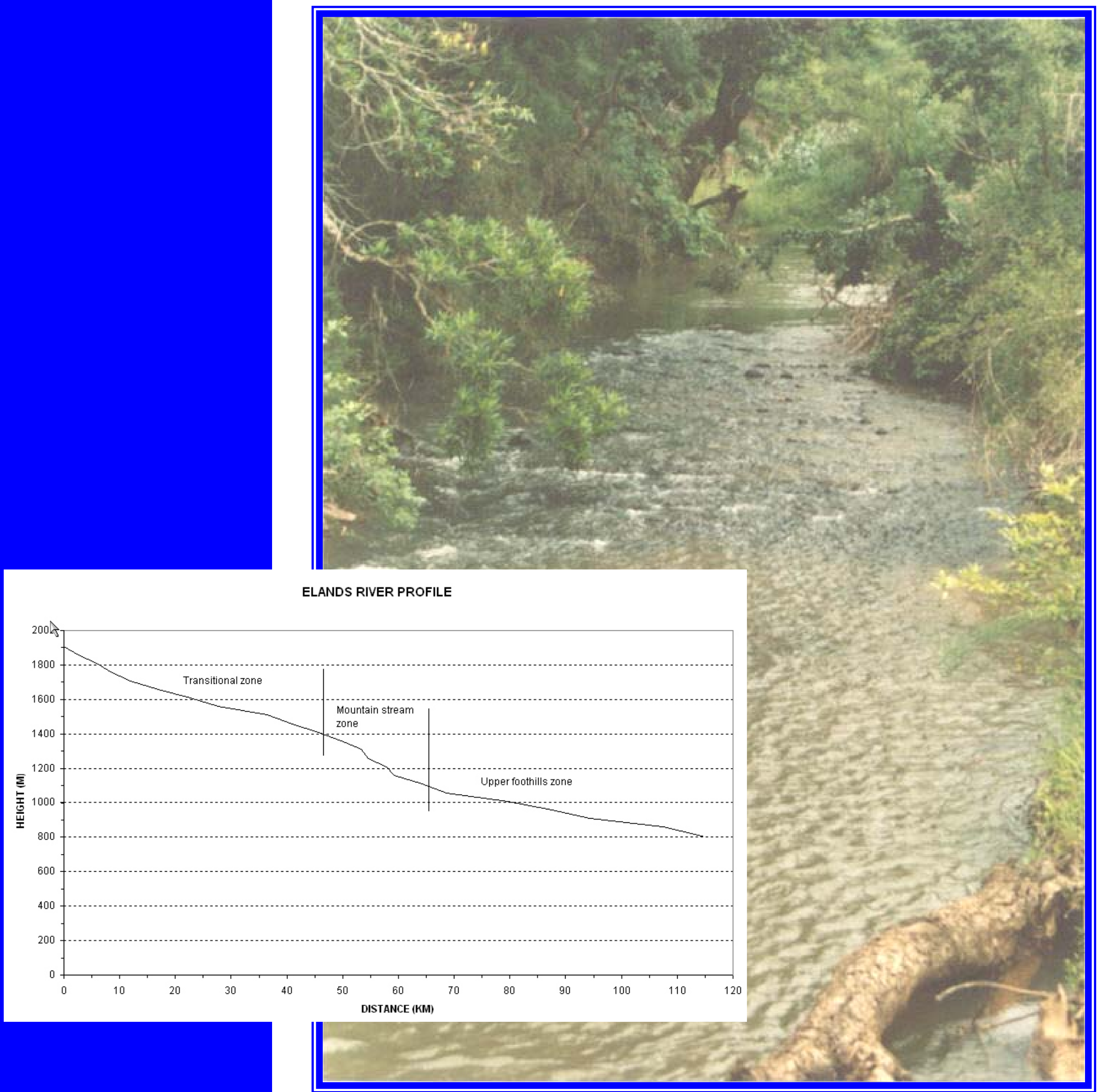
CHANNEL SLOPES IN THE OLIFANTS, CROCODILE AND SABIE RIVER CATCHMENTS



Department of Water Affairs and Forestry
Institute for Water Quality Studies

Republic of South Africa

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AUTHORS:	J Moolman, CJ Kleynhans, C Thirion
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Mr J Carter: *previously* Institute for Water Quality Studies
currently Tait Electronics, PO Box 1645, Christchurch, New Zealand

Mr MJ Silberbauer: Institute for Water Quality Studies

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AML – Arc Macro Language

DEM – Digital Elevation Model

IWQS – Institute for Water Quality Studies

CHANNEL SLOPES IN THE OLIFANTS, CROCODILE AND SABIE RIVER CATCHMENTS

INTRODUCTION

The National Water Act (Act 36 of 1998) requires that the ecological reserve of South African rivers be determined. The ecological reserve defines the water required to protect the aquatic ecosystems. In February 1999 a document was produced outlining the data sets required at each step of the determination of the preliminary ecological reserve (Moolman, 1999). The first step is the delineation of ecotypes in a catchment and one of the requirements for this process is river channel slope. Channel slope is also needed for determining the current river habitat integrity. The aim is to derive a methodology which is rapid and can be applied in any part of South Africa using readily available data. This report describes the procedure used to obtain river channel slopes and the application of this information in the Olifants, Crocodile and Sabie River catchments. The main purpose of this report is to present the results obtained and the differences between the traditional topographic map sheet method of slope determination and river profiles and slopes obtained from a Digital Elevation Model.

BACKGROUND

Study Area

Due to the large amount of information available for the catchment, the Crocodile River catchment was chosen for a pilot study to test the methodology for determining the ecological reserve required for a river. This study was later extended to include the neighbouring Olifants and Sabie River catchments. Furthermore, the Olifants & Inkomati Water Management Areas has been identified as a priority region in terms of the implementation of resource directed measures. Figure 1 shows the location of the Olifants, Crocodile and Sabie River catchments. The specific river channels in these catchments for which slopes have been determined are shown in Figure 2, and Table 1 is the key linking the numbers on Figure 2 to the river names.

Theoretical Background

River zonation describes the longitudinal variation of physical characteristics and associated biological distributions down the length of the river. Wadeson & Rowntree (1999) define a zone as "…a sector of the river long profile which has a distinct valley form and valley slope". Zonal classification has been widely adopted in the past to explain variations in biotic distributions down the long profile of a river (Oliff 1960, Chutter 1967, Harrison 1965 and others). It provides a framework for classification that can be used to describe like streams, but which also retains the idea of longitudinal change down the system.

Figure 1: Location of the Olifants (B), Crocodile (X2) and Sabie (X3) River catchments within South Africa

Table 1: Key to the river numbering in Figure 2: River channels in the Olifants (B), Crocodile (X2) and Sabie (X3) River catchments, for which slopes have been derived

CROCODILE CATCHMENT		SABIE CATCHMENT		OLIFANTS CATCHMENT	
RIVER NAME	No.	RIVER NAME	No.	RIVER NAME	No.
Alexanderspruit	1	Klein Sand	28	Beetgekraalspruit	42
Blouboskraalspruit	9	Mac Mac	19	Belvedere	47
Crocodile	49	Marite }	24	Blyde	45
Elands	7	Maritsana }	23	Bronkhorstspruit	35
Elandsfonteinspruit	5	Mohlomobe	27	Elands	33
Fig Tree Creek	16	Mutlumuvi	26	Klaserie	48
Hartbeesspruit	6	Ngwaritsana	22	Klein Olifants	38
Kaap	15	Phashaphasha	21	Makhutswi	31
Kareekraalspruit	3	Sabie	18	Mohlapitse	32
Leeuspruit	10	Sand	29	Moses	34
Louws Creek	17	Waterhoutboom	20	Ohrigstad	44
Lunskliprivier	2			Olifants	37
NoordKaap	14			Selati	30
Ngodwana	11			Selons	39
Queens	12			Spekboom	43
SuidKaap	13			Steelpoort	40
Tautesloop	8			Treur	46
Wilgekraalspruit	4			Watervals	41
				Wilge	36

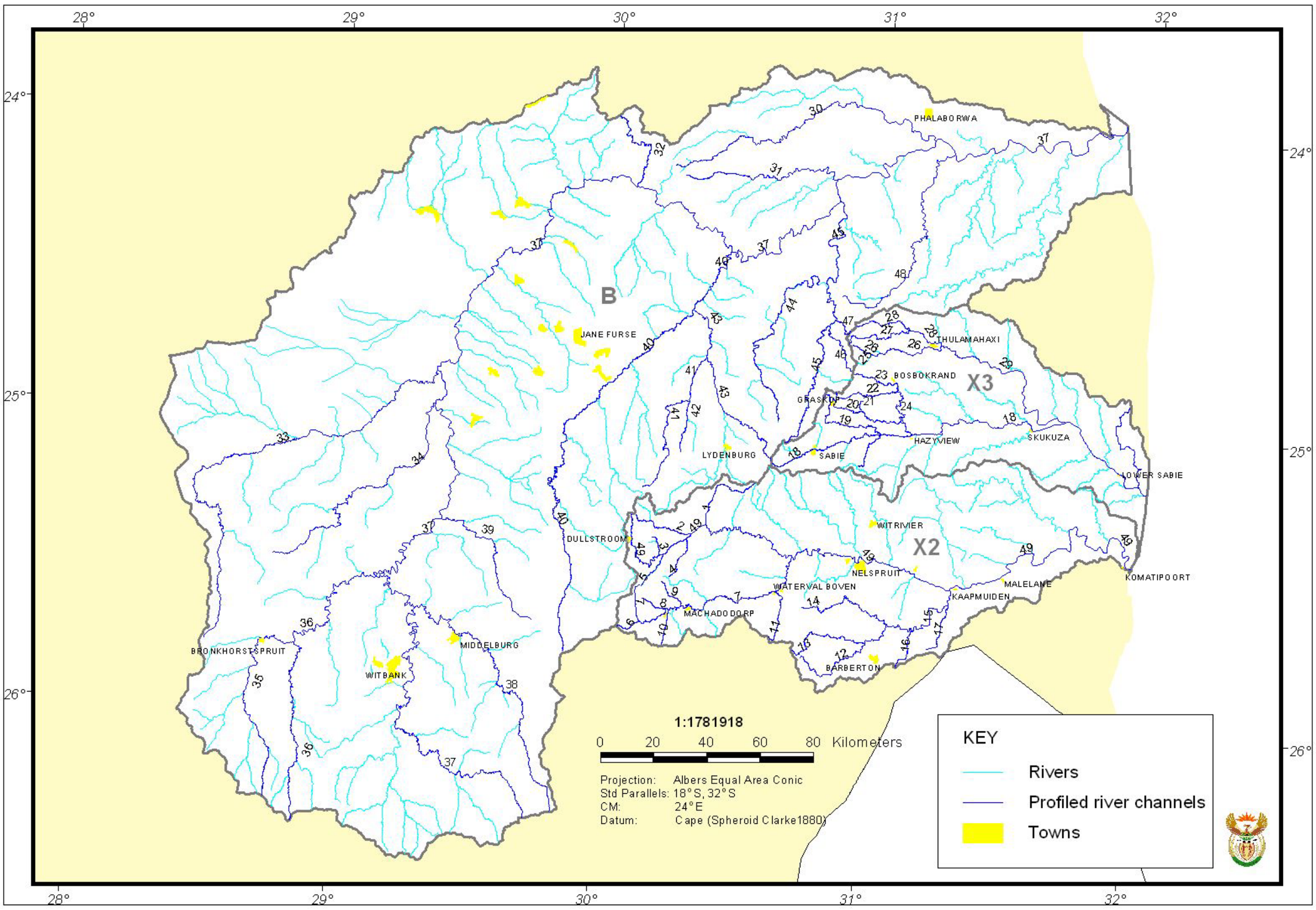

Figure 2: River channels in the Olifants (B), Crocodile (X2) and Sabie (X3) River catchments for which slopes have been derived

The concept of river zonation recognises the longitudinal changes in river characteristics associated with the river long profile. In a graded system there is a natural progression from mountain stream through foothill stream to lowland river. This sequence of river zones is often disrupted to give a complex downstream zonation. One of the most important factors is that of tectonic uplift resulting in rejuvenation of the drainage system. In South Africa this uplift caused steepened long profiles and deep gorges in the middle to lower profile of many rivers. The zone is determined based on valley form and gradient traditionally obtained from 1:50 000 topographical maps (Wadeson & Rowntree, 1999).

DATA

1. A 400m x 400m coverage of elevation points is available from the Dept of Land Affairs: Directorate Surveys and Land Information. In steep, more mountainous areas the points are 200m apart (Figure 3). Although the resolution of this data is rather coarse, it is data that is readily available for the entire country and the final product is sufficiently accurate for the task at hand.
2. A project is currently underway at the Institute for Water Quality Studies (IWQS) to increase the spatial accuracy of the widely used 1:500 000 scale river coverage by adjusting the rivers to fit within 50m of the 1:50 000 scale rivers (Silberbauer & Wildemans, 2001). This study uses these adjusted rivers (Figure 4). 1:50 000 rivers were not used, since, although they are available in digital format, a large amount of editing is still required to remove duplicate and parallel lines.

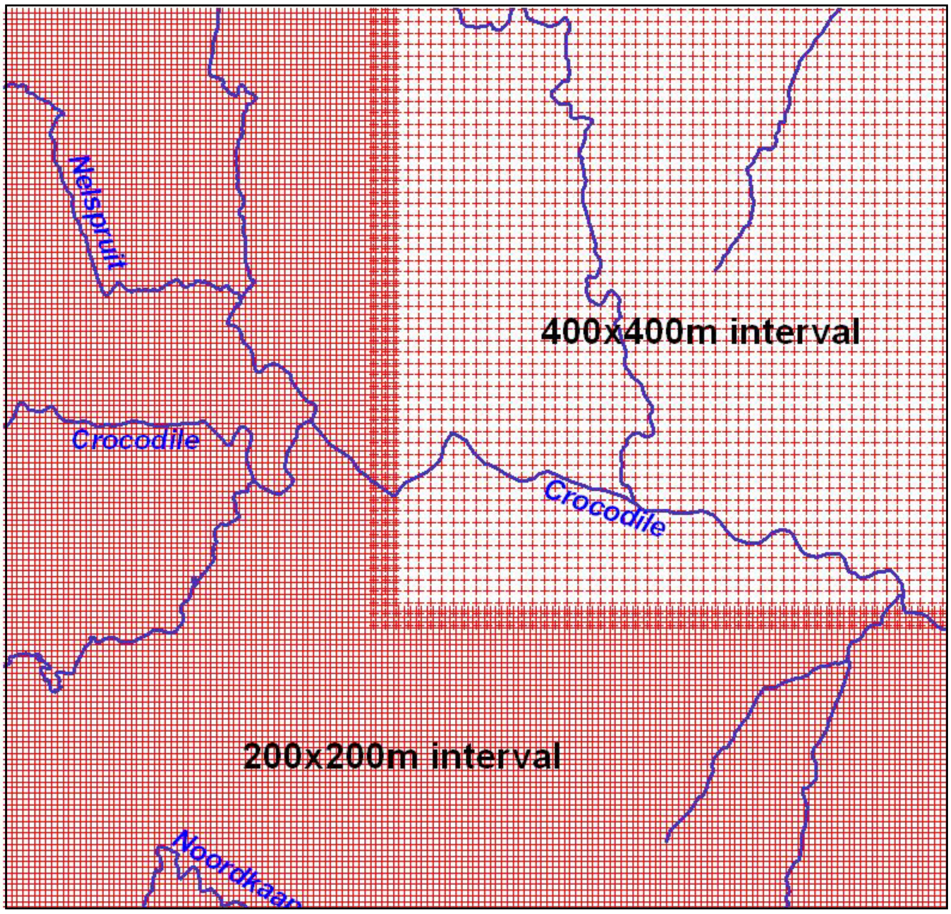

Figure 3: Elevation point coverage for part of the Crocodile River catchment.

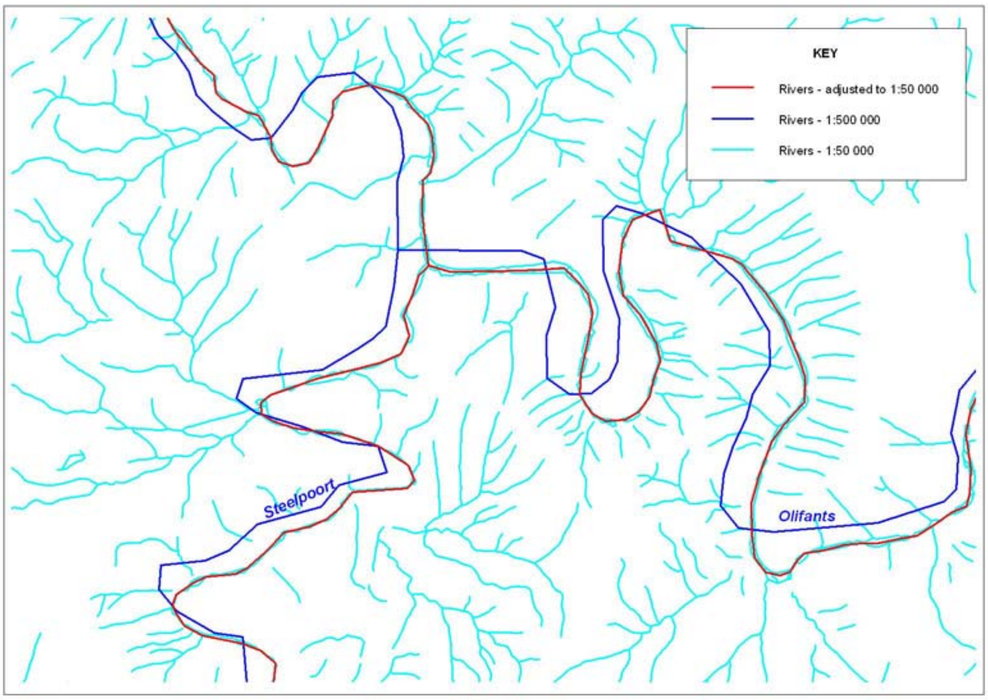

Figure 4: Comparison between 1:500 000 scale rivers adjusted to 1:50 000 rivers, and the original 1:500 000 rivers, in part of the Olifants River catchment

METHODOLOGY

This section describes the technical procedure followed to obtain the channel slope. It also gives an indication of some of the problems encountered and assumptions made during the process.

1. The elevation point coverage and the adjusted rivers are used as inputs to the Arc/Info module TOPOGRID to produce a hydrologically correct 200m resolution Digital Elevation Model (DEM) of the area (Figure 5).
2. The DEM (and the rivers) are used as a lattice for input to the Arc/Info command SURFACEXSECTION to produce a data file of heights vs x,y locations at 50m horizontal distance intervals along the length of a river.

   Long rivers consisting of more than 500 points are split into more than one arc by Arc/Info. These are then numbered internally by Arc/Info (not necessarily increasing sequentially in a downstream direction). The Arc/Info method of profiling computes a separate profile for each section calculating heights at 50m distance from the beginning of each section. Distance is thus reset to zero at the start of each new section.
3. The data is then transferred to MSExcel (Table 2) where the sections of the profile are arranged sequentially according to the river flow direction (if required) and the distances are cumulated from zero at the source, to the total length of the river.

Table 2: Sample of MSExcel spreadsheet showing SURFACEXSECTION output

$RECNO	PX	PY	DISTANCE	SPOT
1	569 001.38	-2 873 071.50	0	1 750.79
2	568 980.23	-2 873 026.19	50	1 751.84
3	568 959.08	-2 872 980.88	100	1 751.60
4	568 937.93	-2 872 935.58	150	1 750.99
6	568 924.80	-2 872 889.68	200	1 749.36
7	568 939.15	-2 872 841.79	250	1 745.47
8	568 953.49	-2 872 793.89	300	1 742.18

Key:
PX and PY: X, Y coordinates of the point on the river (m) (Albers Equal Area Projection)
DISTANCE: Cumulative distance (m) along the river (0 being the source)
SPOT: The height at the point

4. The river profile produced using SURFACEXSECTION will include a number of peaks which are the result of differences in accuracy between the river line and the DEM. These are removed by processing the data obtained from 3 above in an AML (Arc Macro Language) to extract only the lowest points along the length of the profile (assumed to represent the valley bottom), to create a constantly decreasing profile (Figure 6a).
5. The data from this smoothed profile is then processed by another AML to determine a profile based on height at each 50m drop along the river length (Figure 6b). This is the final profile which is used to obtain slopes between points at 50m drop intervals along the river channel.

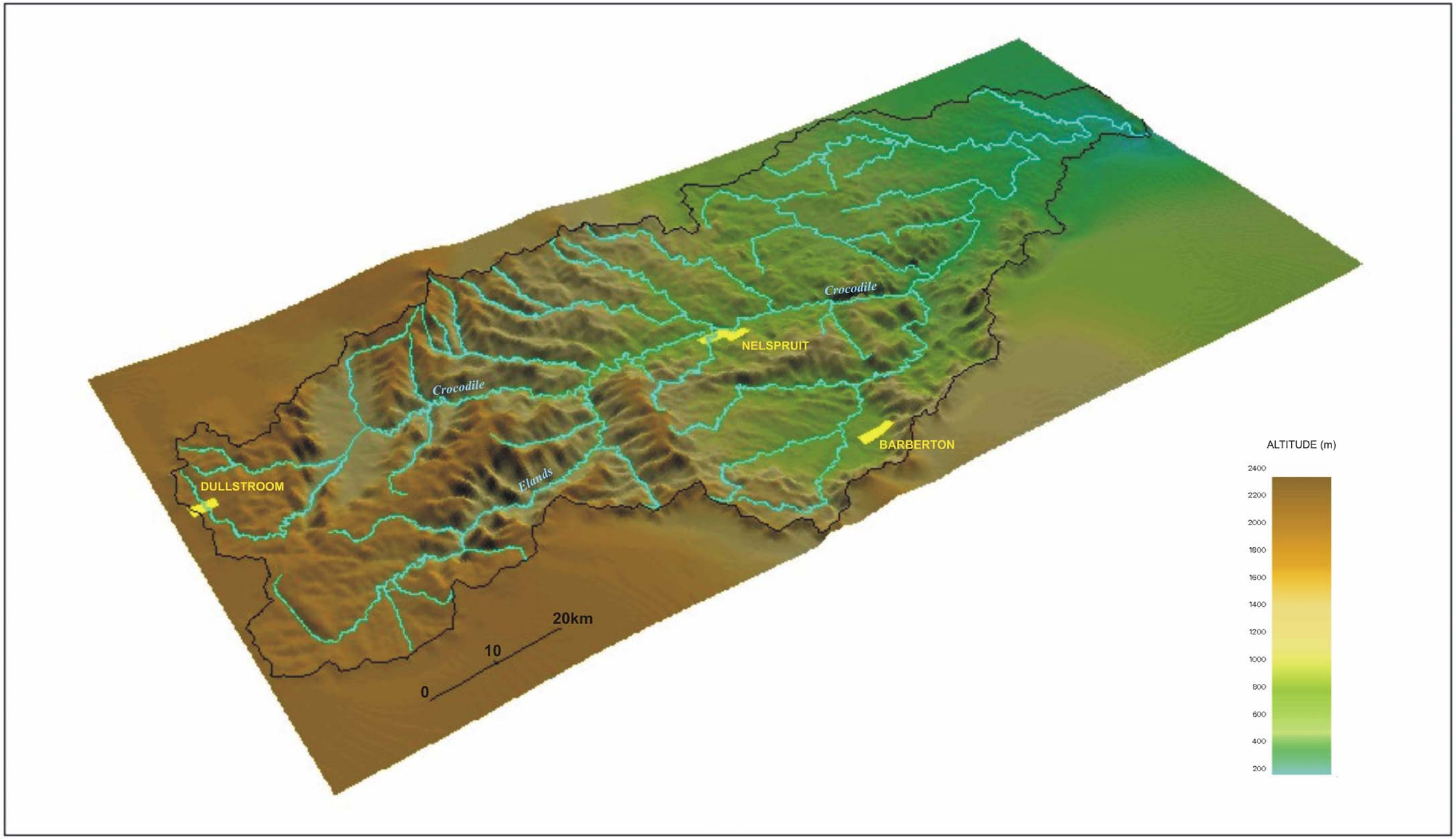

Figure 5: Digital Elevation Model of the Crocodile River catchment, with shaded relief

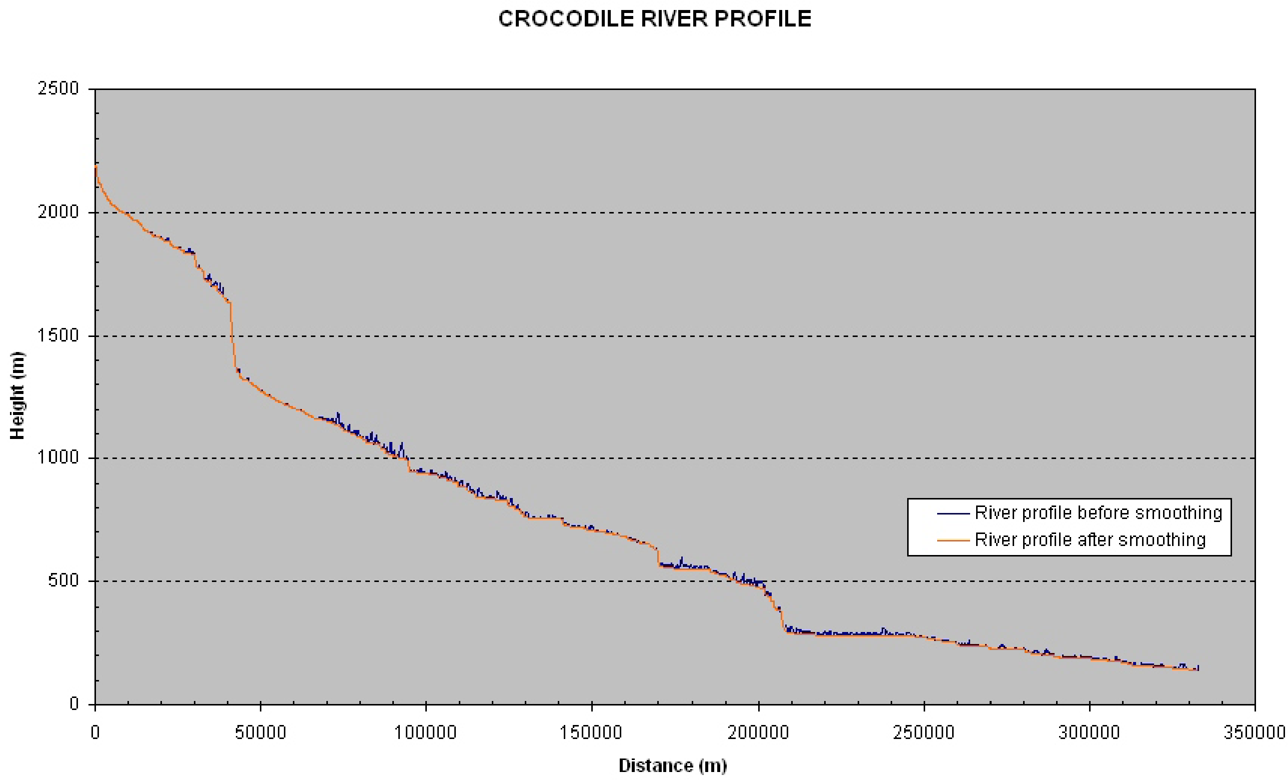

Figure 6a: Crocodile River profile before and after smoothing

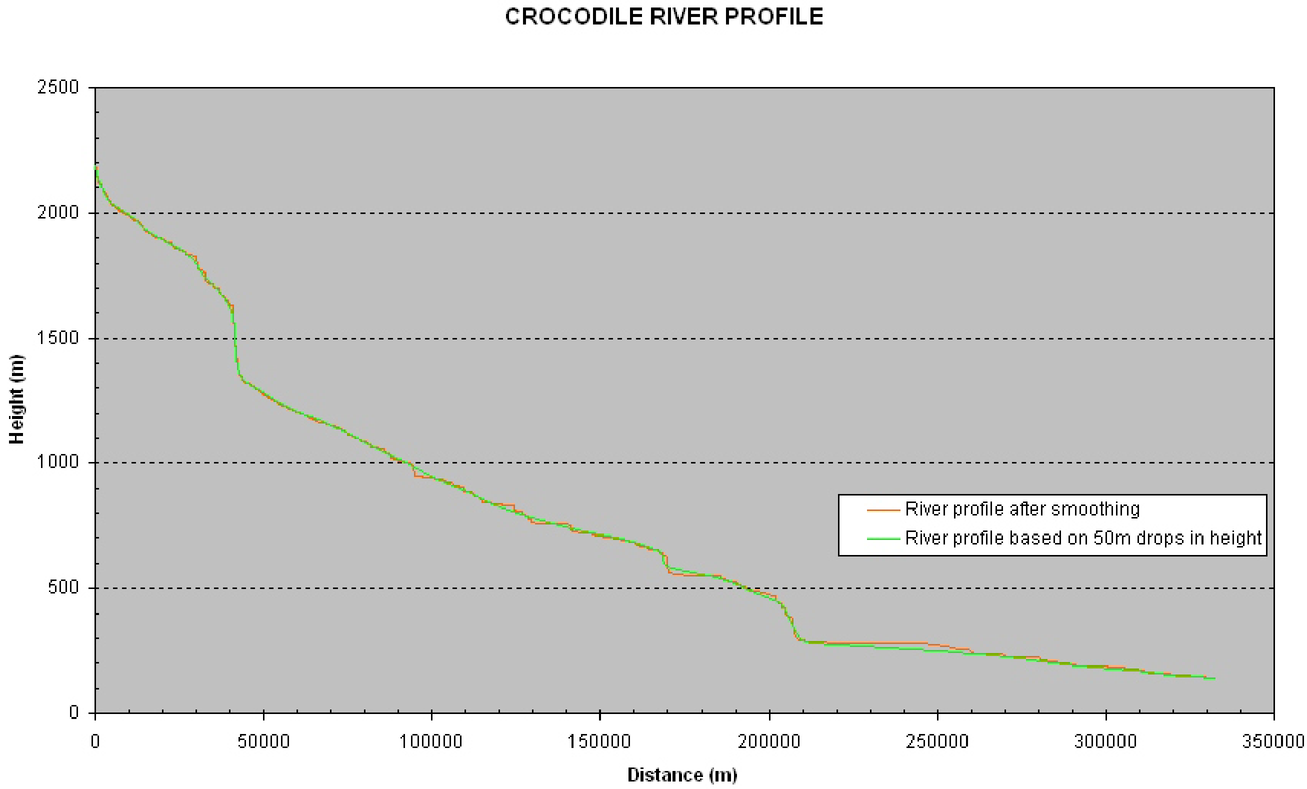

Figure 6b: Crocodile River profile based on intervals of 50m drops in height

RESULTS

Profiles for the rivers in the Crocodile, Sabie and Olifants catchments were derived based on a 50m vertical interval (Appendix A, B and C, respectively).

Statistics

To check the accuracy of the method a comparison was made between river channel profiles in the Olifants River catchment produced using the DEM and the manual method using the contours on a 1:50 000 map sheet (Table 3). The error in heights measured using the two methods and the error in slopes calculated using the two methods, is shown. The profiles derived using the manual method are also included in Appendix C, to provide a visual comparison between the two methods.

Table 3: The success rate of the automated method of calculating river channel profiles, compared to the manual method

RIVER	HEIGHT within:		SLOPE within:		
	20m	30m	1%	2%	5%
Beetgekraalspruit	50%	83%	54%	74%	n/d
Belvedere *	7%	22%	35%	46%	58%
Blyde *	40%	59%	57%	66%	n/d
Bronkhorstspruit	100%	100%	88%	100%	n/d
Elands	95%	100%	92%	97%	n/d
Klaserie	43%	70%	43%	54%	64%
Klein Olifants	96%	100%	86%	95%	n/d
Makhutswi	36%	51%	59%	67%	85%
Mohlapitse	24%	56%	79%	96%	n/d
Moses	94%	100%	97%	100%	n/d
Ohrigstad *	66%	77%	81%	95%	n/d
Olifants *	52%	81%	99%	99%	n/d
Selati	31%	60%	59%	61%	69%
Selons	59%	72%	87%	92%	n/d
Spekboom	26%	63%	60%	73%	n/d
Steelpoort	56%	73%	92%	94%	n/d
Treur *	65%	88%	36%	48%	76%
Watervals *	70%	89%	65%	80%	n/d
Wilge	79%	83%	86%	96%	n/d

*Data points representing waterfalls or dam walls on the 1:50 000 map sheet have been removed from the data set

n/d - not determined

Applications

Once the slopes of a river have been calculated, the river zones can be identified. Figure 7 gives an example of how a river profile - obtained from the DEM - is classified, using the Elands River in the Crocodile River catchment.

In terms of the River Health Programme these zones, in conjunction with Level II ecoregions, can be used to delineate habitat segments for invertebrates and for fish.

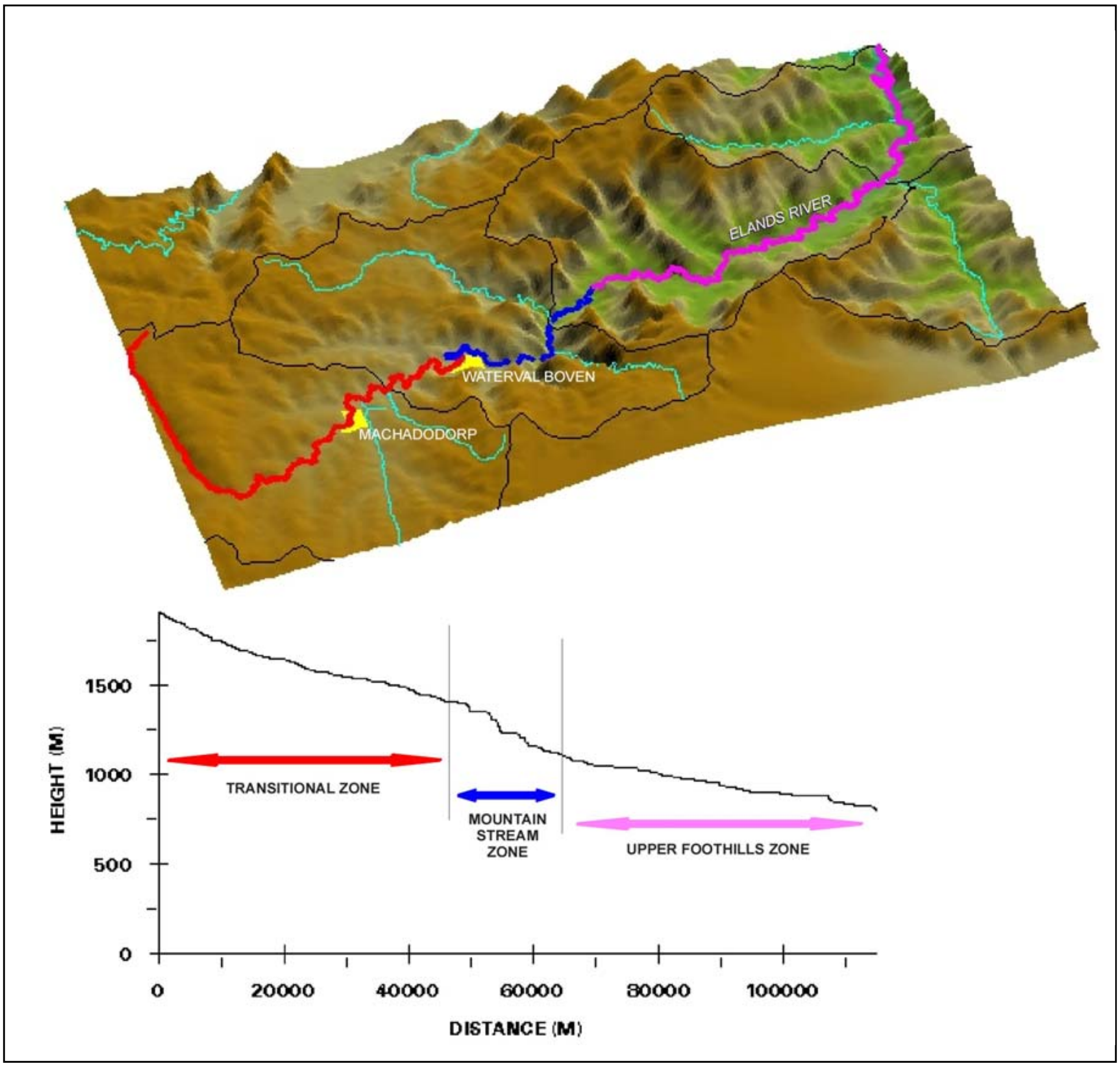

Figure 7: Elands River profile derived from the DEM, showing river zones

DISCUSSION

DEM accuracy issues:

This section is not intended to be a detailed discussion of DEM accuracy, but rather a brief background to the main issues. A Digital Elevation Model (DEM) is, as it's name suggests, merely a model of the earth's surface, rather than an exact representation. Differences between the modeled elevation values and real values can be attributed to the original source data as well as the procedure used to generate the DEM. Errors inherent in either of these factors will affect the accuracy of the final DEM. Whether these errors are of an acceptable magnitude or not depends on the purpose for which the DEM will be used.

- The elevation data on which the DEM used in this study is based, was obtained from the Department of Land Affairs: Directorate Surveys and Mapping. According to them the absolute height accuracy of this elevation data is ±10m.

- The DEM was generated using the Arc/Info TOPOGRID command and point input data. No specific comments concerning accuracies based on point data inputs could be found, but Harvey (2002) stated that TOPOGRID, based on contour data inputs, could not be expected to yield accurate slopes in all cases since slight contour biasing is present in the generated DEM.

River accuracy issues:

- Figure 8 illustrates the differences which arise between the river arc and the DEM river line as a result of the original scale at which the rivers were digitised (smaller scale, less generalization) and the resolution of the DEM.
- The location of the river source varies according to the scale at which the river was digitised, which also affects the river length measurement. This is also portrayed in Figure 8.

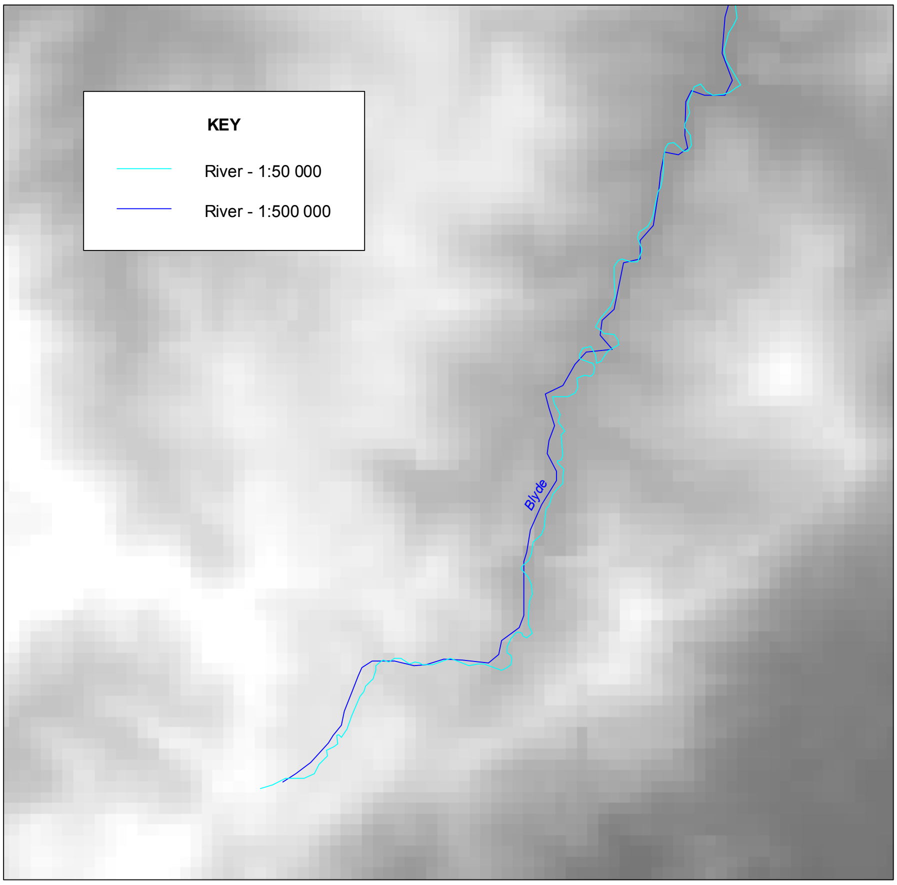

Figure 8: Comparison between rivers digitised at various scales, and the DEM river valley of the Blyde River in the Olifants River catchment

- River length is also affected by scale. More generalization will reduce the measured length. Green (1993) described the relationship between measured length and measuring scale in terms of fractals. He demonstrated this using the measurement of a coastline as an example (Figure 9). As the scale of measurement decreases the length increases.

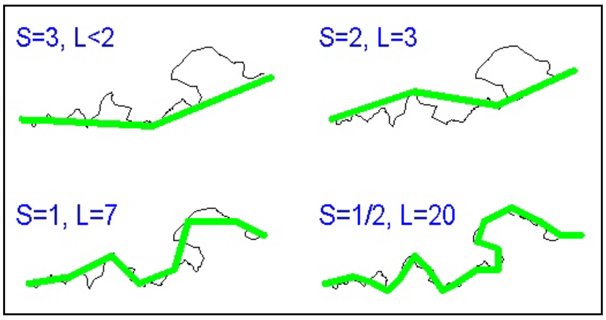

Figure 9: Sections of different size (S) estimate the length (L) of a coastline

General limitations of the technique:

Because of the 200m to 400m resolution of the elevations used as input for the DEM, drops in height associated with waterfalls, or other instances where contours are very close together (eg. Belvedere Creek and Klaserie, Makutswi, Selati and Treur Rivers), tend to be averaged over a grid element, and do not show up clearly. This can cause large local discrepancies in heights and slope measured using the DEM vs the manual method using the contours on a 1:50 000 map sheet. As shown in Table 3 above, the success rate for altitude can vary from as low as 22% of the points occurring within 30m of the height measured on a 1:50 000 map (Belvedere Creek), to as high as 100% of the points occurring within 30m of the height measured on a 1:50 000 map (Bronkhorstspruit, Elands River, Klein Olifants River and Moses River). The error for slopes varies between a low of 46% of DEM calculated slopes being within 2% of the contour measured slope (Belvedere Creek), and a high of 100% of DEM calculated slopes being within 2% of the contour measured slope (Bronkhorstspruit and Moses River). The final slopes are used by ecologists at the IWQS to identify river geomorphological zones, and they are satisfied that these discrepancies are within acceptable limits.

RECOMMENDATIONS

Now that the method has been applied and tested satisfactorily in three catchments, it is proposed that it be extended to rivers in other priority catchments in South Africa.

It is also recommended that an investigation be carried out to see to what extent the limitations introduced by the 400m x 400m resolution of the DEM can be reduced by using a finer resolution DEM. A 20m x 20m DEM is available, and it is suggested that a small piece of this (e.g. the Sabie River catchment) be purchased to do the comparisons.

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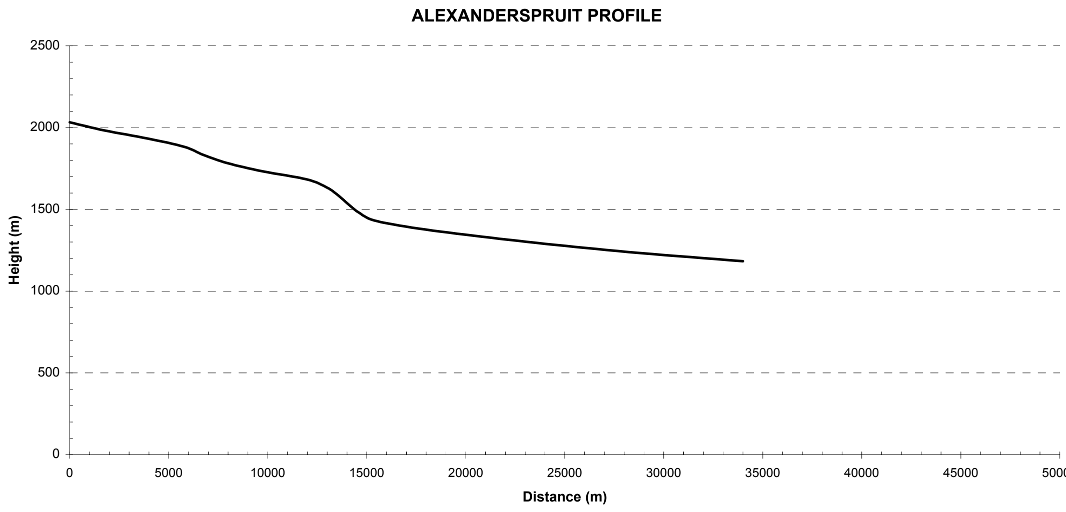
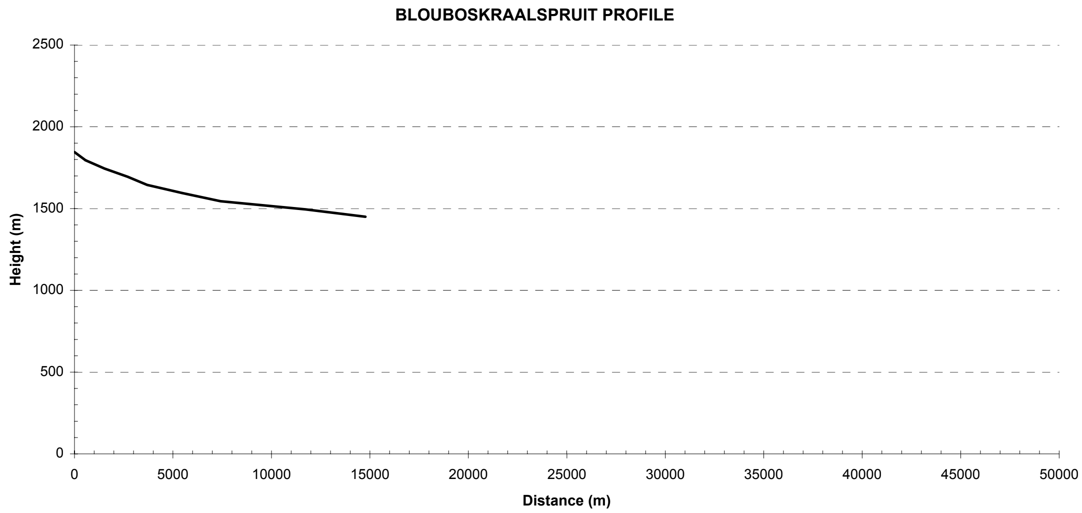
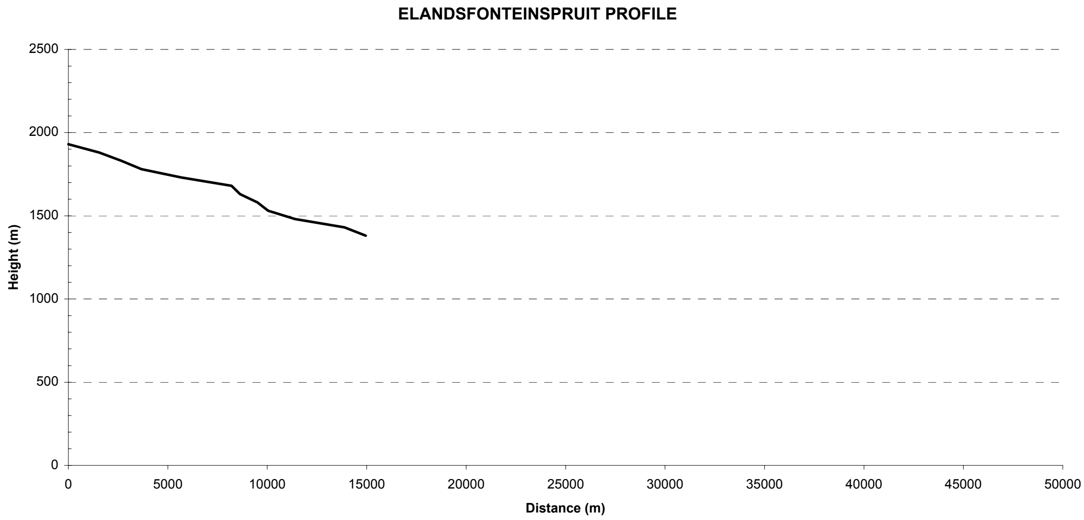
APPENDIX A

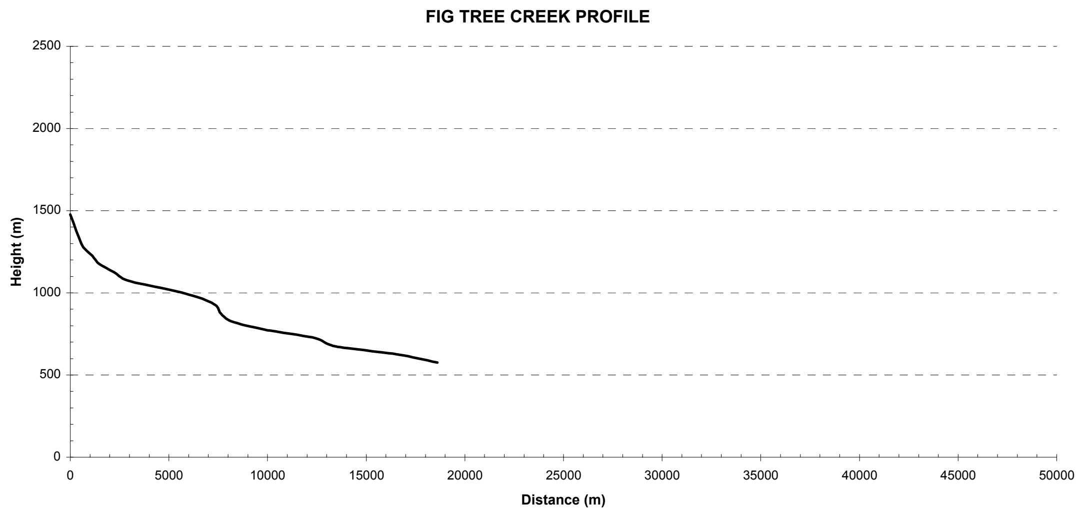
Crocodile River Catchment Channel Profiles

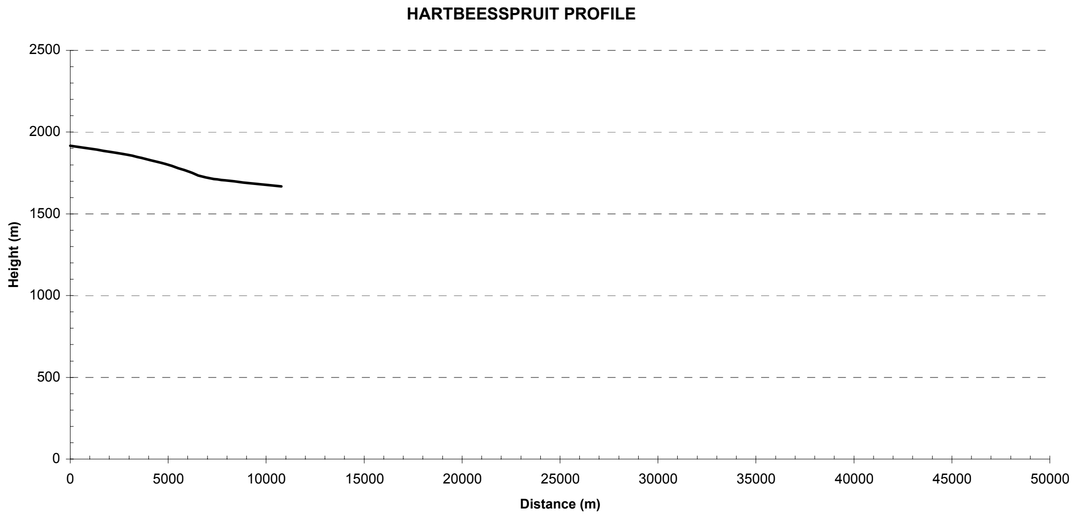


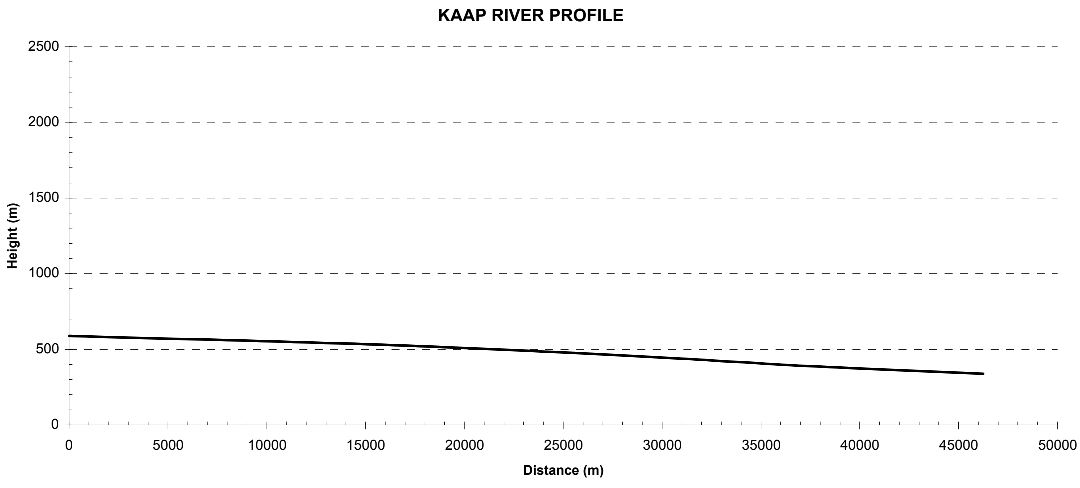




Crocodile catchment: Channel profiles (River length < 50km)







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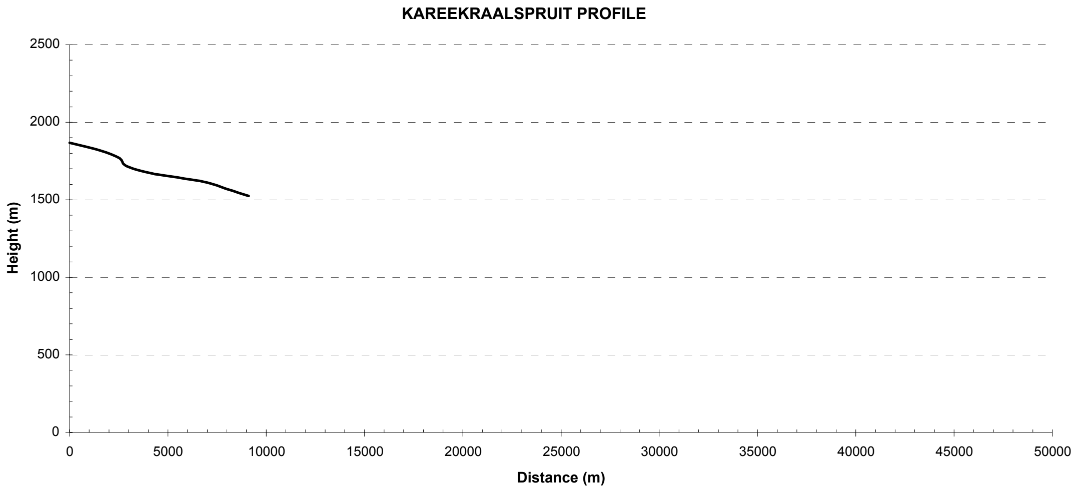
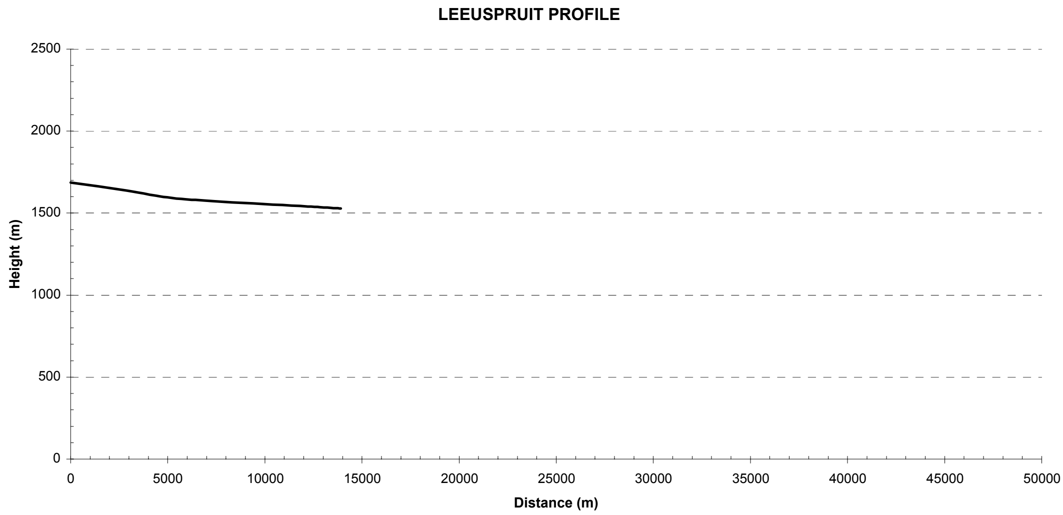
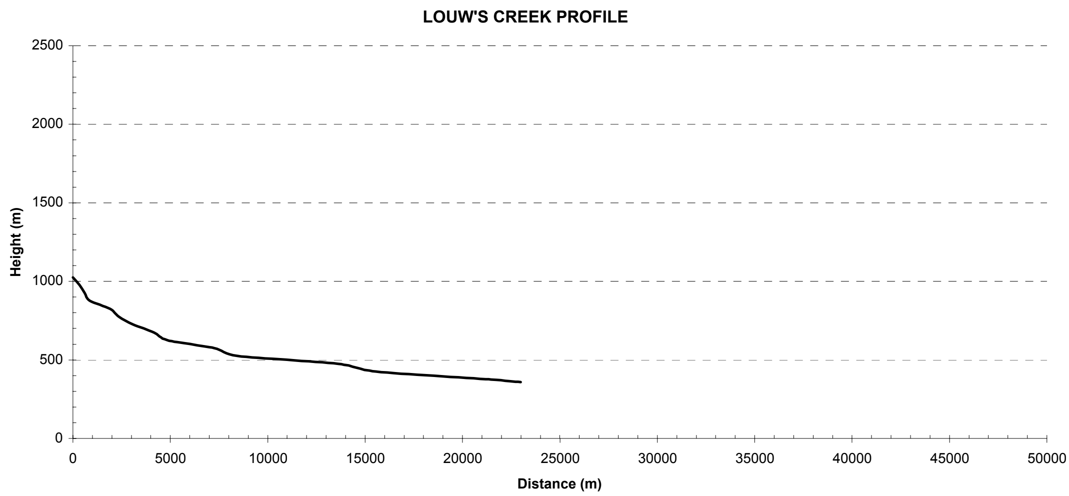
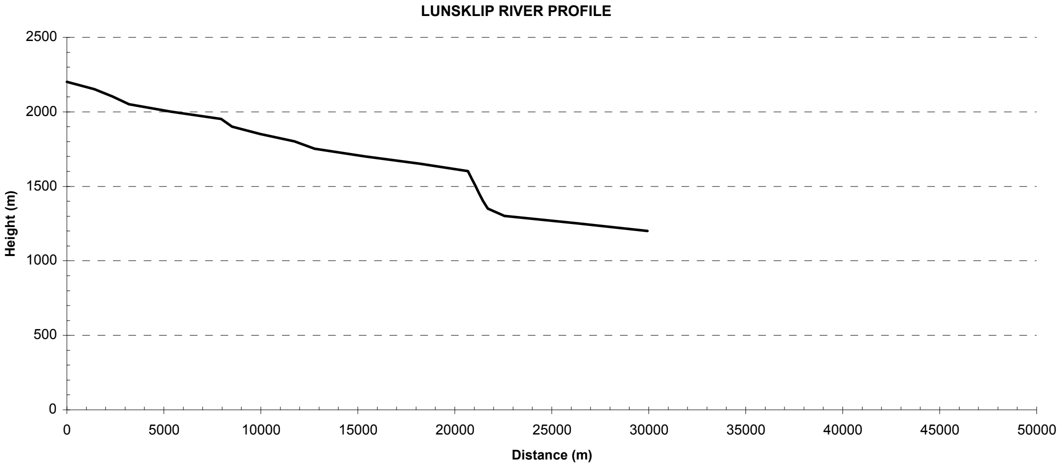
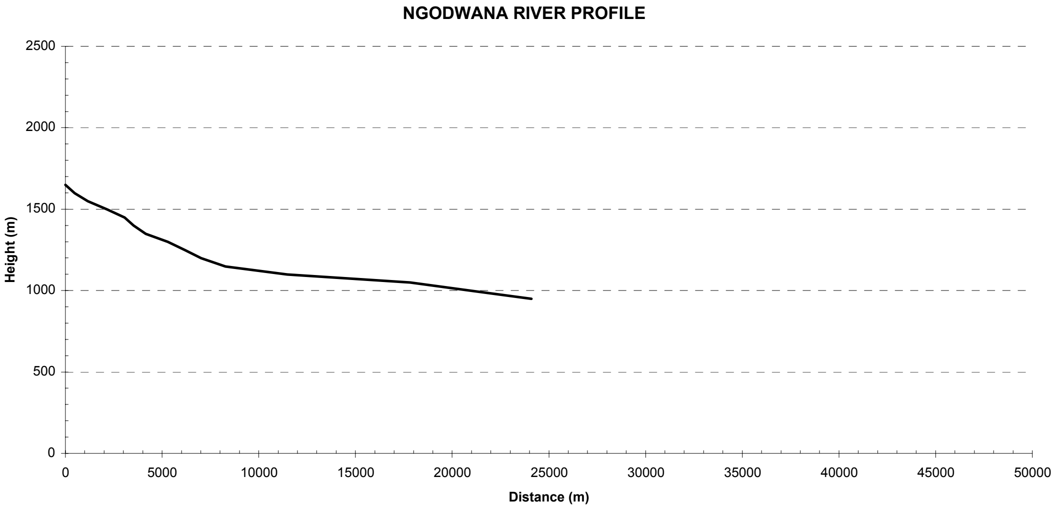


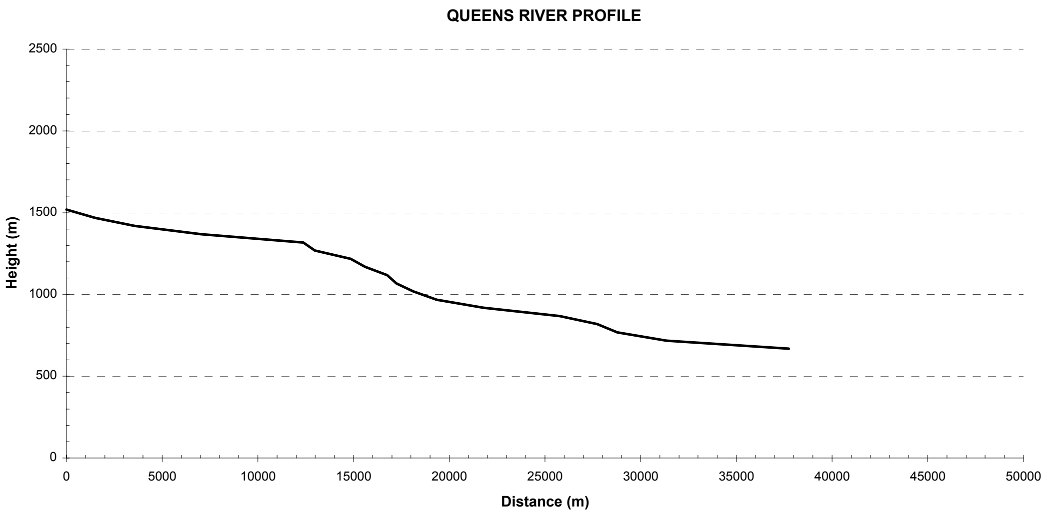




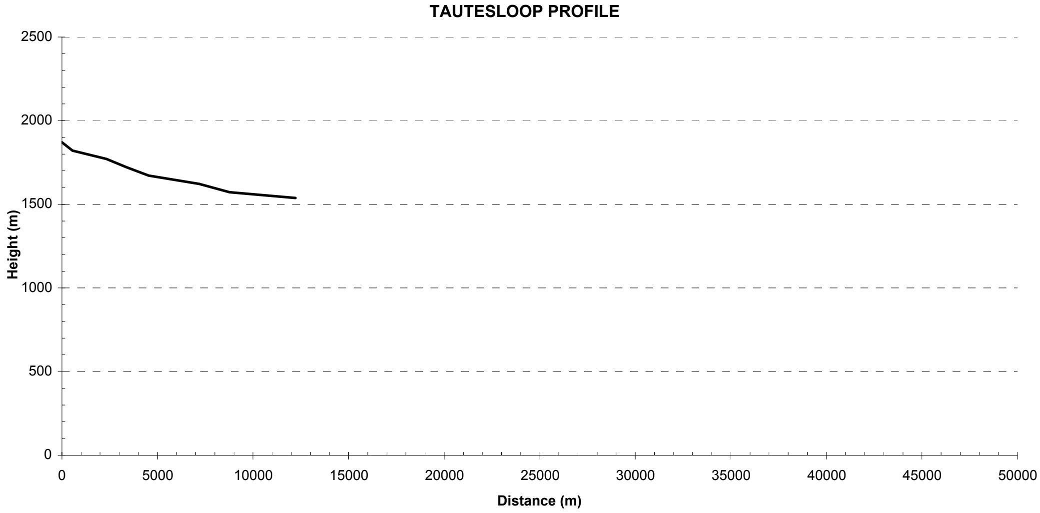
Crocodile catchment: Channel profiles (River length < 50km)

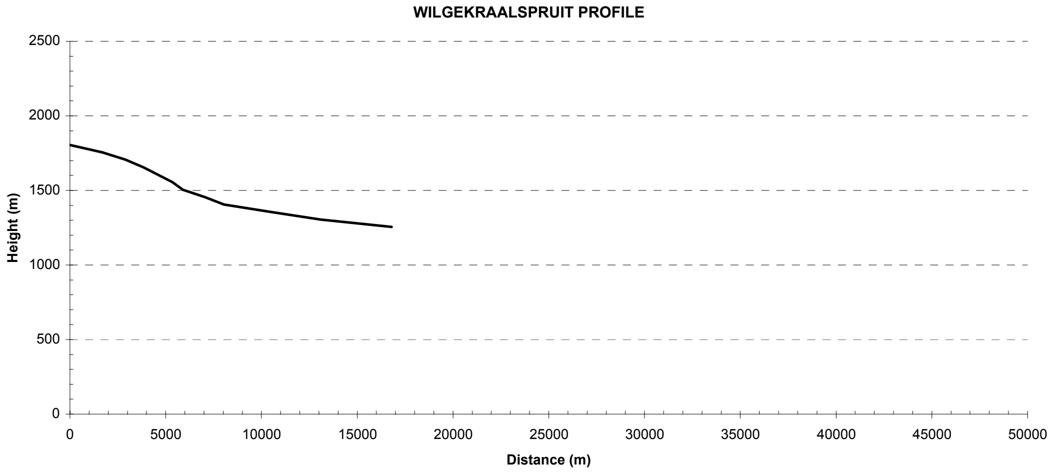






Crocodile catchment: Channel profiles (River length < 50km)





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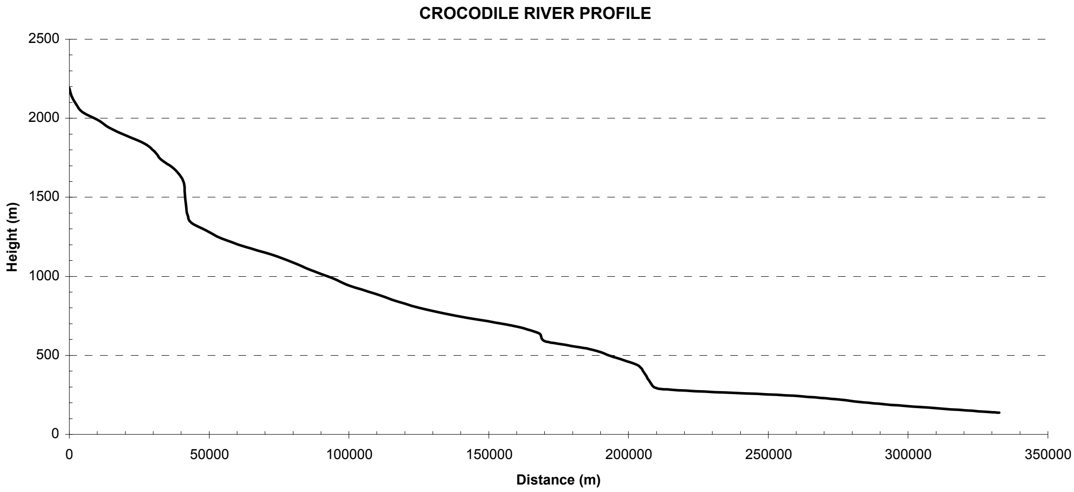
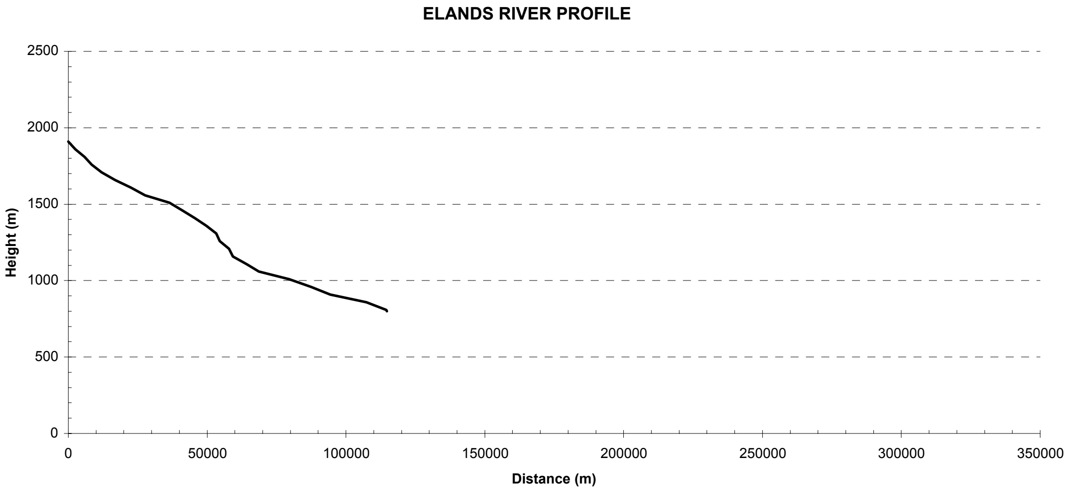
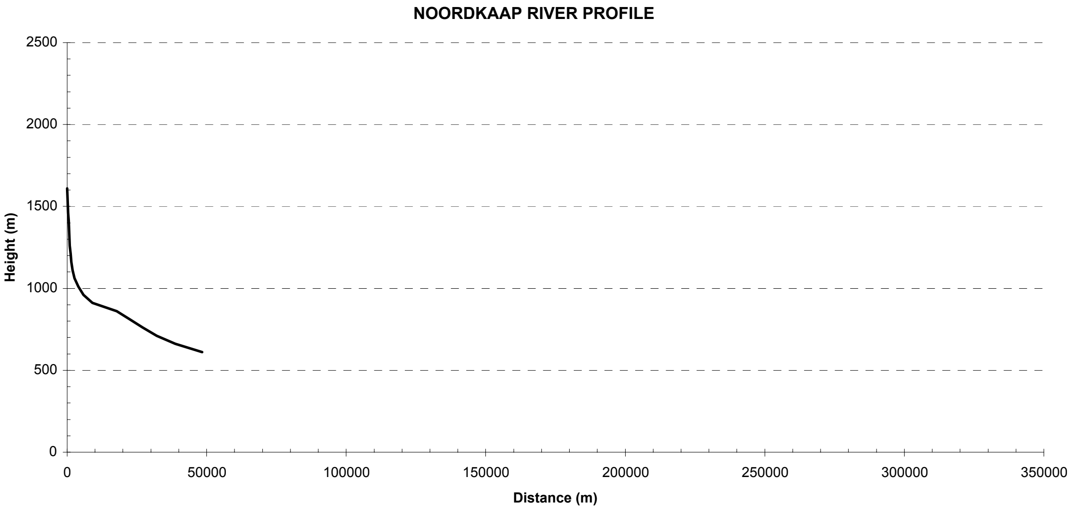
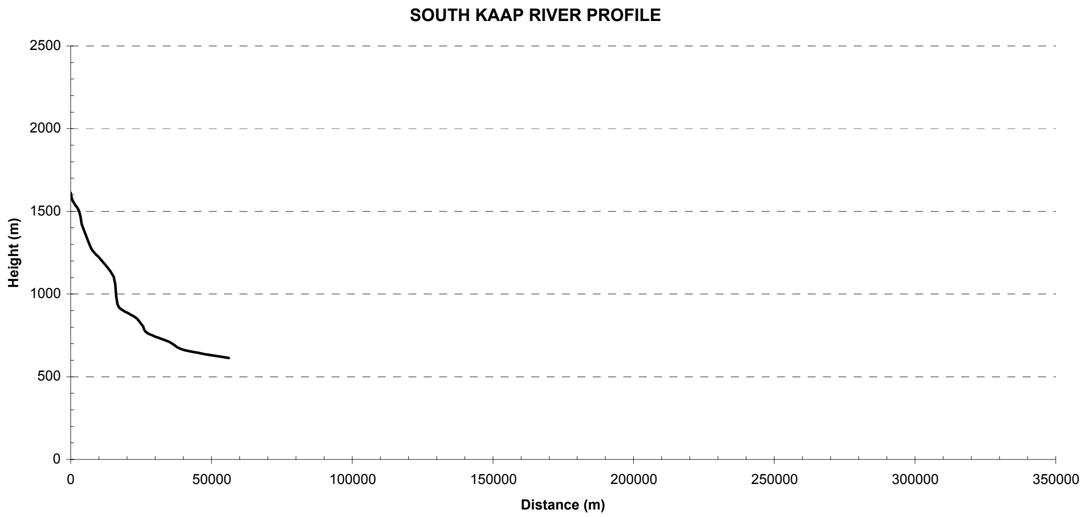






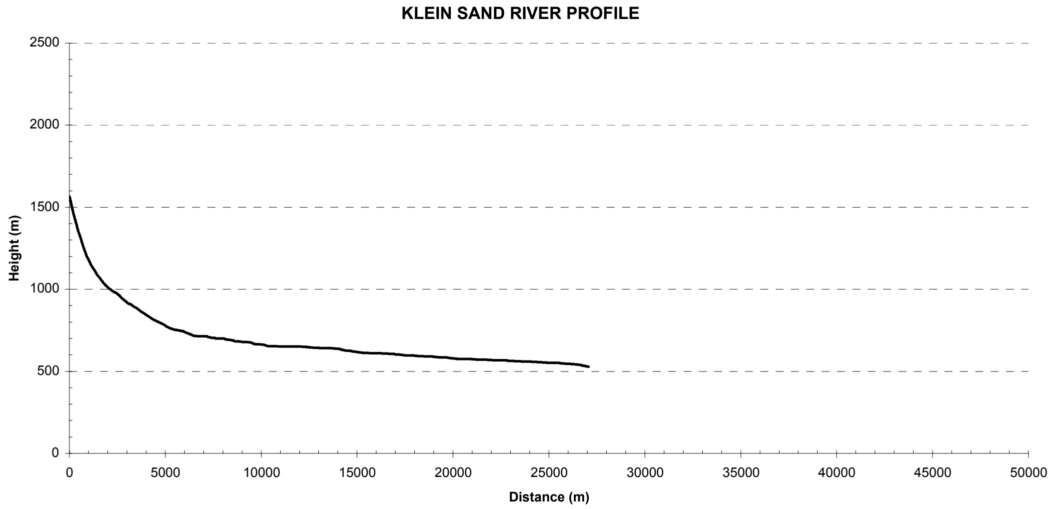
Crocodile catchment: Channel profiles (River length > 50km)

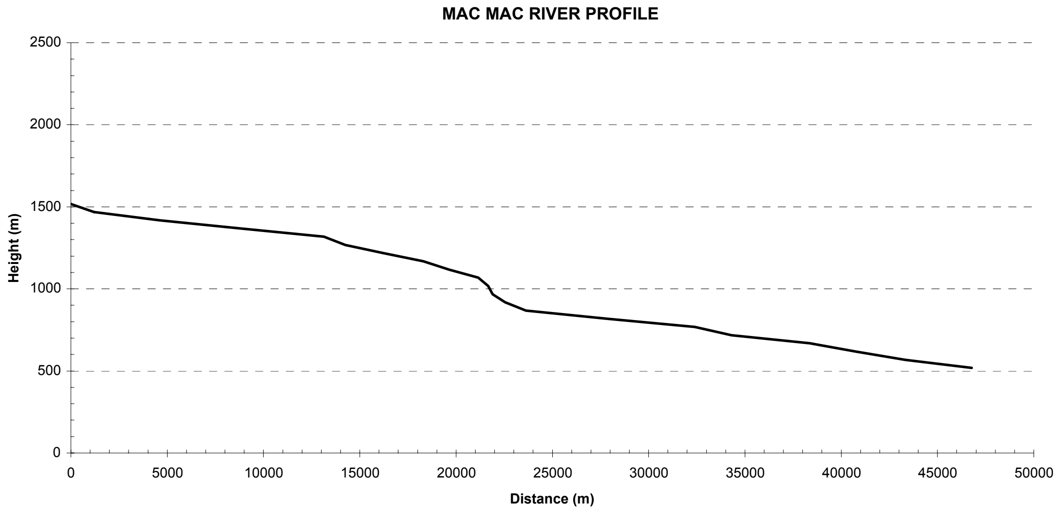


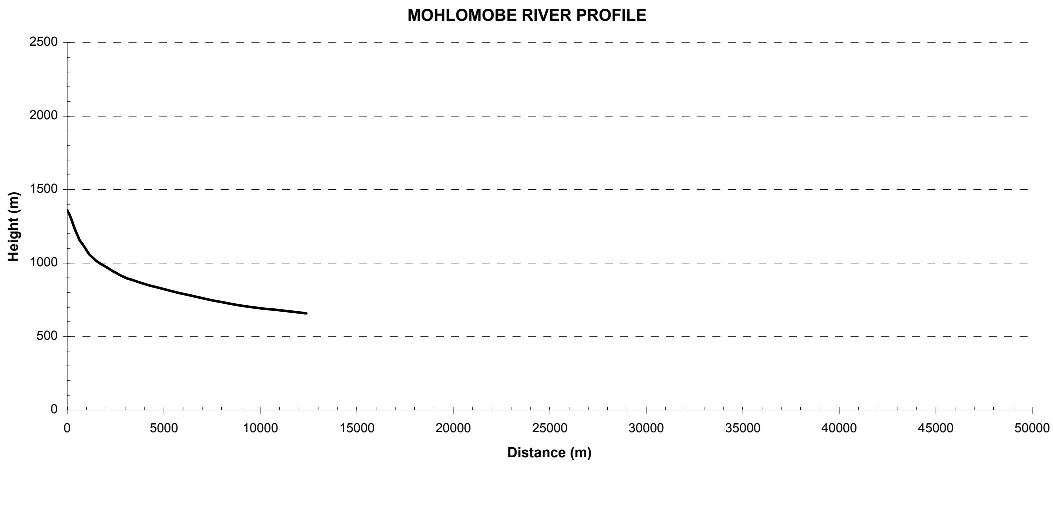
Crocodile catchment: Channel profiles (River length > 50km)

APPENDIX B

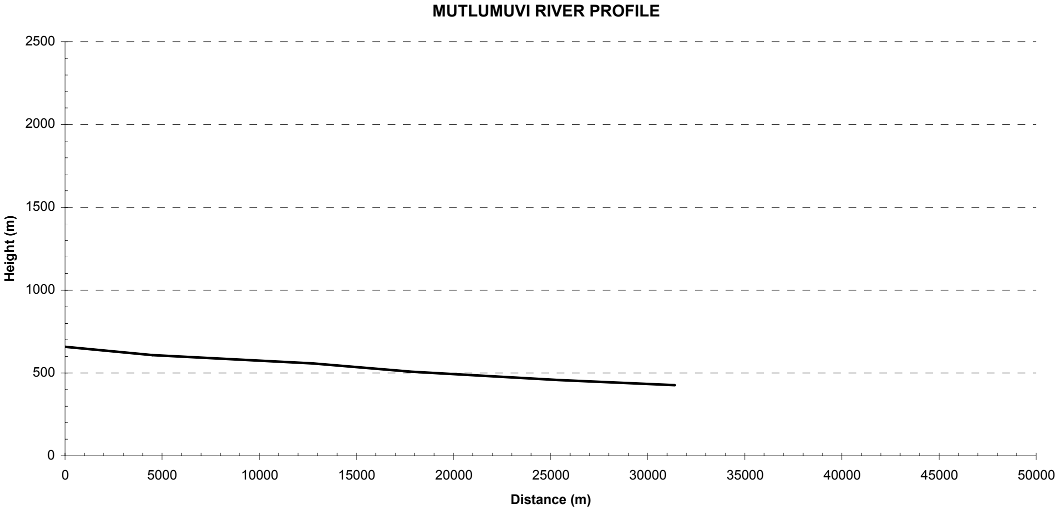
Sabie River Catchment Channel Profiles

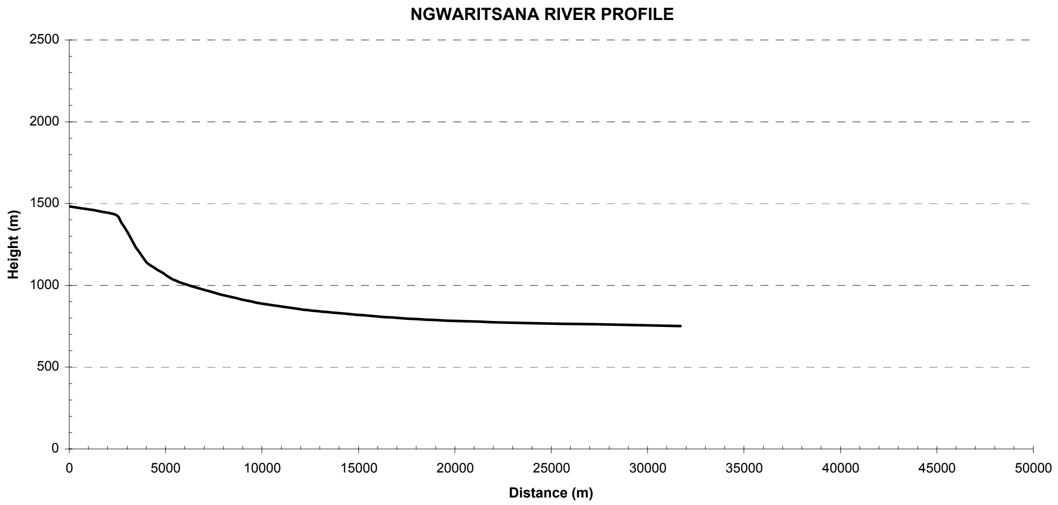


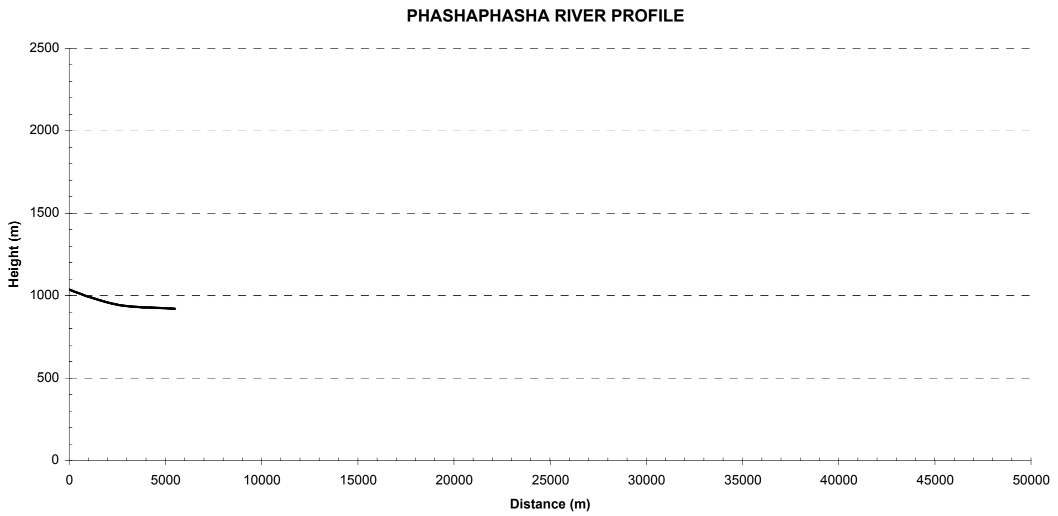




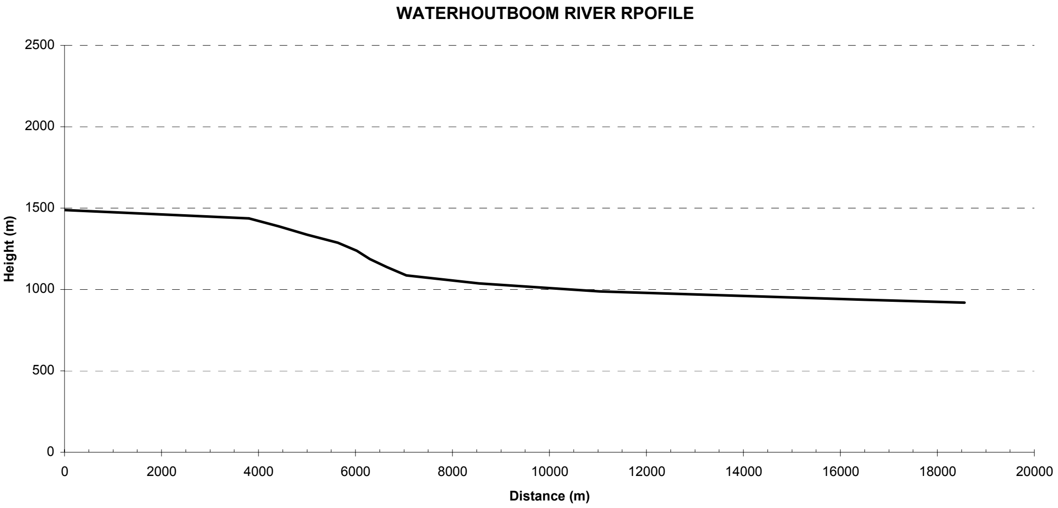
Sabie catchment: Channel profiles (River length < 50km)



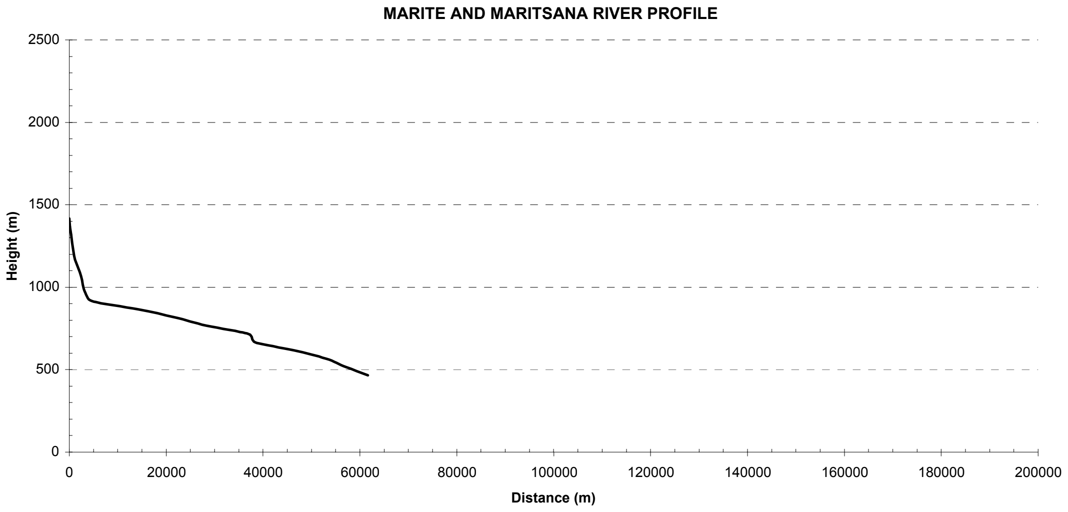


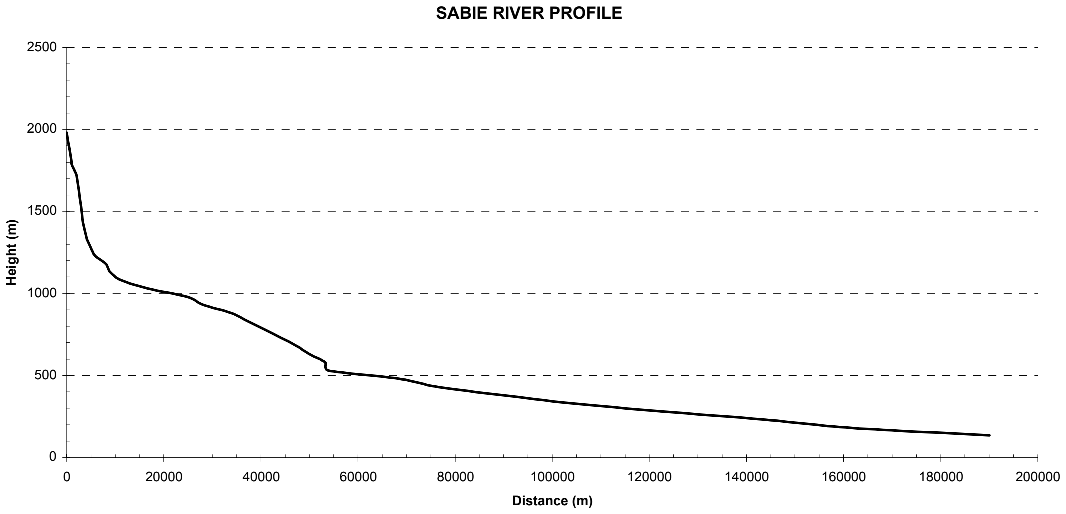


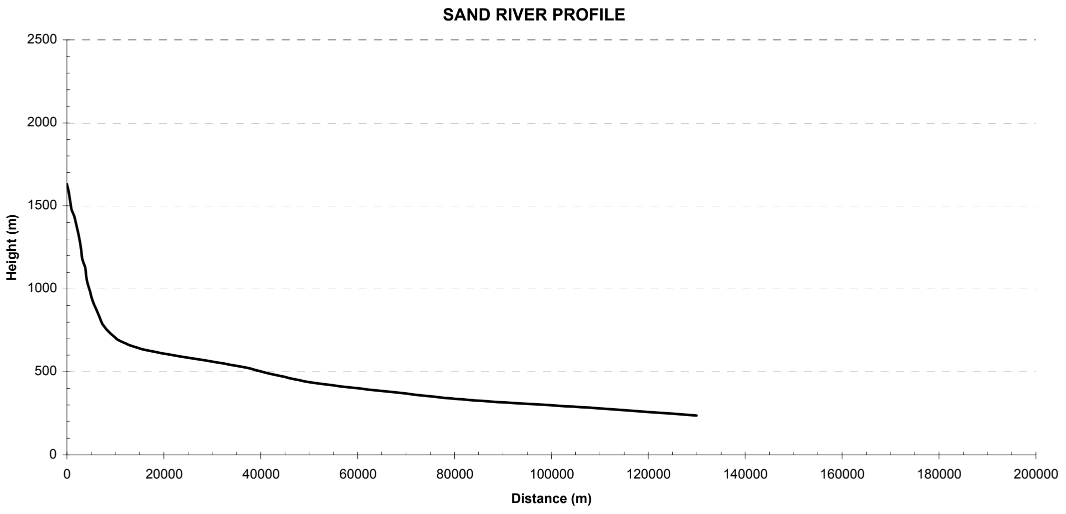
Sabie catchment: Channel profiles (River length < 50km)



Sabie catchment: Channel profiles (River length < 50km)



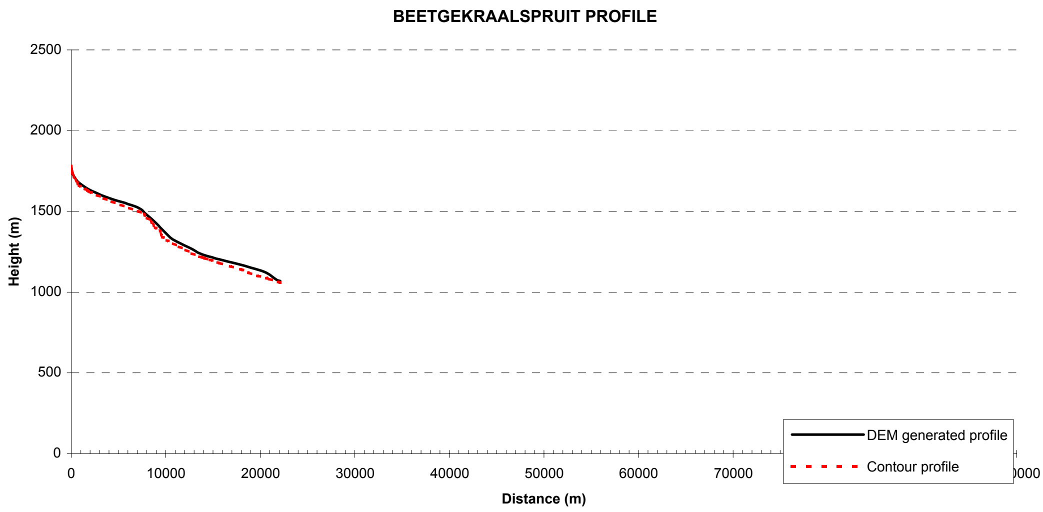


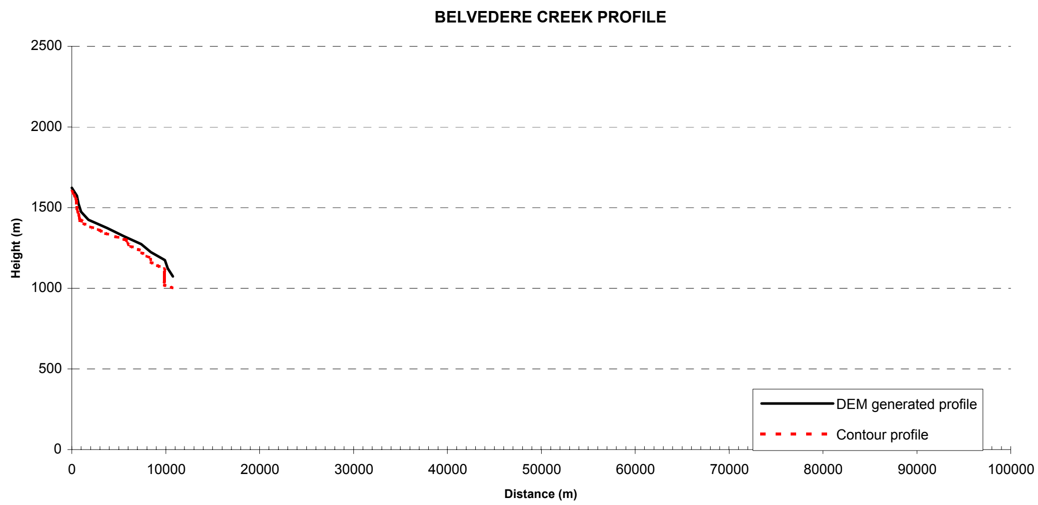


Sabie catchment: Channel profiles (River length > 50km)

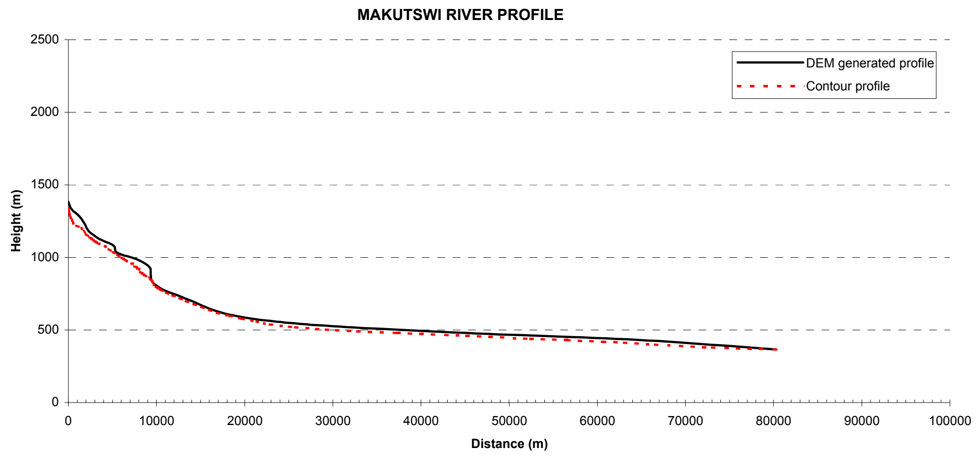
APPENDIX C

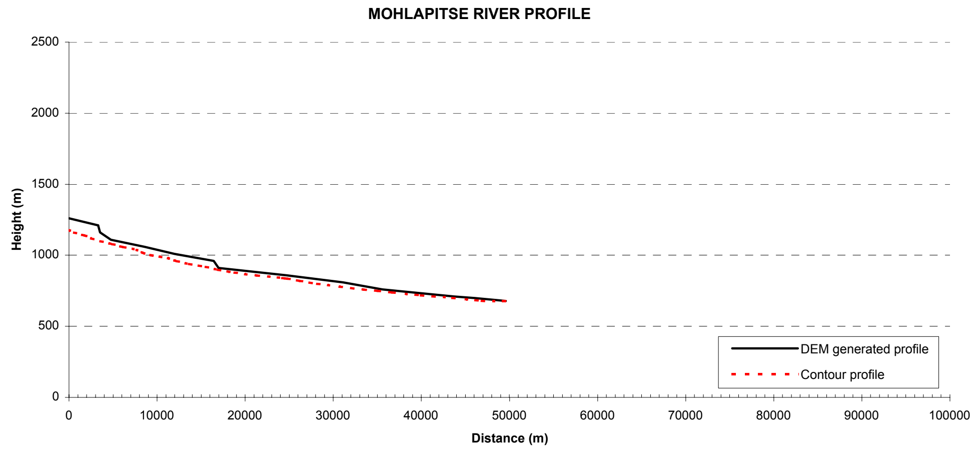
Olifants River Catchment Channel Profiles

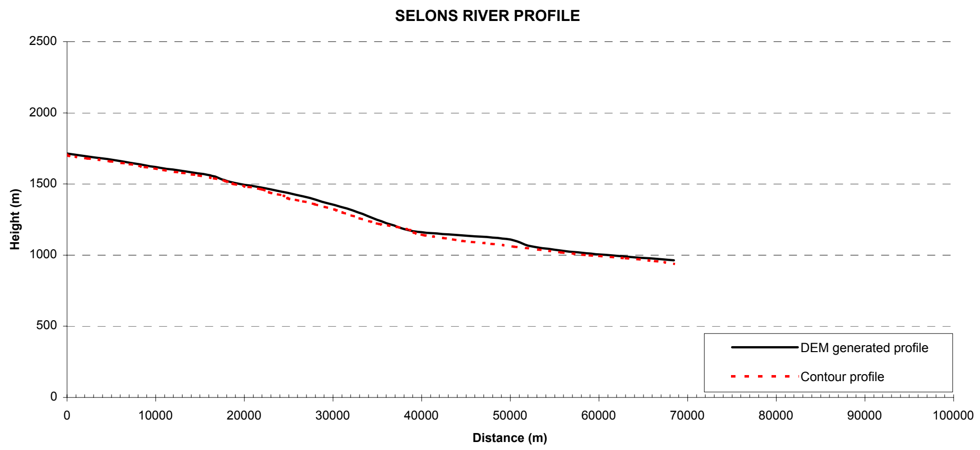




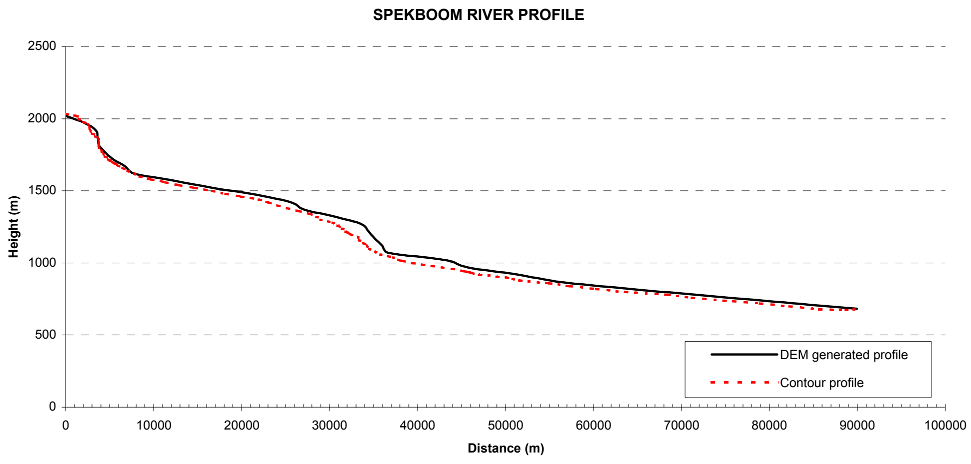
Olifants catchment: Channel profiles showing both the DEM calculated profiles and the profiles measured from 1:50 000 topographical maps (River length < 100km)

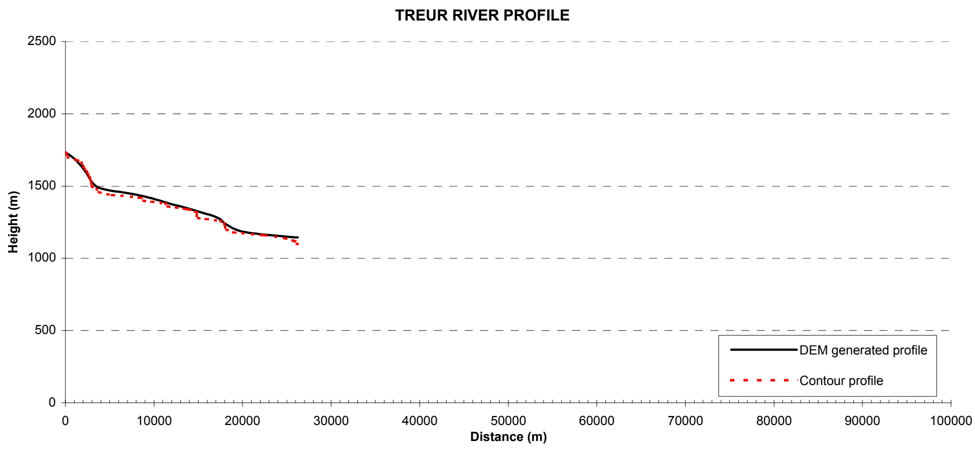


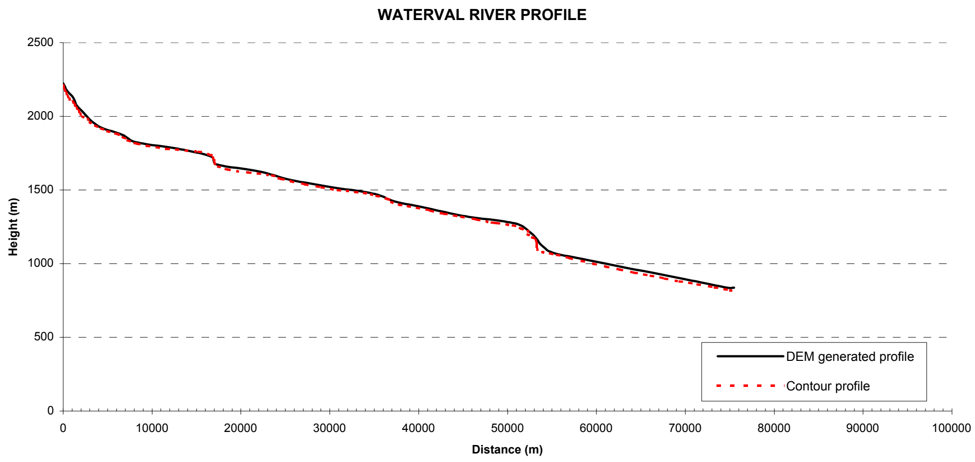




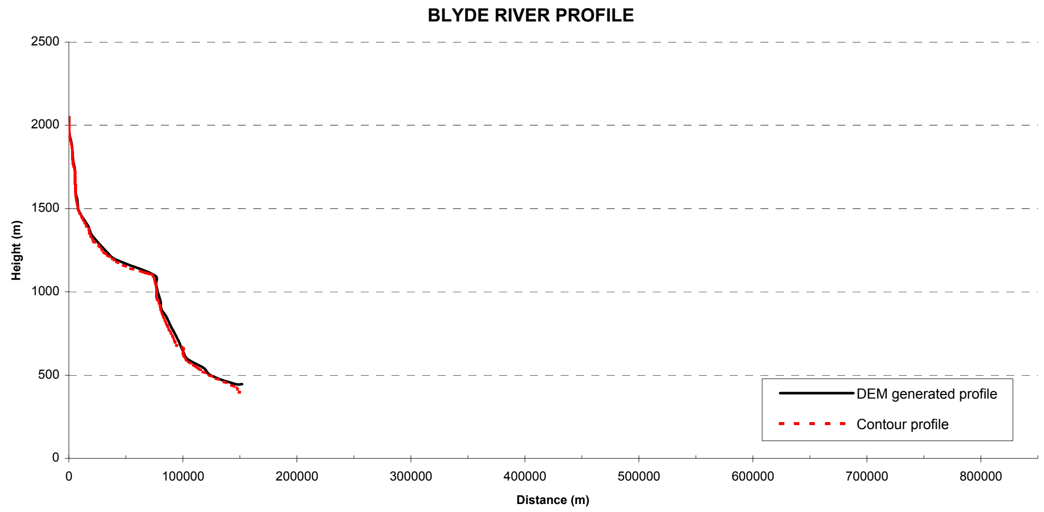
Olifants catchment: Channel profiles showing both the DEM calculated profiles and the profiles measured from 1:50 000 topographical maps (River length < 100km)

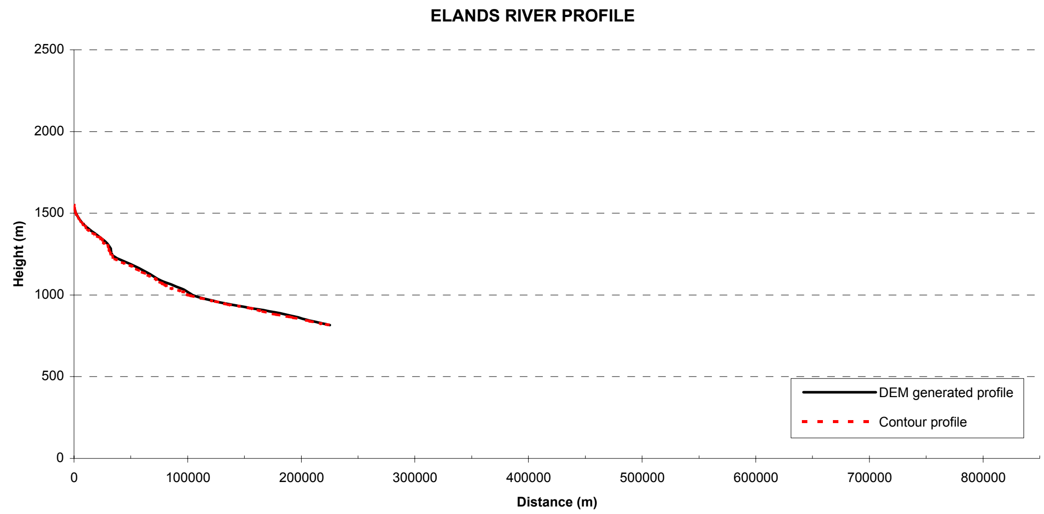


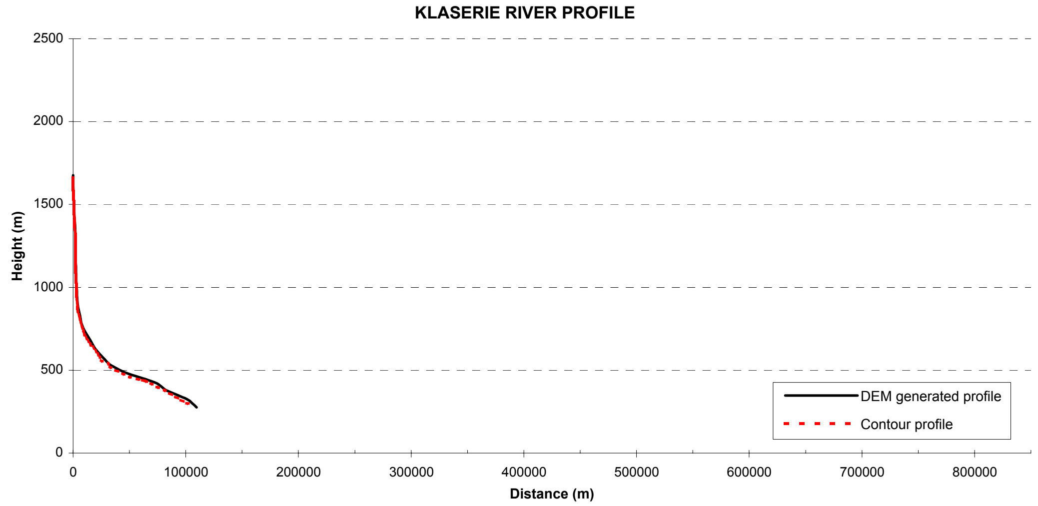




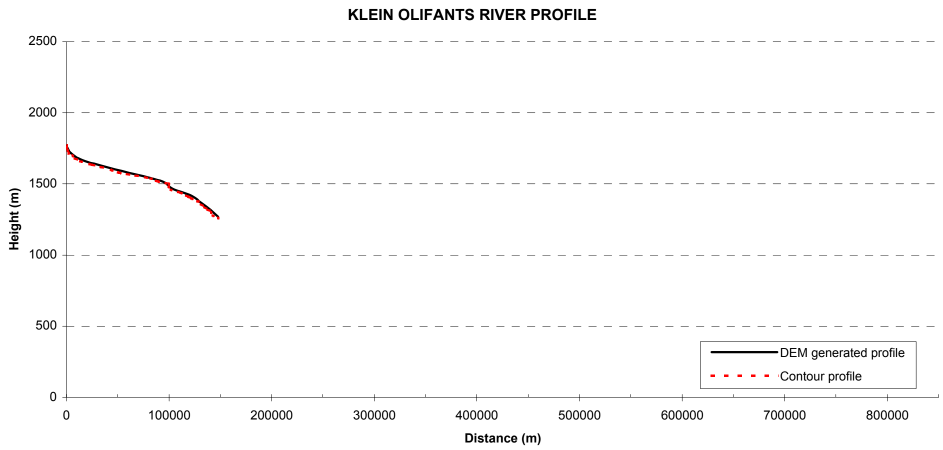
Olifants catchment: Channel profiles showing both the DEM calculated profiles and the profiles measured from 1:50 000 topographical maps (River length < 100km)

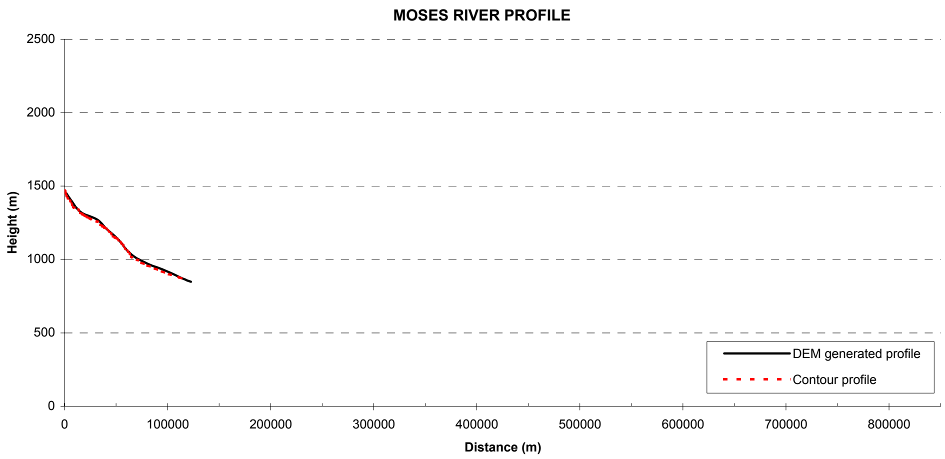


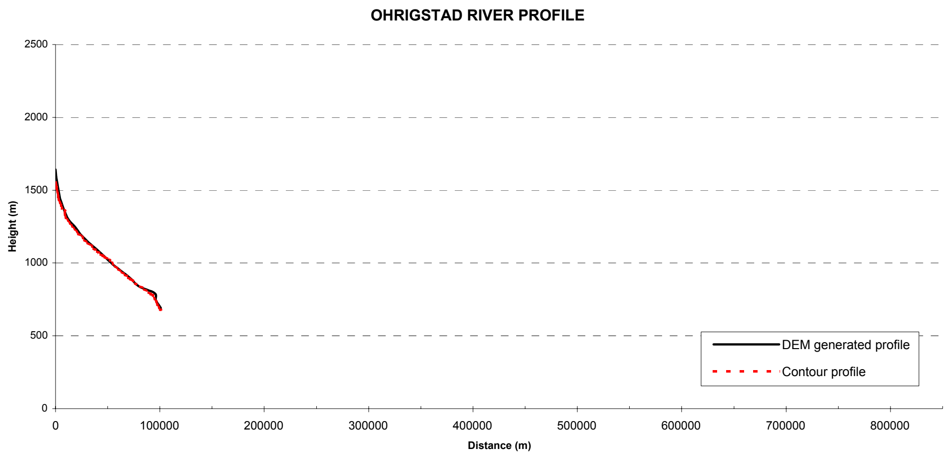




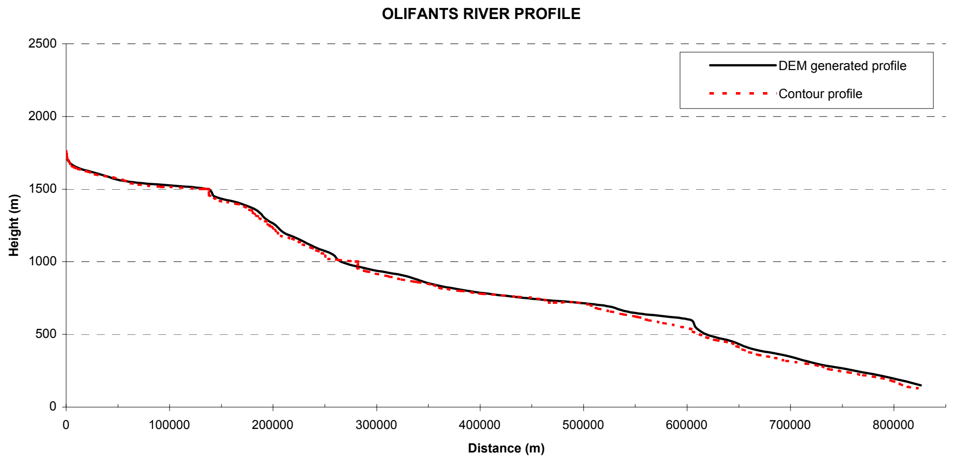
Olifants catchment: Channel profiles showing both the DEM calculated profiles and the profiles measured from 1:50 000 topographical maps (River length > 100km)

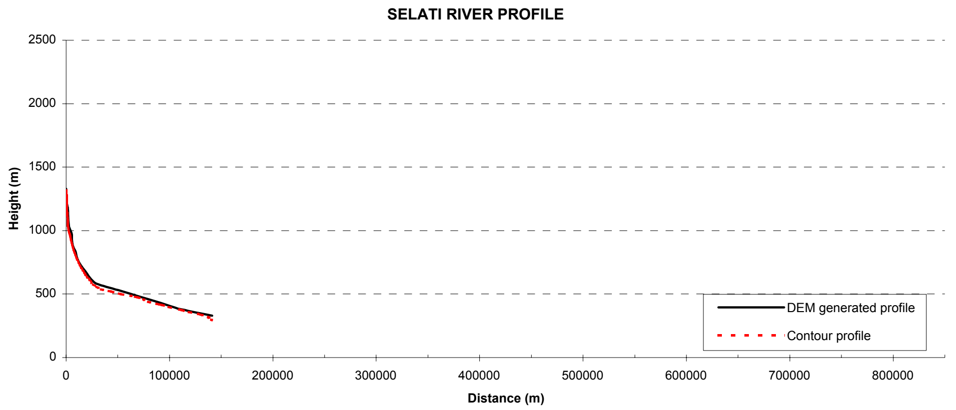


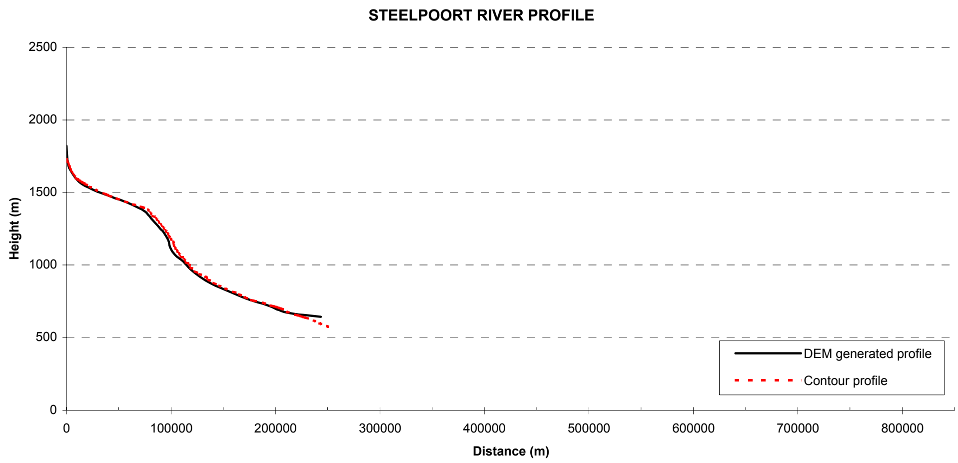




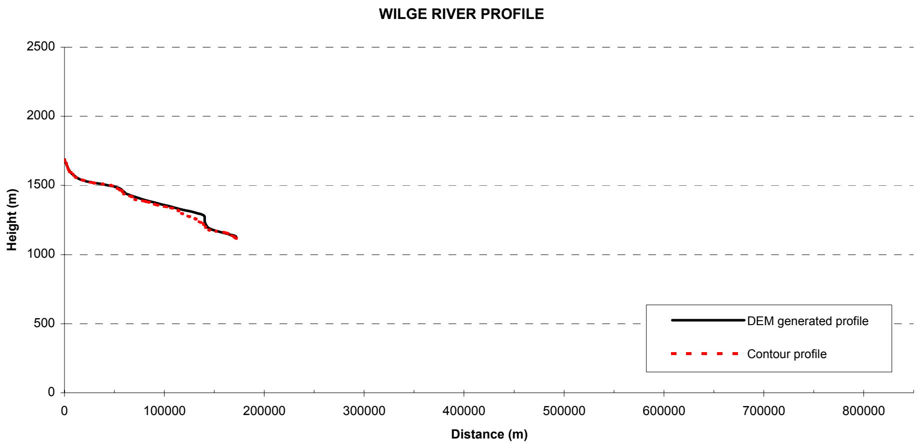
Olifants catchment: Channel profiles showing both the DEM calculated profiles and the profiles measured from 1:50 000 topographical maps (River length > 100km)







Olifants catchment: Channel profiles showing both the DEM calculated profiles and the profiles measured from 1:50 000 topographical maps (River length > 100km)



Olifants catchment: Channel profiles showing both the DEM calculated profiles and the profiles measured from 1:50 000 topographical maps (River length > 100km)