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The uMkhomazi Water Project Phase 1: Module 1: Technical Feasibility Study: Raw Water

WATER REQUIREMENTS AND RETURN FLOWS REPORT

SUPPORTING DOCUMENT 1:

SEDIMENT YIELD REPORT

FINAL

OCTOBER 2014

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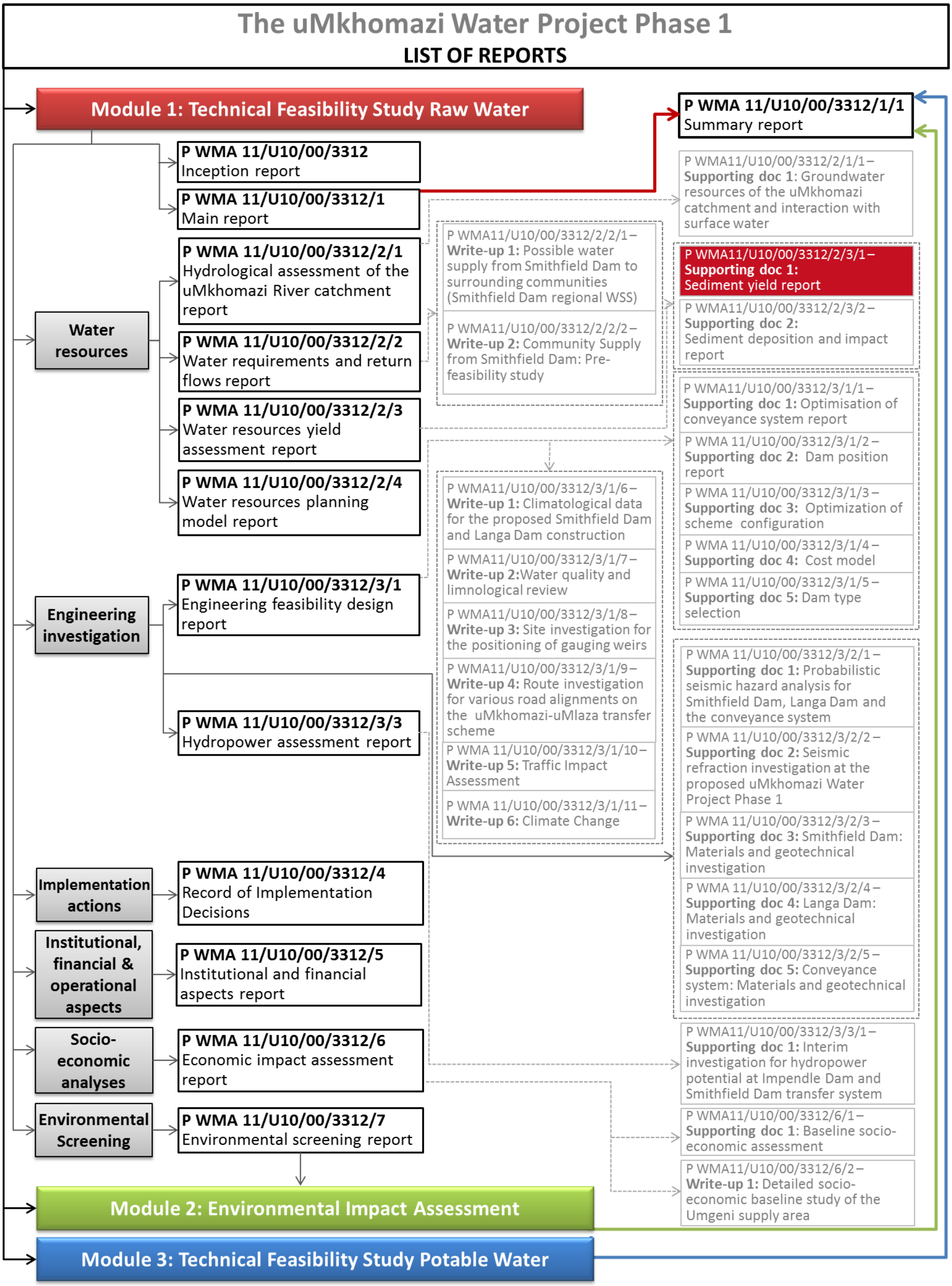
PREAMBLE

1. In June 2014, two years after the commencement of the uMkhomazi Water Project Phase 1 Feasibility Study, a new Department of Water and Sanitation was formed by Cabinet, including the formerly known Department of Water Affairs.

   In order to maintain consistent reporting, all reports emanating from Module 1 of the study will be published under the Department of Water Affairs name.

2. In September 2013, one year after the commencement of the uMkhomazi Water Project Phase 1 Feasibility Study, Sisonke District Municipality was renamed to Harry Gwala District Municipality, as published in the KZN Provincial Gazette 2013.

   The use of Sisonke District Municipality was adopted in numerous reports after the commencement of the study. Reference to Harry Gwala District Municipality was then addressed in reports emanating at a later stage of the study.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Executive summary

The proposed Impendle and Smithfield Dams are located on the uMkhomazi River in the Impendle District of KwaZulu-Natal. The uMkhomazi catchment is bordered by the Mooi and uMngeni River catchments to the north and the uMzimkulu River catchment to the south.

Reservoir sedimentation is dependent on catchment sediment yield, which is a function of catchment location and size, as well as sediment yield potential within the catchment. Selected information on the verification of catchment sediment yield of the proposed Impendle and Smithfield Dams and the potential impact thereof on the proposed dam development is subsequently presented. This includes information on the estimation of catchment sediment yield and the consequent reductions in future storage capacity that can be expected for the proposed reservoir. Since the implementation date of Impendle Dam is unknown at this stage, only the individual catchment sediment yields for Impendle and Smithfield Dams, respectively, are covered and not a combination of Smithfield Dam together with Impendle Dam. Other than the impact on storage capacity, no attention is given to the distribution patterns of deposited sediment within the proposed reservoir.

The most recent sediment yield predictions for the uMkhomazi River catchment were undertaken in 1998 for Umgeni Water, based on work undertaken in 1996 as part of the Mkomazi/Mooi-Mgeni Transfer Scheme Pre-Feasibility Study. Since then, additional catchment sediment yield information became available and a new catchment sediment yield prediction approach has been developed by the Water Research Commission. Based on this new approach an update on the uMkhomazi River catchment sediment yield is recommended.

Given the status of both Impendle and Smithfield as proposed dams, their respective catchment yields were determined by using generalised yield patterns in terms of the 1992 Sediment Yield Map and the 2010 Sediment Yield Prediction, comparing that to actual recorded sediment yield values of dams closest to the Impendle/Smithfield Dam catchment. Sediment yield prediction approaches based on the 1992 Sediment Yield Map and 2010 Sediment Yield Prediction allow for the provision of some statistical confidence. Although the most likely yield value for an area still has to be estimated with due consideration of the availability of sediment within the catchment as well as other factors which influence sediment yields, it is possible to associate some statistical meaning with an estimate and to bring catchment size into consideration.

In terms of the 1992 Sediment Yield Map the catchments of both Impendle and Smithfield Dams relate to:

- *A regional standardised catchment sediment yield of 155 t/km²/a to be the average site specific catchment sediment yield.*
- *A maximum foreseeable catchment sediment yield of 310 t/km²/a based on some statistical confidence around the mean with a confident multiplication factor of 2 assumed for the 80%, 90% and 95% confidence bands.*

In terms of the 2010 Sediment Yield Prediction the catchments of both Impendle and Smithfield Dams relate to:

- *An average catchment sediment yield in the order of 142.5 t/km²/a, which compares well with the 1992 Sediment Yield Value average regional value of 155 t/km²/a.*
- *An assumed 80% confidence catchment sediment yield of 200 t/km²/a on average, a 90% confidence catchment sediment yield varies between 340 to 320 t/km²/a, respectively.*

No major existing dams are located in the uMkhomazi River catchment. The closest large dams are the Midmar, Albert Falls, Nagle and Inanda Dams on the uMngeni River, Wagendrift Dam on the Bushmans River, Craigieburn Dam on the Mnyamvubu River, Henley Dam on the uMzunduze River, Shongweni Dam on the uMlaza River, and the Kilburn, Woodstock and Spioenkop Dams on the uThukela River System.

Available dam survey information based on the 2012 DWA Hydrographic Surveys Dam List for the abovementioned dams, excluding Nagle Dam, are provided in ***Table i*** *in terms of location number, recorded period, sediment volume at end of period (V_T), equivalent 50-year sediment volume (V_{50}) effective catchment area (A_e) and average catchment sediment yield.*

Table i: Recorded reservoir and catchment sedimentation yield

River		uMngeni			uMzunduze	uMlaza	Bushmans	Mnyamvubu	Mnjaneni	uThukela	
Dam		Midmar	Albert Falls	Inanda	Henley	Shongweni	Wagendrift	Craigieburn	Kilburn	Woodstock	Spioenkop
Record period	Date of dam construction	1965	1974	1988	1942	1927	1963	1963	1981	1982	1972
	Date of latest survey	1996	1983	2009	1987	1990	1999	2003	1993	1999	2001
	Survey record length	31	9	21	45	63	36	40	12	17	29
Original capacity (V_W) (million m³)		177.349	289.462	258.676	5.867	12.061	60.001	25.918	35.966	381.306	285.995
Latest capacity at full supply level (million m³)		175.056	289.167	246.56	5.407	4.504	55.900	23.070	35.577	373.260	272.266
Capacity lost (%)		1.3	0.1	4.7	7.8	62.7	6.8	11.0	1.1	2.1	4.8
Volume of sediment deposit (V_T) (million m³)		2.293	0.295	12.116	0.47	7.557	4.101	2.848	0.389	8.046	13.729
Equivalent 50 year sediment volume (V_{50}) (million m³)		2.796	0.831	17.984	0.479	6.954	4.68	3.109	0.84	13.54	17.268
Sediment yield (million t/a)		0.0755	0.022	0.436	0.013	0.188	0.126	0.084	0.023	0.366	0.466
Effective catchment (A_e) (km²)		928	716	1547	238	803	744	152	30	954	744
Sediment yield (t/km²/a)		81.35	31.33	313.88	54.34	233.82	169.8	552.3	766.67	383.2	626.65

The only recorded catchment sediment yields that correspond to the regional based predictions are those of Woodstock (383 t/km²/a), Wagendrift (170 t/km²/a), Shongweni (234 t/km²/a) and Inanda Dams (314 t/km²/a). However, both Shongweni and Inanda Dams are located further downstream near to the coast and in more densely populated and developed areas. Woodstock and Wagendrift Dams represent the only dams with recorded catchment sediment yield data with runoff originating from less developed areas bordering the Lesotho Highlands, but draining the steep slopes of the Drakensberg Mountain range and resulting in erosion, similar to those of the Impendle and Smithfield Dam catchments.

For comparison purposes, the catchment sediment yield for both the Woodstock and Wagendrift Dams were verified, using of the 2010 Sediment Yield Prediction methodology, as 222.45 and 77.5 t/km²/a respectively. Comparing these predicted catchment sediment yield values for Woodstock and Wagendrift Dams with recorded values (383.2 and 169.8 t/km²/a respectively) reveals an 85% confidence in terms of the regional 2010 Sediment Yield Prediction values. Therefore, based on the Woodstock and Wagendrift Dams' records, the minimum catchment sediment yield for both Impendle and Smithfield Dams is recommended to be predicted with a minimum 85% confidence level, resulting in predicted catchment sediment yields of 270.4 and 256.5 t/km²/a respectively. The recorded catchment sediment yield of dams such as Kilburn, Spioenkop and Craigieburn, however, confirms that higher catchment sediment yields are possible.

Based on the estimated catchment sediment yield and reservoir trap efficiency, the loss in reservoir storage can be determined. For water resources planning purposes it is recommended to use the maximum expected retained sediment volumes per confidence level to determine equivalent future sediment volumes. The 85% catchment sediment yield confidence values are to be considered as the minimum values, while the 90% confidence values will ensure a more conservative approach. Based on this approach the maximum expected V_{50} *sediment volumes to be retained are as follows:*

- *Impendle Dam – 17.56 million m³ or 3.3% of the FSC (535 million m³, corresponding to a 100% MAR dam).*
- *Smithfield Dam – 22.11 million m³ or 16.2% of the FSC (137 million m³, corresponding to a 25% MAR dam).*[1]

The impact of sedimentation on reservoir capacity is therefore much more for the smaller Smithfield Dam than for the larger Impendle Dam.

[1] *Full supply capacities as reported in the Mkomazi/Mgeni Transfer Scheme Pre-feasibility Study.*

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A	catchment area
A_H	size of area consisting of soils with high sediment yield potential
A_M	size of area consisting of soils with medium sediment yield potential
A_L	size of area consisting of soils with lower sediment yield potential
A_T	total catchment area
A_e	effective catchment area
BKS	BKS (Pty) Ltd
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
EV	Extreme Value
E_{IW}	weighted Erosion Hazard Class according to sub-catchment areas
F_H	high yield potential factor
F_M	medium yield potential factor
F_L	low yield potential factor
FSC	Full Supply Capacity
GEV	Generalised Extreme Value
kg/m^3	kilogram per cubic metre
km	kilometre
LN	Log Normal
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
masl	metre above sea level
m	metre
m^3/s	cubic metre per second
mm	millimetre
Q	flood peak runoff
Q_T	flood peak runoff for a recurrence period of T years
Q_S	sediment load
Q_{10}	flood peak with a recurrence interval of 1 in 10 years
R_{nd}	river network density
S_O	average river slope
t/a	ton per year
$t/km^2/a$	ton per square km per year
T	recurrence period in years
V_T	volume of sediment after T years

V_{50}	volume of sediment after 50 years
WRC	Water Research Commission
Y_C	estimated catchment sediment yield value
Y_S	standardised sediment yield value

1 INTRODUCTION

Sediment transported by rivers is partly and often largely deposited in reservoirs, causing a loss in storage capacity and adversely affecting reservoir yield. This does not only impact on the active life of a reservoir, but also influences the related infrastructure, e.g. outlet works, as well as the upstream backwater effects and riverine ecological systems. Reservoir sedimentation is dependent on catchment sediment yield, which is a function of catchment location and size, as well as sediment yield potential within the catchment.

The quantity of sediment transported by a given river depends upon the availability of transportable material, i.e. sediment yield potential of the soils within the catchment. One of the practical problems encountered in the analysis of catchment sediment yield is that it not only varies in space but also in time as conditions change. In addition, both the varying water flow and sediment load in a river result in a water/sediment ratio that varies over a wide range with time.

This report forms part of *the uMkhomazi Water Project Phase 1: Technical Feasibility Study Raw Water* and covers **Task 5.12: Sediment Yield** as part of the overall **Task 5: Engineering Investigations** which comprise all the sub-tasks indicated in **Table 1.1**.

Table 1.1: Task 5: Engineering Investigation sub-tasks

Task number	Task description
5.1	Optimization of conveyance system
5.2	Dam position
5.3	Materials investigation
5.4	Geomorphologic and seismic investigation
5.5	Geotechnical investigation
5.6	Survey
5.7	Dam type selection
5.8	Established required capacity of dam
5.9	Flood and backwater calculations of the final dam

Task number	Task description
5.10	Climatological data for the construction site
5.11	Water quality and limnological review
5.12	Sediment yield
5.13	Land requirements
5.14	Optimize scheme configuration
5.15	Assessment of the potential for hydropower
5.16	Feasibility design of the selected scheme
5.17	Creating a cost model for the project

This report deals with the verification of catchment sediment yield of the proposed Impendle and Smithfield Dams and the potential impact thereof on the proposed dam development. This includes information on the estimation of catchment sediment yield and the consequent reductions in future storage capacity that can be expected for the proposed reservoir. Other than the impact on storage capacity, no attention is given to the distribution patterns of deposited sediment within the proposed reservoir.

2 APPROACH TO SEDIMENT YIELD PREDICTION

2.1 PREVIOUS ASSESSMENTS

Sediment yield in the uMkhomazi River catchment were previously assessed as part of the following studies:

- *Mgeni River System Analysis Study*, undertaken in 1992 with study completed in 1994 (DWAF, 1994).
- *Mkomazi/Mooi-Mgeni Transfer Scheme Pre-Feasibility Study*, undertaken in 1996 with study completed in 1999 (DWAF, 1999).
- *Mkomazi Sedimentation Study for Umgeni Water*, completed in 1998 (Umgeni Water, 1998).

2.2 SCOPE OF INVESTIGATION

As indicated above, the most recent sediment yield predictions for the uMkhomazi River catchment were undertaken in 1998 for Umgeni Water, based on work undertaken in 1996 as part of the *Mkomazi/Mooi-Mgeni Transfer Scheme Pre-Feasibility Study*. Since then additional catchment sediment yield information became available and a new catchment sediment yield prediction methodology has been developed and completed by the Water Research Commission(WRC) in 2010 (WRC, 2010), Based on this new approach, an update on the uMkhomazi River catchment sediment yield is recommended.

In addition to the sediment yield predictions for Smithfield Dam as proposed in the Inception Report, Impendle Dam, which is proposed to be located upstream of Smithfield Dam, is also included in the update of sediment yield predictions for the uMkhomazi River catchment. However, since the implementation date of Impendle Dam is unknown at this stage, this report only covers the individual catchment sediment yields for Impendle and Smithfield Dams, respectively, and not a combination of Smithfield Dam together with Impendle Dam.

2.3 RESERVOIR SEDIMENTATION APPROACH

As it is not possible to predict reservoir sedimentation rates accurately, estimates are made of the most likely foreseeable catchment sediment yields, based on basic or generalised erodibility/sediment yield maps and/or available recorded yield data, which are converted into equivalent storage losses.

Given the status of both Impendle and Smithfield as proposed dams, their respective catchment yield is determined by using generalised yield patterns and comparing that to actual recorded sediment yield values of dams closest to the Impendle/Smithfield Dam catchment.

2.3.1 Actual recorded catchment sediment yields

Sediment accumulation at a number of reservoirs throughout South Africa is recorded by the Department of Water Affairs (DWA), over many years, on an annual basis in a Dam List issued by the DWA Hydrographic Surveys. The analysis of these measurements, which involves the conversion of recorded sediment volumes to annual sediment yields per unit area of catchment make it possible to calculate average sediment yields for the catchments in question. An important factor in the conversion of sediment value into mass is the variable density of the sediment deposits (refer to **Section 5.1**).

Sediment yields of catchments can therefore be estimated from or compared to recorded reservoir sedimentation surveys in terms of dam characteristic and sediment accumulation data for nearby reservoirs listed in the latest DWA Hydrographic Surveys Dam List.

2.3.2 Generalised sediment yield patterns

In order to make use of recorded reservoir sedimentation survey data in a regional context, especially for the purposes of predicting sedimentation rates, a regionalised *Sediment Yield Map* was introduced in 1975 and, based on new technology, thereafter updated in 1992 and 2010, respectively.

The updated *1992 Sediment Yield Map* (WRC, 1992) (refer to **Section 5.2.1**) is based on a division of Southern Africa into nine sediment yield regions and subsequent calibration in terms of recorded yield values, with sediment yields calculated according to catchment location and size, as well as sediment yield potential within the catchment. In the absence of comprehensive measured data this sediment yield map formed a basis for catchment sediment yield estimation and was used until recently when it was improved upon during the Water Research

Commission (WRC) study *Sediment Yield Prediction for South Africa – 2010 Edition* (WRC, 2010) (refer to **Section 5.2.2**) which demarcated South Africa in ten relatively homogenous sediment yield regions, with three sediment yield prediction methods proposed, including *probabilistic, empirical* and *mathematical* modelling.

Considering sediment transport as part of a hydrological process, it is a function of the same parameters that influence all hydrological processes. In terms of *the 2010 Sediment Yield Prediction* sediment load is regarded as a dependent variable in terms of the recurrence interval flood, average river slope, river network density, catchment area and weighted Erosion Hazard Class. Based on a regression analysis, relevant empirical equations are proposed for the purposes of catchment sediment yield calculations for Regions 1, 2, 4, 5, 7 and 8. All of these empirical equations are defined in terms of a flood peak discharge for a recurrence interval of 10 years, i.e. Q_{10}.

Because of poor and limited data no equations are available for Regions 3, 6, 9 and 10. Instead, a probabilistic method is recommended for Regions 3, 6 and 9 while it is recommended that Region 10 should be evaluated in terms of locally observed data.

3 CATCHMENT DESCRIPTION

3.1 DAM SITE LOCATION

The proposed Impendle and Smithfield Dams are located on the uMkhomazi River in the Impendle District of KwaZulu-Natal. The Impendle Dam catchment of 1 422 km² includes quaternary catchments U10A, U10B, U10C and U10D, whilst the Smithfield Dam catchment of 2 058 km² includes quaternaries U10E and U10F in addition to the upstream Impendle Dam catchment. The proposed Impendle Dam is located approximately 17.5 km north-east of the town of Bulwer, some 16 km upstream of the proposed Smithfield Dam, with the latter approximately 17 km north-east-east of the town of Bulwer, as indicated in **Figure 3.1**.

The Impendle/Smithfield Dam catchments are bordered by the Mooi and uMngeni River catchments to the north and the uMzimkulu River catchment to the south, as indicated in **Figure 3.1**.

No major dams are located in the uMkhomazi River catchment. With reference to **Figure 3.1** the closest large dams are the Midmar, Albert Falls, Nagle and Inanda Dams on the uMngeni River, Wagendrift Dam on the Bushmans River, Craigieburn on the Mnyamvubu River, Henley Dam on the uMzunduze River, Shongweni Dam on the uMlaza River and the Kilburn, Woodstock and Spioenkop Dams on the uThukela River system.

3.2 CATCHMENT CHARACTERISTICS

The catchment characteristics for the proposed Impendle and Smithfield Dams were determined using 20 m contour information and Google Earth aerial photography. The catchments are predominantly rural with most of the upper reaches steep and mountainous, as shown in **Figures 3.1** and **3.2**.

The physical characteristics of the defined catchments for the proposed Impendle and Smithfield Dams are summarised in **Table 3.1**.

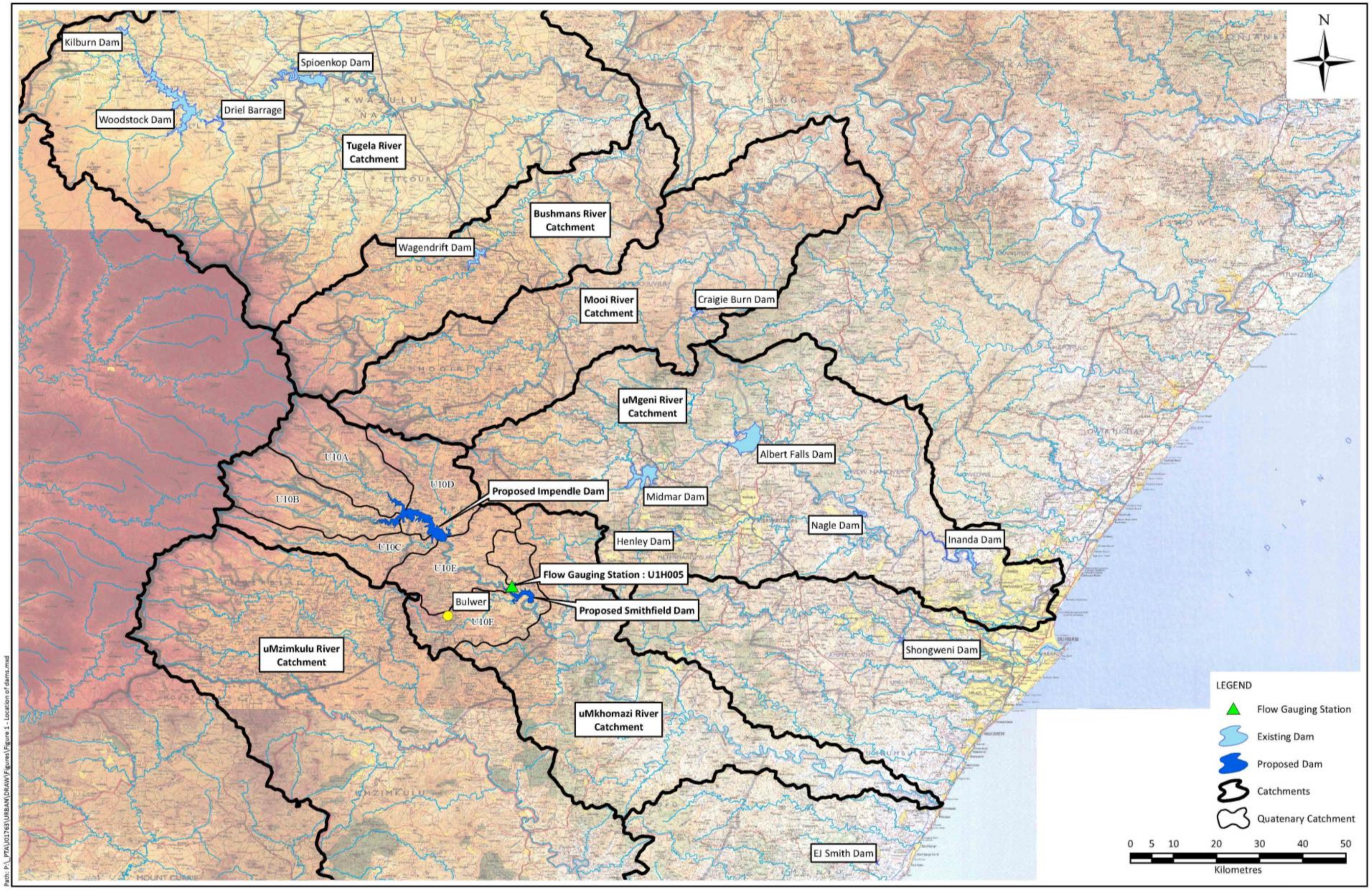

Figure 3.1: Dam site location

Table 3.1: Catchment characteristics

Item	Impendle Dam catchment	Smithfield Dam catchment
Size of catchment (km^2)	1 422	2 058
Longest watercourse (km)	75.9	120.3
Average watercourse slope (%)[1]	0.75	0.61
Average catchment slope (%)	32	29
Mean annual precipitation (mm)	1.068	1.050
Total stream length (m)	308 773	379 528
River density (m/km^2)	217.4	184.42

[1] *Based on Equal Areas Method*

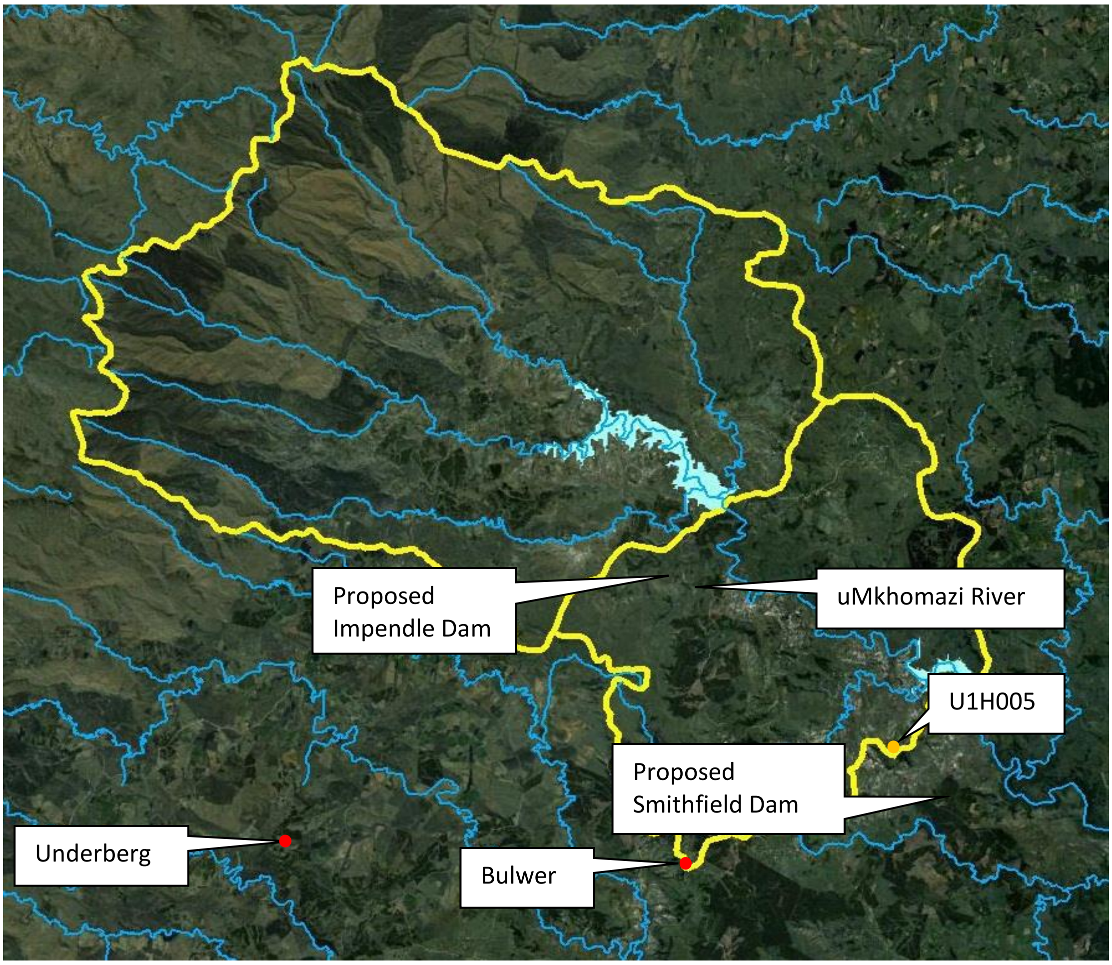

Figure 3.2: Catchments of the proposed Impendle and Smithfield Dams

The average mean annual precipitation (MAP) for the catchment was estimated to be 1 068 mm and 1 050 mm for the Impendle and Smithfield Dam catchments, respectively, based on the rainfall data grid compiled as part of the WRC study *Design Rainfall Estimation in South Africa*, developed by Messrs JC Smithers and RE Schulze (WRC, 2002). In addition, this data grid was used to determine the catchment's average short-term rainfall depths in order to calculate the rainfall intensities for various return periods which were used for the Alternative Rational Method calculations.

4 FLOOD PEAK ANALYSIS

4.1 GENERAL

Since a representative flood peak runoff with a return period of 10 years (Q_{10}) is recommended to be used for the *2010 Sediment Yield Prediction*, the main purpose of a hydrological and associated flood peak analysis is to determine a representative flood runoff for a return period of 10 years.

Flow gauging station U1H005 (refer to **Figure 4.1**) with latitude 29°44' and longitude 29°54' and catchment area 1 744 km² is located some 11.4 km upstream of the proposed Smithfield Dam site (refer to **Figures 3.1** and **3.2**).

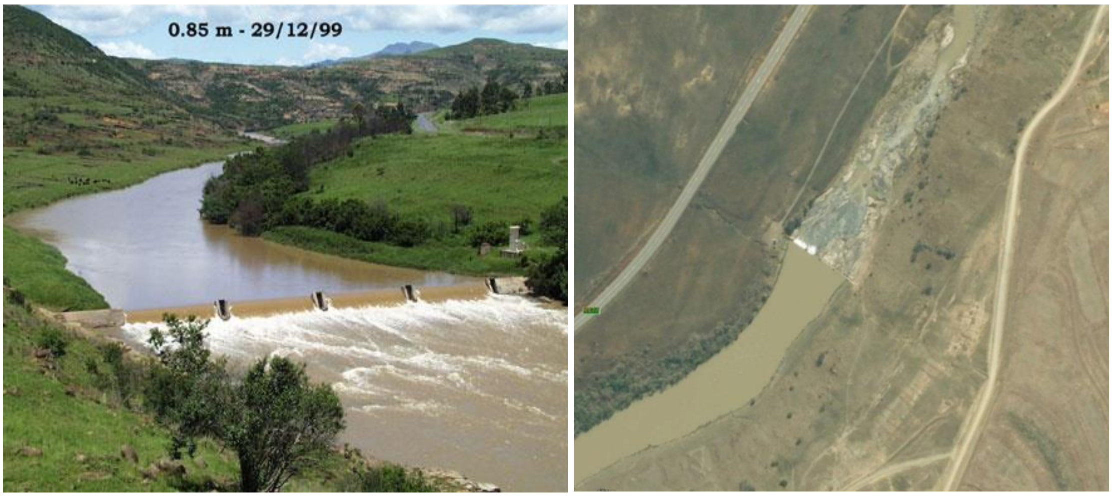

Figure 4.1: Flow gauging station U1H005

4.2 HISTORICAL FLOODS

The existing DWA rating curve for flow gauge U1H005 has only been calibrated up to a flow depth of 2.71 m, correlating to a discharge of 637.8 m³/s, as shown in **Figure 4.2**. The annual series of maximum discharge values at U1H005 indicates that four flood events, summarised in **Table 4.1**, exceeded the maximum rating depth at the flow gauge.

Table 4.1: Exceedance of flow gauge rating depth during floods

Date of flood	Maximum depth of flow (m)
06-02-1976	2.823
29-09-1987	5.275
25-02-1988	3.695
27-01-1996	3.067

The 1976 and 1987 floods were previously determined by the DWA as 1 000 m^3/s (1976) and 2 770 m^3/s (1987), respectively (DWA, 1987).

4.3 HYDROLOGICAL ANALYSIS

Given the available historical flow record from 1961 to 2012 as recorded and compiled by the DWA for flow gauging station U1H005, a detail statistical analysis was conducted using the relevant data to determine flood peaks and compared with other approaches.

4.3.1 Statistical analysis of recorded flow data

In order to estimate the peak discharge of the floods listed in **Table 4.1**, the DWA rating curve was extrapolated using a “best-fit” polynomial trend line in Microsoft Excel, shown in **Figure 4.2** as “Option 1”.

Technical Report (TR) 139 (DWA, 1987) estimated the 1987 peak discharge at U1H005 to be 2 770 m^3/s, and based on this value the rating curve was extrapolated with an adjusted trend line (“Option 2”) to accommodate this value. The peak discharge values determined based on the trend lines (Options 1 and 2) are listed in **Table 4.2** as follows:

Table 4.2: Floods exceeding the flow gauge rating depth

Date of flood	Maximum depth of flow (m)	Peak discharge using extrapolated rating curve Option 1 (m^3/s)	Peak discharge using extrapolated rating curve Option 2 (m^3/s)
06-02-1976	2.823	682	688
29-09-1987	5.275	2 214	2 770
25-02-1988	3.695	1 131	1 264
27-01-1996	3.067	798	833

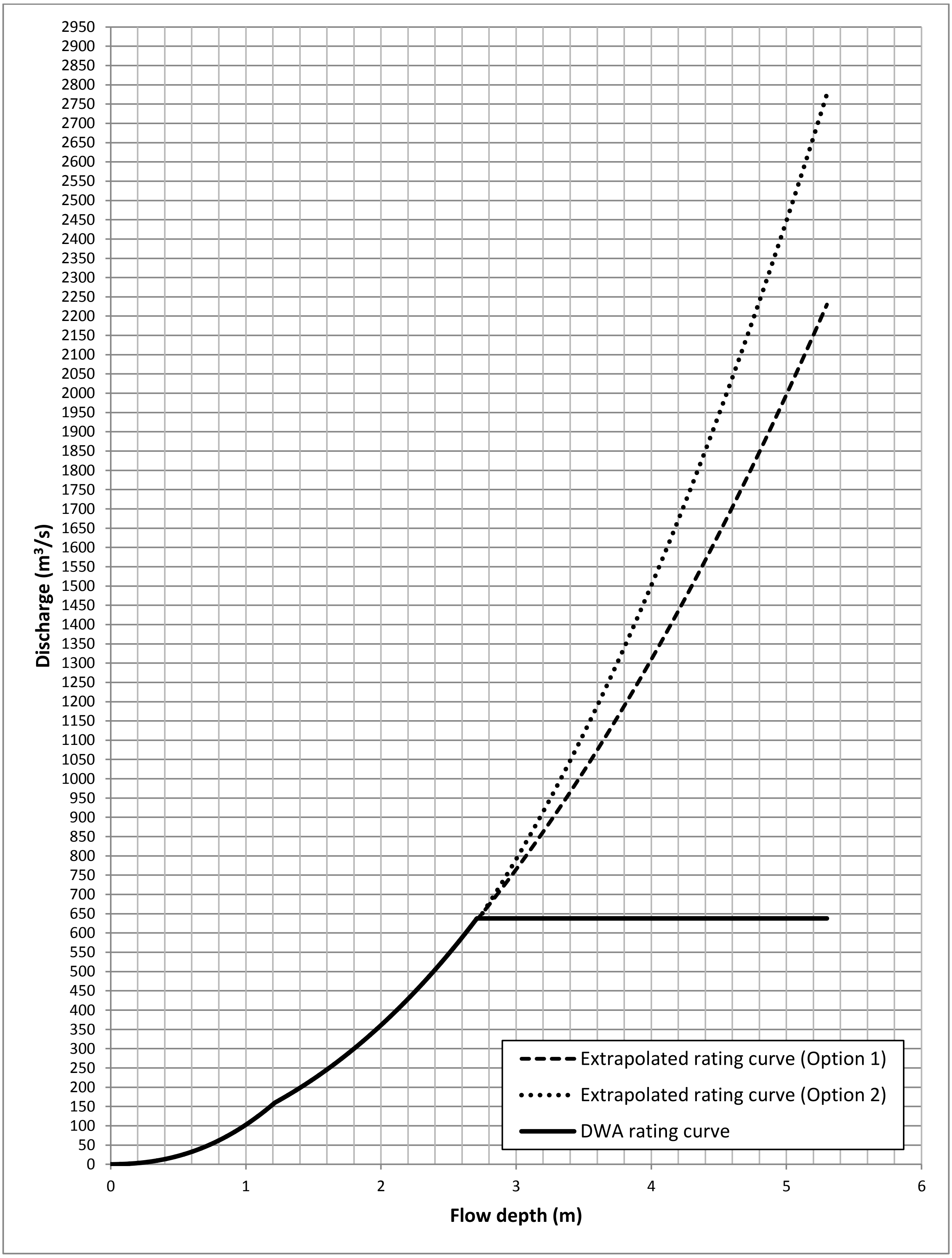

Figure 4.2: Flow gauging station U1H005 rating curve

Following from **Figure 4.2**, the annual maximum flood peak data was analysed in terms of Extreme Value (Gumbel and Generalised for untransformed data) and Log Normal (transformed data) distributions using the software *Utility Programs for Drainage* (Sinotech, 2007). As a result the associated flood peaks for various return intervals are summarised in **Table 4.3**:

Table 4.3: Results of statistical analysis of flood values at flow gauging station U1H005

Return period (years)	Flood peak discharge (m^3/s)			
	Extreme Value (Gumbel) (EV1)	Generalised Exteme Value (GEV)	Log Normal (LN)	Average
2	341	309	320	323
10	916	817	752	828
20	1 136	1 077	956	1 056
50	1 420	1 486	1 257	1 388
100	1 633	1 856	1 515	1 668
200	1 845	2 290	1 790	1 975
500	2 125	2 980	2 187	2 430
1 000	2 337	3 609	2 515	2 820
10 000	3 039	6 599	3 829	4 489

It follows from results of **Table 4.3** that the Log Normal distribution is decreasing in flood peak discharge values with increasing return periods while the opposite apply to the Generalised Extreme Value distribution. Given this, it average flood peak values are proposed. Based on these average values as indicated in **Table 4.3**, the respective flood peak flows for the Impendle and Smithfield Dams, as summarised in **Table 4.4**, were determined by extrapolating the relevant U1H005 flood peak values with the following formula:

$$Q_{Dam} = Q_{U1H005}\sqrt{\frac{A_{Dam}}{A_{U1H005}}}$$

where:

Q = flood peak discharge (m^3/s)

A = catchment area (km^2)

$A_{Impendle}$ = 1 422 km^2

$A_{Smithfield}$ = 2 058 km^2

A_{U1H005} = 1 744 km^2

Table 4.4: Representative flood peak values at dam sites based on a statistical analysis of recorded river flow data

Return period T (years)	Flood peak Q_T (m^3/s)	
	Impendle Dam	Smithfield Dam
2	292	351
10	748	900
20	964	1 147
50	1 253	1 507
100	1 506	1 812

4.3.2 Comparative flood peak analysis

A comparison of the flood peak values as determined by the statistical analysis of recorded river flow data at flow gauging station U1H005 with flood peak values as determined by deterministic and empirical approaches is provided in **Table 4.5**. The flood peak Q_T refers to a flood with a recurrence interval of 1 in T years. The following is to be noted:

- The Rational Method was not used as this method is recommended for catchments less than 15 km^2.
- The highest weighting (0.5) was applied to the Statistical Method since the results are based on observed floods at a flow gauging station relatively close to the dam sites. The data spans a reasonable length of time (over 50 years) and is therefore considered very suitable for statistical analysis.
- A weighting of 0.2 was applied to the Alternative Rational Method, with no limitation on the catchment size when used. This method explicitly takes into

account some of the most significant catchment specific factors influencing runoff, namely MAP, topography, permeability and vegetation.

- The Unit Hydrograph, Empirical and Standard Design Flood methods were given a lower weighting compared to the Alternative Rational Method as they are based on regional rainfall-runoff relationships, which might not be equally applicable to all catchments within the defined regions.

Table 4.5: Summary of flood peak determination

Dam site	Catchment area (km^2)	Recurrence period T (years)	Flood Peak Q_T (m^3/s)						Final flood peak (m^3/s)
			Statistical Method	Alternative Rational Method	Empirical Method (M&P)	Unit Hydrograph Method	Standard Design Flood Method	Regional Maximum Flood Method	
Impendle	*Weighting*		*0.5*	*0.2*	*0.1*	*0.1*	*0.1*		
	1422	2	292	436	-	277	83	-	299
		10	748	1 102	992	660	884	-	848
		20	954	1 457	1 345	923	1 336	-	1 129
		50	1 253	1 992	1 866	1 403	2 020	1 710	1 554
		100	1 506	2 495	2 354	1 957	2 601	2 095	1 943
		RMF	-	-	-	-	-	3 764	3 764
Smithfield	*Weighting*		*0.5*	*0.2*	*0.1*	*0.1*	*0.1*	*-*	
	2058	2	351	441	-	300	84	-	336
		10	900	1 115	1 027	714	902	-	937
		20	1 147	1 474	1 393	999	1 363	-	1 244
		50	1 507	2 015	1 932	1 519	2 061	2 108	1 708
		100	1 812	2 524	2 437	2 122	2 654	2 567	2 389
		RMF	-	-	-	-	-	4 529	4 529

4.3.3 Comparison with previous flood peak analyses

A previous flood peak determination undertaken by the DWA in 1998 for the purposes of the *Mkomazi/Mooi-Mgeni Transfer Scheme Pre-Feasibility Study* was also based on a statistical analysis of available flow data for flow gauging station U1H005. A comparison of the flood peaks provided in **Table 4.5** with the previously determined DWA values is provided in **Table 4.6**.

Table 4.6: Comparative summary of flood peak determination

Dam site	Recurrence period T (years)	Flood peak Q_T (m^3/s)		
		1998 Statistical Method (DWA)	2012 Statistical Method (Average)	2012 Recommended flood peak (refer to Table 4.5)
Impendle	2	320	292	299
	10	830	748	848
	20	1 080	954	1 129
	50	1 460	1 253	1 554
	100	-	1 506	1 943
	RMF	3 760	-	3 764
Smithfield	2	390	351	336
	10	1 000	900	937
	20	1 310	1 147	1 244
	50	1 750	1 507	1 708
	100		1 812	2 389
	RMF	4 520	-	4529

Based on the comparison provided in **Table 4.6**, it follows that the 2012 flood peak values as presented in this report are, in general, in the case of Impendle Dam exceeding the 1998 DWA values, while those related to the Smithfield Dam are lower than the 1998 DWA values. It is therefore recommended to be conservative and use the flood peak values from the 1998 DWA Statistical Method for sediment yield prediction purposes based on the *2010 Sediment Yield Map* (as discussed later in **Section 6.2.2**).

5 CATCHMENT SEDIMENT YIELD

Catchment sediment yield is determined below in terms of generalised catchment sediment yield patterns as depicted by the 1992 and 2010 Sediment Yield Maps, respectively, and compared with recorded catchment sediment yield values from nearby dams.

5.1 RECORDED RESERVOIR SEDIMENTATION

Sediment yields of catchments can be estimated from recorded reservoir sedimentation surveys in terms of dam characteristics and sediment accumulation data within reservoirs as listed in the 2012 DWA Hydrographic Surveys Dam List by converting recorded sediment volumes to annual sediment yields per unit area of catchment.

The sediment volume in a reservoir after any given period of time has been found to follow a logarithmic relationship for accumulations in excess of approximately 10 years. It was found that it is possible to express the volume V_T of a sediment deposit after T years as (Rooseboom, 1975):

$$\frac{V_T}{V_{50}} = 0.376 \ell n \frac{T}{3,5}$$

for $T \geq$ 10 years and V_{50} the reservoir sediment volume after 50 years.

It is thus possible to convert the equivalent 50-year volume into the volume after T years and vice versa. Selection of the 50-year volume as reference is arbitrary, but it is possible to estimate the average density after 50 years more accurately than after, say, 10 years.

A density value of 1 350 kg/m³ for the 50-year sediment was found to be realistic for South African reservoirs. In order to convert the 50-year sediment mass to an annual mass, the average sediment yield is assumed to remain constant over time. This assumption allows working from a common base (i.e. 50-year old sediment) to estimate the volume of sediment for any other age.

5.1.1 Recorded catchment sediment yield

No major existing dams are located in the uMkhomazi River catchment. The closest large dams are the Midmar, Albert Falls, Nagle and Inanda Dams on the uMngeni River, Wagendrift Dam on the Bushmans River, Craigieburn Dam on the Mnyamvubu River, Henley Dam on the uMzunduze River, Shongweni Dam on the uMlaza River, and the Kilburn, Woodstock and Spioenkop Dams on the uThukela River System, as indicated in **Figure 3.1**.

Available dam survey information based on the 2012 DWA Hydrographic Surveys Dam List for the abovementioned dams, excluding Nagle Dam, are provided in **Table 5.1** in terms of location number, recorded period, sediment volume at end of period V_T, equivalent 50 year sediment volume $V_{50,}$ effective catchment area (A_e) and average catchment sediment yield. It is to be noted that the Nagle Dam diversion weir was subject to sluice upgrading during the late 1990's, resulting in sediment washed from the basin.

A comparison of the recorded sediment yield values based on the 2012 DWA Hydrographic Surveys Dam List with similar values determined during the *Mgeni River System Analysis Study* (1992), *Mkomazi/Mooi-Mgeni Transfer Scheme Pre-Feasibility Study* (1996), *Mkomazi Sedimentation Study for Umgeni Water* (1998) and the *Sediment Yield Prediction for South Africa* (2010) for some of the abovementioned dams is provided in **Table 5.2**. It follows from **Table 5.2** that the recorded catchment sediment yield values based on the 2012 DWA Hydrographic Surveys Dam List differ in most cases from previously determined values. These differences are discussed below per relevant dam catchment.

Table 5.1: Recorded reservoir and catchment sedimentation yield

River			uMngeni			uMzunduze	uMlaza	Bushmans	Mnyamvubu	Mnjaneni	uThukela	
Dam			Midmar	Albert Falls	Inanda	Henley	Shongweni	Wagendrift	Craigieburn	Kilburn	Woodstock	Spioenkop
Recorded reservoir information	Record period	Date of dam construction	1965	1974	1988	1942	1927	1963	1963	1981	1982	1972
		Date of latest survey	1996	1983	2009	1987	1990	1999	2003	1993	1999	2001
		Survey record length	31	9	21	45	63	36	40	12	17	29
	Original capacity (V_W) (million m³)		177.349	289.462	258.676	5.867	12.061	60.001	25.918	35.966	381.306	285.995
	Latest capacity at full supply level (million m³)		175.056	289.167	246.56	5.407	4.504	55.900	23.070	35.577	373.260	272.266
	Capacity lost (%)		1.3	0.1	4.7	7.8	62.7	6.8	11.0	1.1	2.1	4.8
	Volume of sediment deposit (V_T) (million m³)		2.293	0.295	12.116	0.47	7.557	4.101	2.848	0.389	8.046	13.729
	Equivalent 50 year sediment volume (V_{50}) (million m³)		2.796	0.831	17.984	0.479	6.954	4.68	3.109	0.84	13.54	17.268
	Sediment yield (million t/a)		0.0755	0.022	0.436	0.013	0.188	0.126	0.084	0.023	0.366	0.466
	Effective catchment (A_e) (km²)		928	716	1547	238	803	744	152	30	954	744
	Sediment yield (t/km²/a)		81.35	31.33	313.88	54.34	233.82	169.8	552.3	766.67	383.2	626.65

Table 5.2: Comparison of recorded catchment sediment yield values

Comparative data		Recorded catchment sediment yield (t/km^2/a)							
River		uMngeni				uMzunduze	uMlaza	Bushmans	Mnyamvubu
Dam		Midmar	Albert Falls	Nagle[1]	Inanda	Henley	Shongweni	Wagendrift	Craigieburn
Relevant study for analysis of recorded sediment yield (t/km^2/a)	Mgeni River System Analysis Study (1992)	9.67	30.88	29.7	n/a	58.92	220.61	n/a	n/a
	Mkomazi/Mooi-Mgeni Transfer Scheme Pre-Feasibility Study (1996)	10	31	-	-	42	231	91	29
	Mkomazi Sedimentation Study for Umgeni Water (1998)	10	31	-	-a	42	231	91	29
	Sediment Yield Prediction for South Africa - 2010	93	31	-	-	74	n/a	167	656
	uMkhomazi Water Project Phase 1: Module 1: Technical Feasibility Study Raw Water (2012)	81.35	31.33	-	313.88	54.34	233.82	169.8	552.3

[1]*Diversion weir*

- **Midmar Dam**: It is assumed that both the 1996 and 1998 catchment sediment yield values were based on the 1983 survey record of the dam basin, thereby using an 18 year record period while the 2012 value is based on the 1996 survey record, resulting in a 31 year record period, providing a more accurate and reliable catchment sediment yield record to be used for comparison purposes.
- **Henley Dam**: The effective catchment area provided by the 2012 DWA Hydrographic Surveys Dam List is larger than previously provided by previous similar sources and therefore the 2012 recorded catchment sediment yield value is recommended to be used for comparison purposes.
- **Shongweni Dam**: The 2012 DWA Hydrographic Surveys Dam List includes a longer dam basin survey record up to 1990, providing a more accurate and reliable catchment sediment yield record to be used for comparison purposes.
- **Wagendrift Dam**: It is assumed that both the 1996 and 1998 catchment sediment yield values were based on the 1983 dam basin resurvey record. However, the 2012 DWA Hydrographic Surveys Dam List includes a 1999 dam basin resurvey record, providing a 16 year longer record period, resulting in a more accurate and reliable catchment sediment yield record to be used for comparison purposes.
- **Craigieburn Dam**: The 2012 DWA Hydrographic Surveys Dam List includes a 2003 dam basin resurvey record, providing a 40 year record period, resulting in a realistic catchment sediment yield record to be used for comparison purposes. Verification of the 1996 and 1998 catchment sediment yield values based on the 1983 dam basin resurvey indicates that the original full supply capacity as presented in the 2012 DWA Hydrographic Surveys Dam List differs from what was previously used as reference. This results in the higher catchment sediment yield being obtained now.

5.2 GENERALISED REGIONAL CATCHMENT SEDIMENT YIELD

Using the *1992 Sediment Yield Map* and *2010 Sediment Yield Prediction*, site specific weighted average catchment sediment yield values were determined for both the proposed Impendle and Smithfield Dam catchments.

Sediment yield prediction approaches based on the *1992 Sediment Yield Map* and *2010 Sediment Yield Prediction* allow for the provision of some statistical band of confidence around the mean. Although the most likely yield value for an area still has to be estimated with due consideration of the availability of sediment within the catchment as well as other factors which influence sediment yields, it is possible to associate some statistical meaning with an estimate and to bring catchment size into consideration.

5.2.1 1992 Sediment Yield Map

The *1992 Sediment Yield Map* is based on a division of Southern Africa into nine sediment yield regions and subsequent calibration in terms of recorded yield values. Sediment yield potential or erodibility is based on a distinction between 20 categories, representing eroding and transporting capacity (e.g. soil types, land use, rainfall characteristics, slopes, etc.). These erodibility index categories are combined to establish three classes of sediment yield potential, i.e. *high, medium* and *low*, creating the sediment yield map. Site specific catchment sediment yield is obtained through the equation

$$Y_C = Y_S \left[F_H \frac{A_H}{A_T} + F_H \frac{A_M}{A_T} + F_L \frac{A_L}{A_T} \right]$$

where

Y_C = estimated catchment sediment yield value (t/km^2/a)

Y_S = standardised sediment yield value (t/km^2/a)

F_H = high yield potential factor

F_M = medium yield potential factor

F_L = low yield potential factor

A_H = size of area consisting of soils with high sediment yield potential (km^2)

A_M = size of area consisting of soils with medium sediment yield potential (km^2)

A_L = size of area consisting of soils with lower sediment yield potential (km^2)

A_T = total catchment area (km^2)

In terms of the *1992 Sediment Yield Map*, both the Impendle and Smithfield Dam catchments fall within Sediment Yield Region 4, including KwaZulu-Natal and Swaziland, with a regional catchment sediment yield pattern with a variability from 5 to 723 t/km²/a. These catchment sediment yields were obtained from reservoir surveys available for 20 sites, resulting in a regional standardised average catchment sediment yield of 155 t/km²/a.

Based on both the Impendle and Smithfield Dam catchments located in the *1992 Sediment Yield Map* Region 4, the site specific parameters for both dams are summarised in **Table 5.3**. The associated erodibility indexes of both dam catchments are graphically indicated in **Figure 5.1** and in **Figure 5.2** shows the sediment yield classifications.

Table 5.3: 1992 Sediment Yield Map values for the Impendle and Smithfield Dam catchments

Parameter		Unit	Dam	
			Impendle	Smithfield[1]
Regional standardised yield	(Y_S)	t/km²/a	155	155
High yield potential factor	(F_H)	-	1.44	1.44
Medium yield potential factor	(F_M)	-	1	1
Low yield potential factor	(F_L)	-	0.18	0.18
Area with high sediment yield potential	(A_H)	km²	0	0
Area with medium sediment yield potential	(A_M)	km²	1 422	2 058
Area with low sediment yield potential	(A_L)	km²	0	0
Total catchment area	(A_T)	km²	1 422	2 058
Site specific weighted average catchment sediment yield		t/km²/a	155	155

[1]*Smithfiled Dam considered with no Impendle Dam in place*

It follows from **Figure 5.1** that the catchments of both Impendle and Smithfield Dams comprise only medium sediment yield regions, resulting in the regional standardised catchment yield of 155 t/km²/a to be the average site specific catchment sediment yield.

Allowing for some statistical confidence around the mean, confidence bands can be adopted with a multiplication factor applied to the weighted average catchment sediment yield. Statistical information related to confidence bands for Region 4 of the *1992 Sediment Yield Map* is, however, only available for catchment areas smaller than 900 km². As a result, the multiplication factors for confidence bands of 50%, 80%, 90% and 95% for Region 4 of the *1992 Sediment Yield Map* for catchment areas equal to approximately 1 100 km² appears to coincide with a factor 2 (WRC 1992), whereafter the 90% and 95% factors decrease much more than the 80% factor. Therefore, for study purposes a multiplication factor of 2 is assumed for the 80%, 90% and 95 % confidence bands, i.e. predicted catchment sediment yield for 80% and more confidence remains the same. The approximate associated catchment sediment yield for Impendle (catchment = 1 422 km²) and Smithfield (catchment = 2 058 km²) dams are indicated in **Table 5.4**.

Table 5.4: 1992 Sediment Yield Map Region 4 confidence factors and associated catchment sediment yield for Impendle and Smithfield Dams

Confidence band	Multiplication factor		Catchment sediment yield (t/km²/a)	
	Impendle Dam	Smithfield Dam	Impendle Dam	Smithfield Dam
50%	0.95	0.95	147.25	147.25
80%	2	2	310	310
90%	2	2	310	310
95%	2	2	310	310

Given the abovementioned information, a likely average catchment sediment of 147.25 t/km²/a together with a maximum foreseeable yield of 310 t/km²/a based on the *1992 Sediment Yield Map*, are proposed. These values are used to verify and compare the *2010 Sediment Yield Prediction* values.

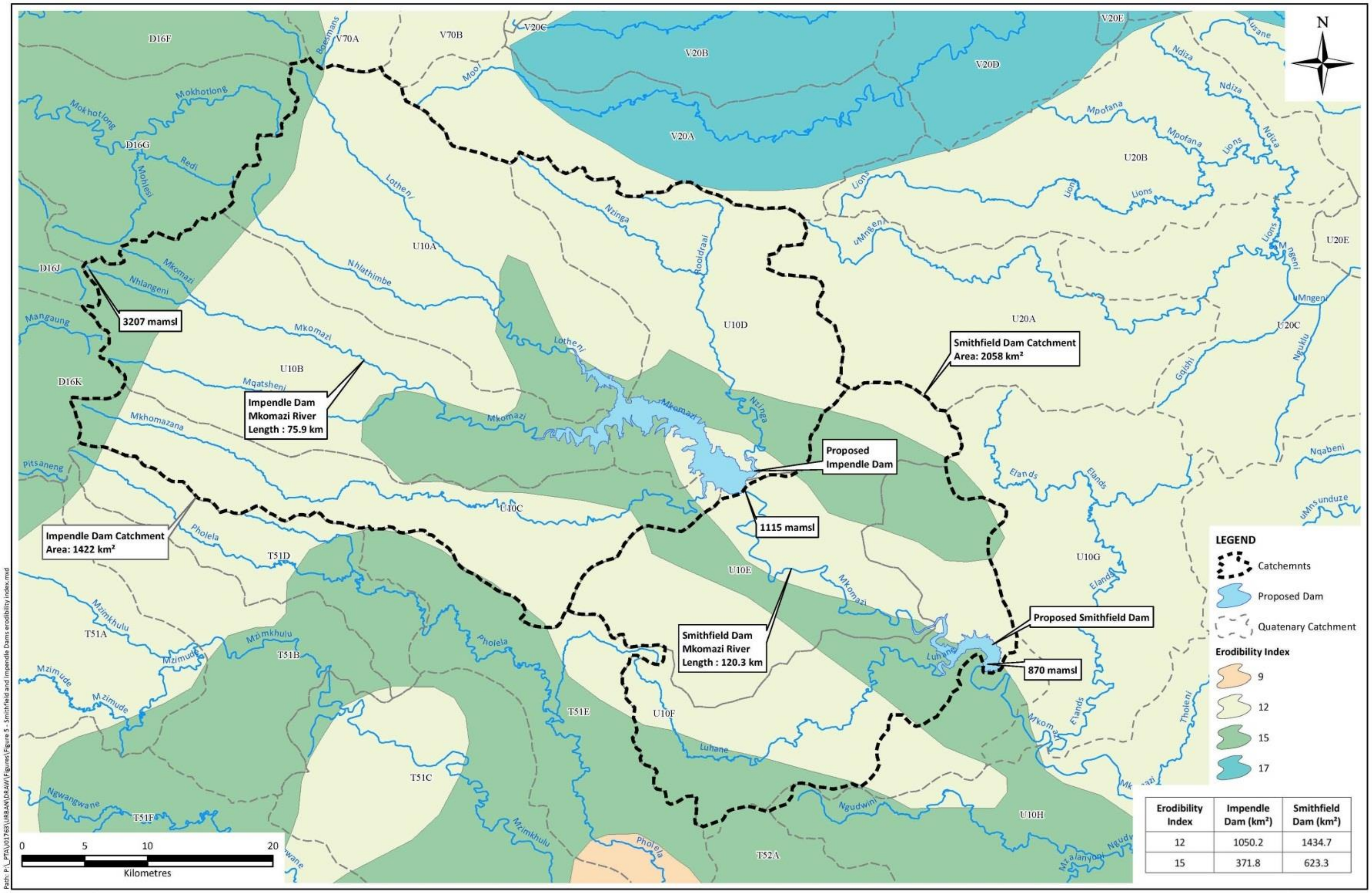

Figure 5.1: Impendle and Smithfield Dam Catchments Erodibility Index (1992 Sediment Yield Map)

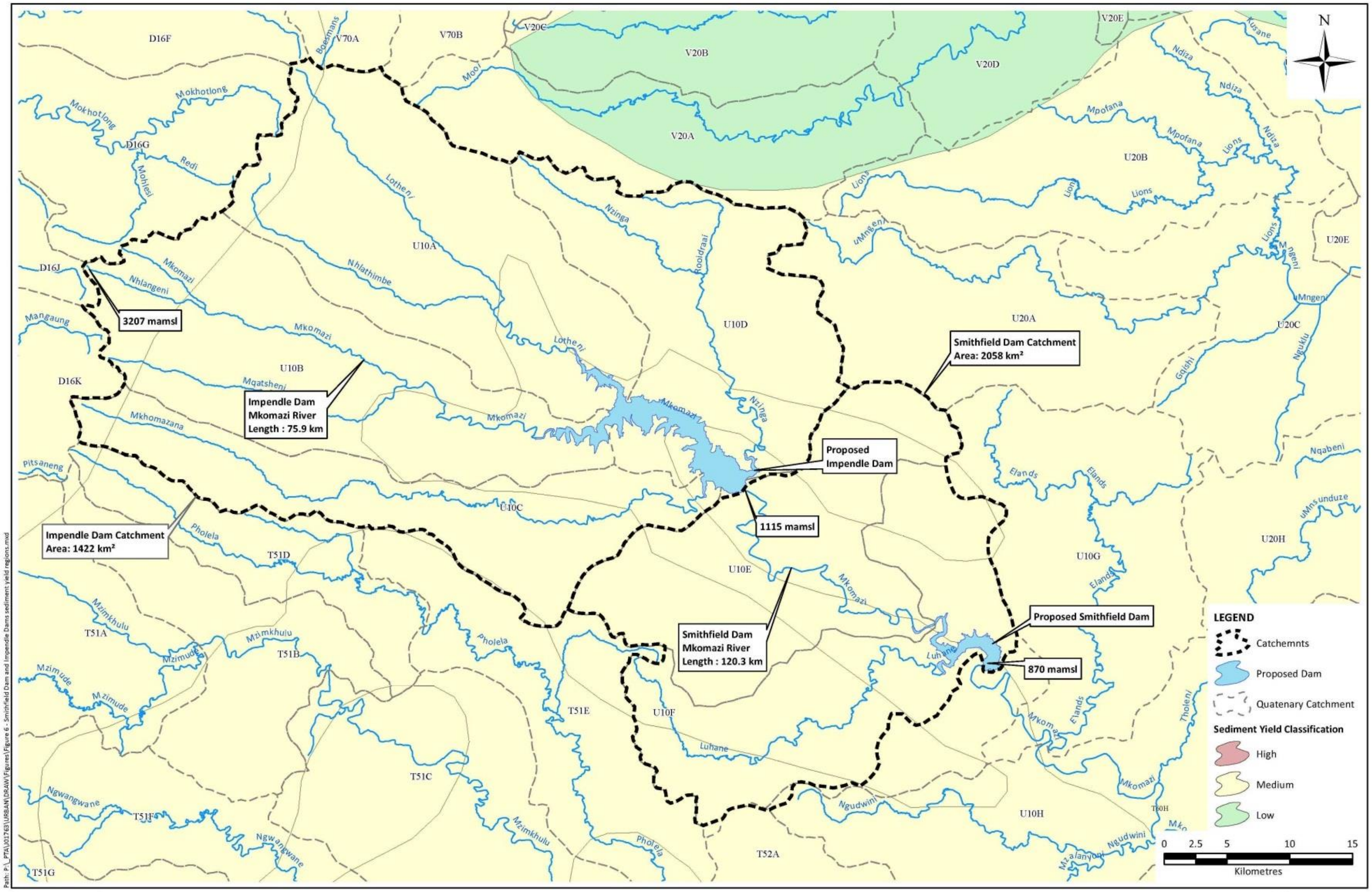

Figure 5.2: Impendle and Smithfield Dam Catchments Sediment Yield Clarification (1992 Sediment Yield Map)

5.2.2 2010 Sediment Yield Prediction

In terms of the *2010 Sediment Yield Prediction*, both the Impendle and Smithfield dam catchment falls within Sediment Yield Region 5, situated mainly in KwaZulu-Natal. Based on available sediment yield information for 12 reservoir sites, measured catchment sediment yield values vary between 30 and 1 037 t/km²/a. However, the reservoirs with available data are not homogenously distributed through the region. Most of the reservoirs are situated in the area between Durban and Lesotho within the catchments of the uMngeni and uThukela Rivers.

Sediment load applicable to the *2010 Sediment Yield Prediction* Region 5 can be obtained through the empirical equation

$$Q_s = 1432 Q_{10}^{1.31}\, S_0^{0.74}\, R_{nd}^{-1.32}\, A_e^{0.41}\, EI_w^{-0.30}$$

where

Q_S = sediment load (t/a)

Q_{10} = a flood with a recurrence interval of 1 in 10 years (m^3/s)

R_{nd} = river network density (m/km^2)

A_e = effective catchment area (km^2)

E_{IW} = weighted Erosion Hazard Class according to sub-catchment areas

S_O = average river slope (%)

The associated erosion indexes of the proposed Impendle and Smithfield Dam catchments in terms of the *2010 Sediment Yield Prediction* are graphically indicated in **Figure 5.2** and **Figure 5.3**, while the relevant Region 5 empirical equation parameters are defined and summarised below:

- Flood peak discharge $\boldsymbol{Q_{10}}$

  Based on the flood frequency analysis comparison provided in **Table 4.6**, it is recommended to be conservative and use the higher flood Q_{10} peak values of 830 m^3/s and 1000 m^3/s as previously determined for the proposed Impendle and Smithfield Dams, respectively, for sediment yield prediction purposes based on the *2010 Sediment Yield Prediction.*

- River network density $\boldsymbol{R_{nd}}$

  River density is a function of the relevant river length at a scale of 1:500 000 and catchment area as summarised in **Table 5.5**.

Table 5.5: River density of the Impendle and Smithfield Dam catchments

River density parameters	Impendle Dam	Smithfield Dam
Total stream length (m)	308 773	379 528
Catchment (km²)	1 422	2 058
River density (m/km²)	**217.14**	**184.42**

- Average river slope $\boldsymbol{S_O}$

  The average river slope, S_O, refers to the average slope of the longest watercourse in a catchment as summarised in **Table 5.6**.

Table 5.6: Average river slope of the Impendle and Smithfield Dam catchments

Average river slope parameters	Impendle Dam	Smithfield Dam
Length of longest watercourse (m)	75 900	120 300
Highest level (masl)	3 207	3 207
Lowest level (masl)	1 115	870
Average river slope (%)	**2.76**	**1.94**

- Weighted Erosion Hazard Class $\boldsymbol{EI_W}$

  A summary of the respective Impendle and Smithfield Dam catchment Erosion Hazard Class as deducted from **Figure 5.3** is provided in **Table 5.7**.

Table 5.7: Erosion Hazard of the Impendle and Smithfield Dam catchments

Erosion Hazard class	Impendle Dam		Smithfield Dam	
	Area (km^2)	Proportion to total	Area (km^2)	Proportion to total
3	n/a	0	92.1	0.045
4	491.8	0.346	1035.6	0.503
5	496.5	0.349	496.5	0.241
6	433.7	0.305	433.8	0.211
Total	1 422	1	2 058	1
Weighted Erosion Hazard Class EI_W	(0.346 x 4) + (0.349 x 5) + (0.305 x 6) = **4.959**		(0.045 x 3) +(0.503 x 4) + (0.241 x 5) + (0.211 x 6) = **4.618**	

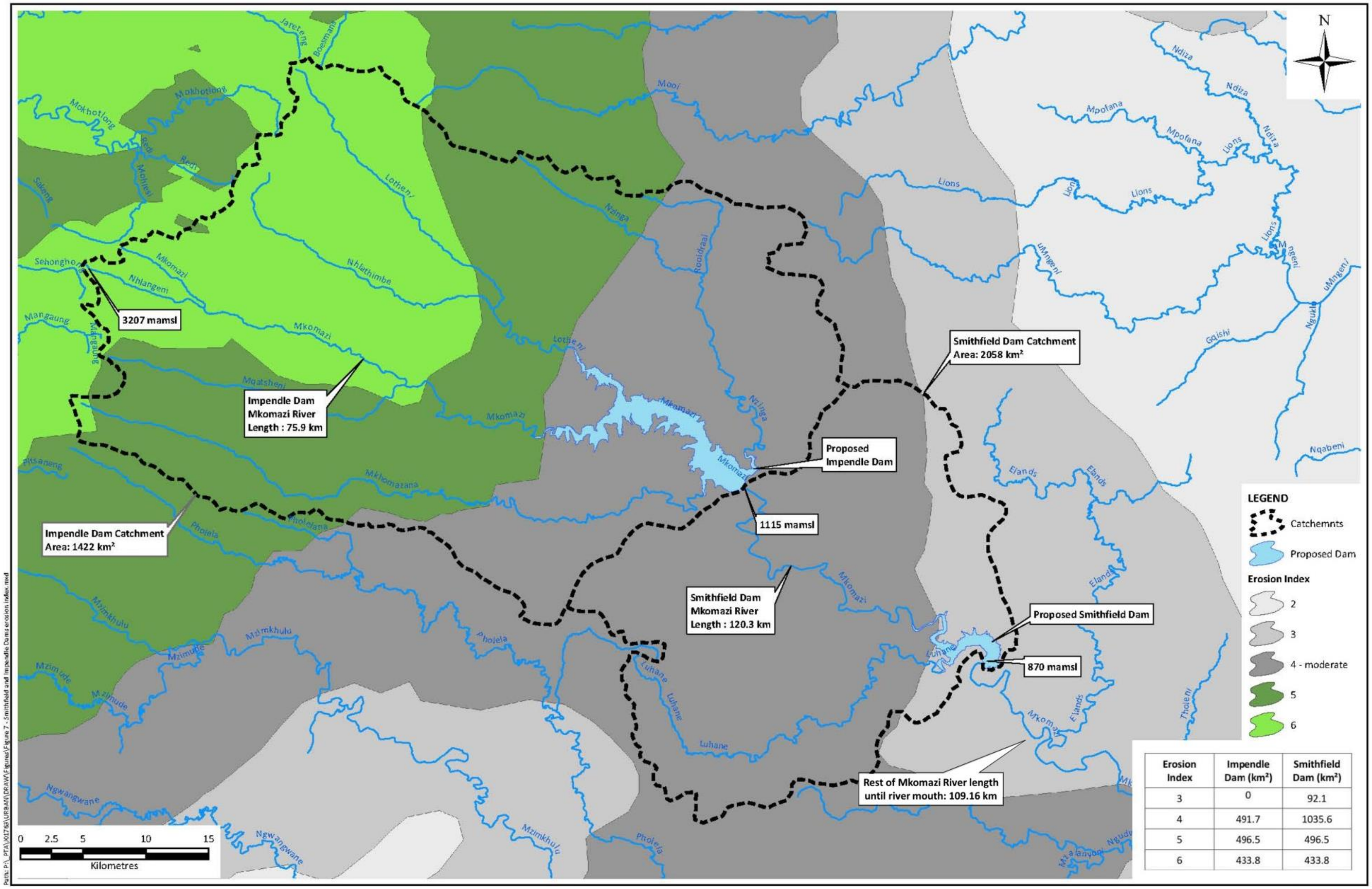

Figure 5.3: Impendle and Smithfield Dam Catchments Erosion Index (2010 Sediment Yield Prediction)

A summary of the abovementioned Region 5 empirical equation parameters for Impendle and Smithfield Dams is provided in **Table 5.8**. As a result of substituting these parameters in the Region 5 empirical equation, the predicted respective Impendle and Smithfield Dam catchment sediment loads and associated catchment sediment yields are also provided in **Table 5.8**.

Table 5.8: Region 5 empirical equation parameters

Parameter		Unit	Impendle Dam	Smithfield[1] Dam
Flood peak with a return period 1 in 10	(Q_{10})	m^3/s	830	1 000
River density	(R_{nd})	m/km^2	217.14	184.42
Average river slope (%)	(S_O)	m/m	2.76	1.94
Weighted Erosion Hazard Class	(EI_W)		4.959	4.618
Effective catchment area	(A_e)	km^2	1 422	2 058
Catchment sediment load	(Q_S)	t/a	202 378.5	293 235.7
Catchment sediment yield		$t/km^2/a$	142.3	142.5

[1] *Smithfield Dam without Impendle Dam implemented*

It follows from **Table 5.8** that the average catchment sediment yield for both Impendle and Smithfield Dams can be assumed in the order of 142.5 $t/km^2/a$ which compares well with the *1992 Sediment Yield* value of 155 $t/km^2/a$. Considering confidence bands of 50%, 80%, 90% and 95% as applicable to Region 5 of the *2010 Sediment Yield Prediction*, the relevant factors and associated catchment sediment yield for Impendle (catchment = 1 422 km^2) and Smithfield (catchment = 2 058 km^2) Dams are indicated in **Table 5.9**.

Table 5.9: 2010 Sediment Yield Prediction Region 5 confidence factors and associated catchment sediment yield for Impendle and Smithfield Dams

Confidence band	Multiplication factor		Catchment sediment yield (t/km^2/a)	
	Impendle Dam	Smithfield Dam	Impendle Dam	Smithfield Dam
50%	0.91	0.89	129.7	126.8
80%	1.45	1.4	206.6	199.5
90%	2.4	2.225	342	317
95%	3.75	3.5	534.4	498.87

A comparison of the values provided in **Table 5.9** with those provided in **Table 5.4** indicates that a catchment sediment yield in excess of 300 t/km^2/a is possible. With reference to **Table 5.9** it can be stated with 80% confidence that the catchment sediment yield for both Impendle and Smithfield Dams can approximately be assumed as 200 t/km^2/a, while it can be stated with 90% confidence that the catchment sediment yield for Impendle and Smithfield Dams can be assumed as approximately 340 and 320 t/km^2/a, respectively.

It will, however, always be necessary to consider existing catchment conditions and compare the values obtained by means of the sediment yield map to recorded values for comparable catchments (refer to **Section 5.3**).

5.3 COMPARISON OF RECORDED AND REGIONALISED SEDIMENT YIELD

It follows from **Sections 5.2.1** (*1992 Sediment Yield*) and **5.2.2** (*2010 Sediment Yield Prediction*) that the only recorded catchment sediment yields (refer to **Table 5.1**) that correspond to the regional based predictions are those of Woodstock (383 t/km^2/a), Wagendrift (170 t/km^2/a), Shongweni (234 t/km^2/a) and Inanda Dams (314 t/km^2/a). However, both Shongweni and Inanda Dams are located further downstream near to the coast and in more densely populated and developed areas. Woodstock and Wagendrift Dams, located in *2010 Sediment Yield Prediction* Region 5, represent the only dams with recorded catchment sediment yield data with runoff originating from less developed areas bordering the Lesotho Highlands, but draining the steep slopes of the Drakensberg Mountain range and resulting in erosion, similar to those of the Impendle and Smithfield Dam catchments (refer to **Figure 5.4**).

The recorded catchment sediment yield of dams such as Kilburn, Spioenkop and Craigieburn, however, confirms that higher catchment sediment yields are possible. Spioenkop and Craigieburn Dams are, however, located further downstream along the respective river systems and are associated with more developed catchments.

The catchment sediment yield for Woodstock Dam and Wagendrift Dam were, for comparison purposes, verified using of the *2010 Sediment Yield Prediction* methodology (refer to **Figure 5.4**). The relevant Region 5 empirical equation parameters are defined and summarised below:

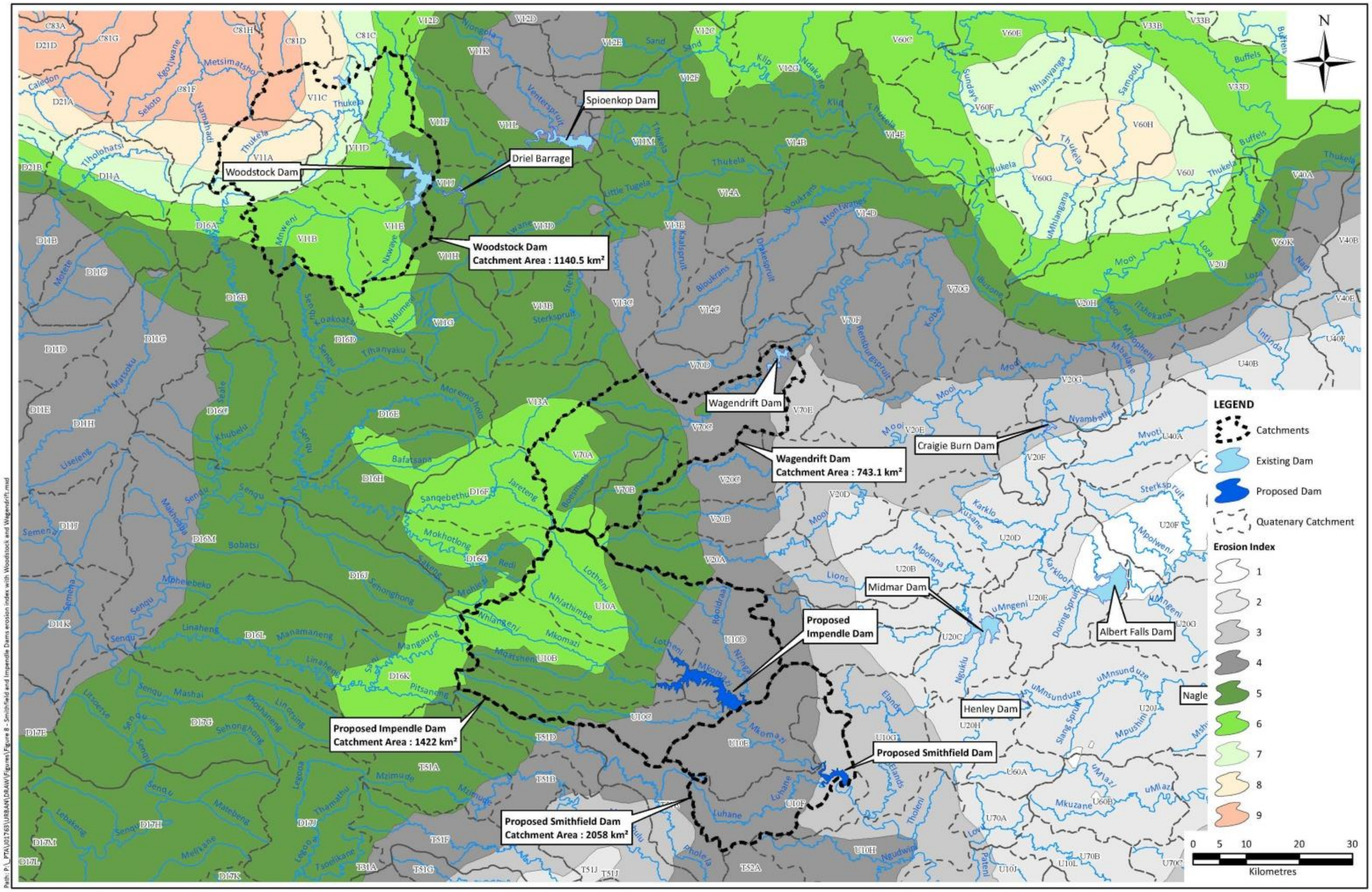

Figure 5.4: Impendle, Smithfield, Woodstock and Wagendrift Dam Catchments Comparative Erosion Index (2010 Sediment Yield Prediction)

- Flood peak discharge $\boldsymbol{Q_{10}}$

Flood peak analyses for Woodstock and Wagendrift Dams are summarised in Table 5.10.

Table 5.10: Flood peak analyses of the Woodstock and Wagendrift Dam catchments

Data description	Woodstock Dam	Wagendrift Dam
Flow gauge stations used	V1H002, V1H026, V1H058	V7H020
No of years of data used	57	49
Statistical analysis Q_{10}(m³/s)	831	219
SDF Q_{10} (m³/s)	938	410
Empirical (M&P) Q_{10} (m³/s)	881	439
Weighted average Q_{10} (m³/s)	**870**	**321**

The weighted flood peak discharge Q_{10} for the Woodstock and Wagendrift Dams was for the purpose of this assessment determined as 50% x Statistical and 25 % x each of SDF and Empirical methods.

- River network density $\boldsymbol{R_{nd}}$

River density as a function of the relevant river length at a scale of 1:500 000 and catchment area was determined as summarised in Table 5.11.

Table 5.11: River density of the Woodstock and Wagendrift Dam catchments

River density parameters	Woodstock Dam	Wagendrift Dam
Total stream length (m)	207 716	150 332
Catchment (km²)	1 140.6	743.1
River density (m/km²)	**182.1**	**202.3**

- Average river slope $\boldsymbol{S_O}$

The average river slope, S_O, of the longest watercourse in the respective catchments is summarised in Table 5.12.

Table 5.12: Average river slope of the Woodstock and Wagendrift Dam catchments

Average river slope parameters	Woodstock Dam	Wagendrift Dam
Length of longest watercourse (m)	59 300	82 900
Highest level (masl)	3 073	2 980
Lowest level (masl)	1 162	1 050
Average river slope (%)	**3.22**	**3.41**

- Weighted Erosion Hazard Class EI_W

A summary of the respective Erosion Hazard Classes as deducted from Figure 5.4 is provided in Table 5.13.

Table 5.13: Erosion Hazard of the Woodstock and Wagendrift Dam catchments

Erosion Hazard Class	Woodstock Dam		Wagendrift Dam	
	Area (km^2)	Proportion to total	Area (km^2)	Proportion to total
3	n/a	n/a	25.5	0.034
4	n/a	n/a	208.4	0.280
5	145.2	0.128	340.1	0.458
6	567.7	0.498	169.1	0.228
7	160	0.140	n/a	n/a
8	189.5	0.166	n/a	n/a
9	78	0.068	n/a	n/a
Total	1140.4	1	743.1	1
Weighted Erosion Hazard Class EI_W	(0.128 x 5) + (0.498 x 6) + (0.140 x 7) + (0.166 x 8) + (0.068 x 9) = **6.548**		(0.034 x 3) +(0.28 x 4) + (0.458 x 5) + (0.228 x 6) = **4.88**	

A summary of the abovementioned Region 5 empirical equation parameters for Woodstock and Wagendrift Dams is provided in Table 5.14. As a result of substituting these parameters in the Region 5 empirical equation, the predicted respective Woodstock and Wagendrift Dam catchment sediment loads and associated catchment sediment yields are also provided in **Table 5.14**.

Table 5.14: Region 5 empirical equation parameters for Woodstock and Wagendrift Dams

Parameter		Unit	Woodstock Dam[1]	Wagendrift Dam
Flood peak with a return period 1 in 10	(Q_{10})	m^3/s	870	321
River density	(R_{nd})	m/km^2	182.1	202.3
Average river slope (%)	(S_O)	m/m	3.22	3.41
Weighted Erosion Hazard Class	(EI_W)		6.548	4.88
Effective catchment area	(A_e)	km^2	1 140.4	743.1
Catchment sediment load	(Q_S)	t/a	253 683.7	57 607.9
Catchment sediment yield		$t/km^2/a$	222.45	77.5

[1] *Woodstock Dam excluding Kilburn Dam*

Comparing the above *2010 Sediment Yield Prediction* catchment sediment yield values for Woodstock and Wagendrift Dams, i.e. 222.45 and 77.5 $t/km^2/a$ with the recorded values of 383.2 and 169.8 $t/km^2/a$, respectively (refers to **Table 5.1**), reveals confidence factors of 1.72 and 2.2, respectively. Considering the *2010 Sediment Yield Prediction* Region 5 confidence bands, it follows that the recorded catchment sediment yield values represents an 85% confidence in terms of the regional *2010 Sediment Yield Prediction* values.

Based on the above comparison, the catchment sediment yield for both Impendle and Smithfield Dams is recommended to be predicted with a minimum 85% confidence level. Given the respective catchment sizes for Impendle and Smithfield Dams and the confidence factors shown earlier in **Table 5.9**, this result in confidence factors of 1.9 and 1.8 for the two dams with associated predicted catchment sediment yields of 270.4 and 256.5 $t/km^2/a$, respectively.

6 SEDIMENT RETENTION WITHIN RESERVOIR

6.1 RESERVOIR TRAP EFFICIENCY

Having estimated the average annual sediment yield for a catchment, this sediment yield could be used to predict the volume which can be lost to reservoir storage. This volume loss is a function of the trap efficiency of the reservoir under consideration as well as a function of time.

The percentage of the total incoming sediment retained in a reservoir is referred to as the trap efficiency of a reservoir. It is commonly expressed as a ratio of the quantity of sediment deposited to the total sediment inflow. The sediment retained in the reservoir is a function of the relative size of the reservoir in comparison to the Mean Annual Run-off (MAR) at the reservoir site. A reasonable estimate of reservoir trap efficiency can thus be based on the ratio of storage capacity to MAR, i.e. the Full Supply Capacity (FSC) to MAR ratio. Depending upon the relative size of the reservoir, the percentage of the sediment to be retained is calculated and from this, the expected future sedimentation rate of the reservoir can be determined. These sediment rates can then be converted to expected volumes for different future dates.

Various trap efficiency curves have been developed for determining the percentage of incoming sediment which will be trapped within a reservoir. In general, the Brune curve is used for large storage or normal ponded reservoirs.

In the case of the Impendle and Smithfield Dams, alternative dams with the statistics as indicated in **Table 6.1** are being considered:

Table 6.1: Statistics of Impendle and Smithfield Dams

Dam	FSC (million m³)[1]	MAR (million m³)	FSC/MAR	Trap efficiency (%)[2]
Impendle	535	571.4	0.936	97.5
Smithfield (without Impendle)	137	725.90	0.189	91.5

[1] *As reported in the Mkomazi/Mgeni Transfer Scheme Pre-feasibility Study*

[2] *Based on the median Brune trap efficiency curve for normal ponded reservoirs*

6.2 FUTURE VOLUMES OF SEDIMENT DEPOSIT IN RESERVOIRS

Considering the *2010 Sediment Yield Prediction* estimated regionalised catchment sediment yield values for the proposed Impendle and Smithfield Dams as indicated in **Table 5.9**, the expected equivalent 50 year sediment volume V_{50}, based on confidence levels of 80%, 85% and 90, respectively, with consideration of sediment retention within the Impendle and Smithfield Dams and assumed sediment deposit densities (see **Section 5.1**), are summarised in **Table 6.2**.

Table 6.2: Expected equivalent 50 year sediment volume V_{50} to be retained

Dam	Confidence level	Catchment sediment yield (t/km²/a)	% trapped sediment	Sediment yield (million t/a)	Expected retained sediment (million t/a)	Equivalent retained 50 year sediment volume V_{50} (million m³)
Impendle	80%	206.6	97.5	0.294	0.287	10.61
	85%	270.4		0.385	0.375	13.89
	90%	342		0.486	0.474	17.56
Smithfield (without Impendle)	80%	199.5	91.5	0.411	0.376	13.91
	85%	256.5		0.528	0.483	17.89
	90%	317		0.652	0.597	22.11

For planning purposes, and based on the 50-year sediment volume V_{50}, the expected retained sediment volumes for periods 10, 20, 30 and 40 years after dam construction completion are indicated in **Table 6.3**.

Table 6.3: Expected future sediment volumes to be retained

Dam	Confidence level	Catchment sediment yield (t/km²/a)	Expected retained sediment (million t/a)	Estimated future sediment volume (million m³) – Sedimentation period (years): 10	20	30	40	50
Impendle	80%	206.6	0.287	4.19	6.95	8.57	9.72	10.61
	85%	270.4	0.375	5.49	9.10	11.22	12.72	13.89
	90%	342	0.474	6.94	11.51	14.19	16.09	17.56
Smithfield (without Impendle)	80%	199.5	0.376	5.49	9.13	11.24	12.74	13.91
	85%	256.5	0.483	7.07	11.72	14.46	16.39	17.89
	90%	317	0.597	8.73	14.49	17.87	20.25	22.11

For water resources planning purposes it is recommended to use the maximum expected retained sediment volumes per confidence level to determine equivalent future sediment volumes. Based on earlier arguments, the 85% confidence values are to be considered as the minimum values, while the 90% confidence values will ensure a more conservative approach.

It follows from **Table 6.3** that the maximum expected V_{50} sediment volumes to be retained within the Impendle (17.56 million m^3) and Smithfield (22.11 million m^3) dams are in the order 3.3% and 16.2% of the FSC, respectively. The impact of sedimentation is therefore much more for the smaller Smithfield Dam (137 million m^3 FSC) than for the larger Impendle Dam (585 million m^3 FSC).

7 CONCLUSIONS AND RECOMMENDATIONS

As it is not possible to predict reservoir sedimentation rates accurately, estimates are made of the most likely foreseeable catchment sediment yields, based on basic or generalised erodibility/sediment yield maps and/or available recorded yield data, which are converted into equivalent storage losses.

Since the previous sediment yield predictions (based on the *1992 Sediment Yield Map*) for the uMkhomazi River catchment in 1996, additional catchment sediment yield information became available and a new catchment sediment yield approach was developed and completed by the Water Research Commission (WRC) in 2010 (WRC, 2010). Based on this new approach, an update on the uMkhomazi River catchment sediment yield was undertaken.

Given the status of both Impendle and Smithfield as proposed dams, their respective catchment yields were determined by using generalised yield patterns in terms of the *1992 Sediment Yield Map* and the *2010 Sediment Yield Prediction*, comparing that to actual recorded sediment yield values of dams closest to the Impendle/Smithfield Dam catchment.

In terms of the *1992 Sediment Yield Map* the catchments of both Impendle and Smithfield Dams relate to:

- A regional standardised catchment sediment yield of 155 t/km2/a to be the average site specific catchment sediment yield.
- A maximum foreseeable catchment sediment yield of 310 t/km²/a based on some statistical confidence around the mean with a confident multiplication factor of 2 assumed for the 80%, 90% and 95 % confidence bands,

In terms of the *2010 Sediment Yield Prediction* the catchments of both Impendle and Smithfield Dams relate to:

- An average catchment sediment yield in the order of 142.5 t/km²/a, which compares well with the *1992 Sediment Yield* value average regional value of 155 t/km²/a.

- An assumed 80% confidence catchment sediment yield of 200 t/km^2/a on average, a 90% confidence catchment sediment yield varies between 340 to 320 t/km^2/a, respectively.

The abovementioned predicted regional catchment sediment yield compare with catchment sediment yields recorded at Woodstock (383 t/km^2/a), Wagendrift (170 t/km^2/a), Shongweni (234 t/km^2/a) and Inanda Dams (314 t/km^2/a). With both Shongweni and Inanda Dams located further downstream near to the coast and in more densely populated and developed areas, the Woodstock and Wagendrift Dams, represent the only dams with recorded catchment sediment yield data with runoff originating from less developed areas bordering the Lesotho Highlands similar to the Impendle and Smithfield Dam catchments. Based on this, it can be concluded that:

- The recorded regional catchment sediment yield can therefore be assumed to be in the order of 170 to 383 t/km^2/a.
- Comparing the recorded and *2010 Sediment Yield Prediction* catchment sediment yield values for Woodstock and Wagendrift Dams reveals confidence factors of 1.72 and 2.2, respectively and an 85% confidence.
- Based on the Woodstock and Wagendrift Dams' records, the minimum catchment sediment yield for both Impendle and Smithfield Dams is recommended to be predicted with a minimum 85% confidence level, resulting in predicted catchment sediment yields of 270.4 and 256.5 t/km^2/a, respectively.

Based on the estimated catchment sediment yield and reservoir trap efficiency, the loss in reservoir storage can be determined. For water resources planning purposes it is recommended to use the maximum expected retained sediment volumes per confidence level to determine equivalent future sediment volumes. The 85% catchment sediment yield confidence values are to be considered as the minimum values, while the 90% confidence values will ensure a more conservative approach. Based on this approach the maximum expected V_{50} sediment volumes to be retained are as follows:

- Impendle Dam – 17.56 million m^3 or 3.3% of the FSC (535 million m^3)
- Smithfield Dam – 22.11 million m^3 16.2% of the FSC (137 million m^3)

The impact of sedimentation on reservoir storage capacity is therefore much more for the smaller Smithfield Dam than for the larger Impendle Dam.

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