River long profiles aid in ecological planning

by Juanita Moolman, Department Water Affairs and Forestry

The sustainable use of South Africa’s water resources is essential to ensure an adequate supply for future generations. Sustainability requires recognition of the importance of the protection of aquatic ecosystems (South African Water Act, No. 36 of 1998). Complex spatial information products, such as river longitudinal channel slope, provide important support for aquatic ecosystem assessments.

Understanding the longitudinal variation of physical characteristics and associated biological distributions down the length of a river provides a framework for classification that can be used to describe similar streams, while still retaining the idea of longitudinal change down the system. Channel slope also contributes to studies of prevailing river habitat integrity - it provides a broad indicator of habitat types (such as pools and rapids) in a river section, thereby affording some indication of the biota (e.g. fish species) that may be expected to be present.

In the past, river channel profile and slope was determined from the contours on 1:50 000 scale topographical paper maps. However, with GIS and digital elevation models (DEM) more rapid methods are now available, enabling large numbers of rivers to be analysed at a time. The method described here provides the preliminary data that can be used by specialists as a basis for further characterising a stream.

Input data

Rivers

During the 1990s a project was undertaken at the Department Water Affairs and Forestry (DWAF) to increase the spatial accuracy of the widely used 1:500 000 rivers layer by adjusting the rivers to fit within 50 m of the 1:50 000 rivers [1]. This is the river input layer used in this study, shown in Fig. 1, and it can be downloaded at http://www.dwaf.gov.za/iwqs/gis_data/river/rivs500k.html. It also incorporates rivers extending into catchments in neighbouring countries, facilitating...
the comprehensive assessment of a catchment in its entirety. All arcs are connected and point in a downstream direction. Each river segment also has a unique code reflecting the DWAF quaternary catchment through which it flows and a sequence number related to the number of segments in that quaternary (Fig. 2). 1:500 000 rivers were not suitable for this procedure, since, although they are available in digital format, a large amount of editing is still required to remove duplicate and parallel lines, and to provide for accurate connectivity in terms of node intersections and downstream flow directions.

Digital elevation data
The Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) was the result of a joint project undertaken by the National Aeronautics and Space Administration (NASA) and the National Geospatial-Intelligence Agency (NGA – previously known as the National Imagery and Mapping Agency, or NIMA) of the USA, including participation from the German and Italian space agencies. The final result is a DEM of almost the whole globe at a 3 arc-second resolution – approximately 90 m – derived by synthetic aperture radar attached to the Space Shuttle Endeavour launched in February 2000.

Data pre-processing
Rivers
Rivers are conventionally identified by name. However, to eliminate confusion arising from duplicate river names and also occasions where river names change downstream, it was necessary to find a way of identifying unique river stems that are continuous from source to sea, or to the confluence with the next main river. This should maintain the connectedness associated with a river, even if the name changes. The procedure developed by Silberbauer [1] to automatically assign attributes to the 1:500 000 rivers has, as a by-product, a text file containing a sequential list of reach codes starting at each source arc and continuing downstream until an end arc is reached.

For this study, these text files are used as input to an automated procedure to uniquely number river main stems. Although continuity based on river names is taken into account, river main stems are finally identified by a unique number (reachnum) within each DWAF primary catchment, illustrated in Fig. 3a and Fig. 3b for the Sabie River catchment in Mpumalanga which is part of the X primary catchment.

Digital elevation data
The standard procedure to fill a DEM involves determining the maximum depth of sinks in the area, and then filling everything below that depth. This process is described below:
• Generate a raster of points where sinks occur.
• Determine a raster of flow directions.
• Determine the upstream contributing area of each sink.
• Calculate the fill depth of each sink by subtracting the sink elevation from the minimum elevation of its catchment boundary.
• Fill the DEM using the maximum depth of all the sinks as the fill value.

<table>
<thead>
<tr>
<th>ID</th>
<th>Distance (m)</th>
<th>Elevation (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>2043</td>
</tr>
<tr>
<td>2</td>
<td>49</td>
<td>2032</td>
</tr>
<tr>
<td>3</td>
<td>100</td>
<td>2023</td>
</tr>
<tr>
<td>4</td>
<td>113</td>
<td>2021</td>
</tr>
</tbody>
</table>

Table 1: Part of a river table showing distance along the length of the river, and the associated elevation at each distance.
**Procedure**

The DEM and the rivers are used as input to an automated process to produce a data file of elevations at intervals along the length of each required river. This section describes the technical procedure followed. Currently a suite of Arc/INFO AML macros is used to automate the process, but the algorithm shown in Fig. 4 could easily be converted into a set of steps to be followed in ArcGIS or automated into a script.

The process is applied for each river, in each primary catchment:

- Assign route topology to the set of arcs comprising a river (based on reachnum) – starting at the river source.
- Check the total river length, and then determine an appropriate profile interval (river length/500) – coverage constraints only allow 500 vertices (points) per arc.
- Derive the river longitudinal profile from the DEM. Sections of the profile are not sorted in a downstream consecutive manner, but according to the internal number of each arc comprising the river. Therefore, the following three steps are required: Export the x and y co-ordinates of the profile to a file; use these x and y co-ordinates to generate a coverage of points at equal intervals along the length of the river; and determine the elevation of the DEM at each profile point.
- Use the route topology to derive the distance of each profile point from the river source.
- Output a data file consisting of distance from source vs elevation.

**Results**

The river profile produced will include a number of peaks as illustrated in Fig. 5 for the Elands River in Mpumalanga. These are the result of differences in resolution between the river line and the DEM, shown in Fig. 6 where the 1:500 000 river at times appears to leave the valley bottom and flow upstream along the valley side.

These points are removed by further processing the data using a script to extract only the lowest points along the length of the profile (assumed to represent the valley bottom), thereby creating a constantly decreasing profile. The final output is a text file (see Table 1) of distances and elevations from the source of the river, downstream to the mouth or
confluence with the next large river. This data can then be further classified or analysed as required.

Data files have been generated for all the rivers in the DWAF 1:500 000 rivers data set (including rivers flowing from or into neighbouring countries) and can be downloaded together with shapefiles indicating the main stem numbers, from http://www.dwaf.gov.za/iwqs/gis_data/rivslopes/rivprofil.htm. The profiles of four Mpumalanga rivers are compared to the profiles that would be obtained using 1:50 000 map sheets (Fig. 7a to Fig. 7d). Elevation differences measured between the SRTM-derived profile and the 1:50 000 profile are indicated on the secondary axis, with 10 m and 15 m cutoffs.

Artificially induced changes in slope, such as those associated with a dam wall, are not always retained by the data smoothing process. Furthermore, analysis of SRTM elevations undertaken as part of the data collection process indicated that the absolute vertical error for SRTM DEM elevations is on average less than 10 m, but can be more in very steep or very flat terrain. Despite these discrepancies, elevations and slopes computed from DEM data compare well to those measured from 1:50 000 contours. Table 2 lists comparisons between elevations and slopes calculated at 100 m horizontal intervals along the profile line for the Sabie, Crocodile, Olifants and Elands rivers (illustrated in Figs. 7a - 7d above).

One application of the data is to use it to classify all rivers according to the geomorphological classification proposed by Rowntree and Wadeson [2], to aid in the ecological understanding of a river. A preliminary classification of all 1:500 000 rivers is shown in Fig. 8. The data is also available in ESRI shapefile format at http://www.dwaf.gov.za/iwqs/gis_data/rivslopes/rivprofil.htm. The geomorphological zone typically associated with each slope class is listed in Table 3. This information can then be used by geomorphologists as a first step to the more detailed classification of rivers.

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<table>
<thead>
<tr>
<th>River</th>
<th>Elevation within:</th>
<th>Slope within:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10 m</td>
<td>15 m</td>
</tr>
<tr>
<td>Sabie</td>
<td>71%</td>
<td>87%</td>
</tr>
<tr>
<td>Crocodile</td>
<td>85%</td>
<td>96%</td>
</tr>
<tr>
<td>Olifants</td>
<td>83%</td>
<td>91%</td>
</tr>
<tr>
<td>Elands</td>
<td>93%</td>
<td>99%</td>
</tr>
</tbody>
</table>

Table 2: The success rate of the automated method of calculating river channel profiles compared to profiles generated from 1:50 000 contours.
Conclusions

Until recently longitudinal profiles and other river physical characteristics were derived manually using calculations based on the contours of 1:50 000 map sheets. However, this process becomes tedious and time consuming if information is required for several rivers, and (unless a large labour force is available) almost impossible for several hundred rivers. The automated procedures described above make use of new technology in GIS and data from digital elevation models that is more readily available than in the past. They can be applied to any number of rivers at a time, by only one person, and will run with relatively minimum intervention thus freeing the person for other tasks.

Using this method it was possible to classify 5296 South African rivers in a period of only six weeks. Furthermore, since the NASA SRTM digital elevation model is available beyond the borders of South Africa, 485 rivers which are extensions of South African catchments could also be included in the process. Distances and elevations are therefore available for nearly 6000 southern African rivers. This data can then be used as input to any procedure requiring river longitudinal slopes for classification or other purposes.

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References


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