19/2/1989	as missing data
B7H009	b71g-j_103	14/7/1985	interpolation
		24-29/12/1985	as missing data
B6H004	b60j_106	22/12/1984-6/1/1985	as missing data
		8-13/1/1986	as missing data
B7H007	b72d_110	5/10/1989-18/10/1990	as missing data
		5-8/11/1990	interpolation
B7H015	b60-73_29	22-26/4/1989	interpolation
		6-23/11/1989	as missing data
		29/11-4/12 1989	interpolation

Note that missing values still exist outside the 1988-1991 simulation period and these should be filled in at some stage.

4.4 Climate Data

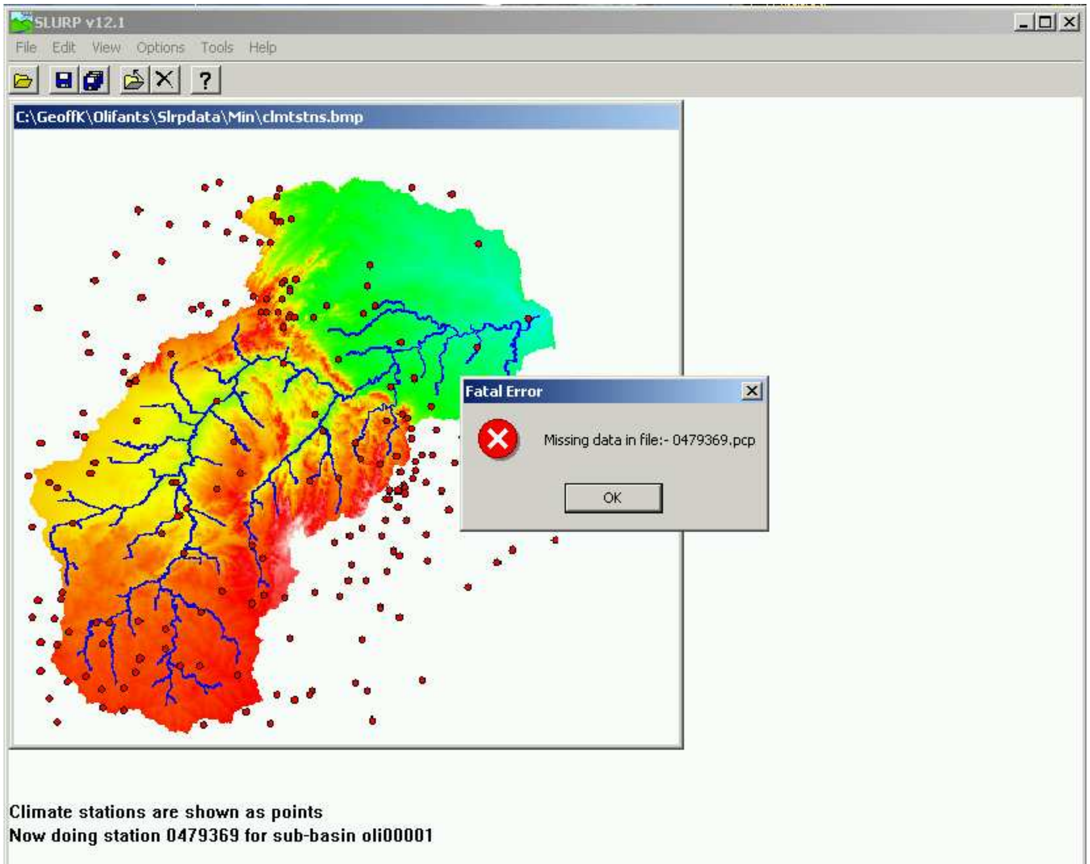
b) Normally, the weights files (.WTS) used by SLURP to compute sub-basin averages from station climate data would be prepared by SLURPAZ from a list of climate stations. In the case of the Olifants, however, CPH Water had already determined average temperatures for each WRC quaternary catchment and had assigned rainfall stations for each quaternary catchment. To make use of this information, climate stations were extracted from the spreadsheets STATIONS FOR ASA_127.XLS and OLIRAINSTADD.XLS to the ASCII files STATIONS1.PRN and STATIONS2.PRN. These files were then used by program MAKE_WTS.EXE to prepare the file OLI_ASA_127.WTS used in SLURP to convert the station climate data to sub-basin average data.



Similarly, climate stations were assigned to sub-basins and the program MAKE_WTS.EXE was used to prepare a .WTS file for the model which combined the detailed Steelpoort sub-basins with a simple 6 sub-basin system for the remainder of the Olifants Basin.

The program MISSING.EXE was used to replace the existing missing value indicators of –99.99, –55.55 and 9999.99 with the standard –9999.99 in all climate and hydrometric data files.

Option\Compute sub-basin data in the SLURP menu was used with the new .WTS files to convert the station point climate data to sub-basin averages. As can be seen from the figure below, some stations contain missing data.



To solve the problem of missing data, the following actions were taken:

i) The period of precipitation data was initially restricted to 1980-1995, the same as the temperature data and then, because many rainfall stations stopped taking measurements in 1991, the period was further restricted to 1980-1991.

The following precipitation stations still had too much missing data and were replaced by alternates:

Original station	**Replaced by**
0515412	0515079
0414408	0513836
0552247	0551853
0594457	0594444
0637503	0637609

ii) Some of the minimum temperature files (.TMN) had missing data. Where average and maximum temperature records existed for the dates when minimum temperatures were missing, the minimums were computed as:

TMN = 2 * TAV – TMX

using program MAKE_TMN.EXE.

To make use of the model easier, the SLURP sub-basin names were renamed to be the same as the WRC quaternary catchment names wherever possible. On some occasions two or more SLURP sub-basins occur within one quaternary catchment. In such cases they have been name, for example, B11A_1, B11A_2, etc where the number refers to the SLURP sub-basin number. On some occasions the SLURP sub-basins include more than one quaternary catchment. In such cases the SLURP sub-basin will be named, for example, B12A_B_16, etc where the number refers to the SLURP sub-basin number. In order to do this renaming, the existing temperature data files first had to be renamed from, for example, B11A.TAV to Q_B11A.TAV since SLURP does not allow climate stations to have the same names as sub-basins to reduce confusion. This was accomplished using program REN_FILES.EXE.

Then the sub-basin names in all the command files (OLI_ASA_127.CMD, OLI_ASA_29.CMD), the weights files (OLI_ASA_127.WTS, OLI_ASA_29.WTS), and the Morton evapotranspiration files (OLI_ASA_127.MOR, OLI_ASA_29.MOR) were changed to the new ones.

Finally, the SLURP option

\Tools\Compute sub-basin climate data

was used to calculate sub-basin average climate data from the station data for both command files.

The final tables of climate and hydrometric stations used for each sub-basin for the two models are given below:

Climate and hydrometric stations used for SLURP modelling of full olifants Basin

River	SLURP ASA numbers	SLURP ASA names	WRC Catchment	Precip stations	Temperature stations TAV,TMX,TMN	Streamflow station
Olifants	1	B11A_1	B11A	479369	b11a.tav	
	2	B11A_2	B11A	479369	b11a.tav	
Koringspruit	**3**	**B11B_3**	B11B	478546	B11B.tav	B1H020
	4	B11C_4	B11C	478292	B11C.tav	
Steenkoolspruit	5	B11D_5	B11D	478292	B11D.tav	
	6	B11D_6	B11D	478292	B11D.tav	
	7	B11E_7	B11E	478406	B11E.tav	
	8	**B11E_8**	B11E	478406	B11E.tav	B1H021
	9	B11F_9	B11F	478008	B11F.tav	
	10	B11F_10	B11F	478008	B11F.tav	
Olifants	**11**	**B11G_11**	B11G	478564	B11G.tav	B1H001
	12	B11H_12	B11H	515826	B11H.tav	
	13	B11J_13	B11J	51542	B11J.tav	
	18	B11K_18	B11K	515079	B11K.tav	
	17	B11L_17	B11L	515412	B11L.tav	
	19	B11L_19	B11L	515412	B11L.tav	
Kl. Olifants	14	B12AB_14	B12A	479552	B12A.tav	
	15	B12AB_15	B12A	479552	B12A.tav	
	see B12A		B12B	516201	B12B.tav	
	16	B12CDE_16	B12C	516201	B12C.tav	
	see B12C		B12D	515826	B12D.tav	
	see B12C		B12E	516190	B12E.tav	
Wilge	20	B20A_20	B20A	477309	B20A.tav	
Koffiespruit	**21**	**B20B_21**	B20B	477309	B20B.tav	B2H007
Wilge	**22**	**B20CD_22**	B20C	513836	B20C.tav	B2H014
	see B20C		B20D	514408	B20D.tav	
	23	B20EF_23	B20E	477762	B20E.tav	
	see B20E		B20F	514537	B20F.tav	
	25	B20G_25	B20G	515079	B20G.tav	
	24	B20H_24	B20H	514618	B20H.tav	
	26	B20H_26	B20H	514618	B20H.tav	
	27	B20H_27	B20H	514618	B20H.tav	
	28	B20J_28	B20J	515079	B20J.tav	
Elands	39	B31A_39	B31A	514010	B31A.tav	
	38	B31B_38	B31B	514010	B31B.tav	
	40	B31CD_40	B31C	550612	B31C.tav	
	41	B31CD_41	B31C	550612	B31C.tav	
	see B31C		B31D	551103	b31d.tav	
	42	B31E_42	B31E	590028	B31E.tav	
	43	B31E_43	B31E	590028	B31E.tav	

	44	B31E_44	B31E	590028	B31E.tav	
	45	B31E_45	B31E	590028	B31E.tav	
	46	B31F_46	B31F	590444	B31F.tav	
	47	B31G_47	B31G	551853	B31G.tav	
Elands	48	B31H_48	B31H	552247	B31H.tav	
	50	**B31H_50**	B31H	552247	B31H.tav	B3H004
	51	B31H_51	B31H	552247	B31H.tav	
	49	B31J_49	B31J	590500	B31J.tav	
	56	B31J_56	B31J	590500	B31J.tav	
	29	B32A_29	B32A	552654	B32A.tav	
	30	B32A_30	B32A	552654	B32A.tav	
	31	B32BC_31	B32B	516190	B32B.tav	
	32	B32BC_32	B32B	516190	B32B.tav	
	see B32B		B32C	516190	B32C.tav	
	33	B32D_33	B32D	552699	B32D.tav	
	34	B32EF_34	B32E	553651	B32E.tav	
	see B32E		B32F	553151	B32F.tav	
	36	B32GH_36	B32G	551853	B32G.tav	
	see B32G		B32H	552610	B32H.tav	
Olifants	35	B32J_35	B32J	552700	B32J.tav	
	37	**B32J_37**	B32J	552700	B32J.tav	B3H001
Steelpoort	91	B41A_91	B41A	516701	B41A.tav	
	92	B41A_92	B41A	516701	B41A.tav	
	93	B41B_93	B41B	553717	B41B.tav	
	94	B41B_94	B41B	553717	B41B.tav	
	96	B41C_96	B41C	553651	B41C.tav	
	95	B41D_95	B41D	553651	B41D.tav	
Steelpoort	**97**	B41E_97	B41E	592474	B41E.tav	B4H003
	98	B41F_98	B41F	593419	B41F.tav	
Dwars	**100**	B41G_100	B41G	593419	B41G.tav	B4H009
	99	B41H_99	B41H	593126	B41H.tav	
	101	B41J_101	B41J	593126	B41J.tav	
	102	B41K_102	B41K	593581	B41K.tav	
Spekboom	81	B42A_81	B42A	554682	B42A.tav	
	80	B42B_80	B42B	554786	B42B.tav	
Dorps	**82**	B42C_82	B42C	554786	B42C.tav	B4H004
	83	B42D_83	B42D	594444	B42D.tav	
	84	B42E_84	B42E	593778	B42E.tav	
	86	B42F_86	B42F	593419	B42F.tav	
	85	B42G_85	B42G	593419	B42G.tav	
	87	B42G_87	B42G	593419	B42G.tav	
	88	B42H_88	B42H	593581	B42H.tav	
	89	B42H_89	B42H	593581	B42H.tav	
	90	B42H_90	B42H	593581	B42H.tav	
	55	B51A_55	B51A	592474	B51A.tav	
	52	B51B_52	B51B	591627	B51B.tav	
	53	B51B_53	B51B	591627	B51B.tav	
	54	B51B_54	B51B	591627	B51B.tav	
	59	B51C_59	B51C	592371	B51B.tav	

	61	B51C_61	B51C	592371	B51B.tav
	63	B51C_63	B51C	592371	B51B.tav
	57	B51E_57	B51E	591125	B51E.tav
	58	B51E_58	B51E	591125	B51E.tav
	60	B51E_60	B51E	591125	B51E.tav
	65	B51E_65	B51E	591125	B51E.tav
	62	B51FG_62	B51F	634580	B51F.tav
	see B51F		B51G	634580	B51G.tav
	64	B51H_64	B51H	592371	B51H.tav
	67	B52A_67	B52A	635208	B52A.tav
	68	B52A_68	B52A	635208	B52A.tav
	66	B52B_66	B52B	592371	B52B.tav
	70	B52CDF_70	B52C	634580	B52C.tav
	see B52C		B52D	635208	B52D.tav
	see B52C		B52F	634580	B52F.tav
	69	B52E_69	B52E	592371	B52E.tav
	73	B52EF_73	B52E	592371	B52E.tav
Olifants	**71**	**B52G_71**	B52G	635208	B52G.tav B5H002
	72	B52HJ_72	B52H	678776	B52H.tav
	see B52H		B52J	636135	B52J.tav
Blyde	104	B60A_104	B60A	594444	B60A.tav
	see B60A		B60B	594590	B60B.tav
	see B60A		B60C	594764	B60C.tav
	see B60A		B60D	594457	B60D.tav
	105	B60E_105	B60E	594444	B60E.tav
	see B60E		B60F	594141	B60F.tav
	see B60E		B60G	594075	B60G.tav
	see B60E		B60H	594075	B60H.tav
Blyde	**106**	**B60J_106**	B60J	637801	B60J.tav B6H004
	74	B71A_74	B71A	678776	B71A.tav
	75	B71B_75	B71B	636135	B71B.tav
Mohlapitse	**76**	**B71C_76**	B71C	679268	B71C.tav B7H013
	77	B71D_77	B71D	636135	B71D.tav
	78	B71E_78	B71E	593126	B71E.tav
	79	B71F_79	B71F	636794	B71F.tav
Olifants	**103**	**B71G-J_103**	B71G	594457	B71G.tav B7H009
	see B71G		B71H	637503	B71H.tav
	see B71G		B71J	637503	B71J.tav
	109	B72AB_109	B72A	636794	B72A.tav
	see B72A		B72B	637609	B72B.tav
	107	B72C_107	B72C	637609	B72C.tav
	108	B72C_108	B72C	637609	B72C.tav
Olifants	**110**	**B72D_110**	B72D	637609	B72D.tav B7H007
	111	B72D_111	B72D	637609	B72D.tav
	112	B72D_112	B72D	637609	B72D.tav
	113	B72D_113	B72D	637609	B72D.tav
Selati	**114**	**B72E-H_114**	B72E	679508	B72E.tav B7H008
	see B72E		B72F	636518	B72F.tav
	see B72E		B72G	679508	B72G.tav

	see B72E		B72H	680354	B72H.tav
	115	B72J_115	B72J	680354	B72J.tav
Selati	**116**	**B72K_116**	B72K	680354	B72K.tav B7H019
Olifants	118	B73AB_118	B73A	594696	B73A.tav
	see B73A		B73B	637609	B73B.tav
Olifants	**117**	**B73C_117**	B73C	637609	B73C.tav B7H015
	119	B73C_119	B73C	637609	B73C.tav B7H015
	120	B73C_120	B73C	637609	B73C.tav B7H015
	121	B73C_121	B73C	637609	B73C.tav B7H015
	122	B73D_122	B73D	637609	B73D.tav
	124	B73EF_124	B73E	595091	B73E.tav
	see B73E		B73F	638748	B73F.tav
	125	B73G_125	B73G	682141	B73G.tav
	123	B73H_123	B73H	682141	B73H.tav
	126	B73H_126	B73H	682141	B73H.tav
	127	B73J_127	B73J	682141	B73J.tav

Climate and hydrometric stations used for
SLURP modelling of simple Olifants with full Steelpoorts Basin

River	SLURP ASAs Numbers	SLURP ASA Names	WRC Catchment	Precip stations	Temperature stations TAV,TMX,TMN	Streamflow station
Olifants	1	B11-12_1	B11A	479369	b11a.tav	
			B11B	478546	B11B.tav	
			B11C	478292	B11C.tav	
			B11D	478292	B11D.tav	
			B11E	478406	B11E.tav	
			B11F	478008	B11F.tav	
			B11G	478564	B11G.tav	
			B11H	515826	B11H.tav	
			B11J	515412	B11J.tav	
			B11K	515079	B11K.tav	
			B11L	515412	B11L.tav	
			B12A	479552	B12A.tav	
			B12B	516201	B12B.tav	
			B12C	516201	B12C.tav	
			B12D	515826	B12D.tav	
			B12E	516190	B12E.tav	
Wilge	2	B20_2	B20A	477309	B20A.tav	
			B20B	477309	B20B.tav	
			B20C	513836	B20C.tav	
			B20D	514408	B20D.tav	
			B20E	477762	B20E.tav	
			B20F	514537	B20F.tav	
			B20G	515079	B20G.tav	
			B20H	514618	B20H.tav	
			B20J	515079	B20J.tav	
Elands	**4**	**B31_4**	B31A	514010	B31A.tav	B3H021
			B31B	514010	B31B.tav	
			B31C	550612	B31C.tav	
			B31D	551103	b31d.tav	
			B31E	590028	B31E.tav	
			B31F	590444	B31F.tav	
			B31G	551853	B31G.tav	
			B31H	552247	B31H.tav	
			B31H	552247	B31H.tav	
			B31J	590500	B31J.tav	
Loskop area	**3**	**B32_3**	B32A	552654	B32A.tav	B3H001
			B32B	516190	B32B.tav	
			B32C	516190	B32C.tav	
			B32D	552699	B32D.tav	
			B32E	553651	B32E.tav	

			B32F	553151	B32F.tav
			B32G	551853	B32G.tav
			B32H	552610	B32H.tav
			B32J	552700	B32J.tav
Steelpoort	17	B41A_17	B41A	516701	B41A.tav
	18	B41A_18	B41A	516701	B41A.tav
	19	B41B_19	B41B	553717	B41B.tav
	20	B41B_20	B41B	553717	B41B.tav
	22	B41C_22	B41C	553651	B41C.tav
	21	B41D_21	B41D	553651	B41D.tav
Steelpoort	**23**	**B41E_23**	B41E	592474	B41E.tav B4H003
	24	B41F_24	B41F	593419	B41F.tav
Dwars	**26**	**B41G_26**	B41G	593419	B41G.tav B4H009
	25	B41H_25	B41H	593126	B41H.tav
	27	B41J_27	B41J	593126	B41J.tav
	28	B41K_28	B41K	593581	B41K.tav
Spekboom	7	B42A_7	B42A	554682	B42A.tav
	6	B42B_6	B42B	554786	B42B.tav
Dorps	**8**	**B42C_8**	B42C	554786	B42C.tav B4H004
	9	B42D_9	B42D	594444	B42D.tav
	10	B42E_10	B42E	593778	B42E.tav
	12	B42F_12	B42F	593419	B42F.tav
	11	B42G_11	B42G	593419	B42G.tav
	13	B42G_13	B42G	593419	B42G.tav
	14	B42H_14	B42H	593581	B42H.tav
	15	B42H_15	B42H	593581	B42H.tav
	16	B42H_16	B42H	593581	B42H.tav
N of Olifants	**5**	**B51-52_5**	B51A	592474	B51A.tav B5H002
			B51B	591627	B51B.tav
			B51C	592371	B51B.tav
			B51E	591125	B51E.tav
			B51F	634580	B51F.tav
			B51G	634580	B51G.tav
			B51H	592371	B51H.tav
			B52A	635208	B52A.tav
			B52B	592371	B52B.tav
			B52C	634580	B52C.tav
			B52D	635208	B52D.tav
			B52E	592371	B52E.tav
			B52F	634580	B52F.tav
			B52G	635208	B52G.tav
			B52H	678776	B52H.tav
			B52J	636135	B52J.tav
East	**29**	**B60-73_29**	B60A	594444	B60A.tav B7H015
			B60B	594590	B60B.tav
			B60C	594764	B60C.tav
			B60D	594457	B60D.tav
			B60E	594444	B60E.tav
			B60F	594141	B60F.tav

B60G	594075	B60G.tav
B60H	594075	B60H.tav
B60J	637801	B60J.tav
B71A	678776	B71A.tav
B71B	636135	B71B.tav
B71C	679268	B71C.tav
B71D	636135	B71D.tav
B71E	593126	B71E.tav
B71F	636794	B71F.tav
B71G	594457	B71G.tav
B71H	637503	B71H.tav
B71J	637503	B71J.tav
B72A	636794	B72A.tav
B72B	637609	B72B.tav
B72C	637609	B72C.tav
B72D	637609	B72D.tav
B72E	679508	B72E.tav
B72F	636518	B72F.tav
B72G	679508	B72G.tav
B72H	680354	B72H.tav
B72J	680354	B72J.tav
B72K	680354	B72K.tav
B73A	594696	B73A.tav
B73B	637609	B73B.tav
B73C	637609	B73C.tav
B73D	637609	B73D.tav
B73E	595091	B73E.tav
B73F	638748	B73F.tav
B73G	682141	B73G.tav
B73H	682141	B73H.tav
B73J	682141	B73J.tav

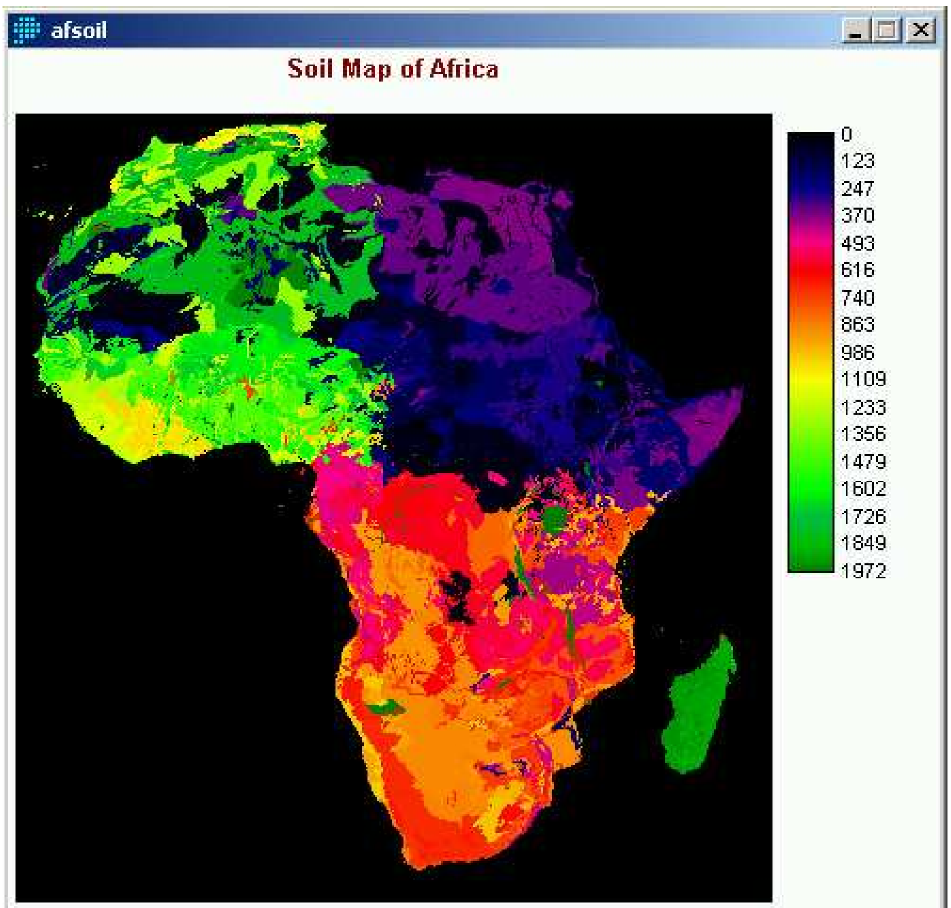
4.5 Soils data

The soils field capacity and wilting point were computed from soil characteristics extracted from the FAO Soils Map of the World.

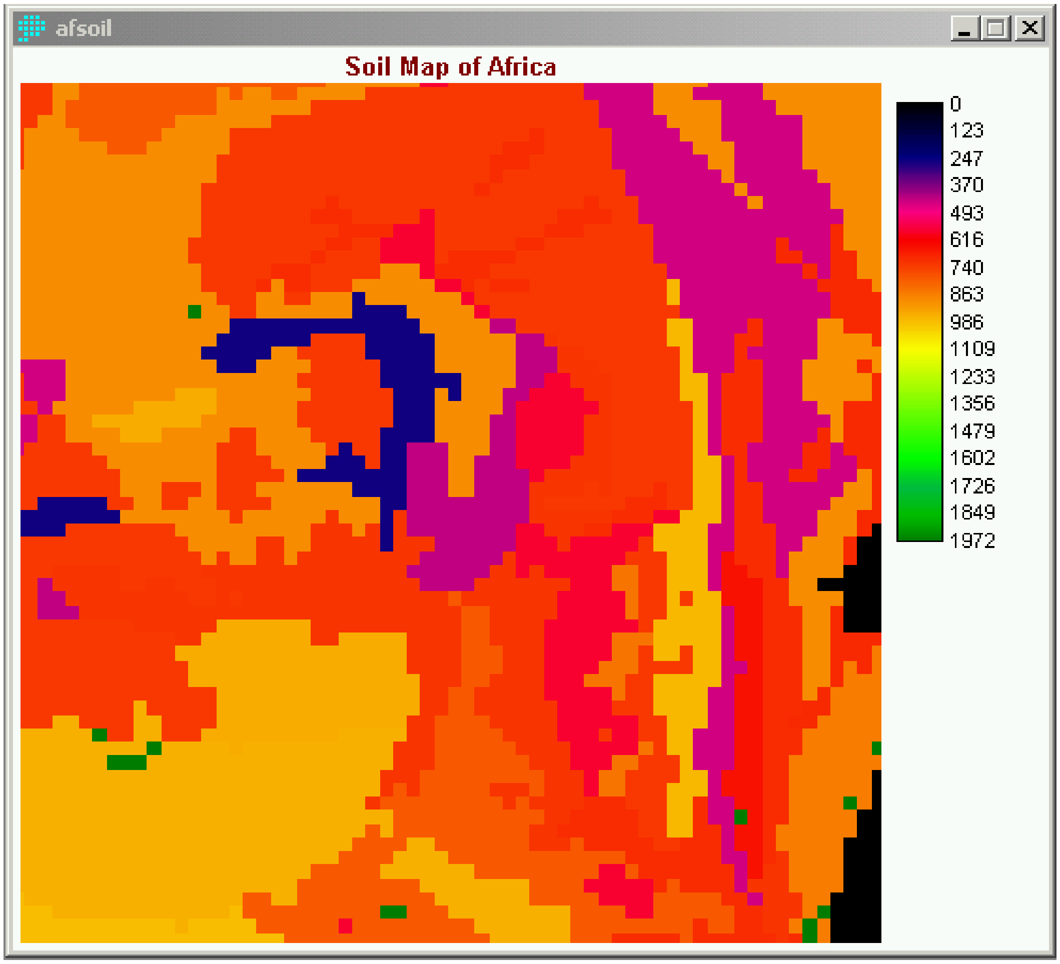
1. Copy the IDRISI 2 .IMG and .DOC image files for the appropriate area from the IDRISI directory on the FAO CD-ROM. There are two errors that need to be fixed in the .RDC files. In a text editor, change the reference system from "lat/long" to "latlong" and change the unit distance from "0.08333" to "1.0". Convert the IDRISI 2 files to the corresponding .RST and .RDC files using:

   \Files\IDRISI Conversion Tools

   in IDRISI 32.



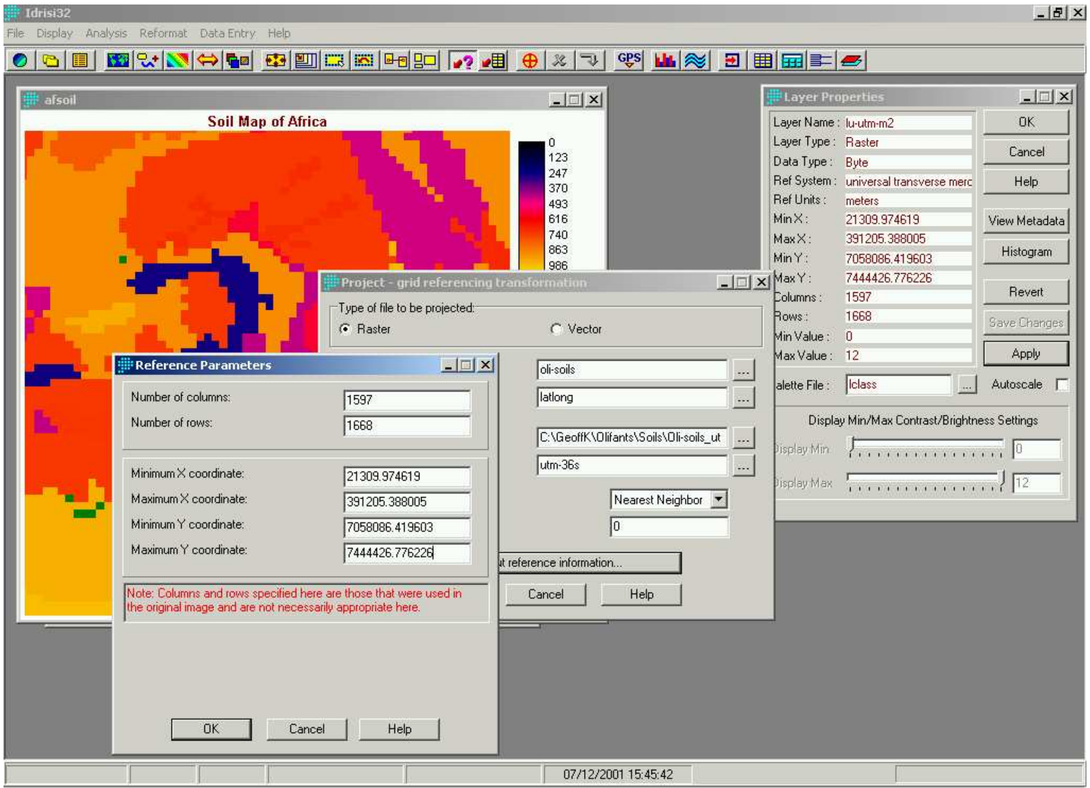
2. Extract a window that contains the river basin area and which is larger all round than the DEM of the river basin. Use the "Zoom Window" icon (a dotted rectangle) on the tool bar. For the Olifants a window of roughly lat. –23 to –27 and long. 28 to 32 was extracted. Save this as a new image using Composer\Save Composition.

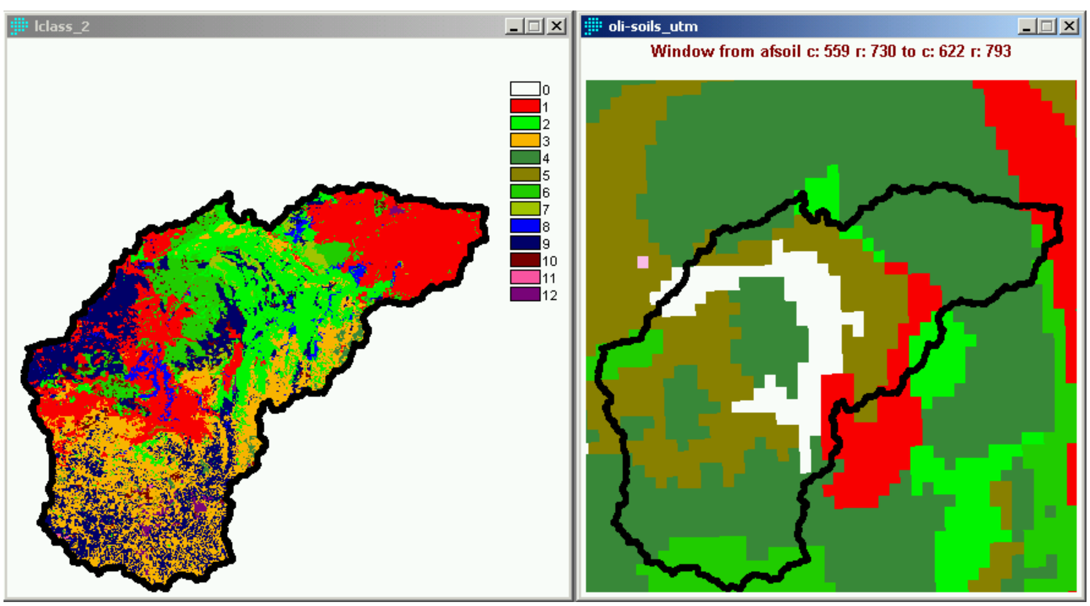


3. The windowed image must now be made to correspond to the land cover image first by converting from the lat/long projection to the UTM-35S projection and second by making the image the same number of rows and columns. Use:

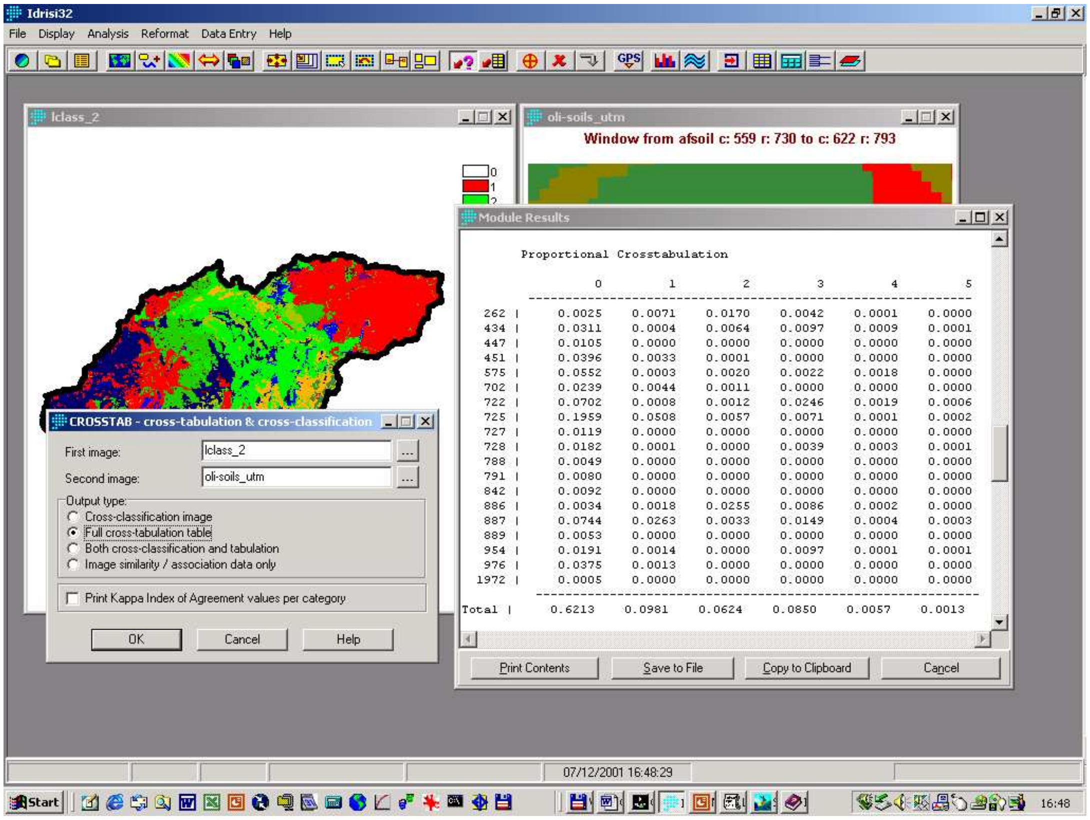
   \Reformat\PROJECT

When the Input file is specified as the windowed image, the Input reference file should appear automatically as "latlong". Specify an Output file name and an output file specification as "UTM-36S". On the next screen, complete the reference parameters using the data from the land use image.





Next, the dominant FAO soil numbers corresponding to each land use class can be extracted using \Analysis\CROSSTAB:



For each soil number, the percentages of each FAO mapunit is given in the cross-tabulation. For simplicity, only the dominant mapunit was selected. The FAO file AfLngX93.dat was then imported into a spreadsheet and the cumulative clay, silt and sand percentages were computed as:

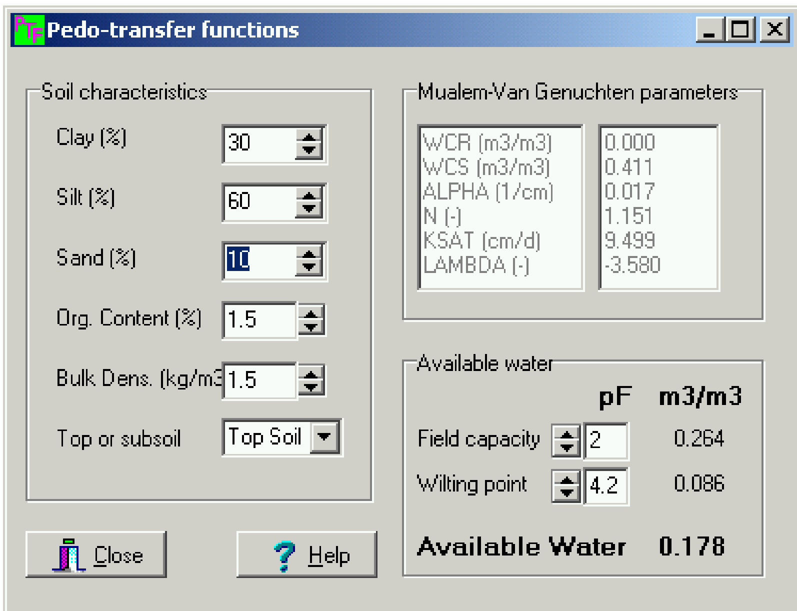
=SUM(J1+M1+P1+V1+Y1+AB1+AH1+AK1+AN1+AT1+AW1+AZ1+BF1+BI1+BL1+BR1+BU1+BX1);
=SUM(K1+N1+Q1+W1+Z1+AC1+AI1+AL1+AO1+AU1+AX1+BA1+BG1+BJ1+BM1+BS1+BV1+BY1)
=SUM(J1+M1+P1+V1+Y1+AB1+AH1+AK1+AN1+AT1+AW1+AZ1+BF1+BI1+BL1+BR1+BU1+BX1)

The results are as follows:

Land class	FAO mapunit	Soil name	%clay	%silt	%sand
1	725	Lc65-1/2ab	30	60	10
2	886	Qc42-1a	65	25	10
3	722	Lc64-b	20	75	10
4	722				
5	722				
6	725				
7	725				
8	887	Qc42-1a	65	25	10
9	722				

10	725				
11	722				
12	722				

Finally, the percentages of soil components can be converted to field capacity, wilting point and porosity (WCS; water content saturated) using pedotransfer functions built in to SLURP in \Tools\Compute soil properties:

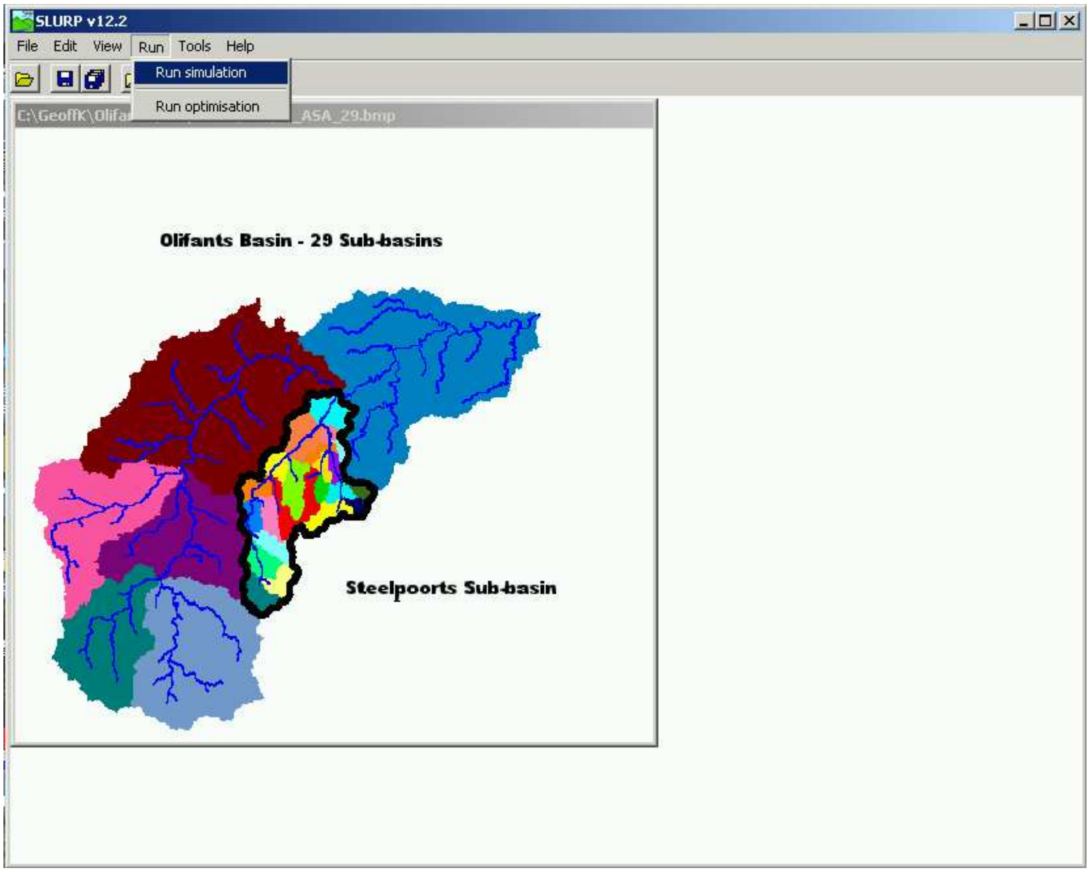


and added to the command files (.CMD). If the soil depths are known, then the parameters p6 and p8, the maximum capacities of the fast and slow store respectively may be computed as:

parameter = soil depth * porosity

4.6 Calibrating the model

At this stage the model was ready to simulate the natural hydrological cycle for the Olifants Basin.



Normally, most of the parameters of the SLURP model are derived from commonly available data and little calibration is required. To demonstrate the process two optimisation techniques were tried. First, the built-in SCE-UA optimisation technique was used. This lowered the standard error from 330 to 110 but resulted in parameters that were hydrologically unacceptable. Next the external PEST 2000 (Watermark Numerical Computing, 2000) independent optimizing technique was used by preparing input files with SLURP option

\Tools\Write PEST control files

No improvement in the hydrograph was made. The problem with purely statistical techniques is that they may reduce standard errors but, at the same time, may make the model less acceptable hydrologically. The simplest solution for an optimisation technique to modelling a sine curve is a straight line at y=0.

A series of model runs were made, changing the parameters manually between each run until a closer hydrograph and better optimization criteria were obtained.

Initial manual calibration runs concentrated on getting the overall basin water balance correct for the three-year period 1/7/88 – 30/6/91 using the last page of the .PRN output file as a guide:

```
                    Slurp basin model
           Date: 09/12/2001   Time: 15:15:12
           ---------------------------------

       Water balance over the entire basin, mm
               Jul 1988 to Jul 1991
--------------------------------------------------------
Average basin precipitation                    1.910E+03
Average basin evapotranspiration demand        6.373E+03
Average computed evaporation                   3.945E+02
Average computed transpiration                 1.543E+03
Basin export/consumption from river            0.000E+00
Basin export/consumption from groundwater      0.000E+00
Import from outside the basin                  0.000E+00
Computed runoff at basin outlet                1.159E+02
Computed runoff still in transit               1.001E-01
Average change in basin canopy store           0.000E+00
Average change in basin snow store             0.000E+00
Average change in basin fast store             4.241E+01
Average change in basin slow store            -1.852E+02
Total of changes in reservoir storage          0.000E+00
Total of diff. in res. in and outflows         0.000E+00
Total of changes in channel storage            1.031E-03
Total irrigation taken from rivers             0.000E+00
Total irrigation taken from groundwater        0.000E+00
Total irrigation return flows to river         0.000E+00
Water balance residual                         7.859E-04
--------------------------------------------------------
```

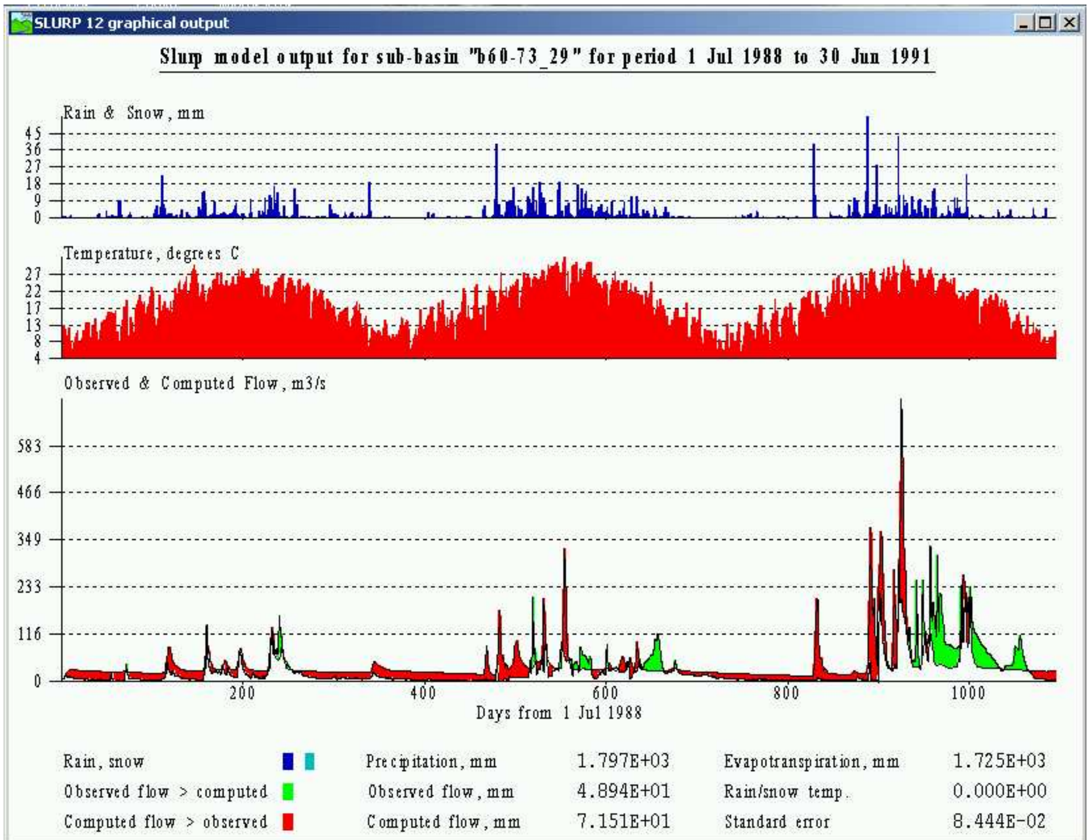
This printout from the first model run shows that computed runoff is being created at the expense of the groundwater (slow store). While this could be correct over such a short period, in this case the infiltration rate and the retention constant for the slow store were increased to correct this. Initially, parameter values are kept the same for all land covers; they will be differentiated later in the procedure.

The following table summarizes the changes made to the parameters and the effects on the water balance (in mm) over the entire basin for the 3 years. The last column in the table is the Nash/Sutcliffe goodness of fit criterion, one of several computed in the model. This criterion varies from $-\infty$ to +1, the latter indicating a perfect fit.

Change	**Precip.**	**PET**	**ET**	**Qobs**	**Qcal**	**N/S**
initial run	1910	7886	1938	49	116	-0.6
changed max cap for fast store to 200mm			1752		94	-2.8
changed slow store retention constant to 1000 and max cap for slow store to 1000			1769		153	-2.4
changed fast store retention constant to 200 and max cap for fast store to 300			1849		69	0.2

The SLURP hydrograph for the final sub-basin (below) shows that there is too much outflow. At this stage, there are two possibilities:

a) Perhaps the precipitation data are not representative. It is evident from the SLURP output that there are problems with the precipitation data. For example, just after day 800 (10 Oct 1990) there is a large rainfall and a corresponding high computed outflow (204m^3/s). However, there is no corresponding peak in the observed flow record (10.26 m^3/s). A look at the recorded rainfall time series using option:



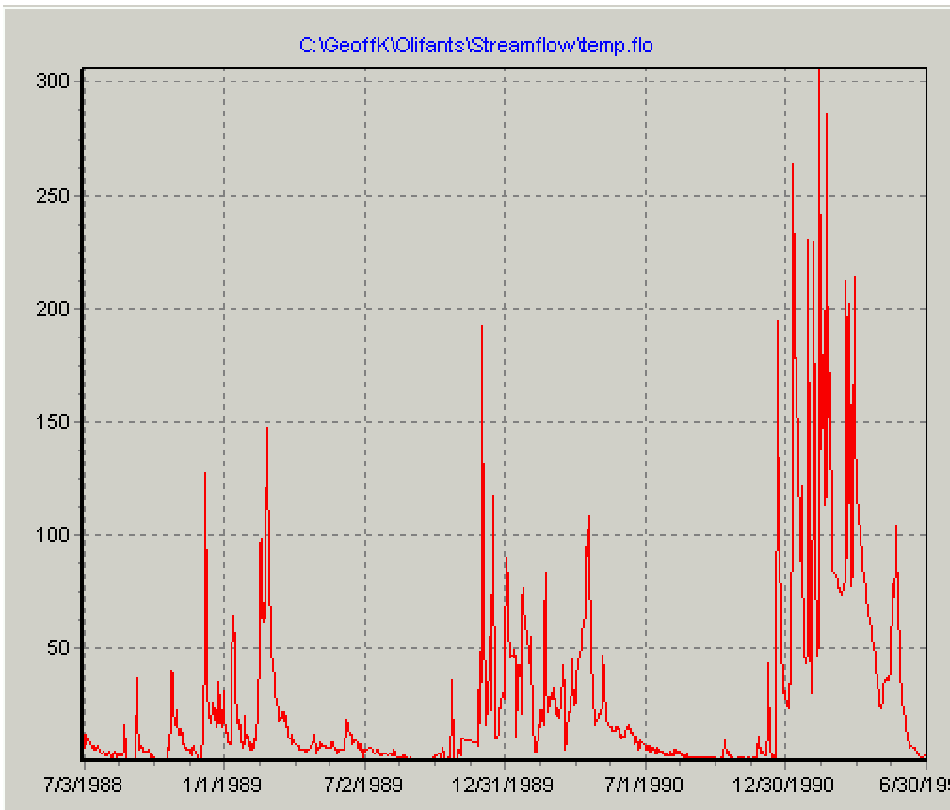
\Tool\Time series statistics

also shows that none of the rainfall stations have the high values needed to cause the peak flow recorded on 22 May 1991 and that only three raingauges out of the 37 used in sub-basins B60-B73 have high values on 18 April 1990 when there is also a high recorded flow.

It would be possible to remove the anomalously high rainfall stations from the .WTS file and to recompute the sub-basin average rainfall time series using different weights. To get a quick idea of whether this would be worthwhile, parameter 9 was adjusted from 1.0 to 0.88 to give the correct average streamflow. This parameter is normally used only to correct for known under- or over-catch but in this case it is used to save time.

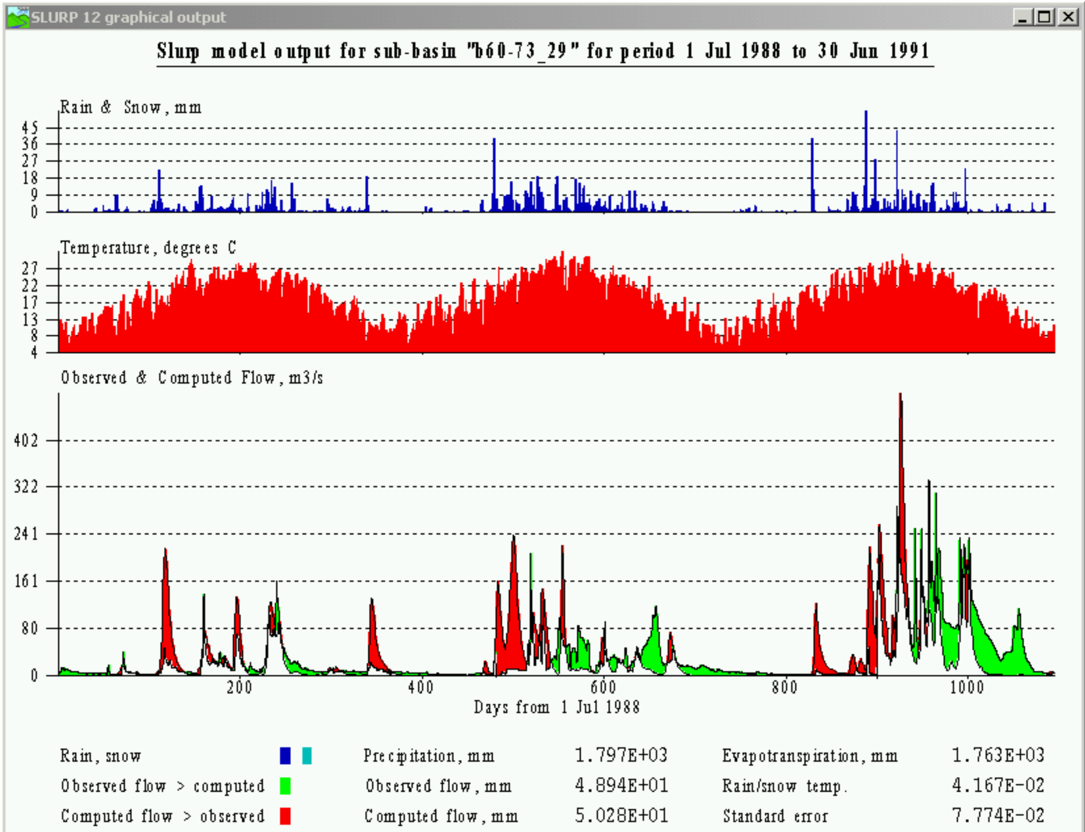
Change	Precip.	PET	ET	Qobs	Qcal	N/S
after adjusting rainfall	1670	7886	1614	49	50	.22
optimize p5 and reset precip	1910		1857		53	.20

b) The recorded hydrograph for the period being simulated, 1/7/1988 to 30/6/1991 is shown below. For a basin of approximately 55,000 km^2 this is a very flashy hydrograph often rising from low flows to $200m^3/s$ in one or two days and showing no evidence of baseflow. Possibly the baseflow is underground if the river bed is sandy and perhaps the streamflow station is only recording the rapid response of the catchments.



It is better to keep simulated flows a little higher than observed and a little peakier because the dams and reservoirs, when included, will tend to flatten the hydrograph and increase evapotranspiration.

The figure below shows the result for the Olifants River at gauging station B7H015 in WRC quaternary catchment B60A.



The model setup for the full Steelpoorts Basin and simple Olifants Basin simulates the southern catchments of the Olifants Basin first, then the Steelpoorts sub-basins and finally the downstream parts of the Olifants Basin. In many applications of the model, it is envisaged that only the Steelpoorts Basin would need to be simulated. In order to make this quicker the command file, the Morton evapotranspiration file (.mor), the Linacre evapotranspiration file (.lin) and the data files were reordered so that the Steelpoorts Basin was simulated first.

The previous organization of files is in directory \SLURPDATA\OLI_29_OLD and the new organization is in directory \SLURPDATA\OLI_29.

4.7 Including structures

The next step in the model application was to include those structures within the Steelpoorts Basin for which data are available. In order to include the effects of dams and reservoirs, SLURP needs information on the area and volume of the reservoir, the initial level of the reservoir and the rules used to operate the dam. Initial data on dam locations and reservoir sizes were obtained from Midgley, D.C., et al. (1994). The structures within the Steelpoorts Basin are as follows:

Sub-basin	Dam	River	Latitude	Longitude	Height	Capacity	Area
			Deg, min	Deg, min	m.	10**6 m**3	10**6 m**2
B41A	Vlakplaas	Klein Tr.	25 33	29 59	8	.076	.04
	Leeuwk		25 37	29 53	12	.180	.03
	Hadeco	Steelpoort	25 45	30 00	12	.373	.07
B41B	Cutwater	Witpoort	25 23	30 01	8	.170	.07
	Cornelius	Welgevonden	25 25	29 55	7	.060	.03
	Ons Eie	Steelpoort	25 25	30 05	10	.120	.04
Total					10	.350	.14
B41C	Vlugkraal	Vlugkraal	25 13	29 57	26	.455	.12
	Tonteldoos	Tonteldoos	25 16	29 56	16	.172	.05
Total					26	.627	.17
B41D	Mapoch	Mapoch	25 06	29 52	25	.512	.08
B41G	Der Brochen	Grt. Dwars	25 03	30 06	31	7.300	0.85
	De Kaffenskraal	Kaffenskraal	25 09	30 11	13	.450	.16
Total					31	7.750	1.10
B41H	Kalkfontein	Steelpoort	24 53	30 03	7	.200	.06
	Tweefontein	Dwars	24 53	30 06	7	.075	.02
Total					7	.275	.08
B41J	Olifantspoortjie	Sterkfontein	24 43	30 14	10	.067	.03
	Tubatse	Steelpoort	24 45	30 12	27	.210	.03
	Kennedys Vale	Dwars	24 50	30 06	43	28.000	1.52
Total					43	28.210	1.55
B42B	du Plessis	Sterk	25 08	30 31	27	1.100	.10
B42E	Klipfontein	Sterk	24 57	30 26	13	.120	.01
B42F	Buffelskloof	Watervals	24 57	30 16	39	5.384	.61

From these data, a figure can be prepared showing the dam locations by putting the longitudes and latitudes into file STRCTURS.INP using option:

\Edit\Data File

on the SLURP main menu. This file looks like (dam number, longitude, latitude and name):

1 29.98 -25.55 Vlakplaas
2 29.88 -25.62 Leeuwk
3 30.0 -25.75 Hadeco
4 30.02 -25.38 Cutwater
5 29.92 -25.42 Cornelius
6 30.08 -25.42 Ons Eie
7 29.95 -25.22 Vlugkraal
8 29.93 -25.27 Tonteldoos
9 29.87 -25.10 Mapoch
10 30.10 -25.05 Der Brochen
11 30.18 -25.15 De Kaffenskraal
12 30.05 -24.88 Kalkfontein
13 30.10 -24.88 Tweefontein
14 30.23 -24.72 Olifantspoortjie
15 30.20 -24.75 Tubatse
16 30.10 -24.83 Kennedys Vale
17 30.52 -25.13 du Plessis
18 30.43 -24.95 Klipfontein
19 30.27 -24.95 Buffelskloof

The .INP file is then converted to an IDRISI vector export file using option:

\Tools\Convert .INP to .VXP file.

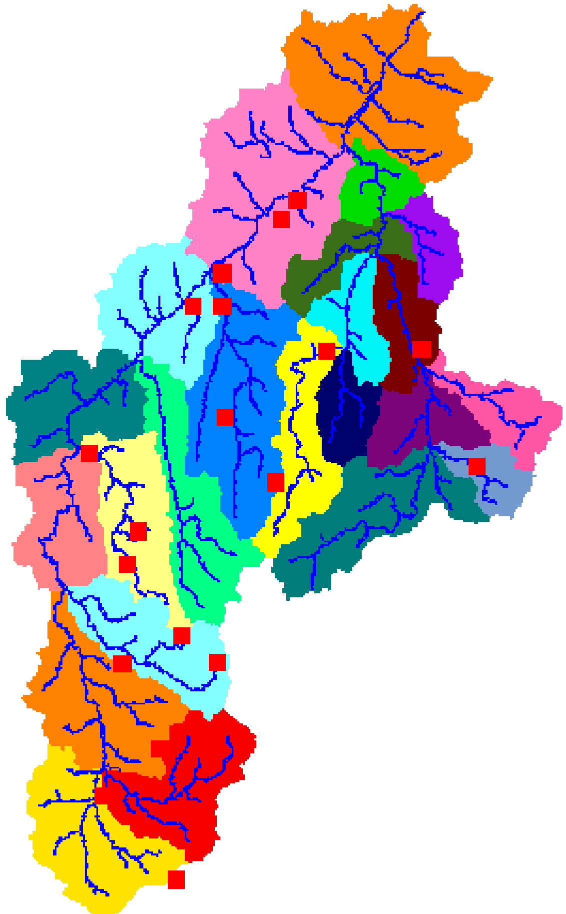
on the SLURP main menu. In IDRISI, import the vector export file using:

\Import\Software specific format\Vector Export Format

and convert the vector file from lat/long to UTM 36S projection using:

\Reformat\Project

Display the structures vector as an overlay on top of the sub-basin image.



Note that a few of the dams appear to be off the rivers; this is probably due to the fact that the latitudes or longitudes are inaccurate.

The level, capacity and area data can now be input to SLURP. For the Vlugskraal (B4R002), Tontelsdoof (B4R001), Mapoch (B4R003), and Buffelkloof (B4R004) Dams the DWAF has published level-area-volume tables. For each dam a number of points were extracted from the tables; for example, the following table shows the data extracted for the Buffelkloof Dam.

Buffelkloof Dam B4R004

Level	Area	Volume
m	10**6 m2	10**6 m3
0.2	0.022	0
1	0.029	0.019
2	0.039	0.053
3	0.05	0.098
4	0.06	0.152
5	0.071	0.217
6	0.088	0.296
7	0.11	0.395
8	0.131	0.515
9	0.152	0.656
10	0.173	0.818

11	0.193	1
12	0.22	1.205
13	0.248	1.438
14	0.276	1.7
15	0.31	1.992
16	0.347	2.32
17	0.384	2.685
18	0.423	3.089
19	0.461	3.531
20	0.502	4.012
21	0.547	4.535
22	0.59	5.104
22.38	0.60654	5.378

Program STADIS.EXE, contained in directory \Programs\Flow\Run_file on the SLURP CDROM, was then used to derive the following level-area and level-volume curves.

$$\text{Area } (10^6 \text{ m}^2) = 0.0142 \, (\text{Level (m.)} - 0.14)^{1.14}$$

$$\text{Volume } (10^6 \text{ m}^3) = 0.0247 \, (\text{Level (m.)} - 0.14)^{1.604}$$

For those dams with no level-area-volume curves (15 out of 19), straight lines between 0.0 and the maximum elevation given were assumed. For example, the curves derived for the Hadeco Dam are:

$$\text{Area } (10^6 \text{ m}^2) = 0.0058 * \text{Level (m.)}$$

$$\text{Volume } (10^6 \text{ m}^3) = 0.0311 * \text{Level (m.)}$$

In the absence of regulation plans for the reservoirs, it is assumed that reservoirs are operated to give outflow only when the reservoir is full.

In those sub-basins with more than one reservoir, the smaller reservoirs are subsumed into the largest reservoir and the area and capacity of the largest reservoir are increased accordingly.

The data for each dam are put into the file OLI_29.RUT. For example, the records for the Hadeco Dam appear as:

```
b41a_13 R 1   Hadeco
b41a_13  0.0058 0.0 1.0
b41a_13  0.0311 0.0 1.0
b41a_13  12.0 0.0
b41a_13  1992 1 1 2010 12 31 1000.
```

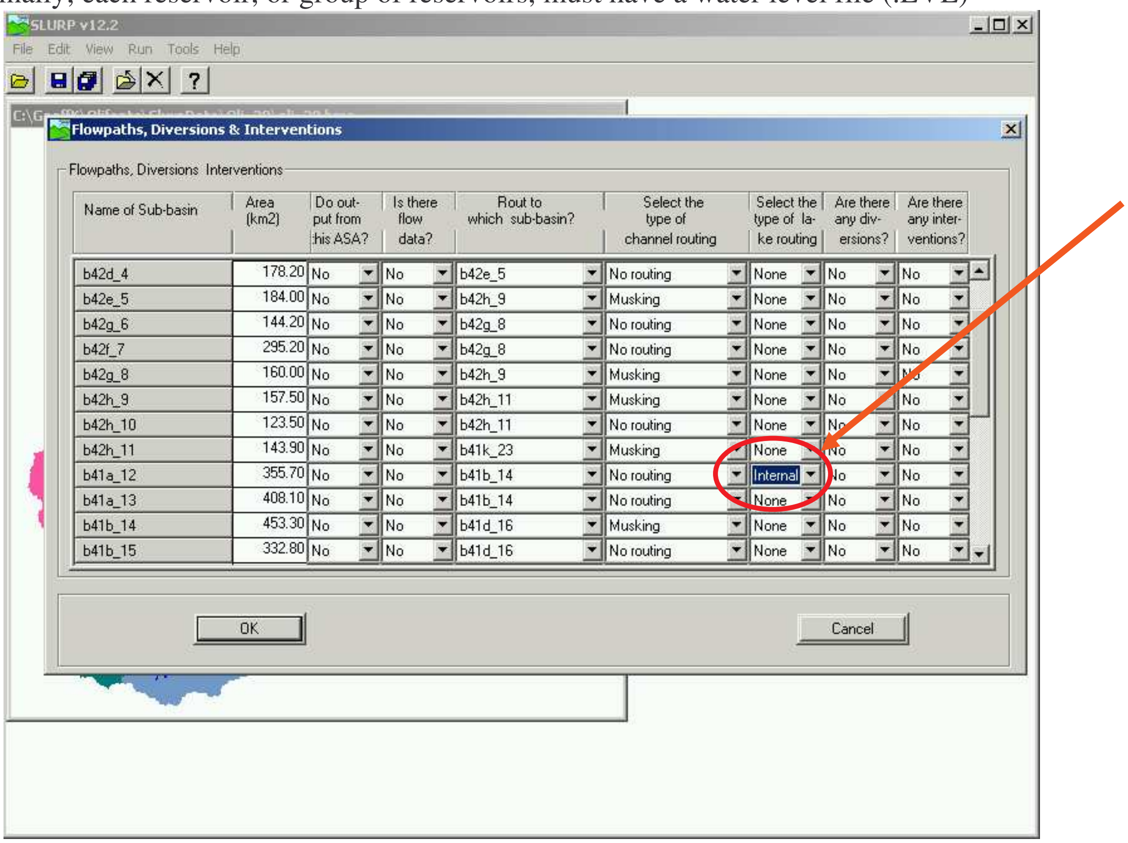
The first record gives the sub-basin in which the dam is located (as the WRC quadrant sub-catchment and the SLURP sub-basin number), the fact that it is regulated and the number of regulating rules. The next two records specify the parameters of the height-area and height-volume relationships. The third record specifies the minimum and maximum allowable levels of the reservoir. In the absence of specific operating rules, the final record specifies that the dam will flow maximum possible outflow from the data of construction onwards. Full details of the regulation simulation and the file formats are given in the SLURP manual.

It is then necessary to specify in the SLURP command file that regulation is to be carried out for each of these sub-basins. This is done by loading the OLI_29 command file into SLURP, using option

\Edit\Flow paths, diversions, interventions

and ensuring that the type of lake routing is set to “Internal” for the relevant sub-basins (see figure below).

Finally, each reservoir, or group of reservoirs, must have a water level file (.LVL)



specifying the daily level of the reservoir over the historic period. This is necessary so that SLURP has an initial level for each reservoir when starting a simulation. Normally, these would be recorded data but in this case these files all contain only the mid-level of the reservoir for the date set in OLI_29.CMD for the start of the simulation, 1 July 1988.

When more data are available, the .RUT and the .LVL files can all be easily changed.

5. CONCLUSIONS AND RECOMMENDATIONS

The Olifants River basin is important for water supply for the riparian peoples, for the South African economy, as an internationally-renowned wildlife refuge and as part of a major international river system with obligations to downstream states and has been identified by the International Water Management Institute (IWMI) as a reference basin for the long-term study of institutional and water resource management.

The SLURP hydrological model has been applied to the basin in two ways. First, the model has been applied in equal detail over the whole basin so that sub-basins correspond as closely as possible to the WRC quaternary catchments. This is not completely possible because not all the quaternary catchments are true hydrological sub-basins. This version of the model has 127 sub-basins and 12 land cover classes.

Second, the model has been applied in detail to the Steelpoort Basin and in less detail to the rest of the Olifants Basin. The idea here is that the Steelpoort Basin is self-contained and modeling studies do not need detailed analysis of the rest of the basin. This version of the model has 29 sub-basins and the same 12 land cover classes.

In their present form, the two models can simulate the natural water resources of the Olifants Basin and the assumed performance of 19 reservoirs in the Steelpoorts Basin. The distribution of water across the basin can be investigated and alternative climate or water supply scenarios can be studied.

The Steelpoorts Basin reservoirs have been included in the model with assumed operating rules and assumed initial water levels. The actual rules and levels should be obtained and then substituted for the existing data in files OLI_29.RUT and in the .LVL files for each sub-basin

The SLURP model has been applied for the years 1988-1991 because of problems with missing data in climatic and hydrometric records outside that period. The missing data may be filled in if it is required to simulate more years than is presently possible.

Some of the rainfall data appear suspect. For example, station 0553651 shows 163mm of rainfall recorded on 2nd January 1990. This produces a peak flow of 440 m^3/s in the model and yet the recorded streamflow shows no peak at all. Either the rainfall is inaccurate or else this station is not representative.

The parameters for the model application to the full Olifants Basin have not been adjusted or optimized at all. These may need modifying as more data become available.

It was noted that the land classification data do not seem to follow the normally-encountered pattern in which land classes roughly correspond to elevation zones within sub-basins. This may be quite correct for South Africa but might be worth investigating further.

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