Annexure 2

Hydrology and Hydraulics

Hydrology & Hydraulic component of the Baviaanskloof Mega Reserve Study

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J&G project number: 02043

July 2009

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1. INTRODUCTION

The hydraulic state of a river system is important in the assessment of critical biotic habitat. The river hydraulics is measured and different flow options (for various ecological classes) are super-imposed onto these hydraulic data to ascertain whether there will be sufficient habitat for the key ecosystem components (invertebrates, fish and vegetation). For the purposes of a Rapid Ecological Reserve Determination, the hydraulic state of the river is calculated on a single specific day. This is to give indications of the following critical aspects for river hydrology:

- River discharge
- Flow depth
- Flow velocity

With these three river characteristics calculated, a Stage Discharge Curve can be generated. The flow velocity is multiplied by the cross-sectional area (average flow depth multiplied by channel width) to generate the discharge. The discharge is plotted against its maximum depth to create the Stage Discharge Curve. From this curve, simulated discharges can be converted to flow depths in order to assess the available river habitat at a specific discharge. Information on the available habitat at varying depths and velocities is critical for ecologists as it enables the determination of critical flows required to maintain the river in a satisfactory ecological state.

For this study, maintenance low flows and drought low flows were assessed for various ecological classes to determine if the desktop Reserve outputs for the rivers are environmentally sustainable.

2. METHODOLOGY

A total survey station was used to determine the channel cross-section at each EWR site. The cross-sections are shown in the results section, with the flow depths for the various measurements and flow simulation outputs superimposed. Using the reference point as the zero mark, the cross-section for each site was logged using the total survey station. Flow velocities were recorded at each measuring point on the cross section in order to determine discharge.

For all five EWR sites, the cross-section was measured at a moderately good site. Each site was measured across a straight part of the reach near a riffle site. This poses certain advantages and disadvantages:

Advantages

- Exact velocity, depth and discharge measurements taken at critical biotopes
- Limited amounts of turbulent water increases the accuracy of the calculations
- No obstructions from external sources, such as overhanging vegetation
- All the sites were on a straight section of river reach

Disadvantages

- Moderately turbulent water in places, hence loss in accuracy of the velocity readings
- Shallow water increase error margins in the depth-flow measurements
- The Groot site was located just before a low level causeway across the river.

In view of the above, the disadvantages are important form a hydraulics perspective. The results will still be satisfactory for use but the confidence in the results will be moderate to good. Once these measurements were obtained, the discharge calculation could begin.

Discharge was calculated by multiplying cross-sectional area by flow velocity. The flow velocity was measured using a propeller type flow rate meter (MeBflügel Current Meter with a No. 3 Shaufel Propeller). The number of revolutions of the propeller was converted to the respective velocity using the equation supplied by the flow rate meter manufacturer, Equations 1 and 2.

Equation 1: where $n < 0.6$ rev/s

$$V = 0.2281(n) + 0.015$$

Equation 2: where $n > 0.6$ rev/s

$$V = 0.2514(n) + 0.001$$

where:

n = number of revolutions of the propeller in 30 seconds

V = velocity of flow in meters per second (m/s)

The flow rate meter has a propeller diameter of 50mm and a pitch of 250mm. For this type of investigation it is assumed that the mean velocity per vertical (sub-section of total cross-section) is four-tenths of the depth from the stream bed upwards (0.4D). The preferred method is to take two velocity measurements per vertical, at 20 and 80 percent of the total depth. These values are then put into an equation to get the average stream velocity for the vertical. Based on the depth of the river at a respective measuring point, either 0.4D or 0.2D and 0.8D were measured. 0.4D was only used when in shallow water and it would make for inaccurate measurements attempting to measure the 0.2D and 0.8D.

The cross-sectional area of the channel profile was calculated by dividing the cross-section up into smaller rectangles based on where the velocity points were measured, Verticals. These Verticals were multiplied by their corresponding velocity to get the discharge in cubic meters per second of flow. All the individual subdivisions' discharges were added to get the total discharge for the respective river, Equation 3.

Equation 3: $$Q = {}_{i}\sum^{n} w_i D_i v_i$$

Where:

Q = Discharge volume (m^3.s-1)

w = Width of subsection (m)

D = Depth of Vertical (m)

V = Mean velocity (m.s-1)

The calculated discharge is plotted against the maximum depth of the measured flow. This is the first point needed to create the Staged Discharge Curve. At least two other points are required, and often more than two are used. The additional points are determined by generating discharge values for different depths using Manning's equation, Equation 4.

Equation 4: $$Q = (1/n) * A * R^{2/3} * S^{1/2}$$

Where:

n = Manning's coefficient of roughness

R = Area/Wetted perimeter (m)

S = Channel slope (Ratio)

A = Area (m2)

Using Equation 4, modelled discharges for a specific depth can be generated by entering Manning's coefficient of roughness. The coefficient for each site was obtained by calculating Manning's n value from the initial discharge figure, measured cross-sectional area and the measured slope of the reach. The other input characteristics are dependant on the cross-section, which changes with depth (i.e. wetted perimeter and cross-sectional area). The data is already known from the cross-sectional data determined from the total survey station. Thus, Staged Discharge Curves were generated for the Baviaanskloof, Wit, Groot and Kouga rivers.

At this stage, EWR values for different ecological classes (REC) were generated by the SPATSIM model. These discharges are converted to depths for each EWR site. The depths are calculated using Equation 5.

Equation 5: $D = \alpha * Q^{\mu}$

Table 1 shows the regression coefficients (α, μ and Manning's n) determined from the stage discharge curves at each EWR site.

Table 1: Regression coefficients used to calculated flow depth from measured discharge

Site	α	μ	n
Baviaanskloof Upstream	0.8184	0.4164	0.245
Baviaanskloof Downstream	0.4788	0.4636	0.087
Wit River	0.8023	0.4534	0.378
Groot River	0.3618	0.4259	0.042
Kouga Downstream	0.5159	0.3305	0.085

The depths are plotted on the cross-sectional profile for each EWR site and used by the aquatic ecologists to determine whether there is sufficient critical habitat for the resident biota in the respective river systems to maintain the recommended ecological state. The following section deals with the results produced from transposing the calculated depths of different environmental flows onto the channel cross-sections.

3. RESULTS

3.1. SITE SELECTION

The GPS coordinates for each cross-section are shown in Table 2.

Table 2: Cross-section co-ordinates for the 5 EWR sites assessed

SITE	SITE CODE	LATITUDE	LONGITUDE
Baviaanskloof upstream	BAV1	S 33°32 17.2	E 23°57'54.5"
Baviaanskloof downstream	BAV3	S 33°37'23.2"	E 24°16'10.9"
Wit River	WIT1	S 33°39'35.1"	E 24°32'05.3"
Groot River (a)	GRO1	S 33°41'41.7"	E 24°36'41.0"
Kouga downstream	KOU2	S 33°37'17.9"	E 24°01'31.4"

A brief description of the location of each hydraulic cross-section is given below.

3.1.1. Upper Baviaanskloof River (BAV1)

The BAV1 site is located at a low water bridge crossing the Baviaanskloof River (Figure 1). The hydraulic cross-section was undertaken 10m upstream of the low water bridge (Figure 2).

Figure 1: Location of the hydraulic cross-section for BAV1, upstream of the bridge

Figure 2: Hydraulic cross-section at the BAV1 site

3.1.2. Lower Baviaanskloof River (BAV3)

BAV3 is situated within the Baviaanskloof Nature Reserve, located at the first instance the road crosses the river. The hydraulic cross-section were undertaken downstream of the bridge (Figure 3).

Figure 3: Location of the cross-section at BAV3

3.1.3. Wit River (WIT1)

Once you enter the Baviaanskloof Nature Reserve gate, the site is at the point where the road first crosses the Wit River. The hydraulic cross section was undertaken about 50m upstream of the where the road crosses the river (Figure 4).

Figure 4: Hydraulic cross-section for WIT1

3.1.4. Groot River (GRO1)

Once you have entered the Baviaanskloof, the site is located where the road crosses the river for the first time. The hydraulic cross-sections was undertaken downstream of the bridge were the SASS was conducted (Figure 5).

Figure 5: Hydraulic cross-section for GRO1 downstream of the bridge

3.1.5. Lower Kouga River (KOU2)

The hydraulic cross-section (Figure 6) was taken approximately 150m downstream of the bridge that crosses the Kouga River and 250m upstream from the DWAF gauging weir.

Figure 6: Location of the hydraulic cross-section for the KOU2 site

3.2. INFORMATION AVAILABILITY ASSESSMENT

Availability of information for the hydrology and hydraulic components are rated from 0 to 4 (Table 3). A score of 0 to 2 indicates that the level of information is adequate for an RERM, while a score of 3 indicates that it is adequate for an IERM and a score of 4 that it is adequate for a CERM. The confidence levels indicate the confidence of the specialists in the information available. A confidence rating of 5 is high whereas a score of 0 indicates no confidence.

Table 3: Assessment of the information availability for each study component

EWR component	Confidence Level	Information availability					Comments
		0	1	2	3	4	
Hydrology	2 - 3			X			The SPATSIM Desktop Reserve Model was conducted per scaled quaternary catchment using the natural flow data files from WR90 as input.
Hydraulics	4	X					One data point was conducted per site. Cross-sectional data including velocity readings were taken from a straight reach section with moderate to low turbulence, thus giving moderate to good accuracy in the discharge calculations.

3.3. SITE SUITABILITY ASSESSMENT

The evaluation of the suitability of the EWR sites with regards to the hydrology and hydraulics assessment is provided in Table 4.

Table 4: Site suitability assessment and confidence levels for all 5 EWR sites

Site	EWR Component	Conf. Level	Advantages	Disadvantages
BAV1	Hydrology	3	Sampling site near outlet of L81B quaternary catchment, decreasing inaccuracies caused by using area weighted hydrology.	Course and outdated monthly flow data from WR90 Area weighting of quaternary catchment hydrology
	Hydraulics	4	Straight section of river No obstructions Good flow conditions for velocity readings Close to critical SASS habitat to provide representative results	Small amount of pooling on side of the river affecting discharge accuracy
BAV3	Hydrology	3	Sampling site near outlet of L81D quaternary catchment, decreasing inaccuracies caused by using area weighted hydrology	Course and outdated monthly flow data from WR90 Area weighting of quaternary catchment hydrology
	Hydraulics	2	Hydraulics analysis directly at SASS sampling site for critical habitat areas Straight section of river	In-stream vegetation along transect decreasing accuracy Turbulent flow conditions decreasing accuracy
WIT1	Hydrology	1	Rough hydrology will provide an indication of the environmental flows required	Course and outdated monthly flow data from WR90 Extremely area weighted hydrology with catchment in the headwaters of the quaternary catchment where source hydrology was adopted
	Hydraulics	3	Straight section of river No obstructions Good flow conditions for velocity readings Close to critical SASS habitat to provide representative results	Some rocks and cobbles in transect Small amount of in-stream vegetation
GRO1	Hydrology	4	Sampling site near outlet of L70G quaternary catchment, decreasing inaccuracies caused by using area weighted hydrology	Course and outdated monthly flow data from WR90 Area weighting of quaternary catchment hydrology
	Hydraulics	1	Straight section of river Mostly good flow conditions for velocity readings	Not near critical SASS habitat Low level causeway downstream of cross-section reducing hydraulics accuracy Pooling occurring near the bank on both sides of the river Small but significant tributary joining downstream also affecting accuracy
KOU2	Hydrology	4	Sampling site at outlet of L82D quaternary catchment, removing inaccuracies caused by using area weighted hydrology	Course and outdated monthly flow data from WR90
	Hydraulics	4	Discharge determined from gauging weir slightly downstream of the site	Any construction or measuring inaccuracies in the gauge itself Not near critical SASS habitat

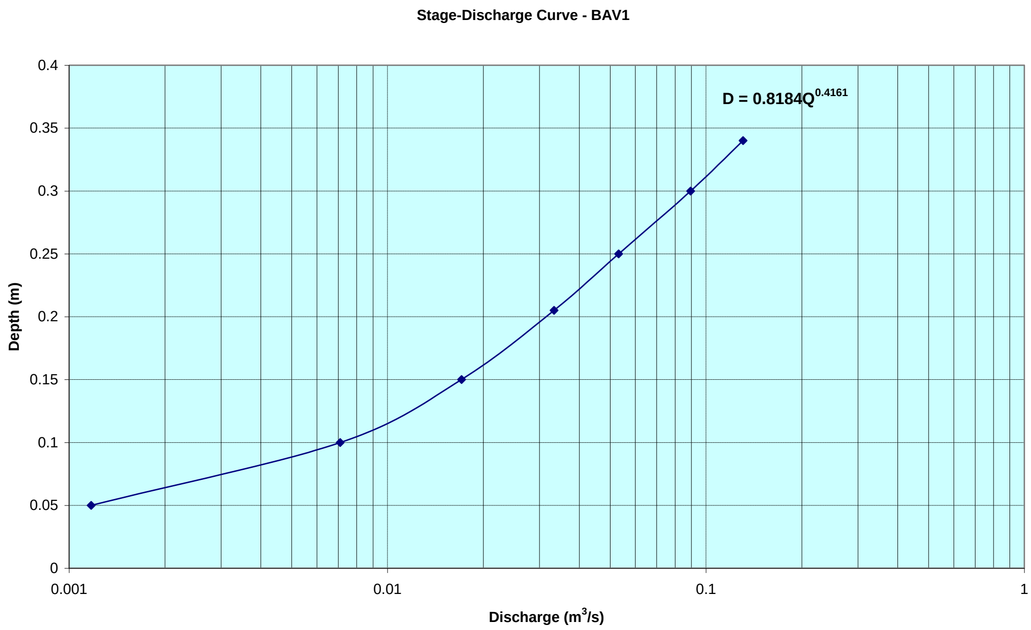
3.4. STAGE DISCHARGE CURVES

The calculated discharge and measured maximum depth of the cross-sections for each EWR site is summarised in Table 5.

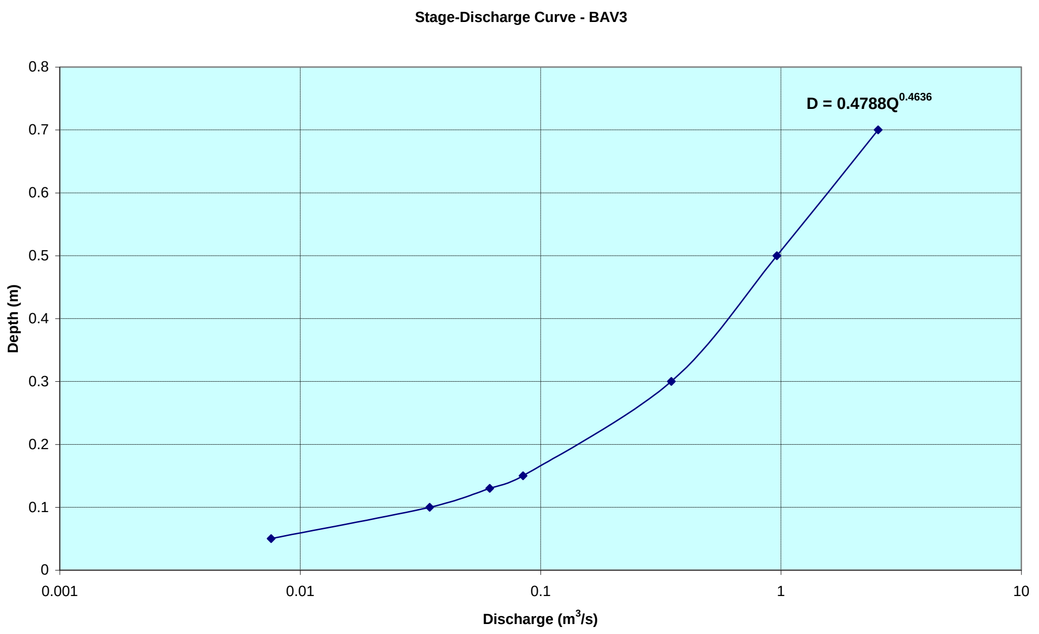
Table 5: Summary site characteristics for all five EWR sites

Site	Calculated Discharge (m^3/s)	Measured maximum Depth (m)
Baviaanskloof Upstream (BAV1)	0.033	0.205
Baviaanskloof Downstream (BAV3)	0.061	0.130
Wit River (WIT1)	0.038	0.180
Groot River (GRO1)	0.318	0.210
Kouga Downstream (KOU2)	2.809	0.850

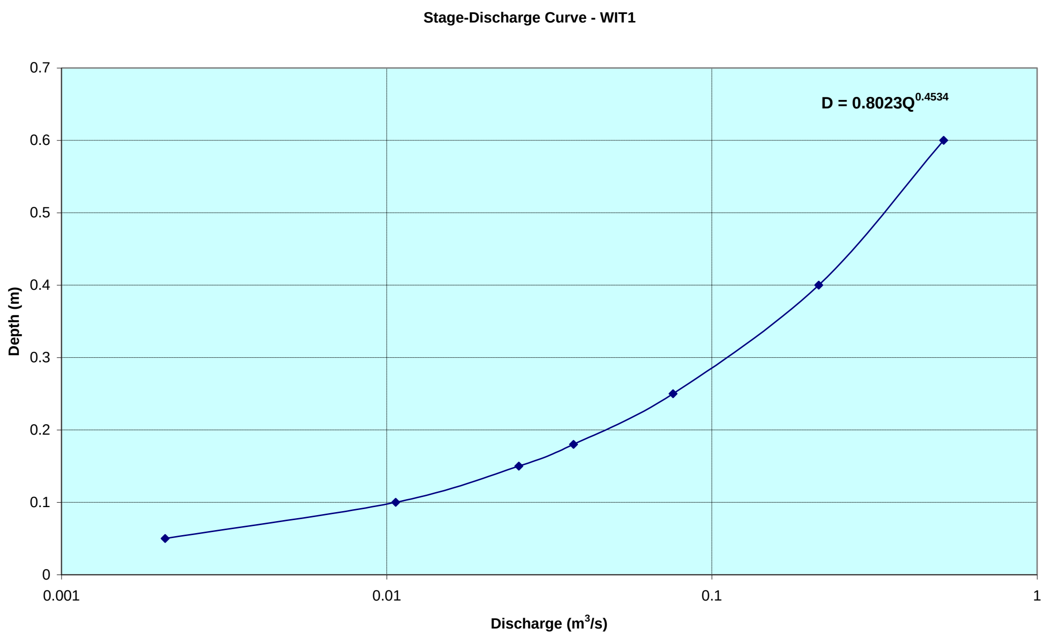
Staged Discharge Curves generated for each EWR site are presented in Graph 1 to Graph 5.



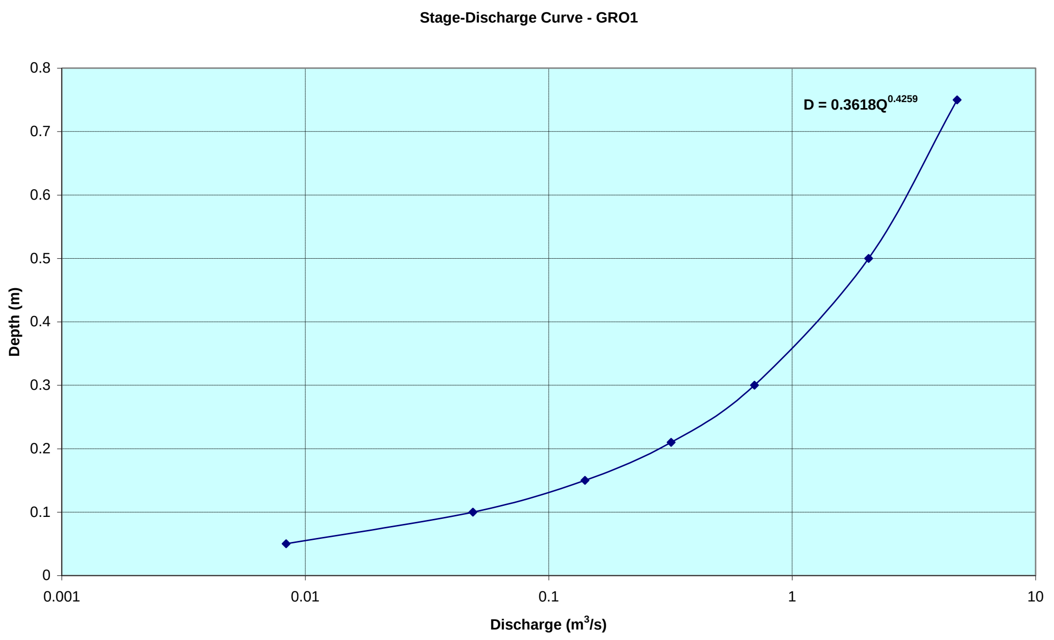
Graph 1: Stage Discharge Curve for the Baviaanskloof River upstream (BAV1)



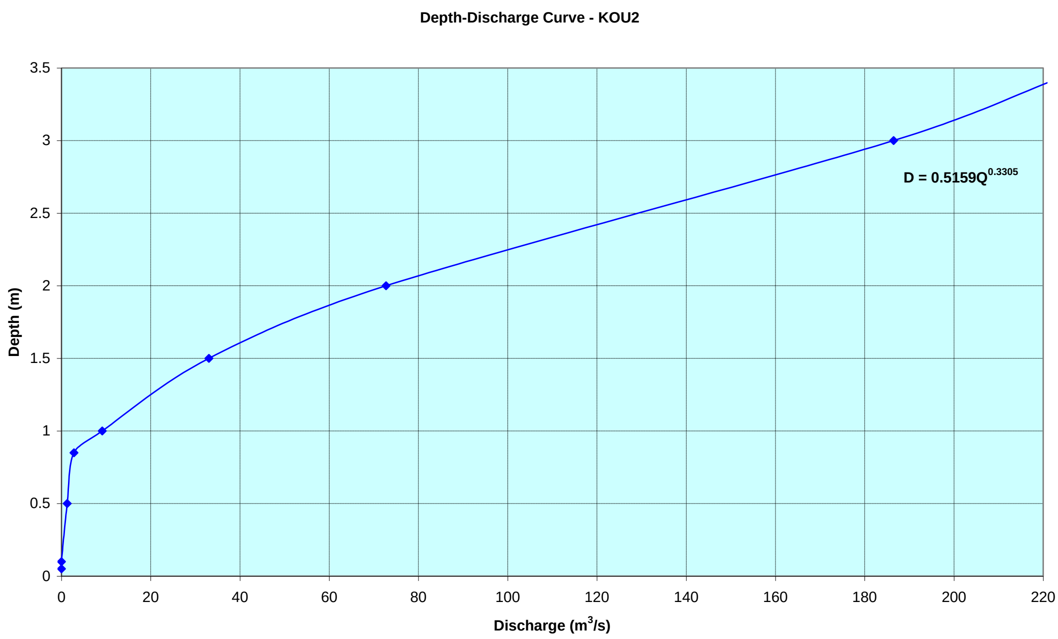
Graph 2: Stage Discharge Curve for the Baviaanskloof River downstream (BAV3)



Graph 3: Stage Discharge Curve for the Wit River (WIT1)



Graph 4: Stage Discharge Curve for the Groot River (GRO1)



Graph 5: Stage Discharge Curve for the Kouga River downstream (KOU2)

3.5. CROSS-SECTION RESULTS

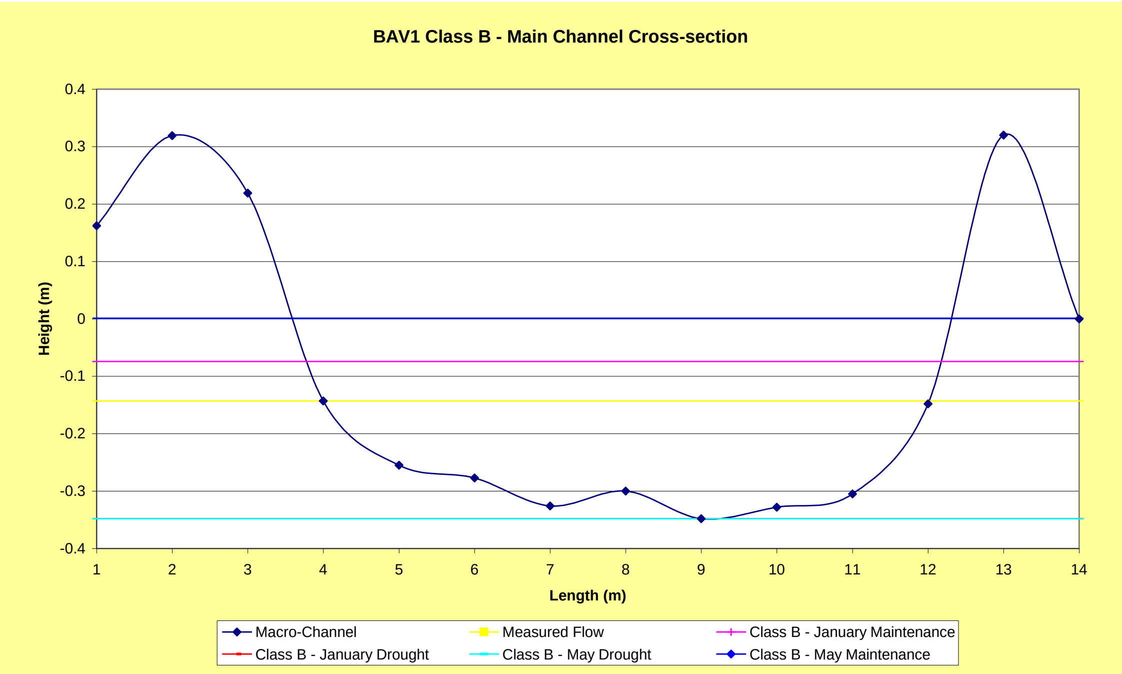
The results for each EWR site is represented graphically and in a summary table for each cross-section. For each EWR site the months with the lowest and highest total EWR values were plotted on the cross-section as the dry and wet season respectively.

3.5.1. Baviaanskloof River

Flows for the upper Baviaanskloof River site (BAV1) were simulated for a Recommended Ecological Class (REC) of B. Table 6 shows a summary of the measured, simulated and calculated discharge, average velocity and the average and maximum depths for the various simulated flows. Graph 6 is a graphical representation of the flow depths transposed onto the cross-section for the upper Baviaanskloof River site.

Table 6: Summary statistics for the upper Baviaanskloof River site (BAV1); REC = B

BAV1	Discharge (m^3/s)	Depth of Flow in Cross-section Profile (m)		Average Velocity (m/s)
		Maximum Depth	Average Depth	
Measured Flow	0.033	0.205	0.127	0.070
Dry season maintenance - January	0.072	0.274	0.196	0.080
Dry season drought - January	0.000	0.000	0.000	0.000
Wet season maintenance – May	0.129	0.349	0.271	0.081
Wet season drought - May	0.000	0.000	0.000	0.000

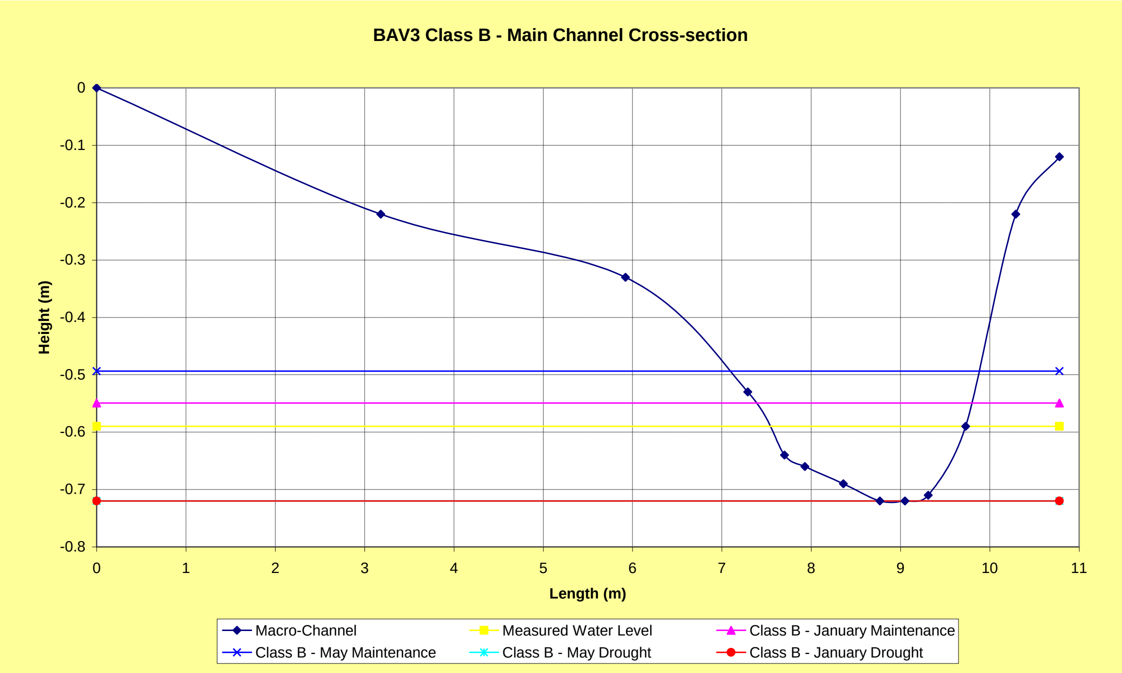


Graph 6: BAV1 cross-section with measured and environmental flow depths transposed

Flows for the lower Baviaanskloof River site (BAV3) were simulated for a Recommended Ecological Class (REC) of B. Table 7 shows a summary of the measured, simulated and calculated discharge, average velocity and the average and maximum depths for the various simulated flows. Graph 7 is a graphical representation of the flow depths transposed onto the cross-section for the upper Baviaanskloof River site.

Table 7: Summary statistics for the lower Baviaanskloof River site (BAV3); REC = B

BAV3	Discharge (m^3/s)	Depth of Flow in Cross-section Profile (m)		Average Velocity (m/s)
		Maximum Depth	Average Depth	
Measure Flow	0.061	0.130	0.068	0.314
Dry season maintenance - January	0.108	0.171	0.126	0.370
Dry season drought - January	0.000	0.000	0.000	0.000
Wet season maintenance - May	0.199	0.227	0.164	0.454
Wet season drought - May	0.000	0.000	0.000	0.000



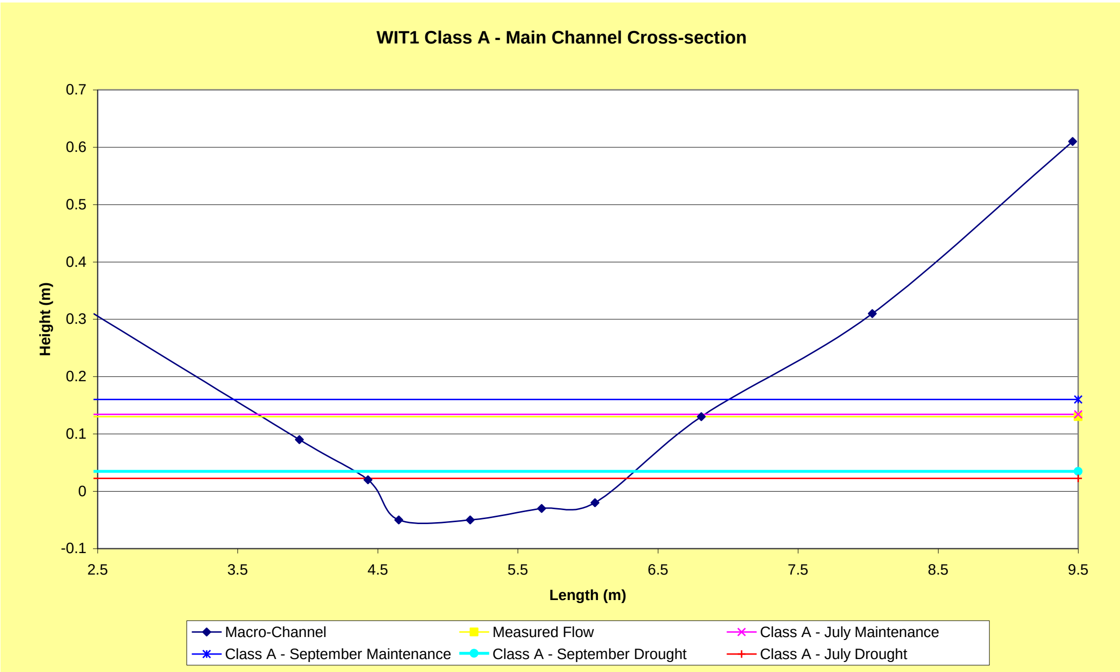
Graph 7: BAV3 cross-section with measured and environmental flow depths transposed

3.5.2. Wit River

The Wit River (WIT1) flows were simulated to provide for an REC of A. Table 8 and Graph 8 show the results for the Wit River site. Table 8 shows a summary of the measured, simulated and calculated discharge, average velocity and the average and maximum depths for the various simulated flows and Graph 8 the flow depths relationships transposed onto the cross-sectional profile.

Table 8: Summary statistics for Wit River site (WIT1); REC = A

WIT1	Discharge (m^3/s)	Depth of Flow in Cross-section Profile (m)		Average Velocity (m/s)
		Maximum Depth	Average depth	
Measure Flow	0.038	0.180	0.117	0.078
Dry season maintenance - June	0.039	0.184	0.121	0.078
Dr season drought - June	0.005	0.073	0.049	0.040
Wet season maintenance - September	0.052	0.210	0.147	0.085
Wet season drought - September	0.007	0.085	0.061	0.045



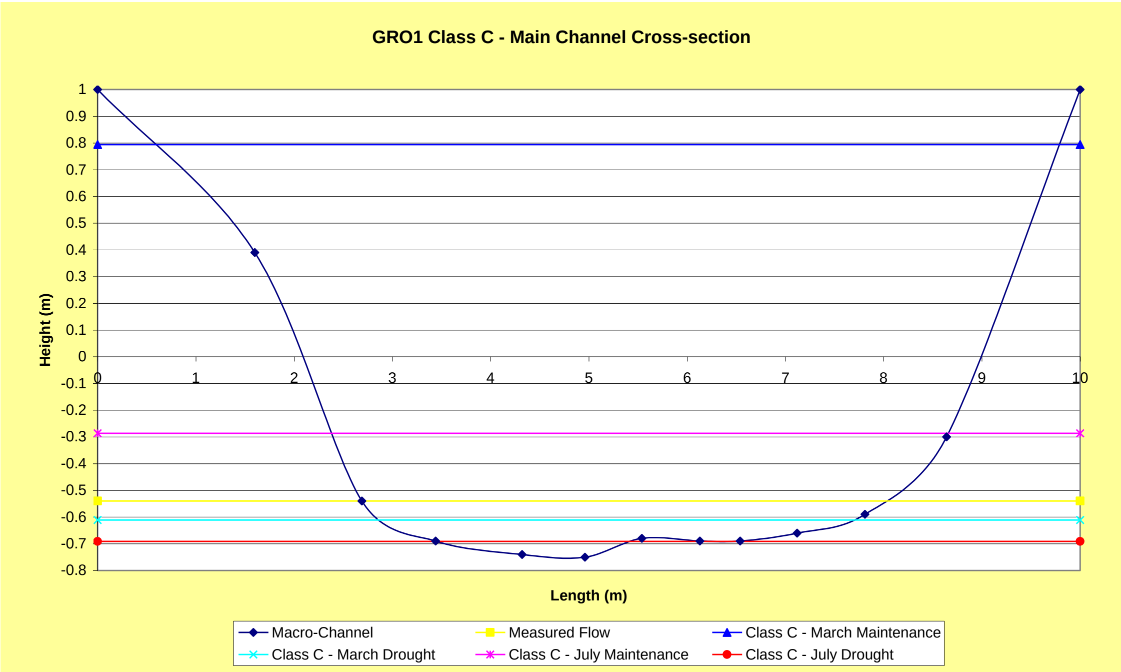
Graph 8: WIT1 cross-section with measured and environmental flow depths transposed

3.5.3. Groot River

The Groot River (GRO1) flows were simulated to provide for an REC of C. Table 9 and Graph 9 show the results for the Groot River site. Table 9 shows a summary of the measured, simulated and calculated discharge, average velocity and the average and maximum depths for the various simulated flows and Graph 9 the flow depths relationships transposed onto the cross-sectional profile.

Table 9: Summary statistics for the Groot River site (GRO1); REC = C

GRO1	Discharge (m^3/s)	Depth of Flow in Cross-section Profile (m)		Average Velocity (m/s)
		Maximum Depth	Average Depth	
Measure Flow	0.318	0.210	0.130	0.435
Dry season maintenance - July	0.140	0.383	0.157	0.302
Dry season drought - July	0.011	0.054	0.053	0.186
Wet season maintenance – March	0.930	1.464	0.351	0.602
Wet season drought - March	0.030	0.089	0.081	0.216



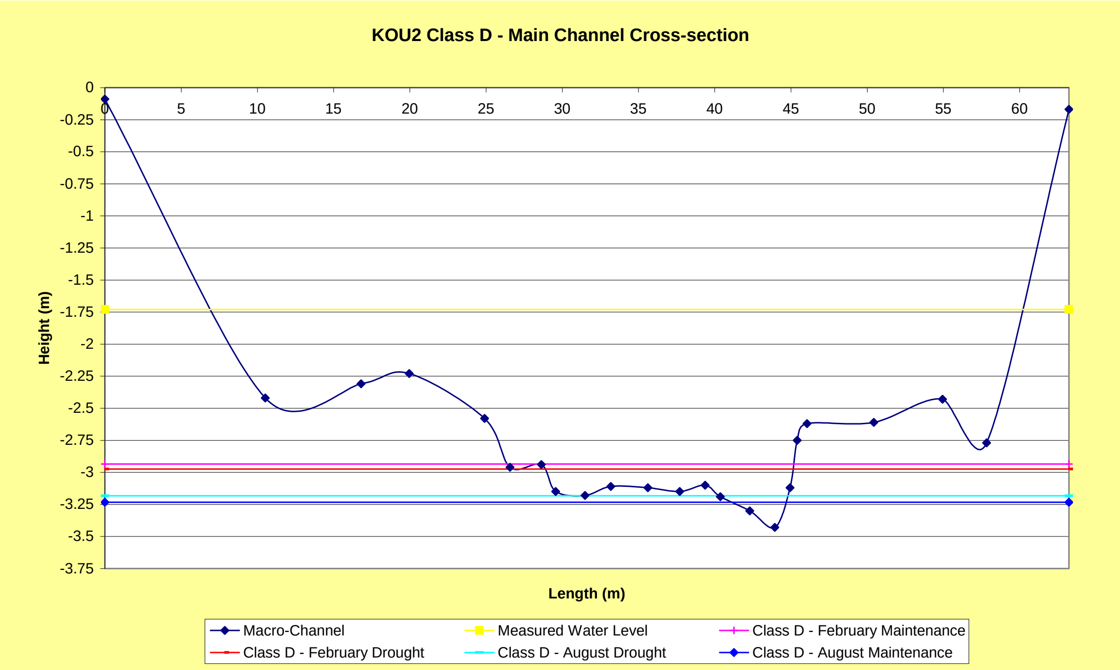
Graph 9: GRO1 cross-section with measured and environmental flow depths transposed

3.5.4. Kouga River downstream

The lower Kouga River site (KOU2) flows were simulated to provide for an REC of D. Table 10 and Graph 10 show the results for the Kouga River site. Table 10 shows a summary of the measured, simulated and calculated discharge, average velocity and the average and maximum depths for the various simulated flows and Graph 10 the flow depths relationships transposed onto the cross-sectional profile.

Table 10: Summary statistics for the lower Kouga River site (KOU2); REC = D

KOU2	Discharge (m^3/s)	Depth of Flow in Cross-section Profile (m)		Average Velocity (m/s)
		Maximum Depth	Average Depth	
Measure Flow	2.809	0.850	0.467	0.255
Dry season maintenance – February	0.883	0.495	0.211	0.248
Dry season drought - February	0.054	0.197	0.132	0.278
Wet season maintenance – August	0.684	0.455	0.210	1.503
Wet season drought - August	0.107	0.246	0.123	0.435



Graph 10: KOU2 cross-section with measured and environmental flow depths transposed

3.6. SUMMARY OF EWR ESTIMATES

The summary of the EWR estimates for each of the EWR site is presented in Table 11.

Table 11: Summary of EWR estimates for all 5 EWR sites

Variable	REC	Total natural MAR	Dominant Rule Region	Total IFR	Low flows		High Flows
					Maintenance	Drought	Maintenance
Unit		MCM (%MAR)					
BAV1	B	26.1	S.Karoo	6.966 (26.29%)	2.791 (10.69%)	0.342 (1.31%)	4.175 (16.00%)
BAV3	B	45.776	S.Karoo	12.228 (26.71%)	4.910 (10.73%)	0.608 (1.33%)	7.317 (15.99%)
WIT1	A	14.504	E.Karoo	5.906 (40.72%)	2.956 (20.38%)	0.373 (2.57%)	2.95 (20.34%)
GRO1	C	209.348	E.Karoo	37.679 (18.00%)	12.319 (5.88%)	3.12 (1.49%)	25.359 (12.11%)
KOU2	D	106.468	S.Karoo	12.708 (11.94%)	2.341 (2.2%)	2.036 (1.91%)	10.367 (9.74%)

4. CONFIDENCE IN HYDRAULIC MODELLING

The confidence in the hydraulic modelling conducted for this study is *moderate to high*. The cross-sectional data including velocity readings were taken from a suitable environment. This environment had moderate to low turbulence and thus provided moderately accurate readings for the final discharge values. Overall the remaining data was collected and used correctly in calculations increasing the confidence in the results presented in this document, thus resulting in a final confidence level of moderate to high.

5. CONCLUSIONS

The above results are reviewed by environmental experts to determine whether the instream flow requirements are sufficient for the sustainable functioning of the aquatic ecosystem.