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REPORT NO: P WMA 11/U10/00/3312/2/3/2

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

WATER RESOURCE YIELD ASSESSMENT REPORT

SUPPORTING DOCUMENT 2: SEDIMENT DEPOSITION AND IMPACT REPORT

FINAL

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PREAMBLE

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.

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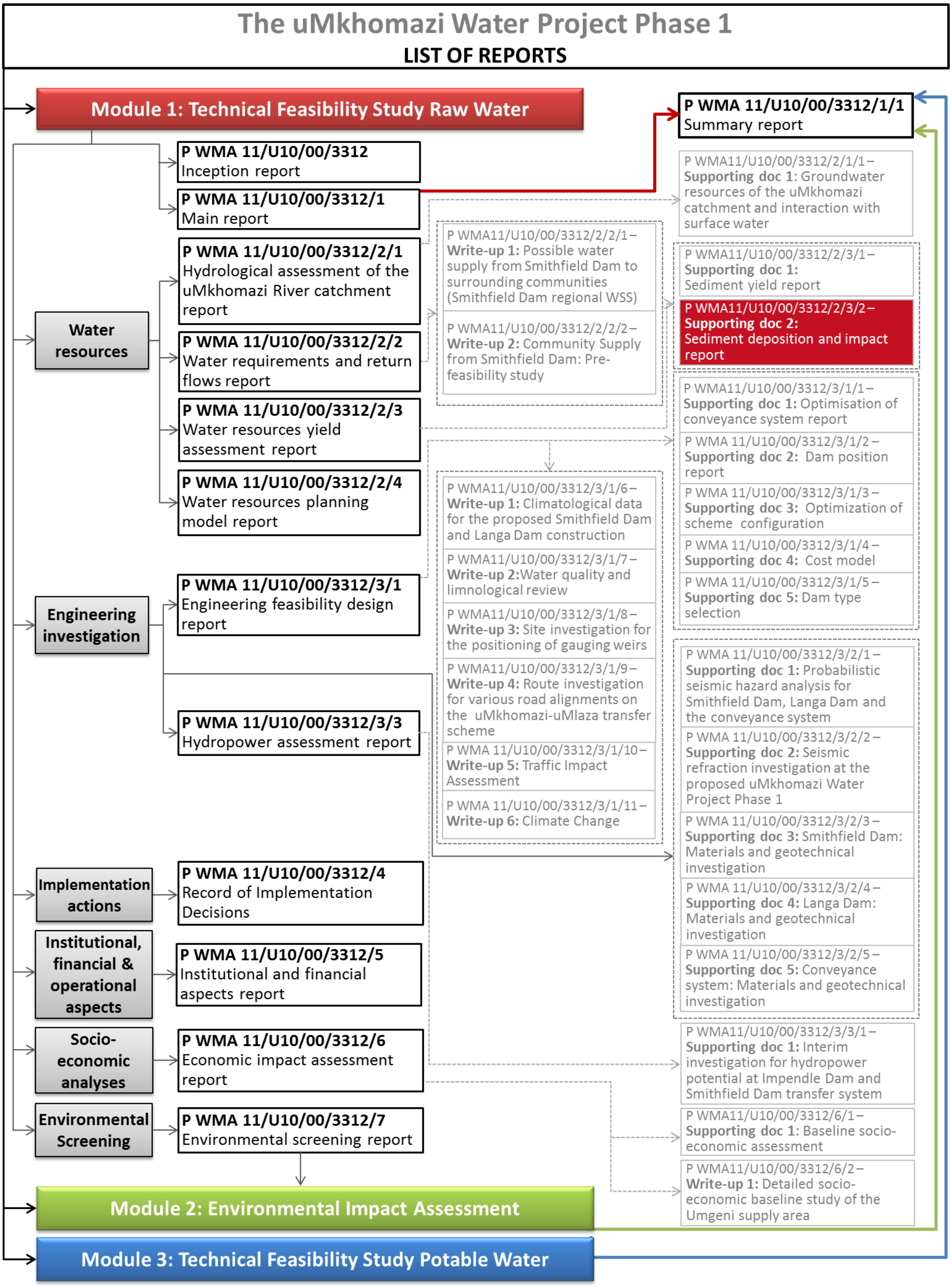

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Executive Summary

The main objectives of this specialist study were to:

a) *review the sediment yield study: Sedimentation Yield study (P WMA 11/U10/00/3312/2/3/2) (2012) and to carry out a hydrodynamic modelling study of the reservoir sedimentation of the proposed Smithfield Reservoir; and*

b) *evaluate how the change in the fluvial sediment (sand) yield at the uMkhomazi River mouth due to the proposed Smithfield Dam, could impact the coastal sediment budget and shoreline stability.*

SMITHFIELD RESERVOIR SEDIMENTATION YIELD STUDY

The key findings of this study are as follows:

- *The sediment yield determined by the Sedimentation Yield Study (P WMA 11/U10/00/3312/2/3/2) (2012) was reviewed and compared with observed sediment yields in the region. Sensitivity testing was also carried out by using the WRC (2012) method by considering the accuracy of the 10 year flood. Based on the relatively high observed sediment yields in the region, it is recommended that a 95% confidence sediment yield is used of 617 t/km^2.a for the proposed dam, which gives a mean annual sediment load of 1.27 million t/a. The sediment yields calculated in this study are similar to those of the Sedimentation Yield Study report, but the recommended sediment yield in this study is higher since it is based on a higher confidence level and agrees with regional reservoir sedimentation data. A possible future sediment yield of double the current yield due to land use change, land degradation and climate change impacts was also considered in the reservoir sedimentation analysis.*

- *Reservoir sedimentation of the proposed Smithfield Reservoir was carried out by using a two dimensional hydrodynamic model. In the model setup 4 sediment fractions were used based on bed sediment grading analysis from field work carried out during this study. The upstream boundary consisted of a scaled observed flow record from a nearby DWS flow gauging station U1H005 using hourly data and a sediment concentration time series for cohesive sediments based on an adjusted discharge-sediment load rating of the Eastern Cape to obtain the correct long term sediment yield. The water levels at the dam site were used as downstream boundary in the model and were simulated by one dimensional hydrodynamic model of the reservoir mass balance, considering inflows, evaporation, rainfall, spillage and diverted flows.*

> *Reservoir sedimentation simulations were carried out for a 100 year period, with the current sediment yield of 617 t/km^2.a. A sensitivity scenario was also simulated with a smaller cohesive fraction of 11 micron (compared to the 33 micron), to evaluate the deposition patterns near the dam. The results were similar after 50 years, but after 100 years of operation the 33 micron cohesive fraction indicated slightly more sediment deposition near the dam.*

The new reservoir trap efficiency is 97% and therefore only colloidal (very fine) sediment will not be deposited in the reservoir. The new Smithfield Dam full supply storage capacity (FSC) of 252 million m^3 could decrease to 208 and 161 million m^3 after 50 years, for the current sediment and possible increased future sediment yields, respectively. The simulated reservoir sedimentation therefore decreases the storage capacity by 18% and 36% for the current and future sediment yield scenarios respectively, over the 50 year period. At the current sediment yield and future possible higher sediment yield over a 100 year period, the FSC could be 163 and 87 million m^3, a decrease of 36% and 66% in the original FSC, respectively.

A scenario was also considered where the Impendle Dam is constructed in future upstream of the proposed Smithfield Dam. ***Table i*** *provides the Smithfield Reservoir FSC's for different sediment yield scenarios after 50 and 100 years of operation, with Impendle Dam commissioned by 2046, and without Impendle Dam. The last row in* ***Table i*** *is the recommended scenario over 100 years of operation of Smithfield Dam, with the current yield sediment over the first 50 years and a doubled future sediment yield over the last 50 year period. With Impendle Dam commissioned by year 2046 the Smithfield Reservoir will only lose 16% of its original FSC over a 100 year period, but if Impendle Dam is not implemented 51% of the original FSC of Smithfield Dam could be lost due to sedimentation.*

Table i Reservoir sedimentation at Smithfield Dam with and without Impendle Dam upstream of Smithfield Dam

Description	Unit	Smithfield Dam-with Impendle Dam (yr 2046)	Smithfield Dam-without Impendle Dam
Year of Smithfield Dam commission	*year*	*2023*	*2023*
New reservoir Full supply storage capacity	*million m^3*	*252.0*	*252.0*
After 50 yr: Full supply storage capacity, at current sediment yield	*million m^3*	*227 (10%)**	*208 (17%)*
After 100 yr: Full supply storage capacity, at current sediment yield	*million m^3*	*219 (13%)*	*163 (35%)*
After 100 yr of Full supply storage capacity, at doubled future sediment yield, for last 50yr	*million m^3*	*211 (16%)*	*124 (51%)*

*Note: * percentage of original FSC loss due to sedimentation indicated in brackets*

The long term reservoir sedimentation simulations indicated possible sediment deposition at the diversion tunnel intake in the Smithfield Reservoir (no Impendle Dam). After 50 years of operation the current and possible high future sediment yield indicated sediment deposition at the intake of 0.4 and 12.8 m respectively. If the high future sediment yield is considered over a 100 year period the sediment deposition at the tunnel intake could be 28.5 m deep and at the dam wall 58.5 m deep. The actual sediment deposition could be less, however, if the high future sediment yield is only considered over the period from 50 to 100 years of operation of the dam, and if Impendle dam is constructed.

It is recommended that for scenarios without the proposed Impendle Dam:

a) *the simulated 50 year reservoir sedimentation of Smithfield Dam (using a cohesive fraction size of 33 micron), for the current sediment yield, should be used to ensure that the required firm water yield of the reservoir is not affected during the first 50 years of operation.*

b) *As a sensitivity analysis in the water resources planning, the high sediment yield (double current yield) reservoir sedimentation assessment after 50 years should also be considered in the firm yield assessment to evaluate the firm yield reduction of Smithfield Dam.*

c) *While the above is typically the methodology followed in South Africa, based on international guidelines (ICOLD and World Bank) the reservoir sedimentation and operation for 100 years should also be considered in the water resources analysis, to assess whether Smithfield Dam will be feasible in the long term. The recommended sediment yield scenario is the last one in* ***Table i*** *(bottom row).*

d) *Sediment control measures should be implemented in the catchment (land care programme) to limit the sediment yield increase in future and engineering measures in the dam at the diversion tunnel intake (concrete wall to prevent delta sediment sliding/slumping into the intake and sediment flushing tunnel for pressure flushing of the intake zone).*

If the proposed Impendle Dam is constructed in future upstream of Smithfield Dam, land care of the catchment to prevent land degradation will remain important for the total catchment of Smithfield Dam. The recommended sediment flushing mitigation measure at the diversion tunnel intake will not be required due to the relatively small FSC storage loss of only 16% over 100 years.

POTENTIAL IMPACT OF THE PROPOSED SMITHFIELD DAM ON THE COASTAL SEDIMENT BUDGET AND SHORELINE STABILITY

The proposed Smithfield Dam is located 187 km upstream of the river mouth and the estimated total sediment yield trapped in the reservoir is 1.2 million t/a,. The coastal impact of the dam is affected by the decrease in sand load at the river mouth (coarse sediment) caused by sediment trapping in the reservoir and also due to the decreased sediment transport capacity downstream of the dam with the attenuated flood peaks and fewer floods spilling at the dam. The simulated net effect of the proposed dam is a 46 000 m^3/a reduction in sand load at the mouth. The pre-dam mean sand load at the river mouth was calculated as 352 000 t/a, while the post dam sand load is calculated to be 287 000 t/a, with an estimated reduction of sand load of 74 000 t/a (a 21% reduction in sand yield on this river). The main focus is on the shoreline stretching from just south of the uMkhomazi River mouth northwards to Durban. This reduction in sand yield represents a reduction of 18% of all the inland sand load of all the rivers (from the river mouth to Durban), and a 10 % reduction in total load at Durban (river and longshore inputs combined).

It should be noted that the sediment yield has increased significantly over the past 100 years on this river due to land use changes. The sand fraction of the sediment yield is however not increased because it is related to the sediment transport capacity based on local hydraulic conditions. The main change is the fine cohesive sediment load (clay and silt) which is now much higher, but does not contribute to the sand budget to limit coastal erosion.

From the aerial photographic analyses and the topographic survey results it cannot be clearly ascertained whether there is currently a significant long-term trend in the shoreline location in the vicinity of the uMkhomazi River mouth. Horizontal shoreline variations are naturally relatively large on this exposed high energy coastline and are further subject to the effects of episodic flood derived pulses of sediment input from the larger rivers in the region. Based on the longer-term aerial photographic analyses it appears that if indeed an eroding trend were present, it would have to be quite small (<=0.3 m/a, i.e. <=15 m over 50 years) to remain undetected at this stage. However, along the Durban Bluff coastline, which is located about 31 km northeast of the uMkhomazi Mouth, the historical observed lateral erosion rate is about 1 m/a.

It is clear that the proposed dam on the uMkhomazi River will possibly have a significant and long-term effect on the coastal sediment budget due to the relatively large volume of sediment (sand) that will not reach the river mouth due to sediment deposition in the *reservoir and due to the reduced sediment transport capacity downstream of the dam. The "substance" of the dam's impact on coastal erosion has to be evaluated further as part of detailed research or additional specialist study. It is however possible to mitigate and limit the impact of the dam by implementing a combination of measures (see below). The impact in terms of net coastal erosion will be most noticeable in the first 10 km to the north of the mouth of the river, but even in this area it may be a decade or more before the impact is clearly apparent. However, in the long-term the impact (although initially insignificant), will gradually spread further north and is likely to eventually even result in a reduction of the longshore sand supply to the Durban Bluff area. Numerical shoreline modelling (1D) could be employed to quantify potential erosion impacts in the medium-term The estimated sea level rise due to climate change could be 0.5 m in about 60 years' time, with an associated 50 m potential lateral erosion of the beach. The effect of sea level rise on coastal erosion will probably become significant from year 2040. The lateral erosion rate due to sea level rise could be on average 0.83 m/a (not linear in reality), while the historical observed lateral erosion rate is 1 m/a along the Durban Bluff. Climate change by year 2075 could therefore almost double the current rate of lateral erosion of the beaches. The proposed Smithfield Dam has an estimated 10 % long term impact (reduction) of the total longshore sediment load at Durban, which is likely to increase the current rate of coastal erosion.*

If major dam developments on the uMkhomazi River are inevitable, then the potential impacts in terms of reduced fluvial sand supply to the coast could be mitigated by:

- *The current impact of sand mining on the uMkhomazi River is as large as the impact on the sand yield of the proposed Smithfield Dam. It is recommended to establish the status quo of sand mining in the uMkhomazi catchment, including illegal/unpermitted mining to quantify the extent of the problem. It is proposed that firstly existing illegal sand mining south of Durban should be prevented.*
- *In general future legal sand mining south of Durban should also be limited. As alternative to the current sources of alluvial river bed sediment, suitable sand sources at the coast could be identified, such as historical beach zones (geologic deposits) currently located inland near the coast, possible quarries, from the Smithfield Reservoir or upstream on the river (but this is relatively far from the coast), and possibly from alluvial river floodplains above the 200 year flood levels,*
- *Coastal control of development could possibly be improved to limit erosion (by not removing coastal dunes, etc.).*
- *Increase the sand load at the mouth by adding a sand bypass tunnel at the Smithfield Dam. A 5.1 km concrete lined tunnel length is required. Flushing of sediment will be*

carried out during floods and the firm yield of the dam could decrease slightly due to the flushing operation. See ***Appendix G*** *for a detailed write-up and costing of the proposed sediment bypass tunnel.*

- *A beach nourishment programme is possible, but requires a suitable off-shore source of coarse sand and dredging cost will be expensive. Critical zones along the beach could be targeted or general dredge disposal could be done to increase the available sediment for longshore transport.*

To limit the environmental impact of the reduction in available sand resources on coastal erosion south of Durban, it is proposed to first address sand mining (legal and illegal) and to control further development in the catchment. A sediment bypass tunnel at the dam may also be considered, however, to better understand the functionality and feasibility of such a tunnel, further research is required, e.g. a study by the Water Research Commission.

If a bypass tunnel around Smithfield Dam is required to transport coarse sediment to limit the impacts of the dam on the downstream river morphology and on the sediment loads at the river mouth, a 5.1 km tunnel with diameter of 7.0 m to 8.3 m (if concrete lined) will be required, to bypass the frequent floods such as the 2 year and 5 year floods, respectively. At the tunnel intake a weir is required in the upper reservoir, with a height of about 12 m.

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kℓ	kilolitre
km	kilometre
km^2	square kilometres
ℓ/c/d	liter per capita per day
m	metre
masl	metres above sea level
mm	millimetre
m^3	cubic metre
m^3/year	cubic metre per year
t/a	tons per annum

LIST OF ABBREVIATIONS

AGES	Africa Geo-Environmental Services (Pty) Ltd
BKS	BKS (Pty) Ltd
DM	District Municipality
DWA	Department of Water Affairs
DWS	Department of Water and Sanitation
KZN	KwaZulu-Natal
LM	Local Municipality
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
MM	Metropolitan Municipality
MMA	Mogoba Maphuthi and Associates
MMM	Mkhomazi-Mooi-Mgeni system
MMTS-1	Mooi Mgeni Transfer Scheme – Phase 1
MMTS-2	Mooi Mgeni Transfer Scheme – Phase 2
ToR	Terms of Reference
uMWP	uMkhomazi Water Project
uMWP-1	uMkhomazi Water Project – Phase 1
UW	Umgeni Water
WRPM	Water Resources Planning Model
WRYM	Water Resources Yield Model

1 INTRODUCTION

The Department of Water Affairs (DWA) appointed **BKS (Pty) Ltd** in association with three sub-consultants **Africa Geo-Environmental Services (AGES), MM&A and Urban-Econ** with effect from 1 December 2011 to undertake the **uMkhomazi Water Project Phase 1: Module 1: Technical Feasibility Study Raw Water** study.

On 1 November 2012, BKS (Pty) Ltd was acquired by **AECOM Technology Corporation**. As a result of the change in name and ownership of the company during the study period, all the final study reports will be published under the AECOM name.

In 2010, the Department of Arts and Culture published a list of name changes in the Government Gazette (GG No 33584, 1 October 2010). In this list, the Mkomazi River's name was changed to the **uMkhomazi River**. *The published spelling will thus be used throughout this technical feasibility study.*

1.1 BACKGROUND TO THE PROJECT

The current water resources of the Mgeni Water Supply System (WSS) are insufficient to meet the long-term water demands of the system. The Mgeni WSS is the main water source that supplies about six million people and industries in the eThekwini Municipality, uMgungundlovu District Municipality (DM) and Msunduzi Local Municipality (LM), all of which comprise the economic powerhouse of the KwaZulu-Natal (KZN) Province.

The Mgeni WSS comprises the Midmar, Albert Falls, Nagle and Inanda Dams in KZN, a water transfer scheme from the Mooi River and the newly constructed Spring Grove Dam. The current system (Midmar, Albert Falls, Nagle and Inanda dams and the Mooi-Mgeni Transfer Scheme Phase 1 (MMTS-1) has a stochastic yield of 334 million m^3/a (measured at Inanda Dam) at a 99% assurance of supply. The short-term augmentation measure, Phase 2 of the Mooi Mgeni Transfer Scheme (MMTS-2), i.e. the recently constructed Spring Grove Dam, will increase water supply from the Mgeni system by 60 million m^3/a. However, this will not be sufficient to meet the long-term requirements of the system.

Pre-feasibility investigations indicated that the development of the undeveloped uMkhomazi River, to transfer water to the existing Mgeni System, most likely will fulfil this requirement. The uMkhomazi River is the third-largest river in KZN in terms of mean annual runoff (MAR).

Eight alternative schemes were initially identified as possible alternatives, and the Impendle and Smithfield scheme configurations have emerged as suitable for further investigation. The pre-feasibility investigation, concluded in 1998, recommended that the Smithfield Scheme be taken to a detailed feasibility-level investigation as its transfer conveyances would be independent of the existing Mgeni System, thus reducing the risk of limited or non-supply to eThekwini and some areas of Pietermaritzburg, and providing a back-up to the Mgeni System.

The ***Mkomazi-Mgeni Transfer Pre-feasibility Study*** concluded that the first phase of the uMkhomazi Water Project (uMWP) would comprise a new dam at Smithfield on the uMkhomazi River near Richmond, a multi-level intake tower and pump station, a water transfer pipeline/tunnel to a balancing dam at Baynesfield Dam or a similar in-stream dam, a water treatment works at Baynesfield in the uMlaza River valley and a gravity pipeline to the Umgeni Water bulk distribution reservoir system, below the reservoir at Umlaas Road. From here, water will be distributed under gravity to eThekwini and possibly low-lying areas of Pietermaritzburg. Phase two of the uMWP may be implemented when needed, and could comprise the construction of a large dam at Impendle further upstream on the uMkhomazi River to release water to the downstream Smithfield Dam. Together, these developments have been identified as having a 99% assured stochastic yield of about 388 million m^3/a.

The DWA aims to have this scheme implemented by 2023.

1.2 OBJECTIVE OF THE STUDY

According to the Terms of Reference (TOR) (November 2010), the objective is to undertake a feasibility study to finalise the planning of the proposed uMWP at a very detailed level for the scheme to be accurately compared with other possible alternatives and be ready for implementation (detailed design and construction) on completion of the study.

The feasibility study has been divided into the following modules, which will run concurrently:

- Module 1: Technical Feasibility Raw Water (DWA) (*defined below*);
- Module 2: Environmental Impact Assessment (DWA); and

- Module 3: Technical Feasibility Potable Water (Umgeni Water) (ranging from the Water Treatment Plant to the tie-in point with the eThekwini distribution system).

The layout as per module is shown in **Figure 1.1**.

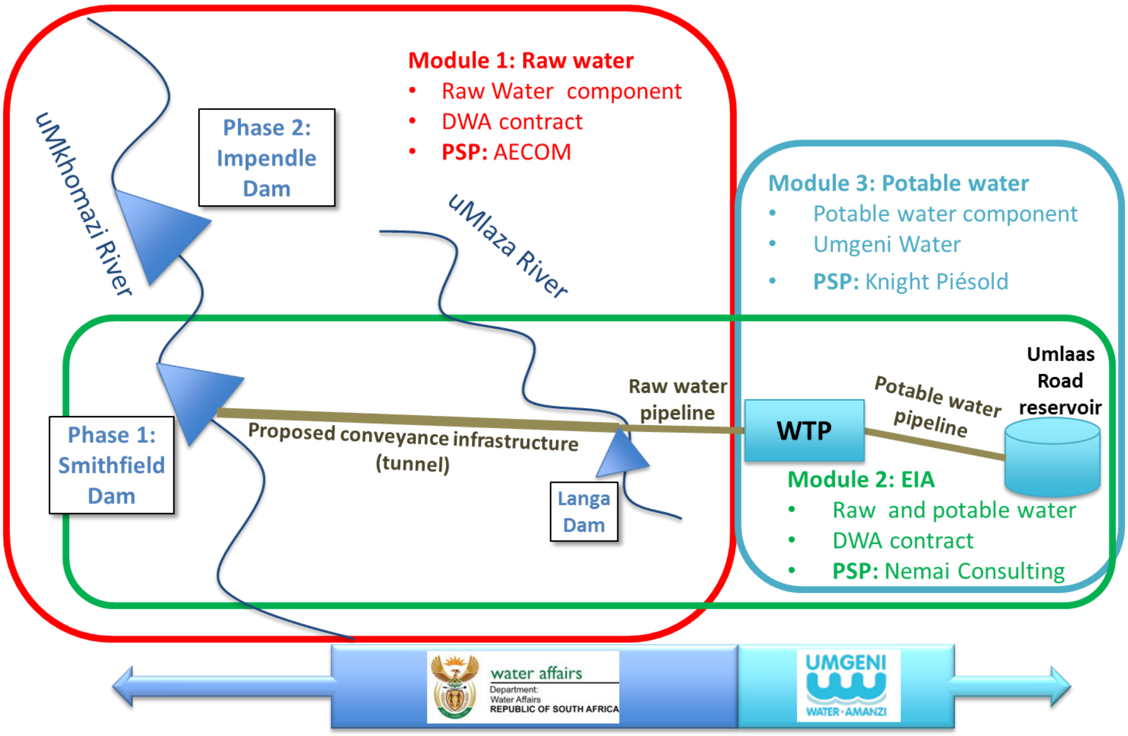

Figure 1.1: Feasibility layout

This module, the raw water technical feasibility study, considers water resources aspects, engineering investigations and project planning and scheduling and implementation tasks, as well as an environmental screening and assessment of socio-economic impacts of the proposed project.

Some specific objectives for this study, recommended in the *Mkomazi-Mgeni Transfer Scheme Pre-feasibility Study* are listed below:

- Smithfield Dam (Phase 1) to be investigated to a detailed feasibility level;
- Investigate the availability of water from Impendle Dam (Phase 2) as a future resource to release to Smithfield Dam, and refine the phasing of the selected schemes;
- Optimise the conveyance system between Smithfield Dam and the proposed Baynesfield Water Treatment Plant;
- Undertake a water resources assessment of the uMkhomazi River Catchment, including water availability to the lower uMkhomazi;
- Evaluate the use of Baynesfield Dam as a balancing dam; and

- Investigate the social and economic impact of the uMWP.

This study, being one of three modules, was undertaken in close collaboration with the DWA, Umgeni Water and the Professional Services Providers (PSPs) of the other modules.

1.3 STUDY AREA

The study focus and key objective is related to the feasibility investigation of the Smithfield Dam and related raw water conveyance infrastructure. However, this is a multi-disciplinary project with the study area defined as the uMkhomazi River catchment, stretching to the north to include the uMngeni River catchment, refer to **Figure 1.2**. The various tasks have specific focus areas, defined as:

- Water resources: uMkhomazi and Mgeni River catchments;
- Water requirements: water users in the Mgeni System and the uMkhomazi River catchment;
- Engineering investigations: proposed dams at Impendle (only for costing purposes) and Smithfield, and the raw water conveyance infrastructure corridor between Smithfield Dam and the proposed Water Treatment Plant of Umgeni Water;
- Environmental screening as input for the Environmental Impact Assessment for the project footprint; and
- Socio-economic impact assessment: regional, provincial (KZN) and national.

1.4 SCOPE OF THIS REPORT

The main objectives of this specialist study are as follows:

- to carry out a hydrodynamic modelling study of the reservoir sedimentation of the proposed Smithfield Dam, based on the Sedimentation Yield study (*P WMA 11/U10/00/3312/2/3/2*); and
- to determine how the change (reduction) in the fluvial sediment yield from the uMkhomazi River due to the development of the proposed Smithfield Dam, could impact on the coastal sediment budget and shoreline stability.

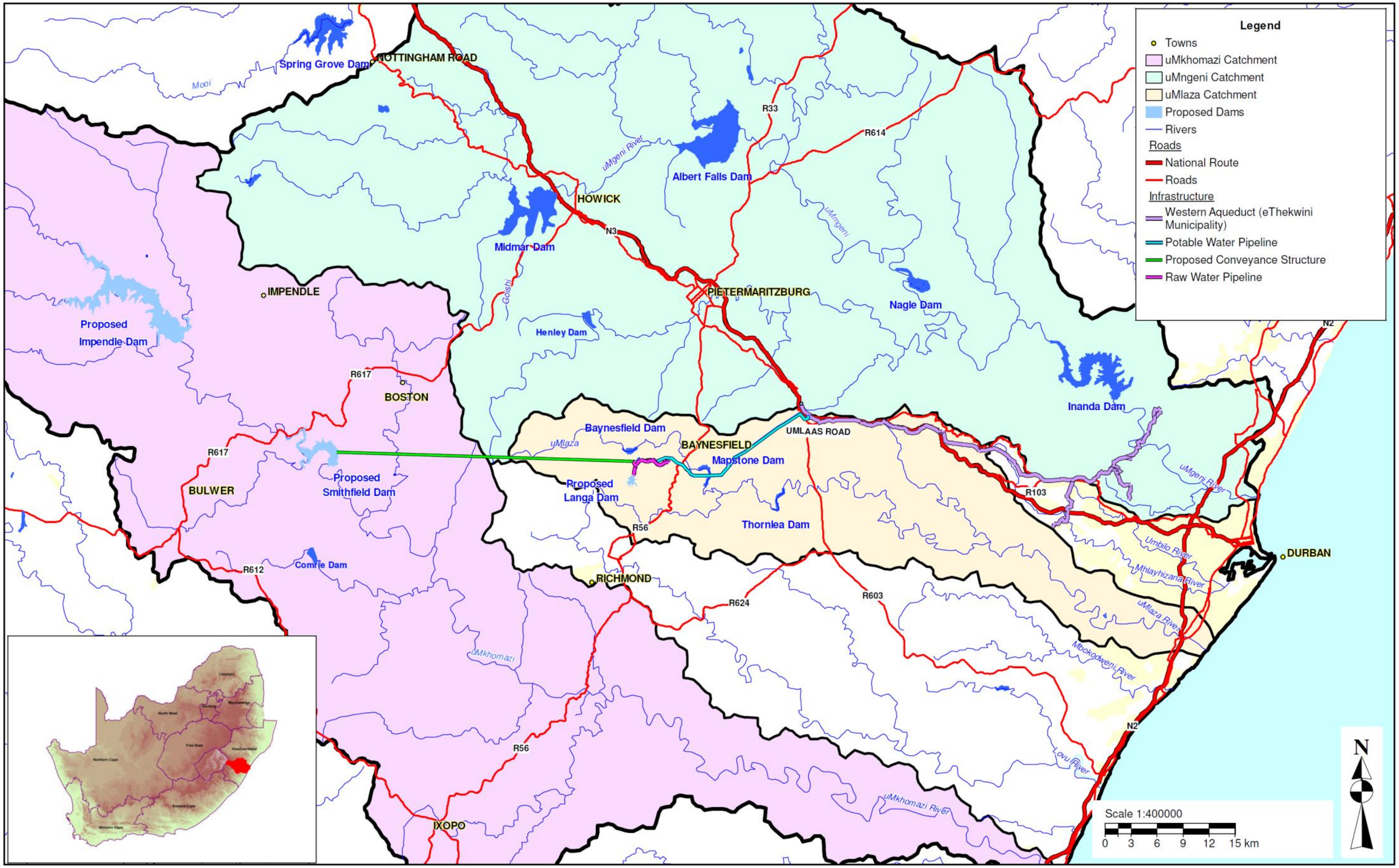

Figure 1.2: Locality map: study area of the uMkhomazi Water Project

2 SEDIMENT YIELD AND LOADS AT THE PROPOSED SMITHFIELD DAM

2.1 SEDIMENT YIELD AND LOAD CALCULATION

The sediment yield of the proposed Smithfield Dam was calculated based on the regional method proposed by the WRC (2012) study for unmeasured catchments. Since no river suspended sediment sampling data or local reservoir sedimentation surveys are available for analysis, the WRC method is the most reliable. **Table 2.1** shows the results of the regional sediment yield approach. The catchment area at the dam site is 2 058 km^2. The sediment yields have been calculated by considering the accuracy in the 10 year flood peak of 30% as a sensitivity test and values were also calculated for different confidence envelopes. The calculated sediment yields and loads compare well with the values calculated in the Sediment Yield report (*P WMA 11/U10/00/3312/2/3/2*).

Table 2.2 shows the observed sediment yields in the region. They vary from 10 to 714 t/km^2.a. Two observed yields marked in red, exceed the 95% confidence yield values of **Table 2.1** (based on 30% larger Q_{10}) of 617 t/km^2.a. The catchment areas of these two observed data sets are relatively small, however, and smaller catchments typically have higher sediment yields than larger ones. The observed sediment yield of the Thukela River at Colenso is also quite high and the catchment area is double that of the proposed Smithfield Dam.

The observed data are all located north of the Smithfield Dam site as shown in **Figure 2.1**. The Great Fish River is the only recorded river data set located far south of Smithfield Dam. The suspended sediment samples were obtained from 1930 to 1940 at Hougham Abrahamson (Area = 18 436 km^2) and the sediment yield was found to be 209 t/km^2.a.

The last column is **Table 2.1** gives the sediment yield and load calculation results calculated by AECOM (2012). The average sediment yield (no confidence factors included) of AECOM (2012) (142 t/km^2.a), falls between the two values given by this report: 125 to 176 t/km^2.a, and is therefore in agreement in terms of the method of calculation.

Table 2.1: Sediment loads and yields at the Smithfield Dam site

Parameter	Unit	Q_{10} based on probabilistic hydrological method	1.3 x Q_{10}*	At Smithfield Dam site - (AECOM, 2012)***
		At Smithfield Dam site	At Smithfield Dam site	
Q_{10}	m^3/s	805	1 047	1 000
River density (Rnd)	m/km^2	166	166	184
Average river slope (%) (S_0)	(%)	2.115	2.115	1.94
Weighted Erosion Hazard Class (EIW)		4.57	4.57	4.62
Effective catchment area at dam site (Ae)	km^2	2 058	2 058	2 058
Catchment sediment load (Q_S) (average)	t/a	257 350	362 748	293 236
Catchment sediment load (Q_S) (50% confidence)	t/a	231 615	326 473	260 954
Catchment sediment load (QS) (80% confidence)	t/a	360 290	507 847	410 571
Catchment sediment load (Q_S) (90% confidence)	t/a	566 170	798 045	652 386
Catchment sediment load (Q_S) (95% confidence)	t/a	90 0725	1 269 617**	1 026 674
Catchment sediment yield (average)	$t/km^2.a$	125	176	142
Catchment sediment yield (50% confidence)	$t/km^2.a$	113	159	127
Catchment sediment yield (80% confidence)	$t/km^2.a$	175	247	200
Catchment sediment yield (90% confidence)	$t/km^2.a$	275	388	317
Catchment sediment yield (95% confidence)	$t/km^2.a$	438	617**	499

Notes: ** Sensitivity testing due to accuracy of flood peak discharge of say 30%*

*** Selected based on sediment yield comparable to observed sediment yields.*

**** Data obtained from Sediment Yield Report (P WMA 11/U10/00/3312/2/3/2)*

Table 2.2: Observed sediment yields at reservoirs and rivers in the region

Dam Name	River	Station	Coordinates – (DWS website)		Effective Catchment area (km^2) - WRC (2012)	Sediment yield ($t/km^2.a$) - WRC (2012)
			S	E		
Wagendrift Dam	Boesmans	V7R001	29.04199	29.85294	755	120
Craigie Burn Dam	Mnyamvubu	V2R001	29.16329	30.28704	156	656*
Hammarsdale Dam	Sterkspruit	NA			48	100
Spioenkop Dam	Thukela	V1R001	28.68130	29.51710	803	411
Woodstock Dam	Thukela	V1R003	28.75871	29.24631	875	416
Thukela River at Colenso	Thukela	-	-	-	4203	571**
Hazelmere Dam	uMdloti	U3R001	29.59838	31.04285	382	714*
Albert Falls Dam	uMgeni	U2R003	29.43109	30.42594	731	31
Midmar Dam	uMgeni	U2R001	29.49509	30.20145	931	10
Goedertrouw Dam	uMhlatuze	W1R001	28.77143	31.46873	1275	524
Henley Dam	uMsunduze	U2H011	29.64708	30.25975	219	62
Proposed Smithfield Dam	***uMkhomazi***	***Downstream of U1H005***	***29.776156***	***29.940313***	***2058***	***617***

*Note: * Values exceed the proposed sediment yield of this study (**Table 2.1**)*

*** Based on river suspended sediment sampling from 1950 to 1958*

Based on the above, it is proposed that a sediment yield of 617 t/km^2.a is used for Smithfield Dam as the current sediment yield and for the first 50 years of operation of the dam. This proposed sediment yield has a 95% confidence band and is equivalent to a mean annual sediment load of 1.27 million t/a. This load includes the bedload, suspended sediment load and washload (cohesive sediments). The Sediment Yield Report (2012) (*P WMA 11/U10/00/3312/2/3/2*) proposed a sediment yield of 257 t/km^2.a, based on an 85% confidence band, which is relatively low if one considers the observed sediment yields (**Table 2.2**).

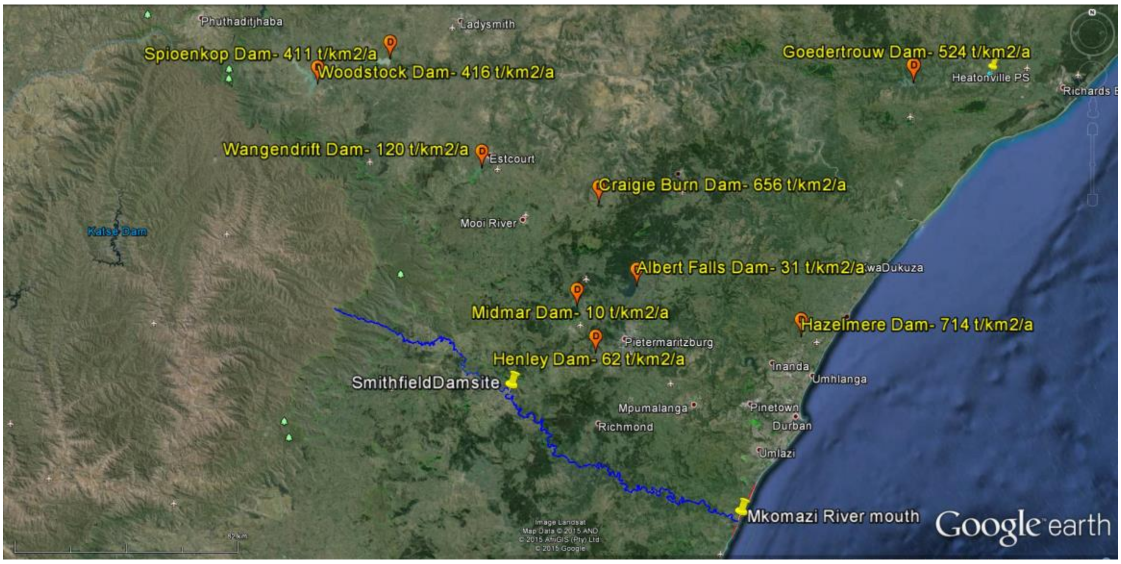

Figure 2.1: Locations of dams with observed sediment yields

2.2 CALIBRATED SEDIMENT LOAD-DISCHARGE RATING AND RESERVOIR INFLOW FINE SEDIMENT CONCENTRATIONS

For the boundary conditions of the reservoir sedimentation model, a time series of sediment concentrations at the upstream end of the reservoir is required. This time series was calculated by using the observed flow record of DWS gauging station U1H005 which is close to the dam site, and by applying a discharge-sediment load relationship for the river calibrated against the long term mean sediment load of 1.27 million t/a. The available flow record is from 1960 to 2014, and is shown in **Figure 2.2**. The maximum observed flood peak is 2 982 m^3/s.

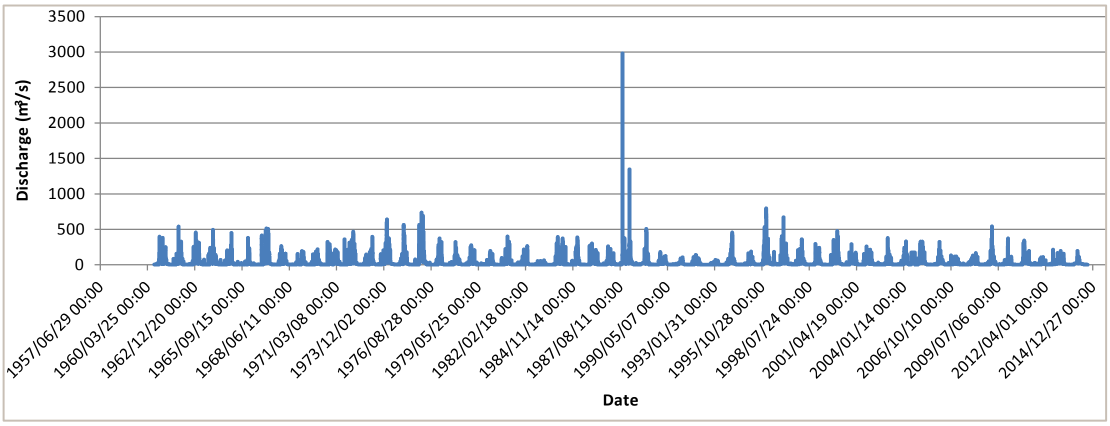

Figure 2.2: Observed flow record at gauging station U1H005 used as inflow record for Smithfield Reservoir (hourly data)

The calibrated sediment load-discharge relationship for Smithfield Dam is shown in **Figure 2.3**, and the calculated sediment concentrations for the cohesive fraction only, are shown in **Figure 2.4**. The basic sediment load-discharge relationship was obtained from observed suspended sediment data at Tsomo in the Eastern Cape, but was calibrated to obtain the long term sediment yield at Smithfield Dam.

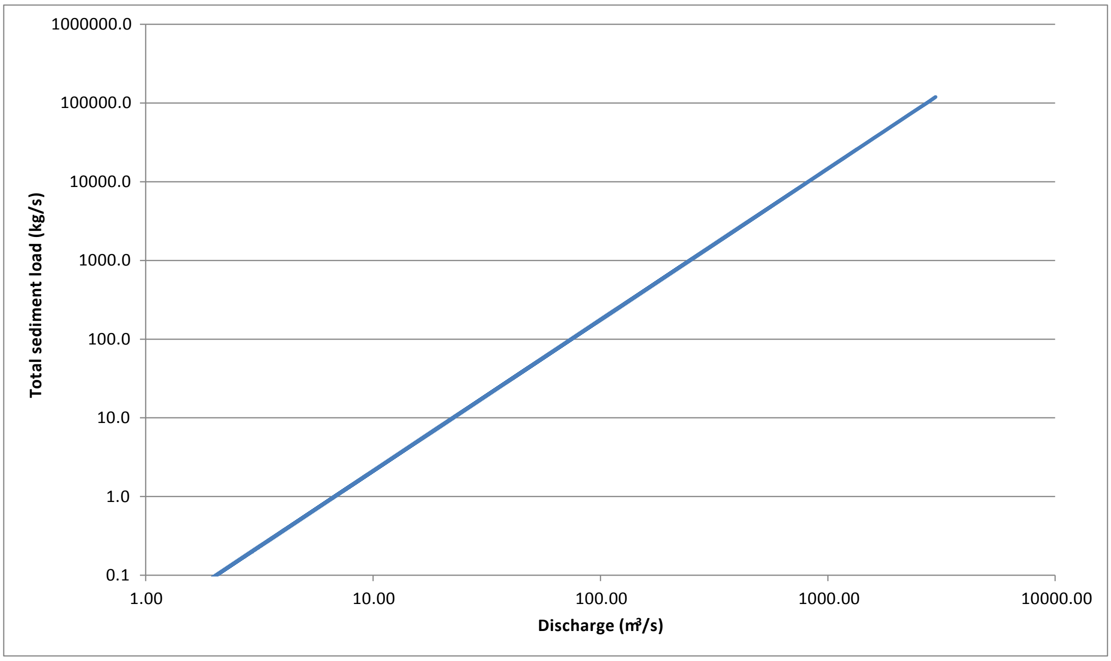

Figure 2.3: Calibrated discharge-sediment total load relationship for the Smithfield Reservoir inflow

It was assumed that the bedload fraction is 10% of the total load. The cohesive fraction (silt and clay) as shown in **Figure 2.4** therefore represents 90% of the total load. While the bedload at the upstream end of the reservoir is calculated based on the sediment transport capacity locally by the hydrodynamic model, the cohesive sediment is related to the conditions in the catchment. In reality without a reservoir the cohesive sediments, the so-called washload, is transported during floods right through the river system with little deposition. Sometimes the washload could be in oversupply following a dry period, or sometimes it could be undersupplied from the catchment. The rating given in **Figure 2.3** is therefore simplified and in reality there will be much more scatter around this average rating. No data is however available on the uMkhomazi River to refine this rating currently. Daily suspended sediment sampling for a period of 5 years is required to obtain a reliable relationship between discharge and sediment load.

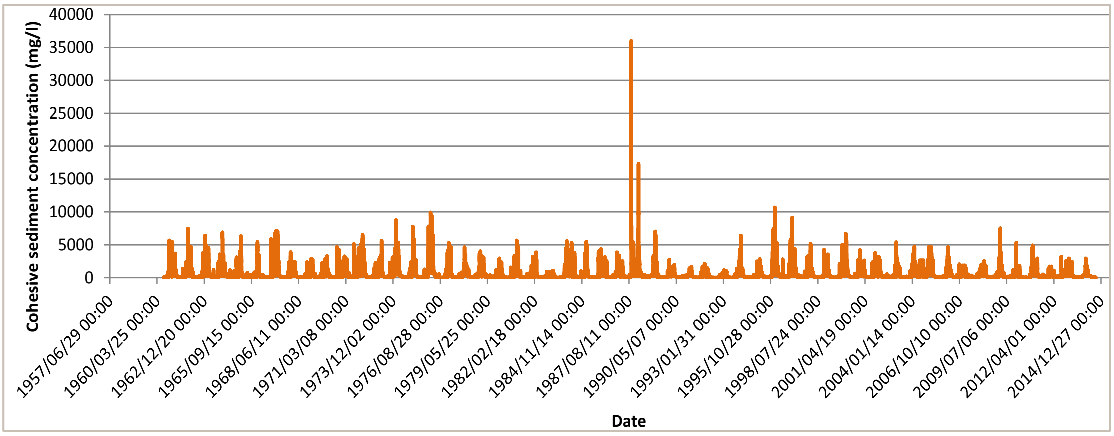

Figure 2.4: Calculated Smithfield Reservoir inflow cohesive sediment concentrations

The total load sediment time series from 1960 to 2014, based on hourly calculated data, has mean and maximum concentrations of 374 mg/l and 35 941 mg/l respectively. The largest flood in the record is estimated to be close to a 100 year annual recurrence interval flood.

2.3 CLIMATE CHANGE AND LAND USE CHANGE IMPACTS ON FUTURE SEDIMENT YIELD

Basson (2013) evaluated possible future changes in sediment yield in Africa and the impacts on reservoir sedimentation in a paper for ICOLD: "*Reservoir Sedimentation in Africa: historical trends and possible future impacts of land use and climate change*". The population in Africa could double between 2010 and 2050. Land use could therefore change dramatically, also in the catchment of the proposed Smithfield Dam. Sediment yields could also increase due to climate change impacts such as more frequent and larger floods, due to more variability in the climatic conditions.

In Africa the current rate of deforestation is 1% per year, which means a 37% increase in CO_2 emissions from this sector by 2050. Deforestation is by far the main source of CO_2 in Africa. The African population will double by 2050 and therefore the rate of deforestation could easily result in a 74% (double from deforestation) to even a 100% increase in CO_2 emissions (due to economic growth) by 2050. The latter is a similar scenario as predicted in Australia, and could result in a 50% increase in fire frequency in Africa, and say70% increase in sediment yields by 2050, mainly due to the impact of deforestation and CO_2 emissions on climate change.

The current rate of deforestation in Africa of 1%/year has resulted in a 0.86%/year average rate of reservoir sedimentation (in South Africa 0.34%/year). By 2050 as the African population has doubled, the deforestation would probably increase and the added effects of land use change and land degradation could result in an estimated sediment yield increase and associated increased rate of reservoir sedimentation of at least 1.5x0.86=1.29% loss of storage capacity/year in Africa (0.51%/year in South Africa).

If one considers the impacts of on-going deforestation and land degradation with the impacts of climate change on the hydrology, increased fire risk days, the long term sediment yield increase in Africa could on average be say 260% (1.7 factor due to climate change and 1.5 factor due to land degradation, land use change and deforestation). This could increase the rate of reservoir sedimentation to 2.2% per year by 2050 in Africa (0.87% per year in South Africa).

For this study a possible increase in sediment yield over the next say 50 years of twice the current yield was assumed. This is based on the discussion above and a recent detailed hydrological modelling study by using the ACRU model on the Lake St Lucia system with the inclusion of climate change and land use change scenarios (iSimangaliso, 2015), which found that on rivers such as the uMfolozi and uMkhuze, a doubling of the historical sediment yield by year 2050 is realistic. The future sediment yield by 2050 for this study could therefore be 1 234 $t/km^2.a$ with a corresponding mean annual sediment load of 2.54 million t/a at the Smithfield Dam site.

3 HYDRODYNAMIC MODELLING OF THE RESERVOIR SEDIMENTATION

3.1 BACKGROUND

The hydrodynamic modelling of the reservoir sedimentation of the proposed Smithfield Reservoir consisted of:

- the simulation of the reservoir water levels at the dam wall to obtain the boundary condition in the 2D hydrodynamic reservoir sedimentation model, by using a one dimensional hydrodynamic model (MIKE11 of the DHI Group); and
- the simulation of the possible long term reservoir sedimentation of the proposed Smithfield Reservoir, by using a two dimensional (2DH) hydrodynamic model (Mike 21C). This model was selected since it has been validated on a number of reservoirs in South Africa during the past 15 years. Sediment transport modelling in this model is for turbulent suspended and bedload transport.

3.2 RESERVOIR AND CATCHMENT CHARACTERISTICS OF THE PROPOSED SMITHFIELD

A reservoir contour survey was obtained from the DWS. Surveys were carried out in 2005 and 2010. The reservoir and key catchment characteristics are as shown in **Table 3.1**. The reservoir is about 14 km long and 75 m deep at FSL at the dam.

Table 3.1: Smithfield Dam catchment and reservoir characteristics

Description	Value
Catchment area (km^2)	2 058
Catchment longest watercourse (km)	120.3
Catchment average watercourse slope (%)	0.61
Mean annual precipitation (mm)	1 050
Full supply level (FSL) of the proposed Dam (masl)	930
Full supply capacity of the reservoir (FSC) (million m^3)	253*
MAR recorded scaled to the dam site (MAR) (1960 to 2014)(million m^3/a)	707
FSC$_{gross}$/MAR (%)	36
FSL water depth at the dam (m)	75.25
FSL reservoir length (km)	15

*Note: * Determined from the Mike21C model; AECOM FSC of the new reservoir is 251 million m^3*

3.3 ROUTING OF FLOWS THROUGH THE RESERVOIR BY ONE DIMENSIONAL HYDRODYNAMIC MODELLING

A one dimensional model Mike 11 was set up of the reservoir by considering the following:

- Cross-sections obtained from the reservoir survey
- An upstream inflow boundary consisting of the DWS primary data of gauging station U1H005 flow record from 1960 to 2014.
- A tunnel abstraction boundary near the dam at the proposed location of the tunnel intake obtained from AECOM.
- A spillway hydraulic structure at the dam to represent an uncontrolled spillway with crest at the FSL = 930 masl, as specified in the firm yield analysis (AECOM, 2014)
- Evaporation and rainfall data on the reservoir surface (obtained from AECOM).

The output from the 1D-hydrodynamic model was a time series of water levels in the reservoir and is discussed in more detail in **Section 3.4** on the reservoir sedimentation modelling. The 1D model setup, boundary conditions and the simulation results are presented in **Appendix A**.

3.4 RESERVOIR SEDIMENTATION MODEL

3.4.1 Model Setup

The objective of the 1D model simulation using MIKE11 was to obtain the water levels at the proposed dam wall. The results were used in the hydrodynamic reservoir sedimentation model calculations. The Mike21C two dimensional hydrodynamic model of the DHI Group was used to simulate the reservoir sedimentation processes. This model deals with cohesive and non-cohesive sediment with multi fraction sediment transport and deposition, as well as scour of the bed. Secondary currents at bends are also simulated.

The DWS survey contours with 1m intervals were used to set up the hydrodynamic model. A grid of about 60 m long by x 20 m wide cells was used in the model. The model bathymetry based on the DWS survey is shown in **Figure 3.1**. Note that the red colours in **Figure 3.1** indicate elevations above the FSL of 930 masl. The reservoir was extended upstream in a southerly direction for 2000 m with the upstream boundary above the FSL, to create stable boundary conditions.

Appendix E provides more details in the form of 3D views of the observed reservoir bed levels.

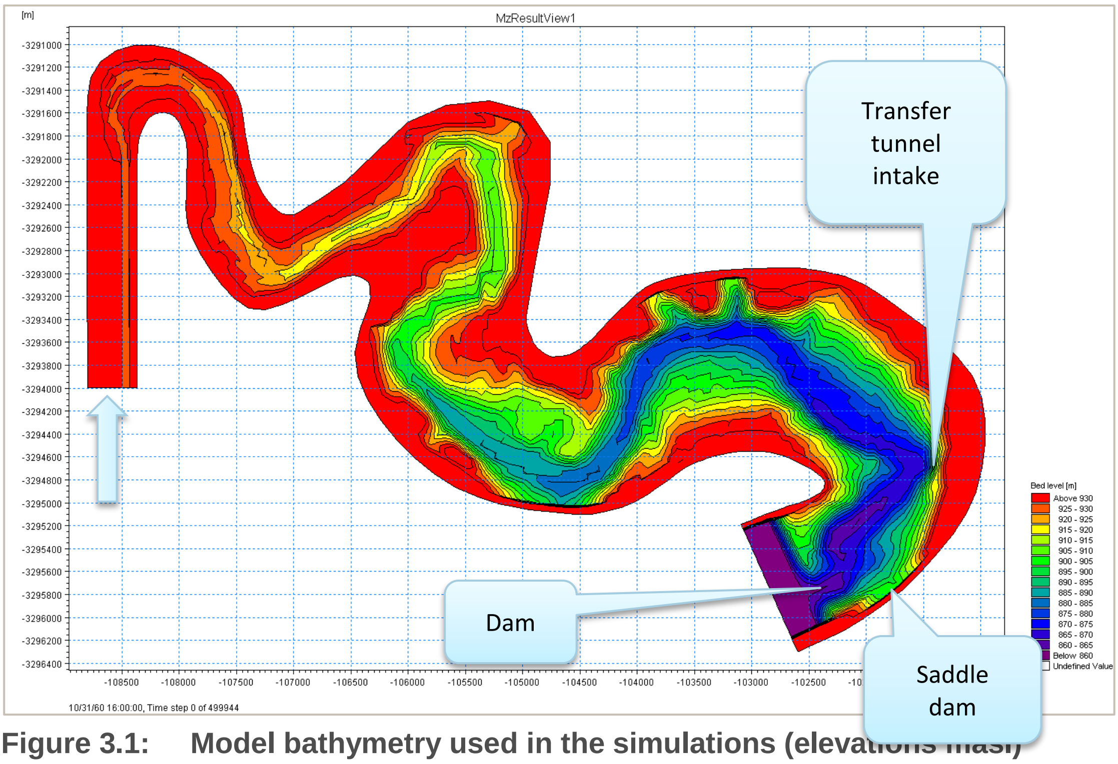

Figure 3.1: Model bathymetry used in the simulations (elevations masl)

The 2D hydrodynamic model of the reservoir was set up as follows:

- Manning n = 0.045 in the Upper of reservoir
- Manning n = 0.020 in the rest of the reservoir
- Sediment porosity = 0.49
- Consolidated deposited sediment density 1350 kg/m^3 based on a simulation period of 50 years
- Sediment particle relative density = 2.65
- Eddy viscosity = 0.01
- Time step in quasi steady mode 120 s

3.4.2 Model Boundary Conditions

The reservoir inflow boundary time series for the period from 1960 to 2014 was determined from observed flow records by using the DWS gauging station data. The observed flow record was taken from the gauging station U1H005, which is located about 11.4 km upstream of the proposed Smithfield Dam site. The above mentioned gauging station theoretical discharge rating is limited to a gauge plate reading of 2.71 m, corresponding to a discharge of 638 m^3/s. According to DWS, four flood events exceeded the maximum rating at the flow gauging station: 1976 (2.82 m), 1987 (5.28 m), 1988 (3.70 m), and 1996 (3.07 m) floods. The corresponding flood peaks for these flood events were determined in the water resources yield assessment report (AECOM, 2014) as follows: 688 m^3/s (1976), 2 770 m^3/s (1987), 1 264 m^3/s (1988) and 833 m^3/s (1996). Based on these values the discharge rating curve was extrapolated using an adjusted trend line which accommodates these values. Finally, the observed flow records at Smithfield Dam site were determined by extrapolating flow records from gauging station U1H005 using the following formula:

$$\mathrm{Q_{Dam}} = \mathrm{Q_{U1H005}} \times \sqrt{\frac{A_{Dam}}{A_{u1h005}}}$$

where:

Q_{Dam} = flow at Smithfield Dam (m^3/s)
Q_{U1H005} = flow at gauging station U1H005 (m^3/s)
A_{Dam} = Smithfield Dam catchment area (= 2058 km^2)
A_{U1H005} = gauging station U1H005 catchment area (=1744 km^2)

Figure 3.2 shows the discharge time series generated from the observed flow record data used as inflow to the reservoir in the hydrodynamic 21C Mike model. The downstream water level time series from 1960 to 2014 was determined by simulating the observed flow records for the same period using Mike11 (one dimensional hydrodynamic model). **Figure 3.3** shows the simulated water level time series used in the 2D model. Water levels above 930 masl indicate spillage at the uncontrolled spillway. The lowest bed level in the reservoir is at 854.75 masl.

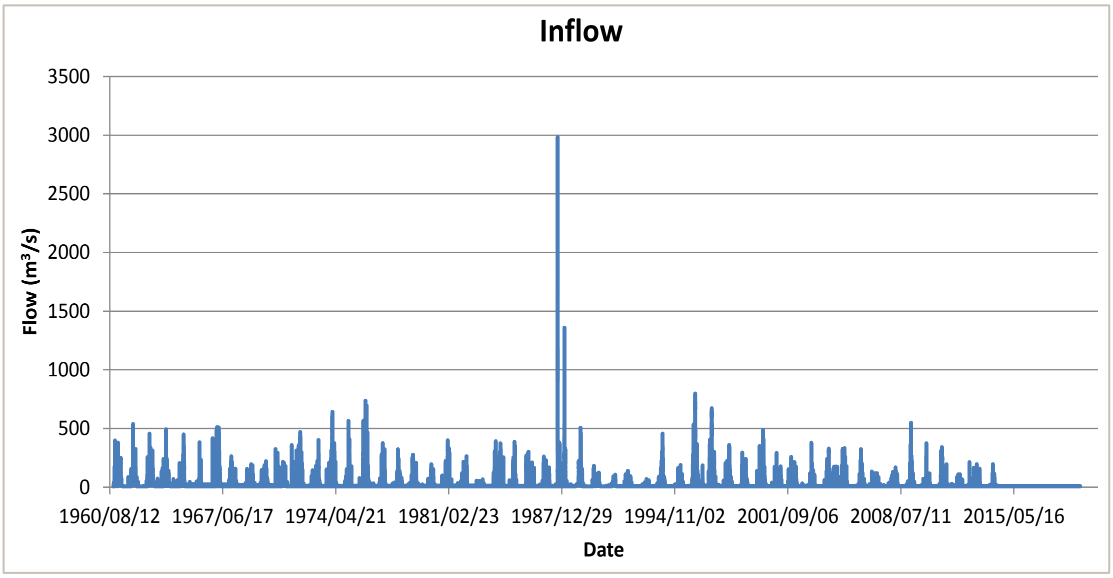

Figure 3.2: Reservoir inflow time series from 1960 to 2014 (hourly data)

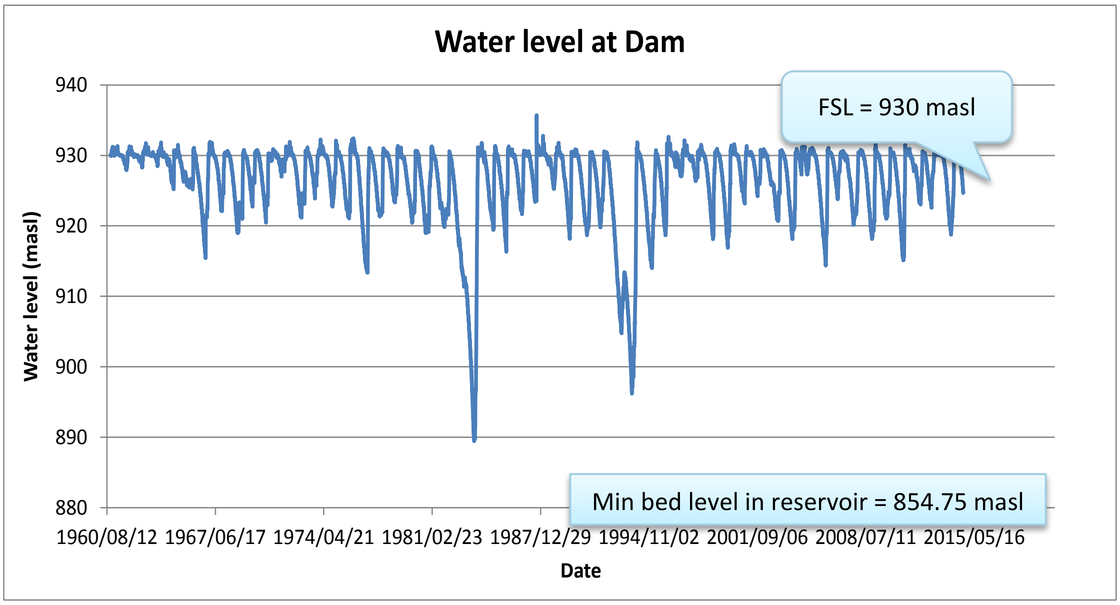

Figure 3.3: Simulated water level time series at the proposed dam for the period 1960 to 2014

For the sediment transport simulation, cohesive and non-cohesive sediment fractions were specified in the model with a time series of sediment concentrations at the upstream inflow boundary for the cohesive fraction. **Figure 2.4** shows the calculated time series of inflow sediment cohesive sediment concentrations used as inputs in the 2D hydrodynamic reservoir model.

Table 3.2 shows the 4 representative fraction sizes and their corresponding percentages as specified on the bed of the reservoir as starting condition of the simulations. This data was obtained from field work sediment sampling carried out during this study and sediment gradings were determined from sieve and hydrometer tests in a geotechnical laboratory. The current bed grading consists mainly of fine sand (refer to **Appendix B**). For the cohesive fraction an effective particle diameter of 33 micron was specified in the model, to represent clay and silt fractions. Sediment transport of the cohesive fraction through the reservoir is simulated by using an advection-dispersion equation.

Table 3.2: Fraction particle percentages in the bed of the reservoir as initial condition

Fraction particle size (mm)	Initial % in bed
10.35	16
1.37	35
0.212	48
0.033	1

The cohesive fraction size is important in the reservoir sedimentation modelling, since most of the sediment entering the reservoir is silt and clay. If the size is too small (mainly clay), the reservoir trap efficiency could be too low. If the fraction is too large (mainly silt), the sediment would be deposited further upstream in the reservoir, and possible problems with sedimentation at the transfer tunnel intake could be underestimated. Based on previous work where the 2D hydrodynamic model was calibrated against observed reservoir sedimentation field data at Grassridge and Elandsdrift Dams in the Eastern Cape, a cohesive fraction size of 33 micron was found to best represent the silt and clay fractions. Grassridge Dam has a relatively short and wide reservoir, while Elandsdrift Reservoir has a narrow valley.

At DeMistkraal Dam (*DWA, 2008*) and Welbedacht Dam (*De Villiers and Basson, 2007*), both relatively narrow valley reservoirs, the cohesive fraction size of

0.011 mm was found from sediment sampling and model calibration to best represent the silt and clay fractions. Welbedacht Dam has very fine sediment due to the geological characteristics of its catchment and it is not expected that the cohesive fraction at Smithfield Reservoir will be quite as small. The cohesive fraction size of 33 micron was used in the Smithfield Reservoir simulations, but as a sensitivity test simulations were also carried out with a cohesive fraction particle size of 11 micron.

To confirm the sediment size of the washload in the uMkhomazi River, large suspended sediment samples have to be taken during flood conditions, over at least a flood season. The river was however not in flood during the field work carried out in this study and suspended sediment samples could not be obtained.

For this study it was assumed that the cohesive fraction makes up 90% of the total load, based on the sediment transport modelling of the non-cohesive fractions in the river upstream of the reservoir. For the 3 non-cohesive fractions, no time series of sediment concentrations were specified at the upstream boundary. The model calculates the inflow sediment concentrations for the coarse fractions by using the local hydraulic conditions and the sediment transport capacity.

3.4.3 Long term simulation results based on the current sediment yield

The reservoir sedimentation modelling was carried out for a 50 year period. The current sediment yield was based on the 95% exceedance yield and it was assumed the future yield would remain the same, but a sensitivity simulation was also carried out with a possible future higher sediment yield of twice the current yield (see **Section 3.4.4**). **Figure 3.4** to **3.6** show the observed bed levels of the reservoir, and the simulated bed levels after 50 and 100 years. Most of the sediment is deposited in the Upper reservoir where the sediment builds up to close to the normal operating level.

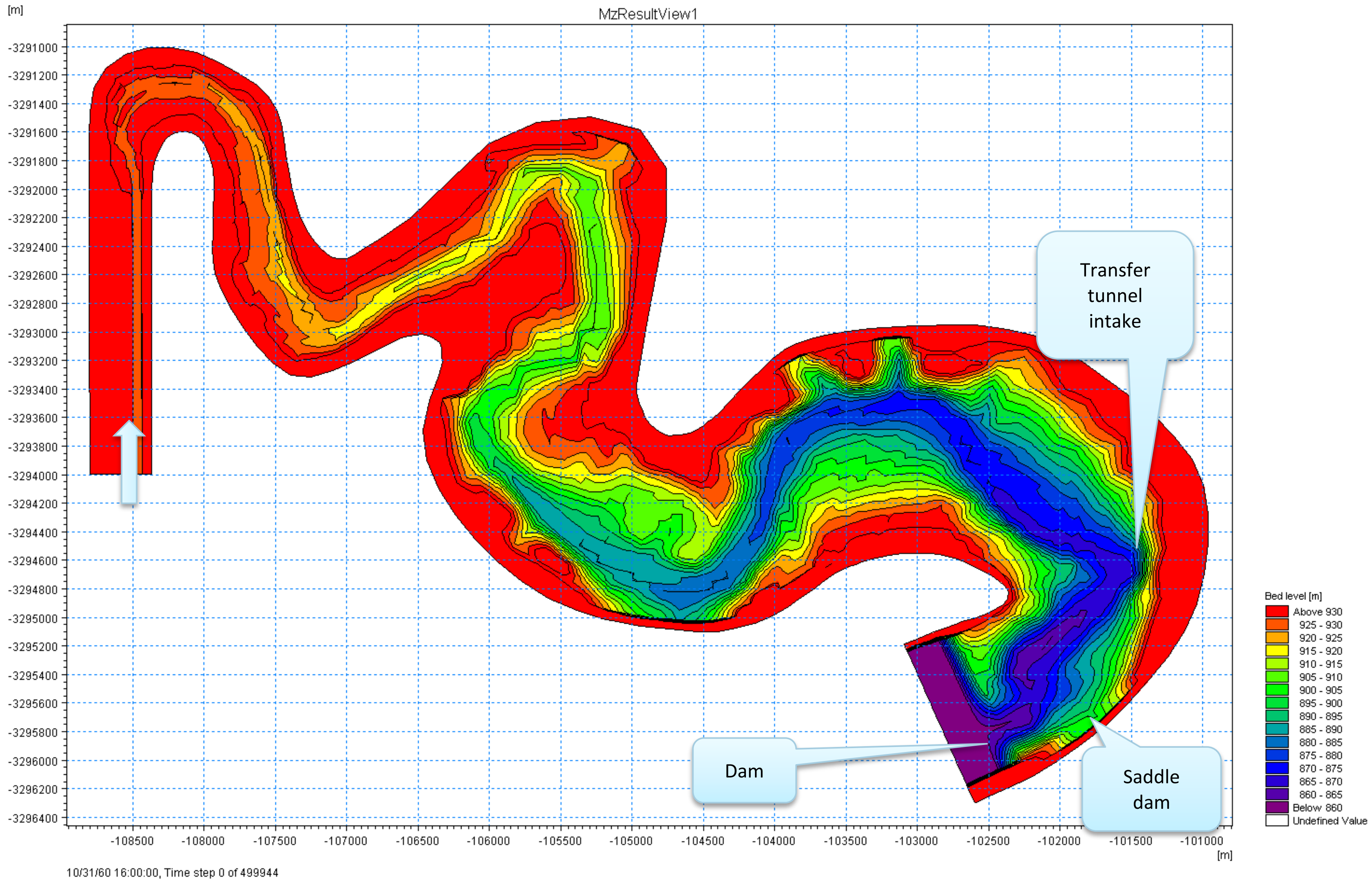

Figure 3.4: Reservoir bed levels after 0 years (initial condition as surveyed)

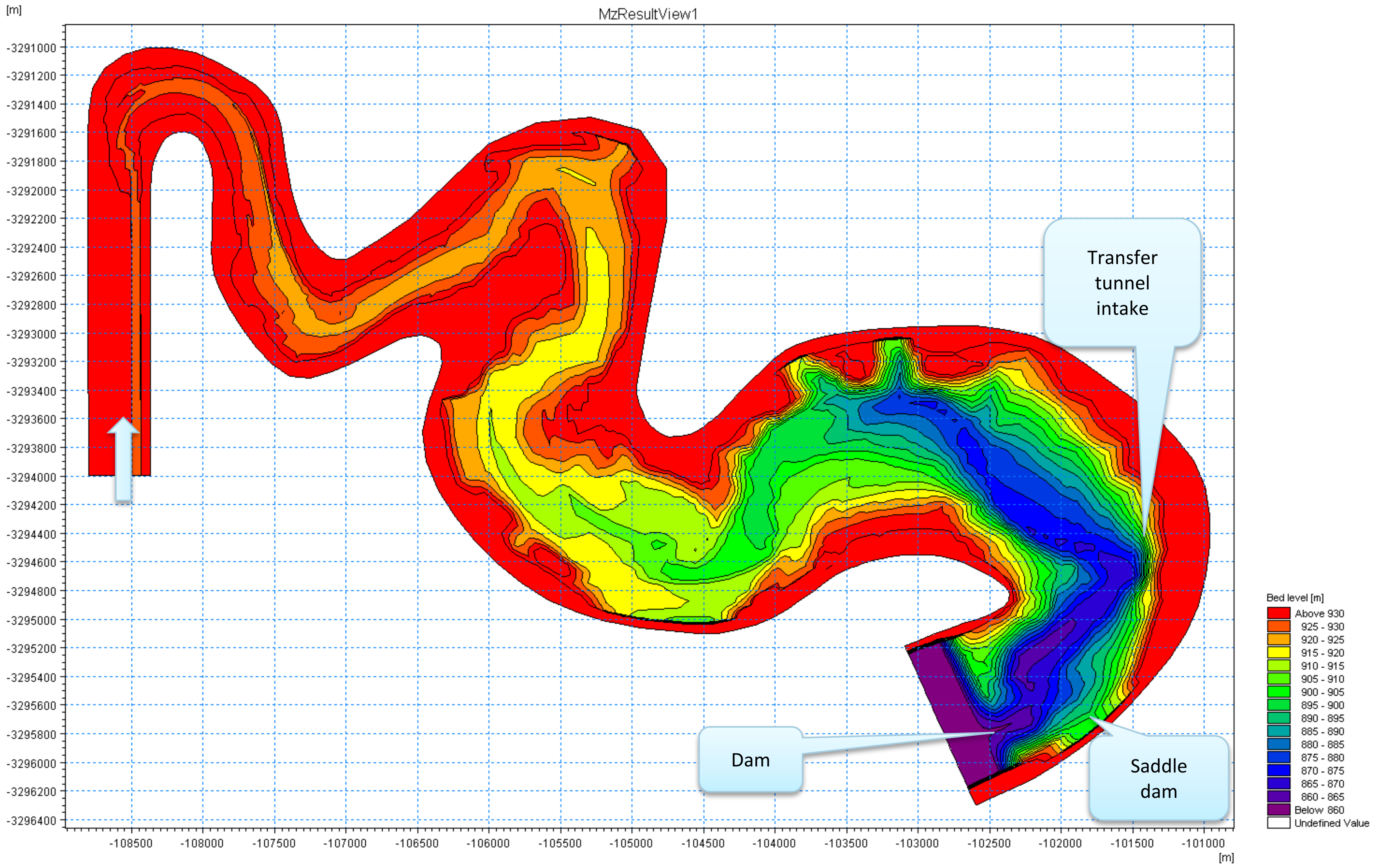

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Figure 3.5: Simulated reservoir bed levels after 50 years (cohesive fraction size 33 micron)

Figure 3.6: Simulated reservoir bed levels after 100 years (cohesive fraction size 33 micron)

Figure 3.7 shows a long section of the current lowest bed levels and the lowest bed levels after 50 years of operation. Most of the sediment is deposited in the Upper reservoir to a distance of about 4 km from the dam after 50 years of operation, but over a 100 year period the sediment delta reaches the dam. Note that in the Upper reservoir the equilibrium deposited bed is about 7 to 10 m below the FSL and this corresponds with the "normal" operating level in the reservoir. The tunnel intake is not located at the lowest position in the reservoir but has a proposed invert level of 881 masl (*AECOM, 2015*) and therefore the longitudinal sedimentation profiles in **Figures 3.7**, **3.8**, **3.10** and **3.11** do not represent the sedimentation at the tunnel intake. Simulated long term sediment deposition at the tunnel intake and at the dam, are indicated in **Tables 3.4** and **3.5** and are discussed in **section 3.4.5**.

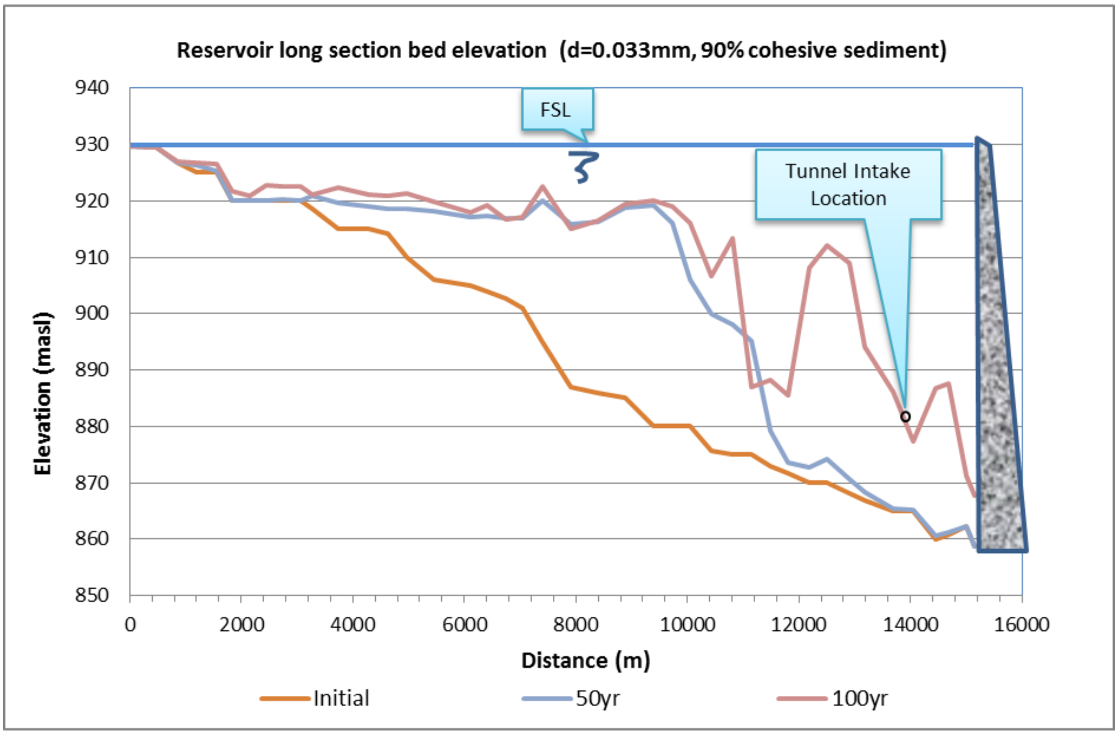


Figure 3.7: **Longitudinal profile of the simulated lowest bed levels in the reservoir for the current sediment yield**

The proposed location of the diversion tunnel as obtained from AECOM is also indicated in **Figure 3.7** at chainage 13 696 m. The FSL is at 930 masl. **Table 3.3** gives the coordinates of the tunnel intake and the dam.

Table 3.3: Locations of the tunnel intake and dam wall

Tunnel intake Chainage 11 581 m		Dam wall (upstream side) Chainage 13 058 m	
X	**Y**	**X**	**Y**
-101575	-3294379	-102463	-3295754

Note: X;Y local survey system based on the survey data provided

Simulation output for a scenario with finer cohesive sediment (11 micron) is enclosed in **Appendix C**. **Figure 3.8** shows the longitudinal profiles of the reservoir sedimentation bed levels after 50 and 100 years of operation for a cohesive fraction of 11 micron and for the current sediment yield. This figure should be compared with **Figure 3.7** which uses a 33 micron cohesive fraction. The 50 year sedimentation profiles are similar, but the 100 year profile has deeper sediment deposition near the tunnel and dam for the 33 micron scenario.

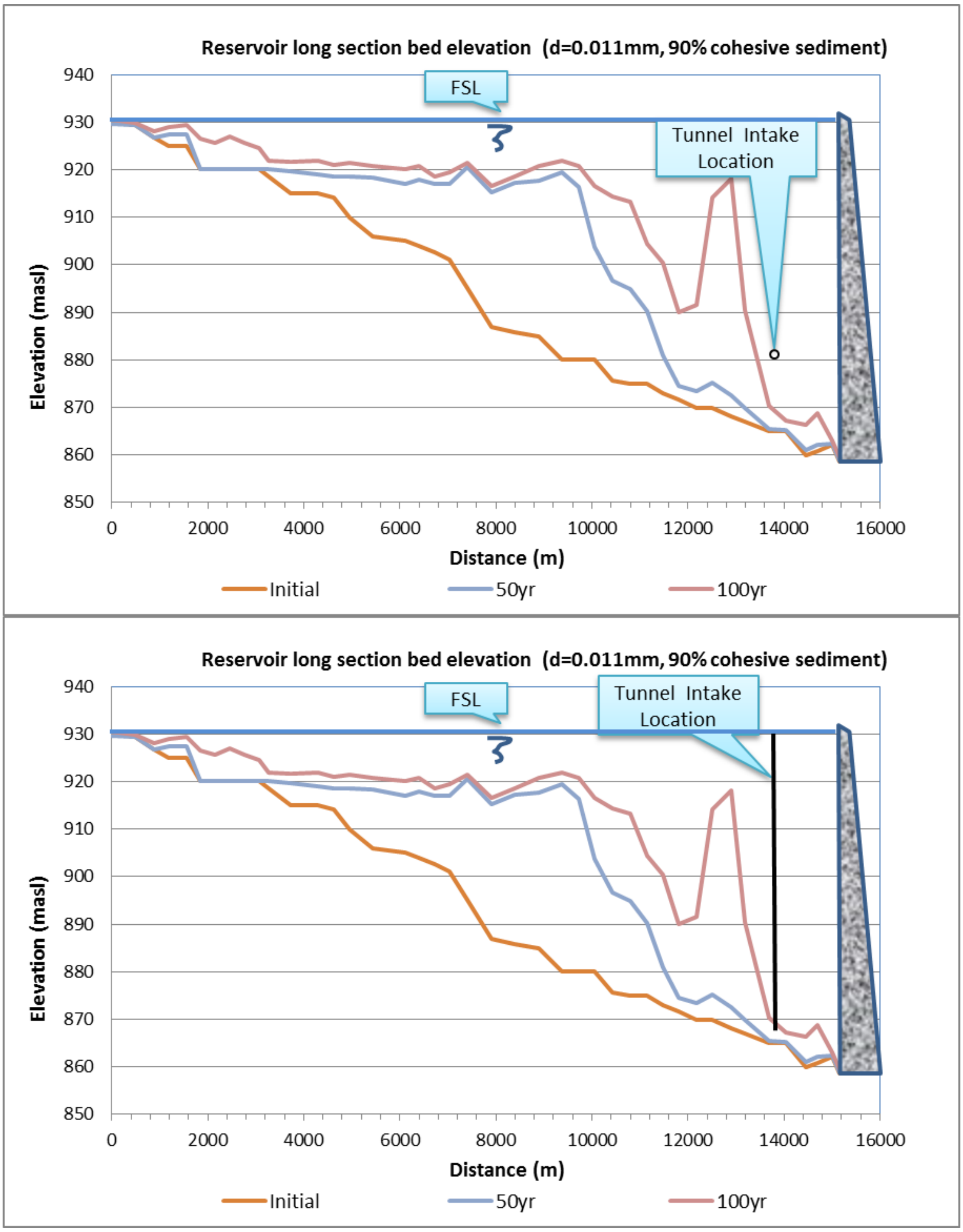


Figure 3.8: **Longitudinal profile of the simulated lowest bed levels in the reservoir for the current sediment yield (d=0.011mm, 90% cohesive sediment)**

3.4.4 Long term simulation results for a future scenario with double the current sediment yield

Long term reservoir sedimentation simulations were also carried out for a scenario with double the current scenario sediment yield, due to land degradation and climate change impacts. The simulated bed levels in the reservoir for this scenario are shown on the RHS in **Figure 3.9**. The Upper reservoir is completely filled with sediment after 50 years of operation and only an equilibrium channel remains. The longitudinal profile of the simulated sediment deposition is shown in **Figure 3.10**. In this scenario the sediment delta after 50 years reaches the dam. The results of the sensitivity testing with a finer cohesive fraction of 11 micron indicated that the longitudinal sedimentation profiles for the 33 and 11 micron scenarios are very similar after 50 years of operation (**Figure 3.11**). (No 100 year simulation was carried out for the sensitivity testing with 11 micron cohesive fraction).

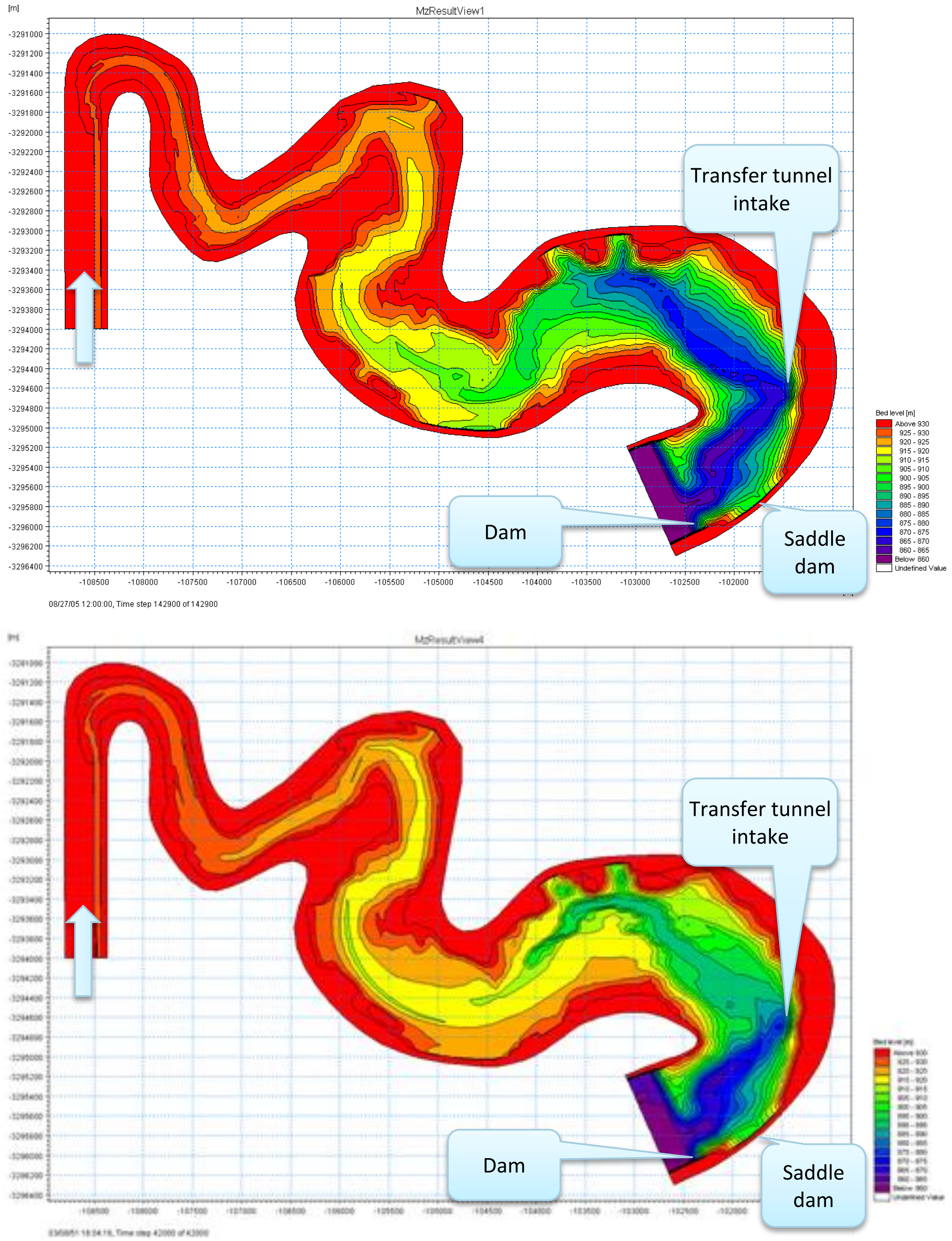


Figure 3.9: Simulated bed levels in the reservoirs after 50 for the current sediment yield (top) and a future sediment yield of double the current yield (bottom) (cohesive fraction 0.033 mm)

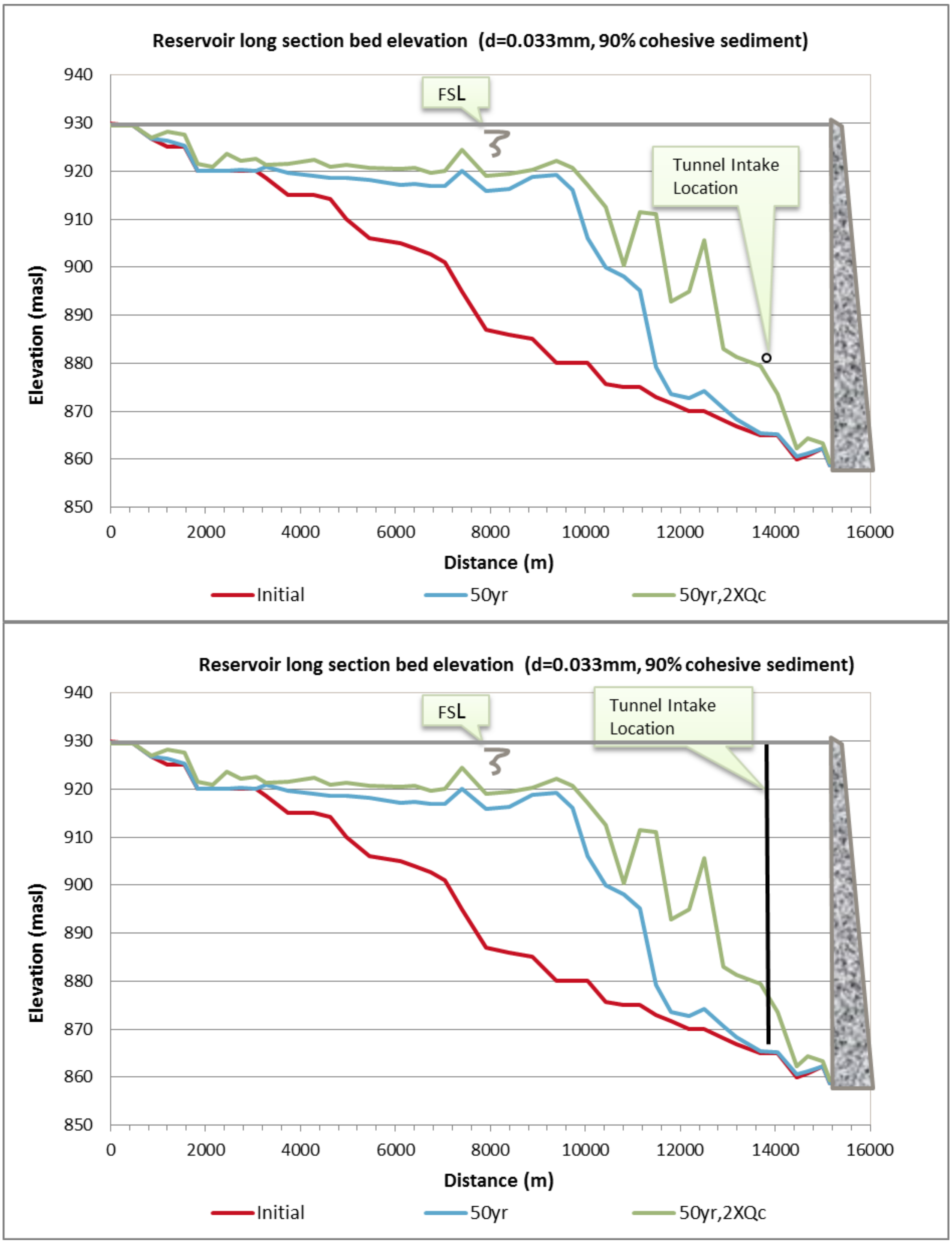


Figure 3.10: Longitudinal profile of the simulated lowest bed elevations in the reservoir based on a future higher sediment yield twice the current sediment yield (33 micron cohesive fraction)

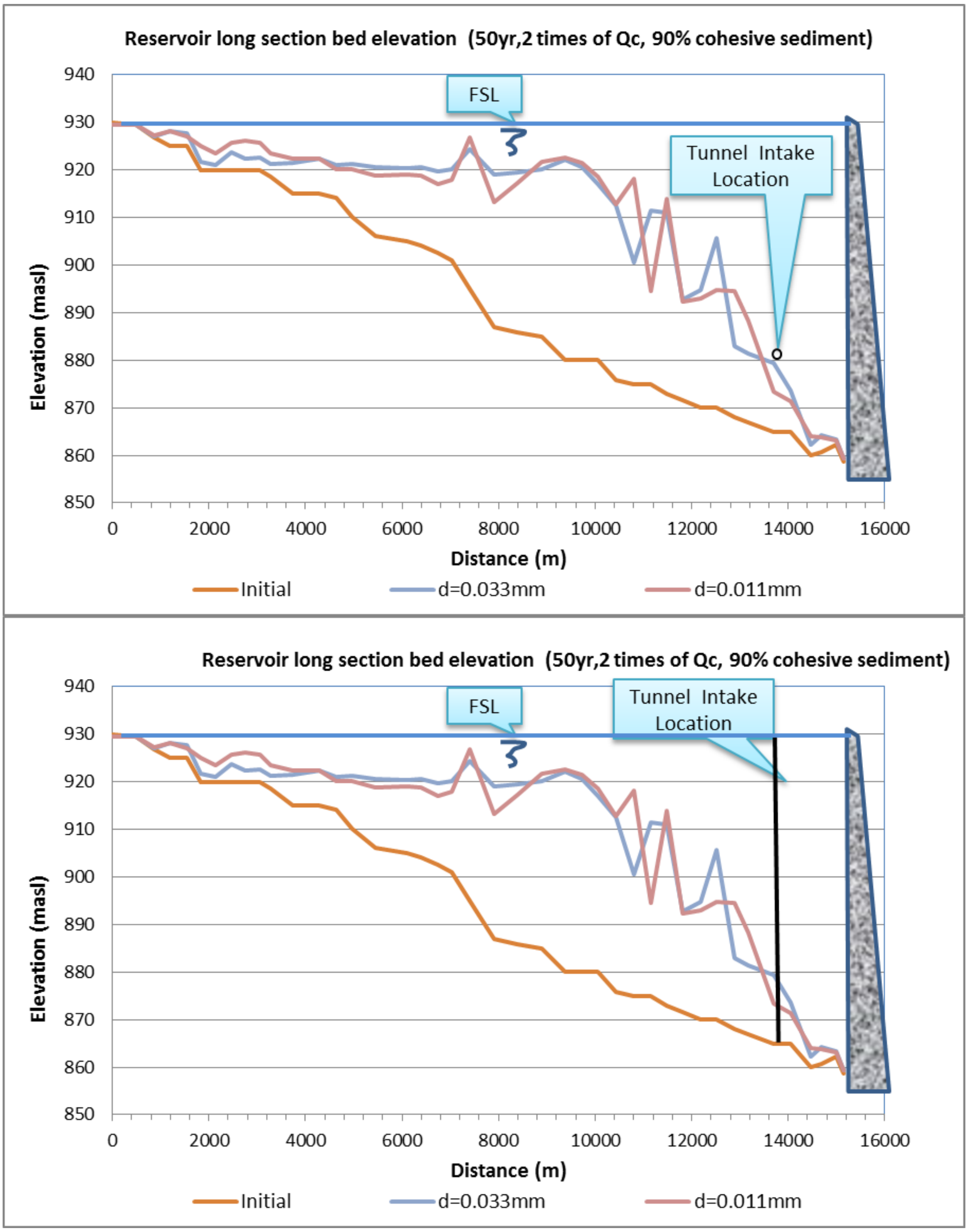


Figure 3.11: Longitudinal profile of the simulated 50 years lowest bed levels in the reservoir for a doubled sediment yield for two different cohesive fraction particle sizes

Figure 3.12 shows the longitudinal profile of the deepest reservoir bed levels simulated over a 100 year period (cohesive fraction 33 micron) for a scenario with the sediment yield double the current yield. More simulation output data for this scenario is provided in **Appendix D**. After 100 years at this high sediment yield the sediment delta filled all the deep areas of the reservoir near the dam. It should be noted that this is very conservative sediment yield scenario (high), and that in reality the sediment yield over the first 50 years of Smithfield Dam could be the current yield and only for the period 50 to 100 years of operation the sediment yield could double. There is also the possibility that Impendle Dam could be constructed upstream of Smithfield Dam which could reduce the sedimentation of the latter dam significantly (refer to **section 3.5**).

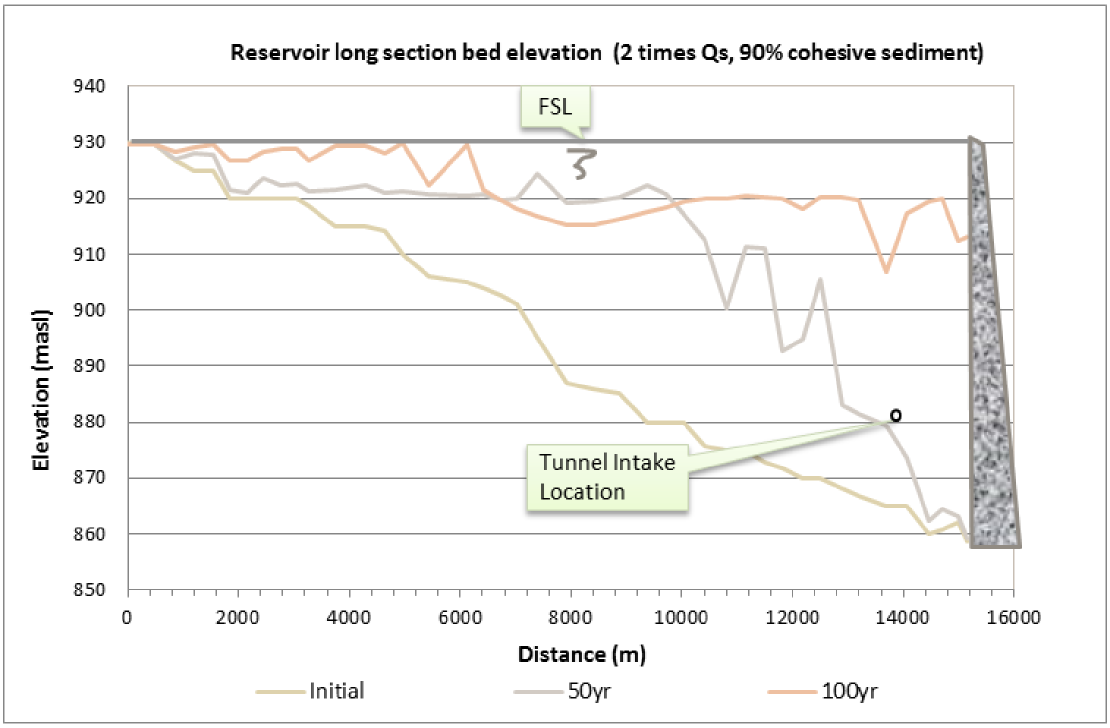


Figure 3.12: Longitudinal profile of the deepest reservoir bed levels simulated over a 100 year period (cohesive fraction 33 micron) for a scenario with the sediment yield double the current yield

3.4.5 Simulated future reservoir storage capacity and bed levels due to reservoir sedimentation

The simulated possible reservoir sedimentation impacts on the future storage capacity are indicated below in **Tables 3.4** and **3.5**. These results are for the 33 micron cohesive fraction scenario which indicated a very similar sedimentation pattern in the reservoir than for the 11 micron size after 50 years, but deeper deposition near the dam and tunnel intake after 100 years.

For the current sediment yield scenario, the storage capacity after 50 and 100 years could be 208 and 163 million m^3 respectively, a reduction of 17% and 36% of the original FSC. The sediment deposition depths at the tunnel intake and at the dam after 50 and 100 years for the current sediment yield simulation are 0.4

m and 0.1 m after 50 years, and 2.9 m and 9.1 m after 100 years, respectively (33 micron cohesive fraction scenario).

For the possible future sediment yield scenario of twice the current sediment yield, the storage capacity after 50 years could be 161 million m^3, a reduction of 36% of the current FSC. The sediment deposition depths at the tunnel intake and at the dam after 50 years for the high sediment yield scenario, are 12.8 m and 4.6 m deep respectively (33 micron cohesive fraction scenario).

Table 3.4: Long term reservoir storage capacity at FSL as well as bed levels at the tunnel intake and the dam for the current sediment yield (33 micron cohesive fraction)

Years	Full supply storage capacity (million m³)	Full supply capacity loss (%)	Reservoir sediment trap efficiency (%)	Bed level at tunnel intake location (masl)	Lowest bed level at dam wall (masl)
0	252	-	97	881.0	854.75
50	208	18	94	881.4 (881.4)*	854.85 (854.93)
100	163	36	95	883.9 (885.2)*	863.85 (859.50)

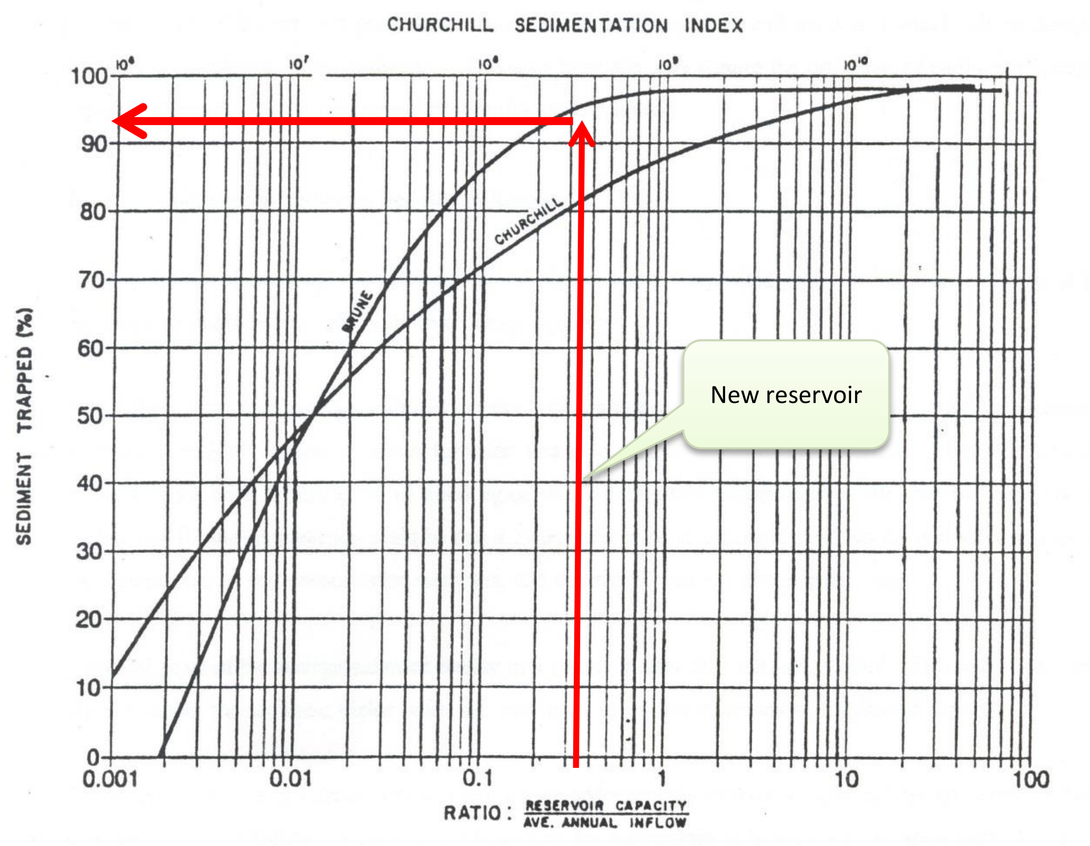
*Note: *Bed levels for 11 micron cohesive sediment shown in brackets*

Table 3.5: Long term reservoir storage capacity at FSL as well as bed levels at the tunnel intake and the dam for the future sediment yield of twice the current yield (33 micron cohesive fraction)

Years	Full supply storage capacity (million m³)	Full supply capacity loss (%)	Reservoir sediment trap efficiency (%)	Bed level at tunnel intake location (masl)	Lowest bed level at dam wall (masl)
0	252.0	-	97	881.0	854.75
50	161	36	97	893.8	859.3
100	87	66	88	909.5	913.2

*** Bed levels for 11 micron cohesive sediment shown in brackets*

Based on the empirical sediment trap efficiency curve of Brune (1953) (**Figure 3.13**), the trap efficiency of the Smithfield Reservoir should be close to 97%, which is the same as the simulated average sediment trap efficiency for the 50 year simulations in both scenarios.



1 Ratio of reservoir capacity to average annual inflow.
2 Sediment trapped in percent.
3 K = IS (Churchill Sedimentation Index) x g.
4 Brune Median Curve.
5 Churchill Trap Efficiency.

Figure 3.13: Empirical trap efficiency curve by Brune (1953)

3.4.6 Predicted water level-area-storage capacity relationship of Smithfield Reservoir at a FSL = 930 masl

The water level-area-storage capacity relationship for the Smithfield Reservoir is as shown in **Table 3.6**. AECOM calculated the FSC at 251.4 million m^3. The data from the hydrodynamic model bathymetry is also shown in **Table 3.6**. The FSC calculated from the hydrodynamic model bathymetry (251.5 million m^3) is basically the same as the value of AECOM.

Table 3.6: Calculated new reservoir storage surface area and capacities versus water level

Contour (masl)	AECOM Surface Area of new reservoir (km²)	AECOM Storage Volume of new reservoir (million m³)	This report Surface Area of new reservoir (km²)	This report Storage Volume of new reservoir (million m³)
854.75	0.00	0.00	0.00	0.00
856	0.08	0.00	0.00	0.0
857	0.01	0.04	0.01	0.0
858	0.02	0.06	0.01	0.0
859	0.03	0.08	0.01	0.0
860	0.08	0.13	0.02	0.1
864	0.19	0.63	0.10	0.4
865	0.26	0.86	0.16	0.5
870	0.48	2.68	0.49	2.2
875	0.93	6.12	0.97	5.8
880	1.45	12.02	1.47	12.0
885	1.92	20.40	1.98	20.7
890	2.50	31.38	2.57	32.4
895	3.09	45.32	3.07	47.0
900	3.75	62.39	3.66	64.3
905	4.50	82.98	4.50	85.3
910	5.33	107.51	5.22	110.2
915	6.15	136.18	6.01	138.9
920	7.09	169.26	6.81	171.8
925	8.15	207.31	7.85	209.3
930	9.53	251.43	9.55	251.5

Table 3.7 shows the simulated reservoir storage capacities at different water levels (contour levels).

Table 3.7: Future reservoir sedimentation impacts on storage capacity and surface area versus water levels from this study

Contour (masl)	New reservoir storage capacity (million m^3)	This report Surface Area of new reservoir (km^2)	Old reservoir capacity after 50 years at current sediment yield- cohesive fraction size = 0.033mm (million m^3)	Surface Area after 50 years at current sediment yield- cohesive fraction size=0.033mm (km^2)	Old reservoir capacity after 100 years at current sediment yield- cohesive fraction size=0.033mm (million m3)	Surface Area after 100 years at current sediment yield- cohesive fraction size=0.033mm (km^2)	Old reservoir capacity after 50 years at double sediment yield- cohesive fraction size=0.033mm (million m3)	Surface Area after 50 years at double sediment yield- cohesive fraction size=0.033mm (km^2)
854.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
856	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
857	0.0	0.01	0.0	0.01	0.0	0.00	0.0	0.00
858	0.0	0.01	0.0	0.01	0.0	0.00	0.0	0.01
859	0.0	0.01	0.0	0.01	0.0	0.00	0.0	0.01
860	0.1	0.02	0.1	0.01	0.0	0.00	0.1	0.01
864	0.4	0.10	0.3	0.10	0.0	0.00	0.2	0.05
865	0.5	0.16	0.5	0.11	0.0	0.00	0.3	0.06
870	2.2	0.49	2.0	0.36	0.2	0.03	1.2	0.17
875	5.8	0.97	4.9	0.70	0.7	0.07	2.8	0.33
880	12.0	1.47	10.0	1.07	1.8	0.21	5.1	0.44
885	20.7	1.98	16.7	1.39	3.9	0.54	8.0	0.57
890	32.4	2.57	25.3	1.73	8.6	1.13	11.8	0.75
895	47.0	3.07	35.5	2.05	15.9	1.52	17.4	1.37
900	64.3	3.66	47.8	2.58	25.1	1.85	26.7	1.93
905	85.3	4.50	63.0	3.00	36.1	2.14	38.2	2.20
910	110.2	5.22	80.4	3.50	48.9	2.52	51.3	2.53
915	138.9	6.01	100.7	4.11	63.7	3.00	66.7	3.24

Contour (masl)	New reservoir storage capacity (million m³)	This report Surface Area of new reservoir (km²)	Old reservoir capacity after 50 years at current sediment yield- cohesive fraction size = 0.033mm (million m³)	Surface Area after 50 years at current sediment yield- cohesive fraction size=0.033mm (km²)	Old reservoir capacity after 100 years at current sediment yield- cohesive fraction size=0.033mm (million m3)	Surface Area after 100 years at current sediment yield- cohesive fraction size=0.033mm (km²)	Old reservoir capacity after 50 years at double sediment yield- cohesive fraction size=0.033mm (million m3)	Surface Area after 50 years at double sediment yield- cohesive fraction size=0.033mm (km²)
920	171.8	6.81	128.4	6.37	85.8	5.32	87.7	5.18
925	209.3	7.85	165.4	7.64	120.5	7.52	120.6	7.19
930*	251.5	9.55	207.9	9.44	162.6	9.34	160.9	9.24

*Note: * FSL*

3.4.7 Reliability of the reservoir sedimentation prediction

The reliability of the reservoir sedimentation prediction was ensured as follows:

a) Sediment yield: The regional method (WRC, 2012) was used with sensitivity testing on the 10 year flood used in the method. The 95% confidence band current sediment yield was selected and agrees with observed sediment yields in the region. A future higher sediment yield of double the current yield was also considered due to the impacts of population growth, land degradation and climate change. The current and future sediment yields are applicable over the first 50 years and second 50 years of operation of the dam, respectively.

b) In the reservoir sedimentation prediction, state-of-the-art two dimensional hydrodynamic modelling was carried out with a model calibrated on other reservoirs in South Africa in the past, considering non-cohesive and cohesive sediment fractions, operational water levels in the reservoir, and reservoir inflows based on the historical observed flow records (50 years). A sensitivity test was carried out by using a smaller cohesive fraction sediment particle size but results were found to be similar to those with slightly more silt in the fine fraction, after 50 years. The large flood of about 3000 m^3/s in the historical flow record transports a significant part of the long term total load and if this flood occurs after a drought with low reservoir levels, the sediment could be transported much closer to the dam and diversion tunnel intake. In the 100 year simulations of reservoir sedimentation, the historical flow record of 50 years was repeated, and therefore the large flood (estimated to be a 100 year annual recurrence interval flood) is considered twice over a 100 year period which is conservative.

3.5 IMPACTS ON THE SMITHFIELD RESERVOIR SEDIMENTATION IF THE PROPOSED IMPENDLE DAM IS CONSTRUCTED IN THE FUTURE.

Based on information provided by AECOM during this study, the Impendle Dam (**Figure 1.2**) could be constructed in future upstream of Smithfield Dam. The Impendle Dam site has a relatively large catchment area of 1422 km^2 and will therefore trap most of the sediment yield of the proposed Smithfield Dam. Some of the key Impendle Dam and catchment characteristics are shown in **Table 3.8**. The expected commissioning date of Impendle Dam is 2046, while that of Smithfield Dam is year 2023.

Table 3.8: Proposed Impendle Dam and catchment characteristics

Description	Unit	Value
FSC	million m^3	535
MAR	million m^3/a	571
Possible commissioning	year	2046
Catchment area	km^2	1422

The sediment yield calculation for Impendle Dam site is shown in **Table 3.9**. The 95% confidence band current sediment load is 1.05 million t/a (740 t/km^2.a sediment yield was selected for analysis of the impact of the proposed Impendle Reservoir sedimentation on the Smithfield Reservoir sedimentation). The 95 % sediment load for Smithfield Dam without Impendle Dam is 1.27 million t/a, and therefore the yield at the Impendle Dam site is 83% of the total yield at the Smithfield Dam site.

Table 3.9: Sediment yield calculation for the proposed Impendle Dam site

		Sediment yield	
Parameter	**Unit**	**Impendle Dam**	**1.3X Q_{10}**
10 year flood (Q_{10})	m^3/s	670	871
River density (Rnd)	m/km^2	185.1	185.1
Average river slope (%) (SO)	(%)	2.825	2.825
Weighted Erosion Hazard Class (EIW)		4.959	4.959
Effective catchment area (Ae)	km^2	1 422	1 422
Catchment sediment load (Q_S) (average)	t/a	184 492	259 889
Catchment sediment load (Q_S) (50% confidence)	t/a	175 267	246 895
Catchment sediment load (Q_S) (80% confidence)	t/a	295 187	415 822
Catchment sediment load (Q_S) (90% confidence)	t/a	479 679	675 711
Catchment sediment load (Q_S) (95% confidence)	t/a	747 193	**1 052 550**
Catchment sediment yield (average)	t/km^2/a	130	183
Catchment sediment yield (50% confidence)	t/km^2/a	123	174
Catchment sediment yield (80% confidence)	t/km^2/a	208	292
Catchment sediment yield (90% confidence)	t/km^2/a	337	475
Catchment sediment yield (95% confidence)	t/km^2/a	525	**740**

Table 3.10 provides the Smithfield Reservoir FSC's for different sediment yield scenarios after 50 and 100 years of operation, with Impendle Dam commissioned by 2046, and without Impendle Dam. The last row in **Table 3.10** is the recommended scenario over 100 years of operation of Smithfield Dam, with the current yield over the first 50 years and a doubled sediment yield over the last 50 year period. With Impendle Dam commissioned by year 2046 the Smithfield Reservoir will only lose 16% of its original FSC over a 100 year period, but if

Impendle Dam is not implemented 51% of the original FSC of Smithfield Dam could be lost due to sedimentation.

Table 3.10: Reservoir sedimentation at Smithfield Dam with and without Impendle Dam upstream of Smithfield Dam

Description	Unit	Smithfield Dam-with Impendle Dam (yr 2046)	Smithfield Dam-without Impendle Dam
Year of Smithfield Dam commission	year	2023	2023
New reservoir Full supply storage capacity	million m^3	252.0	252.0
After 50 yr: Full supply storage capacity, at current sediment yield	million m^3	227 (10%)*	208 (17%)
After 100 yr: Full supply storage capacity, at current sediment yield	million m^3	219 (13%)	163 (35%)
After 100 yr of Full supply storage capacity, at doubled future sediment yield, for last 50 yr	million m^3	211 (16%)	123 (51%)

*Note: * percentage of original FSC loss due to sedimentation indicated in brackets*

3.6 POSSIBLE RESERVOIR SEDIMENTATION MITIGATION MEASURES

If Impendle Dam is not constructed upstream of Smithfield Dam, the reservoir sedimentation of the latter dam could impact on the day to day operation of the dam. According to the International Commission on Large Dams Bulletin on sustainable development of dams, the dam should be feasible for a 100 year period. With the risk of possible blockage of the diversion tunnel intake by cohesive sediment, it is proposed that a concrete underwater wall is designed upstream of the intake to prevent sediment sliding into the intake from the sediment delta. In addition it is also proposed to add a sediment flushing tunnel at the diversion tunnel intake to clear the local area of deposited sediment. This flushing tunnel could initially form part of the diversion tunnel used during construction of the dam, and could be used later for local sediment control to discharge sediment downstream of the dam.

In addition to possible engineering sediment mitigation measures in the reservoir, it is important that a land care programme is established so that the catchment upstream of the Smithfield Dam site does not degrade over time due to uncontrolled development.

It is possible to bypass most of the coarse sediment load to downstream of the Smithfield Dam by construction of bypass weir in the Upper reservoir and a bypass conduit (tunnel). This will improve the availability of sand downstream of the dam to be transported to the river mouth and will also limit bed degradation downstream of the dam following the construction of the dam. Such bypass systems are not unique and have been used in the past at Nagle and Henley Dams in South Africa, and internationally with success over long periods. Bypassing of sediment requires sluicing during regular floods,, which also means some loss in inflow to the main reservoir, but on the other hand the reservoir sedimentation by coarse sediment is controlled and the coarse sediment balance downstream of the dam restored to some extent.

A bypass system at Smithfield Dam could be very effective because the reservoir is relatively short and the available head is high. The required tunnel length is 5.1 km. It would be ideal to design the bypass for 2 year (380 m^3/s) to 5 year (580 m^3/s) ARI floods and for these floods tunnel the tunnel diameter (if concrete lined), should be 7.0 m and 8.3 m respectively. In the reservoir a weir has to be constructed at the intake of the tunnel. The weir could be at chainage 3200 m (**Figure 3.7**), with invert level at say 920 masl. The crest of the weir should be above FSL of Smithfield Reservoir. The location of the diversion weir has to be optimized by hydrodynamic modelling of the sedimentation processes to ensure coarse sediment will be trapped upstream of the weir and that the sediment flushing is effective.

4 IMPACTS OF THE PROPOSED SMITHFIELD DAM ON THE COARSE SEDIMENT LOADS AT THE RIVER MOUTH

The proposed Smithfield Dam is located 187 km from the uMkhomazi River mouth (**Figure 1.2**), and there is a large incremental catchment downstream of the dam (2 329 km^2) which contributes to the sediment load at the river mouth. The proposed dam has the characteristics as shown in **Table 3.1**.

Smithfield Dam will trap sediment. Based on the storage capacity/MAR ratio of the reservoir and the empirical relationship by Brune (1953), more than 95% of the sediment will be trapped. Only fine sediment (clay) will be released from the reservoir when the dam spills during floods. The fine sediment, however, does not contribute to the coastal sediment budget, because it is the coarse sediment (sand and gravel) that is important for the coastal budget.

The methodology followed in this study was to set up a hydrodynamic model of the river, from the Smithfield Dam site to the river mouth, to simulate the pre-dam and post-dam sediment transport downstream of the dam site. For the pre-dam scenario the upstream boundary of the model was based on a DWA flow record using hourly flows (**Figure 2.2**).

Post dam inflows were determined by simulating the full mass balance of the Smithfield Dam using a one-dimensional (1D) hydrodynamic model. For this model the inflows were observed, and the tunnel diversion flows, evaporation and rainfall on the reservoir data was obtained from the *Water Resources Yield Assessment Report* (AECOM, et al., 2015). A dam spillway was built into the model as the FSL. The output of the model was reservoir water levels and spillage flows. The post-dam spillage flows are shown in **Figure 4.1**, which indicates the reduction of the flood peaks and the number of floods locally downstream of the dam. For more details on the reservoir modelling please refer to the *Sediment Impact Report* (AECOM, et. al., 2015).

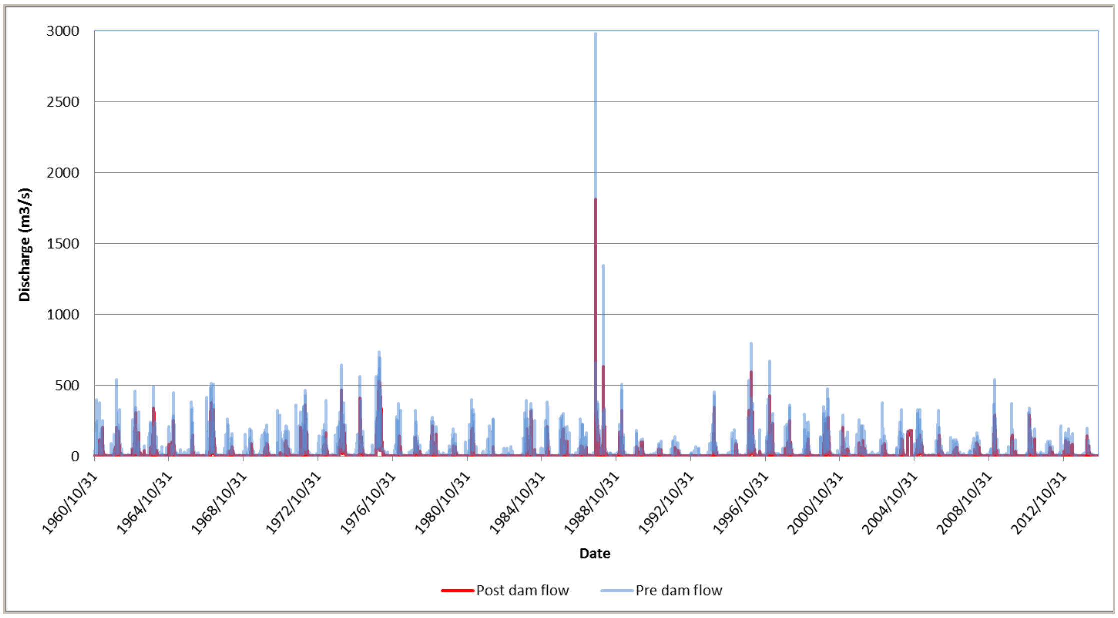


Figure 4.1: **Pre- and post-dam simulated spillage flow record at the dam site**

The bed sediment grading specified in the 1D-hydrodynamic model, from the dam site to the ocean, was obtained from sediment samples collected in the field. Refer to **Appendix F** for the grading analysis by sieve and hydrometer. The coarse sediment fractions used in the model river bed are shown in **Table 4.1**.

Table 4.1: **Coarse sediment fractions in the hydrodynamic model river bed**

Fraction No.	Sediment Size	Percentage in range
	mm	%
1	7.28	6
2	1.17	22
3	0.14	72

At the downstream end of the model, at the river mouth, a discharge-water level relationship was determined based on normal flow depths for the river. It was assumed that the estuary would not affect the long-term sediment load of coarse sediment to the ocean.

Two tributaries were included in the hydrodynamic model between the dam and the river mouth. The inflow time series of these tributaries were such that the pre-dam MAR of 1 078 million m^3/a was obtained for the total catchment. The pre-dam MAR at the river mouth was obtained from the *Water Resources Yield Assessment Report* (AECOM, et al., 2015) during this study. The total catchment area for the river at the mouth is 4 287 km^2.

The Mike 11 model (DHI Group) was used to simulate the sediment transport, deposition and erosion processes in the river from the dam site to the mouth. Since post-dam narrowing of the river will occur due to reduced flood peaks and number of floods spilling at the dam, the main channel of the river was narrowed for the post-dam scenario, based on empirical data for South Africa. ***The river channel adjusts to a new post-dam equilibrium due to a smaller dominant flood and decreased non-cohesive sediment transport capacity***. The largest impact on the river channel would also be closest to the dam, upstream of a major tributary (**Table 4.2**). Typically it takes about 7 years of dam operation for the new river equilibrium to be established. **Table 4.2** indicates a near dam site reduction of post-dam top width of the main channel of 24 %, and at the river mouth the main channel top width is 18% narrower than under pre-dam conditions. The relative width change from upstream to downstream is not much because the river length downstream of the dam is relatively short (187 km).

Table 4.2: Main river channel narrowing due to the reduced flood peaks in a post dam scenario

Chainage (m)	Pre dam river top width (m)	Post dam river top width (m)	Difference (m)	Difference (%)
0 -Smithfield Dam	40	31	9	24%
0 - Smithfield Dam	40	31	9	24%
14700	42	33	9	21%
20000	42	33	9	21%
40000	42	33	9	21%
60000	132	108	24	18%
80000	46	36	10	21%
85700	54	44	10	19%
100000	150	123	27	18%
120000	72	59	13	19%
140000	48	39	9	19%
160000	72	59	13	19%
180000	54	44	10	19%
186690 - river mouth	132	108	24	18%

The simulated coarse sediment loads for the period 1960 to 2014 is shown in **Figure 2.3**, with the simulated data summed to annual values. Coarse non-cohesive sediment transport is based on the local hydraulic conditions and sediment transport capacity of the stream. Post-dam the upstream inflow into the river is the spillage from the dam with attenuated floods and fewer floods, and no coarse sediment could be transported through the reservoir. Inflows and sediment input from tributaries downstream of the dam pre- and post-dam are the same. The land use upstream of the dam does not play a role because all the coarse sediment is trapped in the proposed reservoir.

The simulated mean long term sediment loads at the mouth are indicated in **Table 4.3**. The long term average reduction in coarse sediment by the proposed Smithfield Dam is 74 000 t/a.

Table 4.3: Long-term mean coarse sediment loads at the river mouth (t/a)

Pre-dam scenario	Post-dam scenario	%-difference
352 000	278 000	21%/a

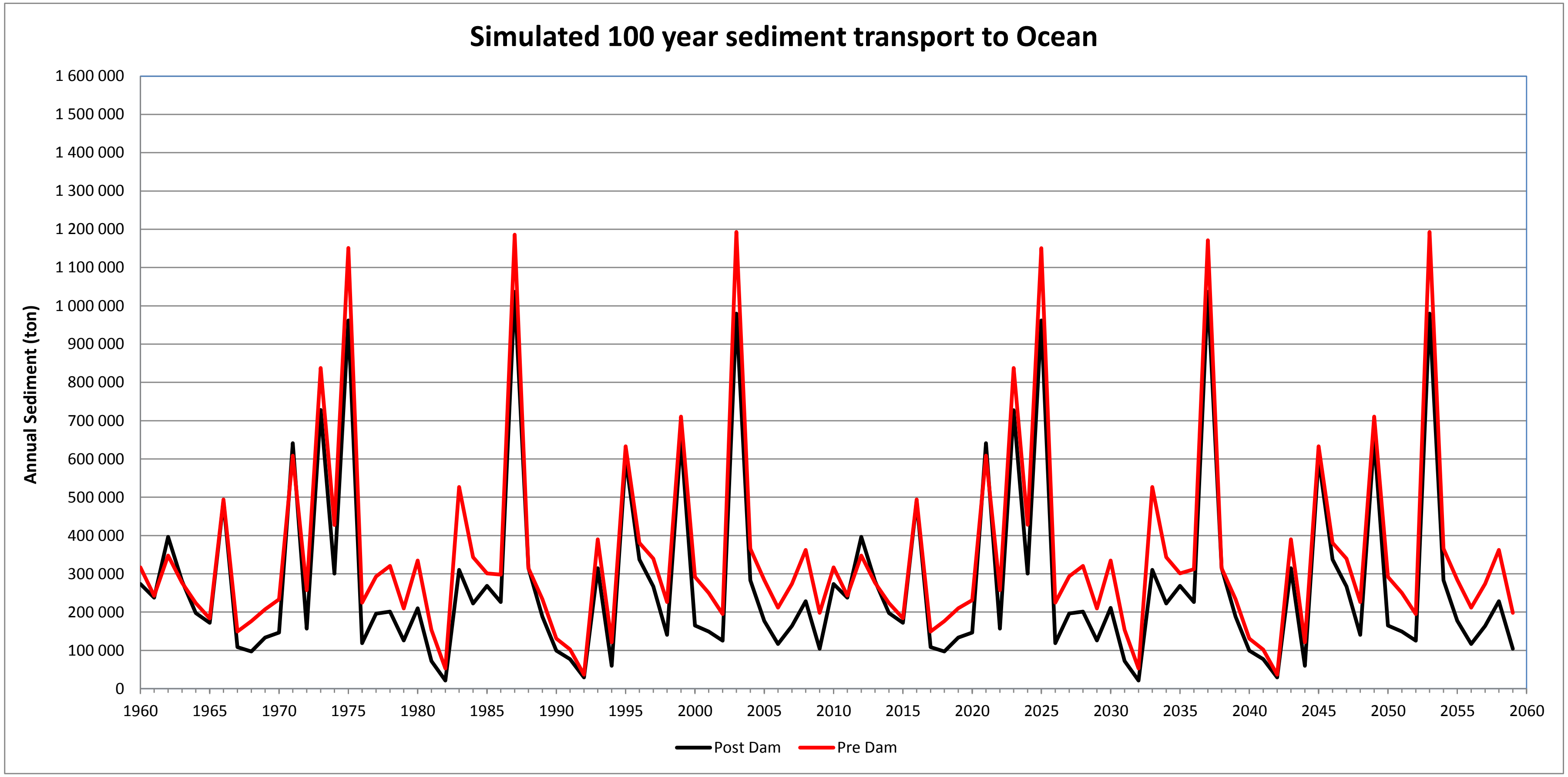


Figure 4.2: Simulated annual coarse sediment loads at the uMkhomazi River mouth

5 CONSIDERATION OF THE CENTRAL KWAZULU-NATAL COASTAL SEDIMENT BUDGET

5.1 INTERPRETATION OF PREVIOUS STUDIES INTO THE CENTRAL KWAZULU-NATAL COASTAL SEDIMENT BUDGET

In 2007/2008 *Theron et al* (2008) conducted an investigation on behalf of the eThekwini Municipality regarding the long-term sustainability of the coastal sand resource and potential implications for coastal "stability", which specifically entailed quantifying the possible reduction in sand supply to the central KZN coast. This study included deriving estimates of sediment yield for all rivers within the eThekwini Municipal jurisdiction, and an assessment of the impacts of dams and sand mining on fluvial sand yields. It was found that there are 12 large dams on the 18 rivers within the eThekwini jurisdiction (Tongati River to Mahlongwa River) and that these dams reduce the sand yield to the eThekwini coast by about one third. Based on a survey of sand mining operations on the 18 eThekwini related rivers, the total mined volumes were estimated to be at least 400 000 m^3/a in 2008.

Potential sediment sources along the KZN coast are fluvial discharge, coastal and submarine erosion, aeolian transport, biogenic products and in situ authigenic mineralisations. These were all assessed and quantified, clearly indicating that the sediments contributed by river discharge dominate total production. (The potential sediment sources were assessed as part of the comprehensive study conducted in 2008, as well as other research). From these studies, it follows that in the long-term, the amount and character of central KZN coastal sediments is ultimately determined by the larger rivers (and the nature of their catchments) within the region. Large floods in the larger rivers are required to transport the large volumes of sand to the coast. It is also important to understand that the net littoral drift (i.e. the longshore sediment transport) along the southern and central KZN coast is strongly towards the north-east (i.e. "upcoast"). The only really large potential sources of sediments to the central KZN coast from further south are the Kei, uMzimvubu and uMzimkulu rivers. The sand loads of the rivers south of Durban have in the past not been seriously affected by dam construction since very few large dams have been constructed in this region. The conclusion from the 2008 investigation is that relatively little sand reaches the southern to central KZN shoreline from downcoast river sources (i.e. from all potential river sources located to the south, including the larger rivers e.g. Kei and uMzimvubu) or longshore drift (*Theron et al,* 2008). The amounts and locations of the sand sources and sinks, as well as longshore transport rates are graphically indicated in a synthesis of the southern-central KZN coastal sediment budget as depicted in **Figure 5.1** (*Theron et al, 2008*).

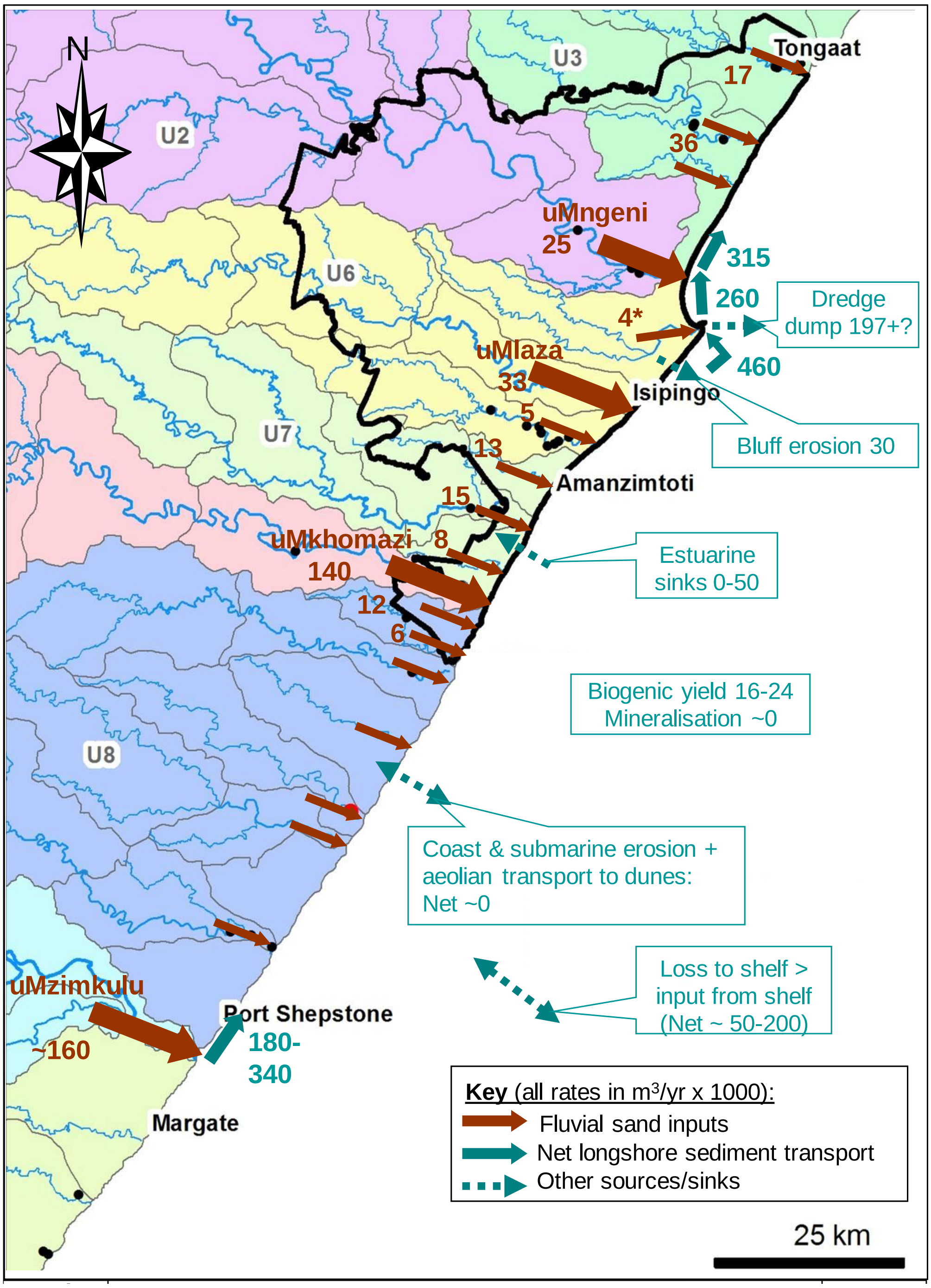


Figure 5.1: **Present understanding and quantification of the Durban regional sediment budget (including dams and dredging, but excluding sand mining). (*Theron et al, 2008*)**

Reservoir sediment survey data by DWS was used in the calibration of the catchment sediment yield models.

It was concluded in the 2008 study that the combined impacts of the dams and mining could result in mean coastal erosion of > 1 m/a. This was based on about 30 years of beach survey data and historical aerial photographs. (The coastal erosion rate refers to the horizontal beach/shoreline erosion. Thus 30 m of erosion over 30 years = 1 m/year on average). New research has confirmed this rate of recession over the period 1984 to 2012 (*Habets, 2015 pers. com.*). A strong recommendation was made to ban river sand mining from the eThekwini rivers as soon as practicable, while urgently seeking and evaluating other sources of sand. (The eThekwini Municipality have attempted to halt such mining, and have opposed new sand mining applications.) In the more comprehensive 2008 study, the issue of sand mining in the main channel versus in the flood plain is considered. The focus was however on the mining from the main channels. If the river bed is in a long-term state of (dynamic) equilibrium, then the assumption is made that the sediment in and outputs are also balanced in the long-term. Thus, mining of the sand means that were will be a deficit and reduction of sand supply to the coast.

The fact that large in-stream impoundments have significant detrimental impacts, including on sediment yield to coastal areas and thus on coastal stability, was also emphasised.

5.2 uMKHOMAZI RIVER SAND YIELD REDUCTIONS IN THE CONTEXT OF THE COASTAL SEDIMENT BUDGET

Regarding the present study on the uMkhomazi River, it must be emphasised that this river is by far the most dominant source of fluvial sand supply to the whole coastline between the uMzimkulu River mouth and Durban. (This can also be seen from the fluvial sand yields for each river as indicated in Figure 6.1.) The 2008 study (*Theron et al, 2008*), estimated the sand (i.e. coarse sediment fraction only) yield of the uMkhomazi River to the coast at between about 140 000 m^3/a to 215 000 m^3/a, while the present (2015) study on the impacts of the Smithfield dam estimates the sand yield at about 220 000 m^3/a (refer to **Section 2**). (This is based on conversion of the coarse sediment loads from tons to volumetric loads assuming an appropriate in situ sediment density of 1 600 kg/m^3. Thus, for example, the pre-dam sand yield of 352 391 ton/a equates to a volume rate of 220 244 m^3/a.) The present (2015) study (refer to **Table 4.3**) further estimates that the sand yield will reduce by about 46 000 m^3/a to about 174 000 m^3/a as a result of sand trapping due to the proposed dam and reduced sediment transport capacity downstream of the dam, which would be a 21% reduction in sand supply to the coast from this river. (As indicated, the focus here is on the coarse sediment fraction, i.e. the *sand* fraction of the total sediment load, as this is the material that replenishes the beach sand found along the seashore. The sand fraction is typically only about 10% of the total fluvial sediment load (i.e. including fines). The geology of some of the river catchments are such that only the upper catchments yield coarse sediments and it is known that these rivers supply sand to the coast. The attenuation of flood peaks by the proposed dam, however, also plays a major role in reducing the sand transport capacity down to the river mouth.

In terms of the regional coastal sediment budget, the sand yield of the uMkhomazi River (and reductions thereof) should also be considered in the wider context (as for example depicted in **Figure 5.2**). In this regard, the most important other factors are the coastal sediment input (i.e. the longshore transport rate) from further south, and the net longshore transport rate towards the Port of Durban along the Durban Bluff. An actual net north-eastward longshore sediment transport rate of about 500 000 m^3/a (on average) is estimated along the Durban Bluff coastline (*Theron and Rautenbach, 2014*). The actual net longshore transport rate at Port Shepstone (north-east of the uMzimkulu Mouth) is estimated to be about 240 000 m^3/a, north-east bound (*Schoonees and Theron, 2001*), which is about half of the net north-eastward longshore sediment transport rate along the Durban Bluff. Thus, it is estimated that the uMkhomazi River naturally contributed between about 50% to 85% of the additional sand inputs required for the coast from Port Shepstone to Durban. Besides the longshore transport input from further south of Port Shepstone, the uMkhomazi River is thus by far the most dominant source of fluvial sand supply to the whole coastline between the uMzimkuluRiver mouth and Durban. The next biggest source here, is the uMlaza River at only about 33 000 m^3/a (2008 estimate). Thus the uMkhomazi River is truly by far the most dominant source. Based on a mean fluvial sand yield at about 220 000 m^3/a for the undeveloped (i.e. without proposed Smithfield dam) uMkhomazi River and trapping of some 46 000 m^3/a due to the proposed dam, this sand trapping represents a reduction of 18% of the additional sand inputs required for the coast between Port Shepstone and Durban. This is a significant reduction and may lead to various impacts as discussed in **Chapter 6**.

Unfortunately, in addition to the above potential impact to the sand yield of the uMkhomazi River, this important source of sand has also already been impacted on by sand mining (as is the case with many of the other central KZN rivers and some rivers in southern and northern KZN). Much of the sand mining operations extract sand directly from the main river channel and active/dynamic sand banks along the main channel, as can clearly been seen in the example shown in **Figure 5.2**. In the 2008 study (*Theron et al, 2008*), it was estimated that the sand mining rate from the uMkhomazi River is at least 42 000 m^3/a. It is possible that present (2015) sand mining volumes could be higher than the 2008 value, but this has to be confirmed by the local authorities. The 2008 study for eThekwini estimated that the total sand mining rate from all 18 ''eThekwini rivers'' was at least 400 000 m^3/a.Based on the 2015 estimate of fluvial sand yield of the uMkhomazi River, the sand mining (2008 volume) constitutes a loss of about 19% of the "natural" sand yield. Thus, the sand trapping in the proposed dam and the sand mining would have about equal impact on the sand yield from this river, and in total would reduce the sand yield of the uMkhomazi River by as much as about 18+19 = 37%. The 2008 study on which much of this is based, was reviewed, and the findings were then strongly backed by DWAF, DEA and eThekwini Municipality.

Figure 5.2: Example of sand mining operations directly in uMkhomazi main river channel (Aerial view generated from Google EarthTM 2008©)

A historical reduction in longshore sand supply to the Durban Bluff has been observed. Long-term dredging records of the sand trap in Cave Rock Bight appear to indicate a declining trend in the annual dredging rate since the 1970's (TNPA and eThekwini data), and as indicated in **Figure 5.3**.

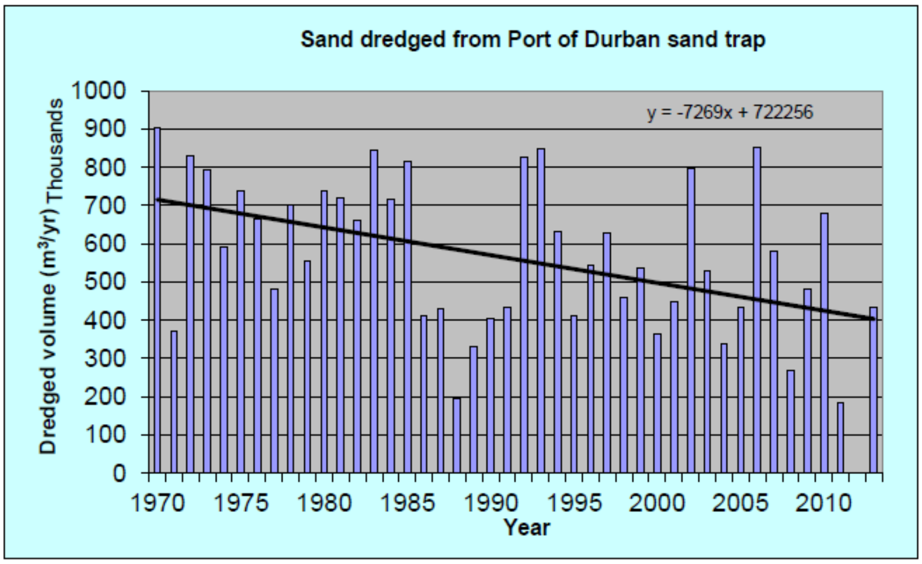


Figure 5.3 Annual sand volumes dredged from Durban sand trap since 1970 (Theron and Rautenbach, 2014)

6 SHORELINE VARIABILITY AND LONG-TERM STABILITY

A brief interpretation of selected data and information from the study area is provided here regarding specific parameters relevant to coastal sediment supply and long-term shoreline stability issues along this portion of the central KZN coast, focussing mainly on the approximately 10 km of shoreline from Umkomaas northward to Umgababa.

6.1 INTERPRETATION OF AERIAL PHOTOGRAPHY

The beach and shoreline morphology in the direct vicinity of the mouth of the uMkhomazi River is highly dynamic and variable. Episodic events, especially river floods and sea storms move large volumes of sand in the short-term (days), interspersed by longer periods (usually weeks to months) of more moderate change as milder conditions allow a gradual return towards the longer-term equilibrium configuration. These dynamics result in large natural shoreline variations (e.g. **Figure 6.1** (from CSIR, 1973)) which would tend to obscure possible slight long-term trends in shoreline location.

A previous investigation of the coastline south of Durban (*Theron et al, 2003*) included aerial photograph analyses and determination of coastline changes and long-term beach stability derived there from. The long-term shoreline variability was quantified by considering the variation in shoreline location over an extended period based on vertical aerial photography. Historical shorelines were referenced relative to ortho-corrected aerial photography. The limitations of assessing shoreline variation and stability using aerial photographs analysis are the level of accuracy when establishing the position of the high-water mark (accurate to within 10 m) and especially the availability of aerial photographs (for example the number of photographs available for the last 50 years). By using the high-water run-up mark and not the water line, uncertainties relating to the tidal level at the time of the photography are eliminated.

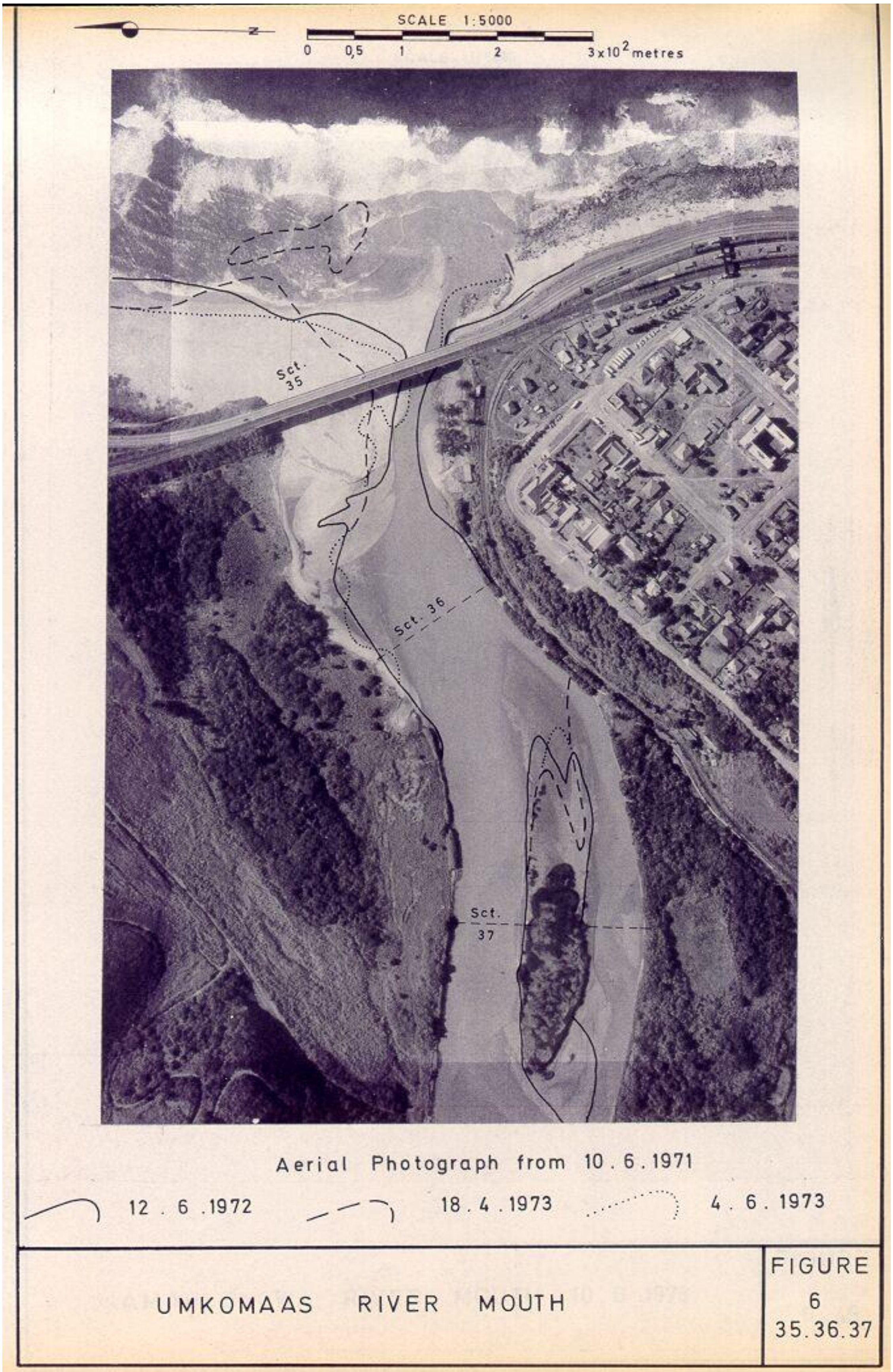


Figure 6.1: Shoreline changes at the mouth of the uMkomazi River

Thus, time series aerial photograph mosaics, which show historical shoreline configurations and locations, were produced. Aerial photographs used in the analysis covered 63 years. Photographs were available for the years 1937, 1959, 1967, 1973, 1976, 1978, 1987, 1990 and 2000. The historic high-water lines were transposed onto the "master" ortho-corrected aerial photograph mosaics. The results for the area in the vicinity of Umkomaas to Umgababa are show in **Figures 6.2** to **6.4**.

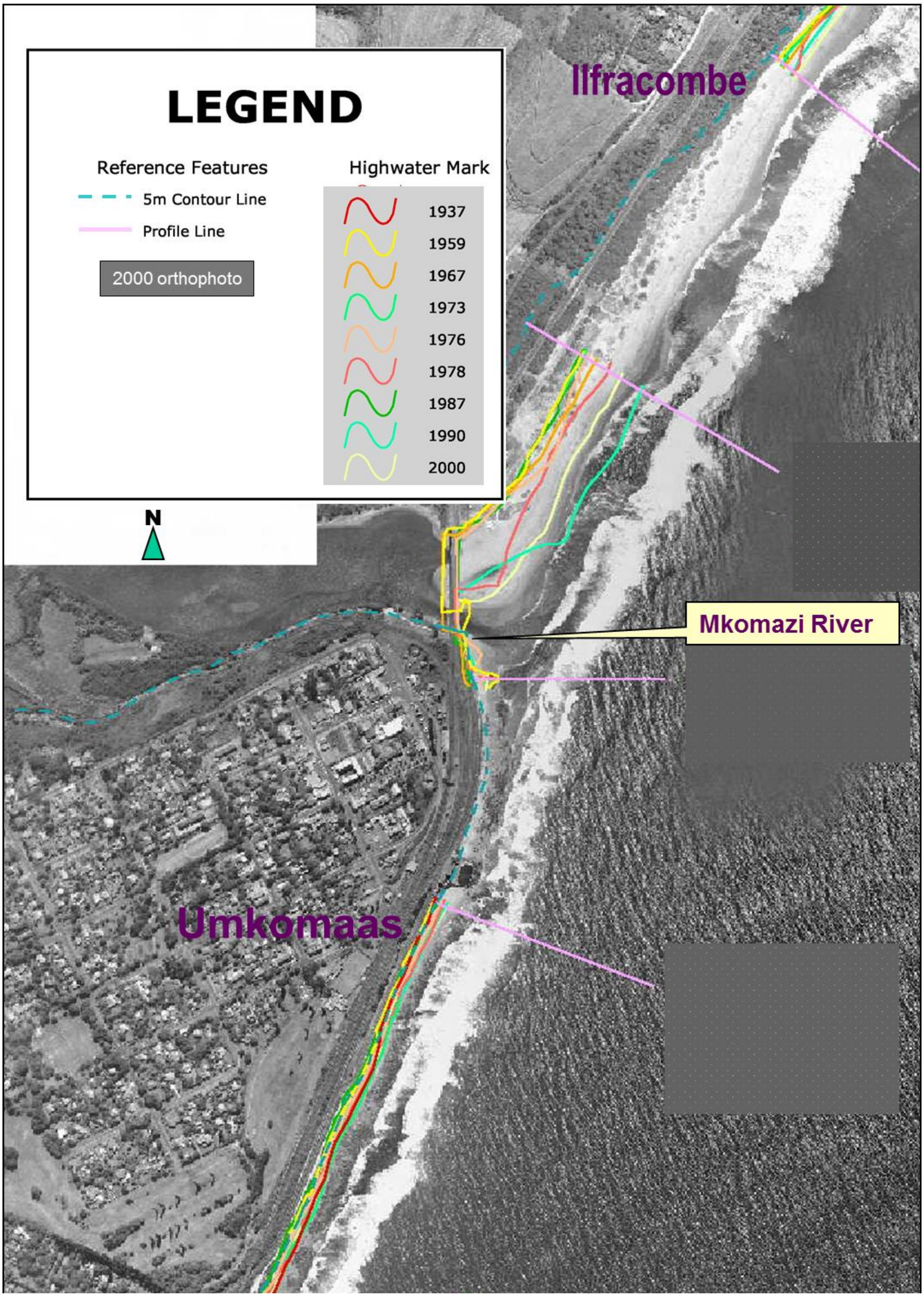


Figure 6.2: Coastal high-water lines at and south of uMkomazi Mouth

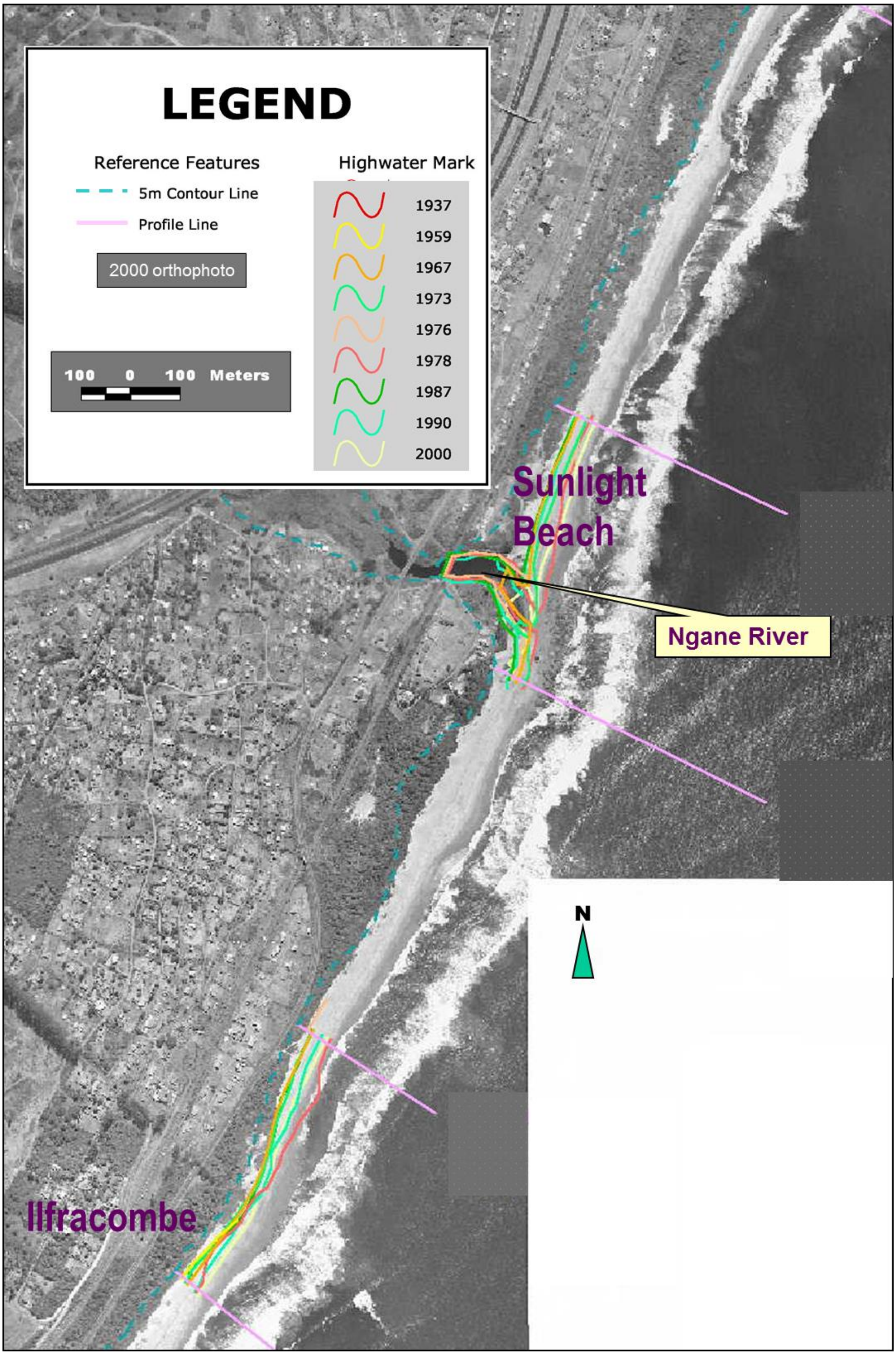


Figure 6.3: Coastal high-water lines north of uMkomazi Mouth - Ifracombe to Sunlight Beach

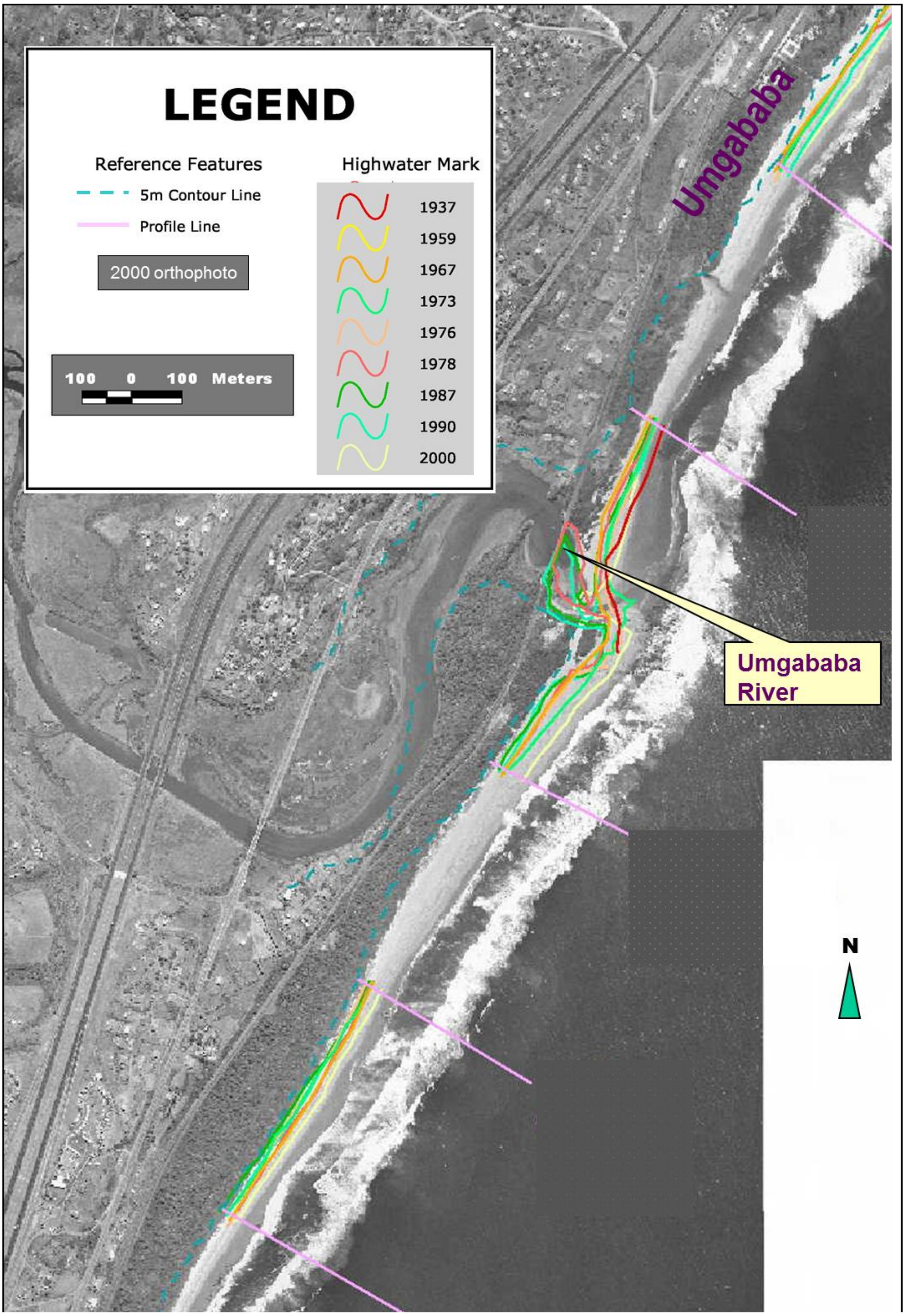


Figure 6.4: Coastal high-water lines north of uMkomazi Mouth - Sunlight Beach to Umgababa

In the uMsimbazi to uMkhomazi River Mouth area, rocky headlands have a significant impact on shoreline morphology. Between Ifracombe and the uMkhomazi River Mouth, relatively large accretion was exceeded by erosion in the ensuing periods. This might be linked to a large influx of sediment during floods, while in the ensuing periods erosion caused retreat of the shoreline. Between Umgababa and Sunlight Beach, envelopes of mobility are relatively low and rates of change between successive photographs are also relatively low. In the Umkomaas area to the south of the uMkhomazi River Mouth the shoreline is mainly rocky, with low to medium temporal patterns of erosion and accretion.

No significant eroding or accretionary long-term trend in the shoreline location is apparent in the Umkomaas to Umgababa area from the aerial photography (**Figures 6.2** to **6.4**). In general, it seems that the beaches of the study area have remained dynamically stable since the 1930s. Note that this statement refers to the interpretation of aerial photography and the Umkomaas to Umgababa area. Elsewhere in the report the erosion along the Bluff is clearly discussed.

6.2 INTERPRETATION OF COASTAL TOPOGRAPHIC SURVEYS

In the early 1970s (October 1970 to June 1973) the CSIR measured 11 beach profiles at each of three locations, one of which was located just north (ca. 0.5 km) of the mouth of the uMkhomazi River, and another at the Umgababa Holiday Resort also to the north of the uMkhomazi Mouth (*CSIR, 1973*). Profile envelopes based on these surveys for Umkhomaas North and Amahlongwa River South are shown in **Figure 6.5**. From the profile envelope of the beach near the uMkhomazi mouth, it can be seen that short-term horizontal variations of the upper beach (within approximately the 0 m to +2 m to mean sea level elevations) ranged up to 50 m within the recording period, while variations near the low-tide mark can be even more. More recent survey data were also evaluated as part of this study.

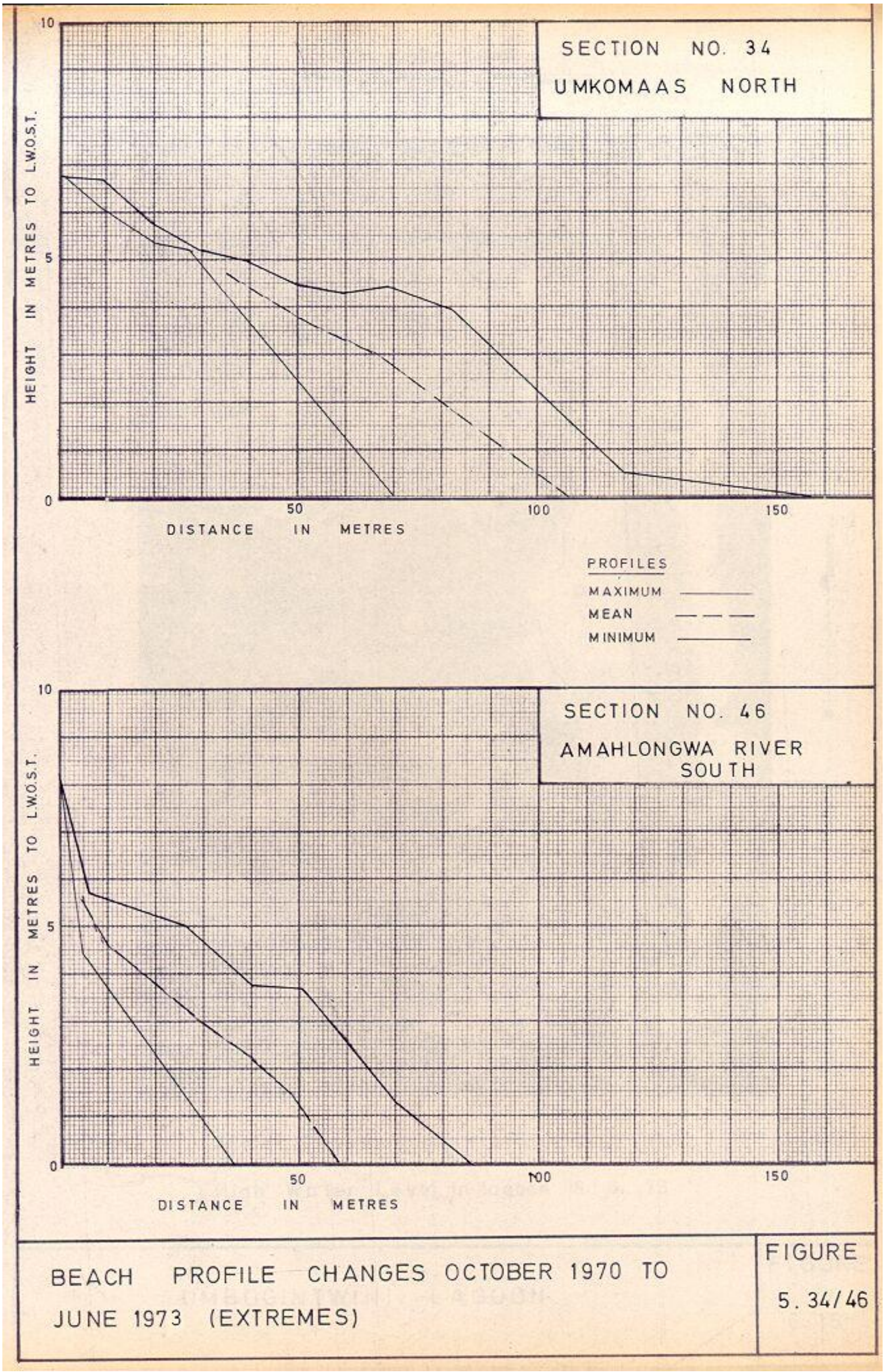


Figure 6.5: Beach profile envelope October 1970 to June 1973

The eThekwini Municipality’s extensive coastal monitoring programme includes surveyed profiles of the beaches located to the south of Durban (refer to **Figure 6.6**) and even south of the uMkhomazi Mouth. In **Figure 6.6** the monitoring sections are given together with their locations. Profile SC38 is located near Umkomaas just south of the uMkhomazi Mouth, while Profiles SC33 and SC34 are located to the north of the mouth, with SC34 being the nearest to the mouth. Over the 7 year monitoring period (approximately 3 months between surveys) Profile SC38 showed small short-term horizontal variations of the +2 m contour (up to in the order of 10 m), due to this being a rocky shoreline with only limited sandy patches. In comparison Profile SC34 located just north of the uMkhomazi River mouth has shown short term horizontal variations of the +2 m contour of up to 50 m within the 7 year period, while Profile SC33 located a bit further north of the uMkhomazi River mouth has shown short term horizontal variations of the +2 m contour of up to 40 m over the same period. Profiles SC 33 and SC34 located just north of the uMkhomazi River mouth show net shoreline erosion over the 7 years, but this “trend” does not extend further northwards to Profiles SC31 or SC32.

The apparent erosion nearer to the uMkhomazi River mouth might be linked to an initial large influx of sediment during floods resulting in an initially accreted shoreline, while in the ensuing periods erosion caused retreat of the shoreline relative to the initial shoreline location. In general, the 7 year monitoring period is still insufficient to identify possible underlying long-term trends with any certainty, especially under the larger prevailing natural short-term fluctuations due to sea storms and river floods.

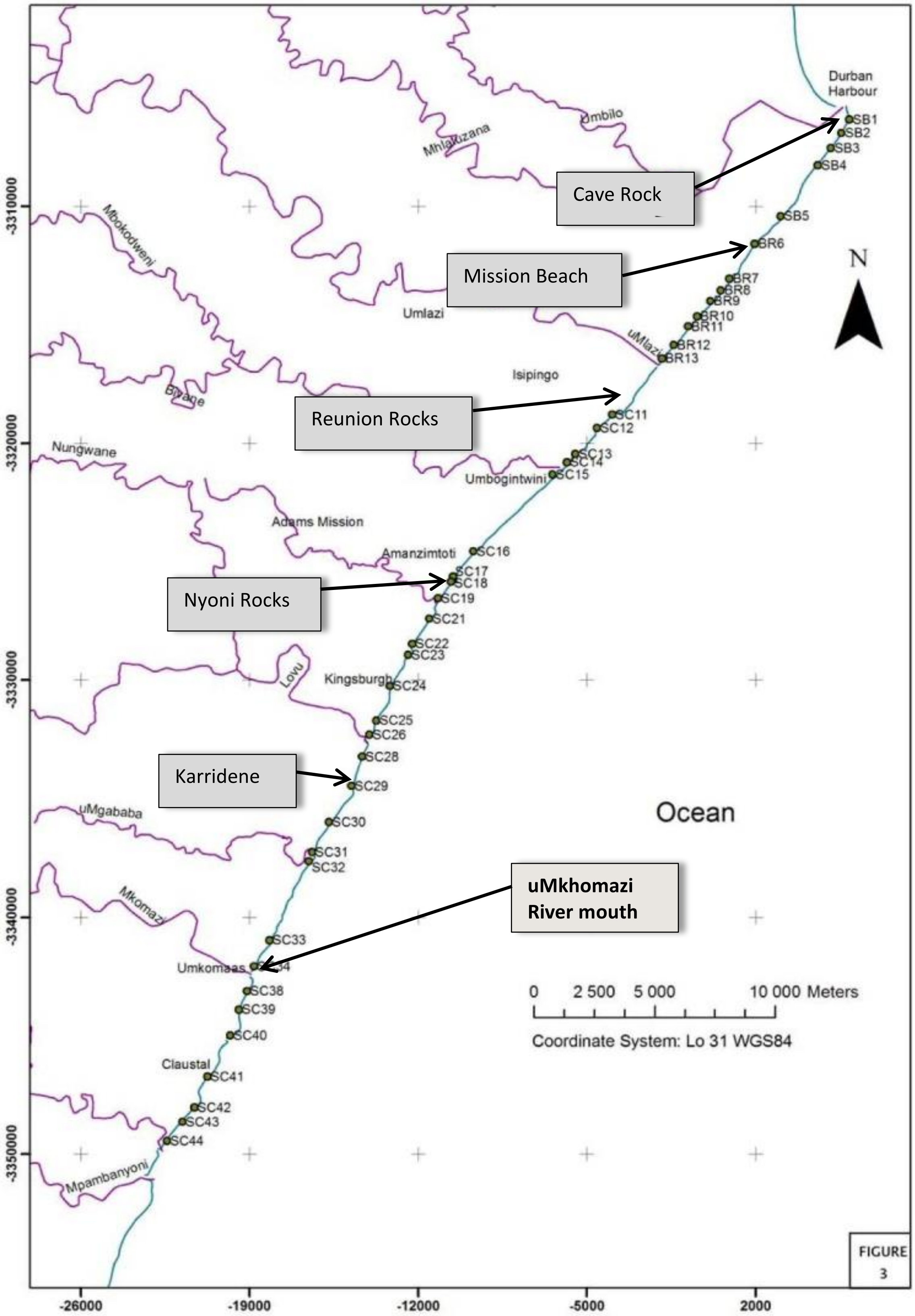


Figure 6.6: Location of Durban southern beach profiles survey stations (adapted from *Theron and Rautenbach, 2014*)

6.3 POSSIBLE CLIMATE CHANGE SEA LEVEL RISE IMPACTS ON COASTAL EROSION

Although climate change impacts on coastal erosion are not part of the scope of this report, some comments are given here. The estimated sea level rise could be 0.5 m in about 60 years' time, with an associated potential 50 m lateral erosion of the beach. The effect of sea level rise on coastal erosion will probably become significant from year 2040. The lateral erosion rate due to sea level rise could be on average 0.83 m/a (not linear in reality), while the historical observed lateral erosion rate along the Durban Bluff is 1 m/a. Climate change by year 2075 could therefore almost double the current rate of lateral erosion of the beaches. The proposed Smithfield Dam has an estimated 10 % long term impact (reduction) of the total longshore sediment transport rate at Durban Bluff, which is likely to increase the current rate of beach erosion.

7 POSSIBLE MITIGATION MEASURES TO LIMIT COASTAL EROSION

Identification of mitigation measures did not form part of the TOR of this study and will only be listed here for possible future investigation. Through implementation of one or more mitigation measures it should be possible to limit the long term impacts on the coastal erosion. The following are possible measures:

a) Increase the sand load at the mouth by adding a sand bypass tunnel at the Smithfield Dam. A 5.1 km concrete lined tunnel length is required. Flushing of sediment will be carried out during floods and the firm yield of the dam could decrease slightly due to the flushing operation. This bypass tunnel could also be used for releasing the environmental water requirements at the dam, such as base flows and small floods. For more details refer to section 3.6.

b) The current impact of sand mining on the uMkhomazi River is as large as the impact on the sand yield of the proposed Smithfield Dam. It is therefore proposed that firstly existing illegal sand mining south of Durban should be prevented. In general future legal sand mining south of Durban should also be limited. As alternative to the current sources of alluvial river bed sediment, suitable sand sources at the coast could be identified, such as historical beach zones (geologic deposits) currently located inland near the coast, possible quarries, from the Smithfield Reservoir or upstream on the river (but this is relatively far from the coast), and possibly from alluvial river floodplains above the 200 year flood levels,

c) Coastal control of development could possibly be improved to limit erosion (by not removing coastal dunes).

d) A beach nourishment programme is possible, but requires a suitable off-shore source of coarse sand and dredging cost will be expensive. Critical zones along the beach could be targeted or general dredge disposal could be done to increase the available sediment for longshore transport.

The proposed order of further investigation of the above measures to limit the environmental impact of the reduction in available sand resources on coastal erosion south of Durban is to address (b) and (c) first, followed by (a).

8 CONCLUSION AND RECOMMENDATIONS

8.1 SMITHFIELD RESERVOIR SEDIMENTATION YIELD STUDY

The key findings of this study related to reservoir sedimentation are as follows:

a) The sediment yield determined by AECOM at the Smithfield Dam site was reviewed and compared with observed sediment yields in the region. Sensitivity testing was also carried out in using the WRC (2012) method by considering the accuracy of the 10 year flood. Based on the relatively high observed sediment yields in the region, it is recommended that a 95% confidence sediment yield is used of 617 t/km^2.a for the proposed dam, which gives a mean annual sediment load of 1.27 million t/a. The sediment yields calculated in this study are similar to those of the AECOM report, but the recommended sediment yield in this study is higher since it is based on a higher confidence level and agrees with regional reservoir sedimentation data A possible future sediment yield of double the current yield due to land use change, land degradation and climate change impacts was also considered in the reservoir sedimentation analysis.

b) Reservoir sedimentation of the proposed Smithfield Reservoir was carried out by using a two dimensional hydrodynamic model. In the model setup 4 sediment fractions were used based on bed sediment grading analysis from field work carried out during this study. The upstream boundary consisted of a scaled observed flow record from a nearby DWS flow gauging station using hourly data and a sediment concentration time series for cohesive sediments based on an adjusted discharge-sediment load rating of the Eastern Cape to obtain the correct long term sediment yield. The water levels at the dam site were used as downstream boundary in the model and were simulated by one dimensional hydrodynamic model of the reservoir mass balance, considering inflows, evaporation, rainfall, spillage and diverted flows. Reservoir sedimentation simulations were carried out for a 100 year period, with the current sediment yield of 617 t/km^2.a. A sensitivity scenario was also simulated with a smaller cohesive fraction of 11 micron (compared to the 33 micron), to evaluate the deposition patterns near the dam. The results were similar after 50 years, but after 100 years of operation the 33 micron cohesive fraction indicated slightly more sediment deposition near the dam.

A possible future sediment yield of double the current yield due to land use change, land degradation and climate change impacts was investigated for a 100 year operation period.

The new reservoir trap efficiency is 97% and therefore only colloidal (very fine) sediment will not be deposited in the reservoir. The new dam full supply storage capacity of 252 million m^3 could decrease to 208 and 161 million m^3 after 50 years, for the current sediment and possible increased future sediment yields, respectively. The simulated reservoir sedimentation therefore decreases the storage capacity by 18% and 36% for the current and future sediment yield scenarios respectively, over the 50 year period. At the current sediment yield and future possible higher sediment yield over a 100 year period, the FSC could be 163 and 87 million m^3, a decrease of 36% and 66% in the original storage capacity, respectively.

A scenario was also considered where the Impendle Dam is constructed in future upstream of the proposed Smithfield Dam. **Table 8.1** provides the Smithfield Reservoir FSC's for different sediment yield scenarios after 50 and 100 years of operation, with Impendle Dam commissioned by 2046, and without Impendle Dam. The last row in **Table 8.1** is the recommended scenario over 100 years of operation of Smithfield Dam, with the current yield sediment over the first 50 years and a doubled sediment yield over the last 50 year period. With Impendle Dam commissioned by year 2046 the Smithfield Reservoir will only lose 16% of its original FSC over a 100 year period, but if Impendle Dam is not implemented 51% of the original FSC of Smithfield Dam could be lost due to sedimentation.

Table 8.1: Reservoir sedimentation at Smithfield Dam with and without Impendle Dam upstream of Smithfield Dam

Description	Unit	Smithfield Dam-with Impendle Dam (yr 2046)	Smithfield Dam-without Impendle Dam
Year of Smithfield Dam commission	year	2023	2023
New reservoir Full supply storage capacity	million m^3	252.0	252.0
After 50 yr: Full supply storage capacity, at current sediment yield	million m^3	227 (10%)*	208 (17%)
After 100 yr: Full supply storage capacity, at current sediment yield	million m^3	219 (13%)	163 (35%)
After 100 yr of Full supply storage capacity, at doubled future sediment yield, for last 50yr	million m^3	211 (16%)	124 (51%)

*Note: * percentage of original FSC loss due to sedimentation indicated in brackets*

The long term reservoir sedimentation simulations indicated possible sediment deposition at the diversion tunnel intake in the Smithfield Reservoir (no Impendle Dam). After 50 years of operation the current and possible high future sediment yield indicated sediment deposition at the intake of 0.4 and 12.8 m respectively. If the high future sediment yield is considered over a 100 year period the sediment deposition at the tunnel intake could be 28.5 m deep and at the dam wall 58.5 m deep. The actual sediment deposition could be less, however, if the high future sediment yield is only considered over the period from 50 to 100 years of operation of the dam, and if Impendle dam is constructed.

It is recommended that for scenarios without the proposed Impendle Dam:

- The simulated 50 year reservoir sedimentation of Smithfield Dam (using a cohesive fraction size of 33 micron), for the current sediment yield, should be used to ensure that the required firm water yield of the reservoir is not affected during the first 50 years of operation.
- As a sensitivity analysis in the water resources planning, the high sediment yield (double current yield) reservoir sedimentation assessment after 50 years should also be considered in the firm yield assessment to evaluate the firm yield reduction of Smithfield Dam.
- While the above is typically the methodology followed in South Africa, based on international guidelines (ICOLD and World Bank) the reservoir sedimentation and operation for 100 years should also be considered in the water resources analysis, to assess whether Smithfield Dam will be feasible in the long term. The recommended sediment yield scenario is the last one in **Table 8.1** (bottom row).
- Sediment control measures should be implemented in the catchment (land care programme) to limit the sediment yield increase in future and engineering measures in the dam at the diversion tunnel intake (concrete wall to prevent delta sediment sliding/slumping into the intake and sediment flushing tunnel for pressure flushing of the intake zone).

If the proposed Impendle Dam is constructed in future upstream of Smithfield Dam, land care of the catchment to prevent land degradation will remain important for the total catchment of Smithfield Dam. The recommended sediment flushing mitigation measure at the diversion tunnel intake will not be required due to the relatively small FSC storage loss of only 16% over 100 years.

8.2 POTENTIAL IMPACT OF THE PROPOSED SMITHFIELD DAM ON THE COASTAL SEDIMENT BUDGET AND SHORELINE STABILITY

The key findings of this study related to the impacts of the change in sediment loads at the river mouth due to the proposed Smithfield Dam are as follows:

- From the aerial photographic analyses and the topographic survey results it cannot be clearly ascertained whether there is currently a significant long-term trend in the shoreline location *in the vicinity of the uMkhomazi River Mouth*. Horizontal shoreline variations are naturally relatively large on this exposed high energy coastline and are further subject to the effects of episodic flood derived pulses of sediment input from the larger rivers in the region. Based on the longer-term aerial photographic analyses it appears that if indeed an eroding trend were present, it would have to be quite small (<=0.3 m/a, i.e. <=15 m over 50 years) to remain undetected at this stage. However, further north, in the Durban Bluff area, a long-term shoreline erosion trend of 1 m/a has been established.
- It is clear that the proposed Smithfield Dam on the uMkhomazi River will possibly have a significant and long-term (ongoing) effect on the coastal sediment budget due to the relatively large volume of sand that will be trapped by the dam (resulting in a reduction in the order of 18% of the additional sand inputs required for the coast between Port Shepstone and Durban, and a 10 % reduction of the total longshore load at the Bluff). The "significance" of the dam's impact on coastal erosion has to be evaluated further as part of detailed research or additional specialist study. The impact of the dam on coastal erosion could however be mitigated/limited by a number of mitigation measures as discussed below and in Section 7. The impact in terms of net coastal erosion will be most noticeable in the first 10 km to the north of the mouth of the river, but even in this area it may be a decade or more after completion of the dam before the impact is clearly apparent. However, in the long-term the impact (although reducing in magnitude/intensity towards the north), will gradually (probably noticeable from a few decades onwards becoming progressively worse) spread further north and is likely to eventually even result in a reduction of the longshore sand supply to the Durban Bluff area. Long-term dredging records of the sand trap in Cave Rock Bight appear to indicate a declining trend in the annual dredging rate since the 1970's (TNPA and eThekwini data),

- The estimated sea level rise due to climate change could be 0.5 m in about 60 years' time, with an associated potential 50 m lateral erosion of the beach. The effect of sea level rise on coastal erosion will probably become significant from year 2040. The lateral erosion rate due to sea level rise could be on average 0.83 m/a (not linear in reality), while the historical observed lateral erosion rate along the Durban Bluff is 1 m/a. Climate change by year 2075 could therefore almost double the current rate of lateral erosion of the beaches. The proposed Smithfield Dam has an estimated 10 % long term impact (reduction) of the total longshore sediment transport rate at Durban Bluff, which is likely to increase the current rate of coastal erosion.

Through implementation of one or more mitigation measures it should be possible to limit the long term impacts on the coastal erosion. The following are possible measures:

- The current impact of sand mining on the uMkhomazi River is as large as the impact on the sand yield of the proposed Smithfield Dam. It is recommended to establish the status quo of sand mining in the uMkhomazi catchment, including illegal/unpermitted mining to quantify the extent of the problem. It is proposed that firstly existing illegal sand mining south of Durban should be prevented. In general future legal sand mining south of Durban should also be limited. As alternative to the current sources of alluvial river bed sediment, suitable sand sources at the coast could be identified, such as historical beach zones (geologic deposits) currently located inland near the coast, possible quarries, from the Smithfield Reservoir or upstream on the river (but this is relatively far from the coast), and possibly from alluvial river floodplains above the 200 year flood levels,
- Coastal control of development in the catchment could possibly be improved to limit erosion (by not removing coastal dunes, etc.).
- Increase the sand load at the mouth by adding a sand bypass tunnel at the Smithfield Dam. A 5.1 km concrete lined tunnel length is required. Flushing of sediment will be carried out during floods and the firm yield of the dam could decrease slightly due to the flushing operation. See **Appendix G** for a detailed write-up and costing of the sediment bypass tunnel.
- A beach nourishment programme is possible, but requires a suitable off-shore source of coarse sand and dredging cost will be expensive. Critical zones along the beach could be targeted or general dredge disposal could be done to increase the available sediment for long shore transport.

To limit the environmental impact of the reduction in available sand resources on coastal erosion south of Durban, it is proposed to first address sand mining (legal and illegal) and to control further development in the catchment. A sediment bypass tunnel at the dam may also be considered, however, to better understand the functionality and feasibility of such a tunnel, further research is required, e.g. a study by the Water Research Commission.

It should be noted that this study was carried out at desktop level of detail with the following assumptions:

- Sediment routing from the dam to the river mouth done by hydrodynamic model with no topographical survey data available and therefore simplified river cross-sections were used.
- Simplified incremental hydrology assumed downstream of the dam site. In a more detailed study a daily rainfall-runoff model is required to simulate the tributary flows and sediment inputs.
- Sediment samples with grading were obtained from the river, but more data is needed for a more detailed study, with sediment transport measurement in the field for model calibration.

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Appendix A

One dimensional hydrodynamic modelling of Smithfield Reservoir to generate the reservoir water levels based on the historical hydrological records

A.1 INTRODUCTION

A1.1 BACKGROUND

The software used to simulate the reservoir water levels on an hourly time step in this study is called Mike 11. The boundary conditions used in the model to simulate the reservoir mass balance are listed below:

- A time series of historical inflow data was used for the upstream boundary condition of the dam. The flow data was obtained from DWS gauging station U1H005. The complete historical data series was used in the simulation as hourly data and has a time span of 54 years.
- A time series for the evaporation was used over the reservoir surface area.
- A time series for the diversion tunnel abstraction three years after construction of the dam was used.
- A time series was used for the rainfall on the reservoir surface.
- A discharge-stage relationship (Q-h) was used on the downstream side of the simulation based on the local slope and normal flow conditions.

A1.2 OBJECTIVES

The objective of this simulation was to obtain the water levels at the proposed dam wall. The results were used in the hydrodynamic reservoir sedimentation model calculations, using Mike21C software.

A1.3 METHODOLOGY

The required model input files of Mike 11 are listed below:

- Network,
- Cross section,
- Boundary conditions,
- HD parameters and
- Simulation file

The available data was inserted into the correct files as discussed in section A0. The simulation process started and various parameters including the dx and the Δt values were changed in an iterative process to find the best results.

A.2 PROCEDURES

A2.1 SETUP

The setup of the model is discussed in this section in more detail.

A2.1.1 NETWORK

The network file contains the X and Y coordinates of the lowest points in the cross sections. After all the coordinates are inserted, the branch (river section) was connected and the branch name was inserted. The maximum dx-value is the maximum distance between consecutive iterations. It is stipulated in the network file. The spillway structure that was used to simulate the reservoir water levels is a weir. The weir was selected in the program to be 200 m wide.

A2.1.2 CROSS SECTIONS

The cross sections have a dx-value of 600 m, therefore the minimum distance between consecutive cross sections is 300,5m. This value was selected to decrease the simulation time since fewer iterations will be done if the dx-value increases. The cross sections of the reservoir were initially selected to be 1000m apart. More cross sections were added to have a more detailed model, with the closest cross sections selected to be 466 m apart. The Manning’s n value is 0.045 for the upstream first three and the most downstream cross sections downstream of the dam, and 0.02 for the rest of the twenty-three cross sections in the reservoir. The resistance is uniformly distributed along the whole cross section.

A2.1.3 BOUNDARY CONDITIONS

The hydrodynamic model done in Mike 11 is much depended on the boundary conditions to obtain accurate simulation results. The following conditions were added in the model setup:

- A time series of historical inflow data was used for the upstream boundary condition of the dam. The flow data was obtained from gauging station U1H005. The complete historical data series was used in the simulation; it has a time span of 54 years (**Figure A-1**).
- A time series for the evaporation was used over the reservoir area. The evaporation data for the S-pan evaporation (mm) was obtained from WR2005, Evaporation Zone 30B. The conversion factor from S-Pan to lake

evaporation was obtained from WR90, Appendix 3.3.1. The factor was multiplied with the S-Pan data to generate the lake evaporation data. The evaporation data was interpolated from monthly to daily data (**Figure A-2**).

- A time series for the tunnel abstraction three years after construction of the dam was used. The data for the tunnel abstraction was provided by AECOM. Abstractions first started three years after the completion date of the dam wall to allow for initial filling of the dam (**Figure A-3**).
- A time series was used for the rainfall on the reservoir. The data was obtained from the rain gauges in the catchment area (**Figure A-4**).
- A stage-discharge (Q-h) ratio time Series was used on the downstream boundary condition of the model, in the river downstream of the dam.

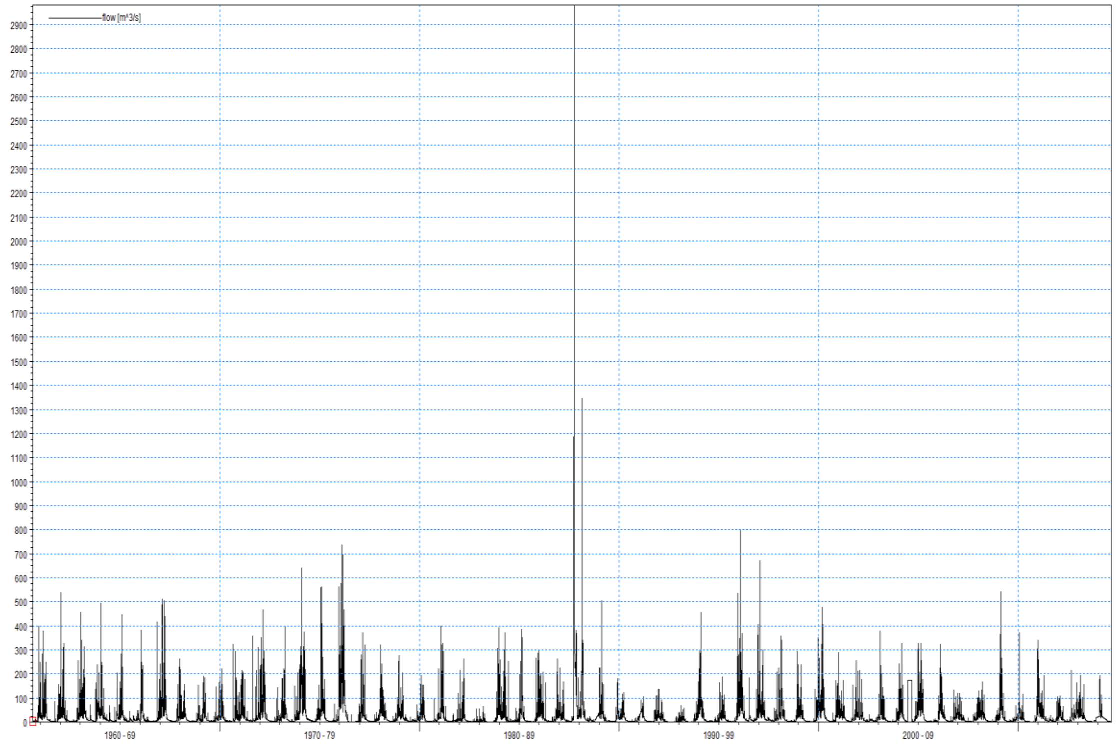


Figure A-1 Hourly reservoir inflow data (m^3/s) (scaed from DWS flow gauging station)

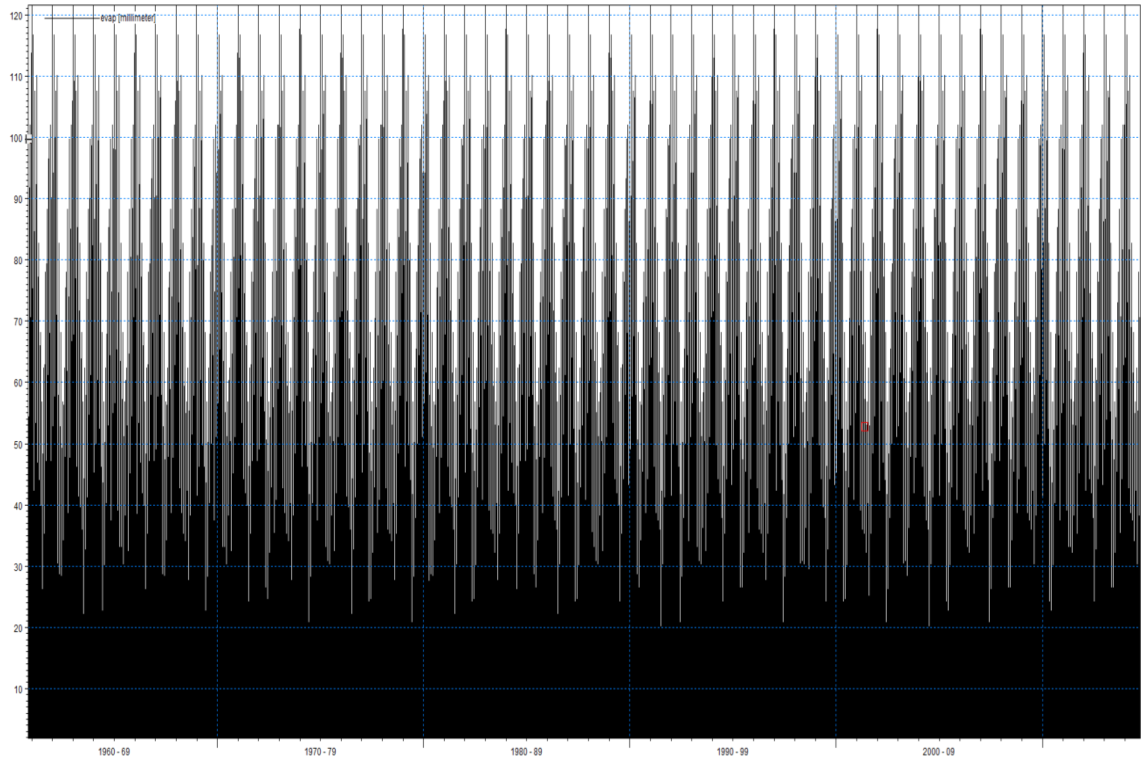


Figure A-2 Evaporation time series (mm) (AECOM)

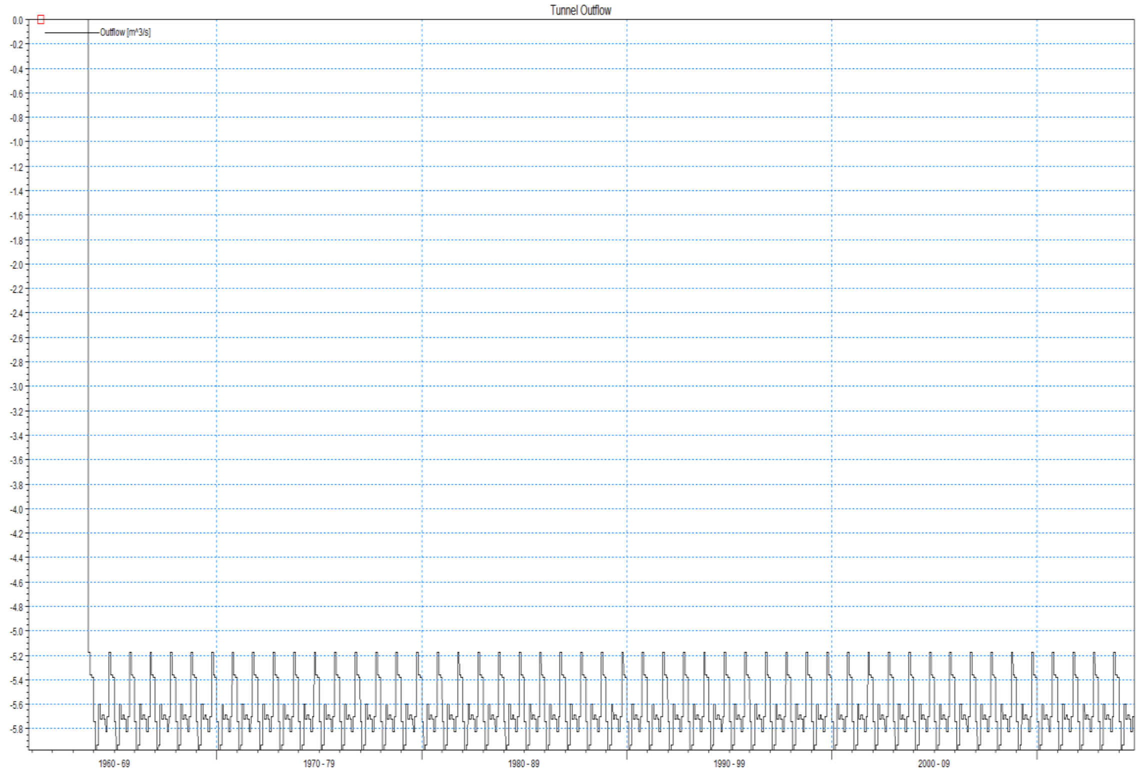


Figure A-3 Tunnel outflow data (AECOM)

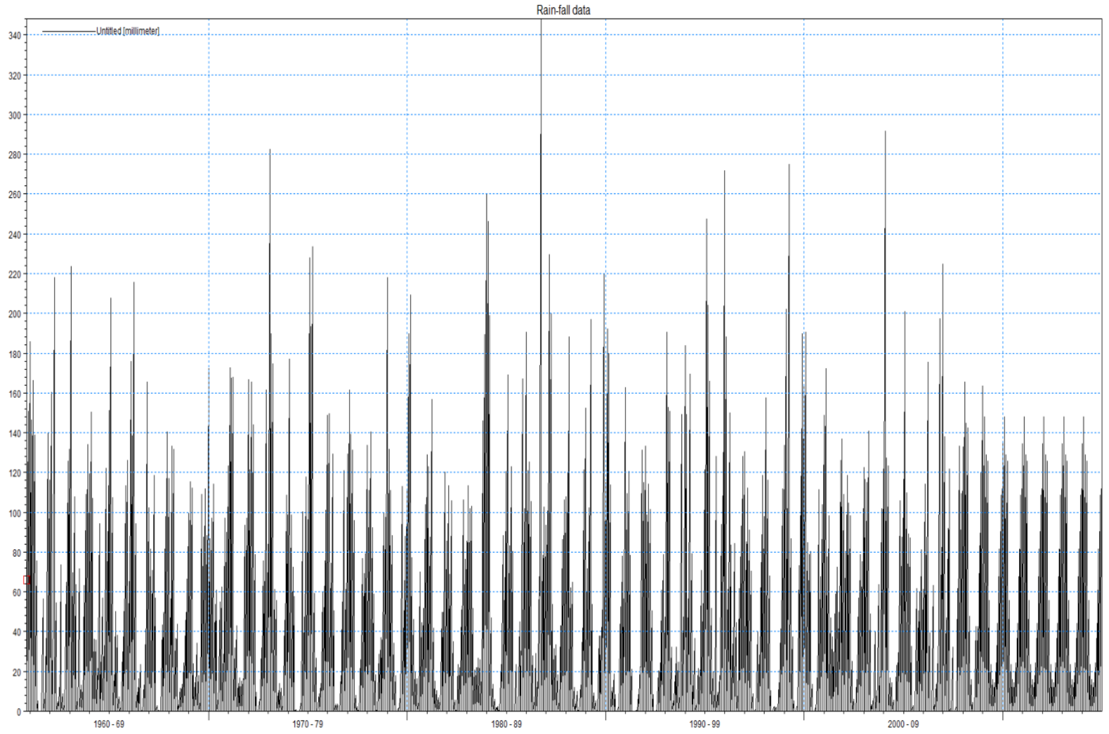


Figure A-4 Rainfall data mm (AECOM)

A2.1.4 HD PARAMETERS

The water level, water depth and the discharge for the simulation are specified in this boundary condition. The water level is measured in masl (meters above sea level). Smithfield Dam's FSL (Full Supply Level) is 930 masl. Water depth is measured in (m) meters above cross sectional bed level.

A2.1.5 SIMULATION FILE

The simulation file contains all the files required for the hydrodynamic model. It has the input for the time step Δt, which resulted to be 40 seconds. The output file (storing frequency) was set as 1 hour.

A.3 SIMULATIONS

The dx and Δt values are some of the variables that were changed frequently to obtain numerically stable results. A graph of the simulated water level time series at the proposed Smithfield Dam wall, at chainage 14 739 m, is presented in **Figure A-5**.

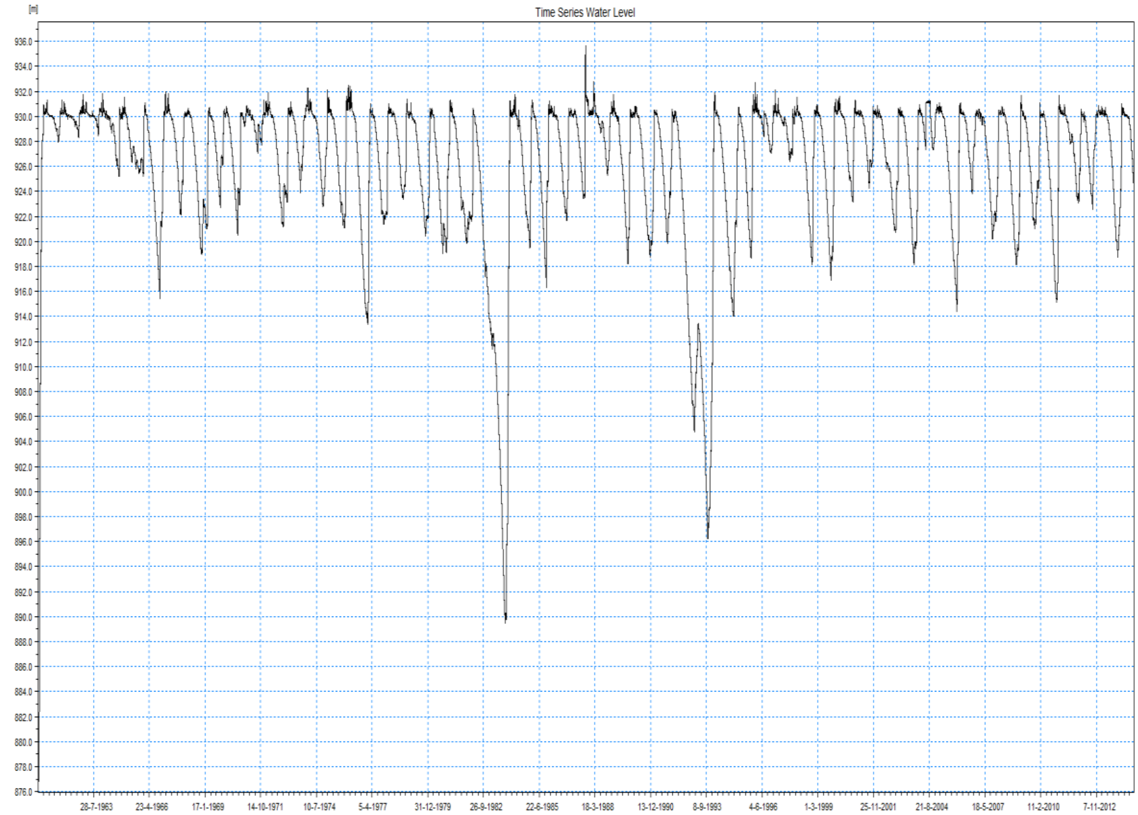


Figure A-5 Simulated water levels at the Smithfield Dam wall

Appendix B

Sediment grading from field sediment samples

Constructing dams on a river channel traps large volumes of sediment. Hydrodynamic models are used to estimate the quantity and spatial distribution of sediment deposition into a reservoir. It is essential to determine the representative sediment fraction sizes when setting up a hydrodynamic reservoir model. To achieve this, sediment samples were taken along the uMkhomazi River, located in the Kwa-Zulu Natal province of South Africa. The proposed Smithfield Dam will be situated along the above mentioned river.

Grading analysis tests involving sieve and hydrometer tests were conducted for each sample to investigate the representative fraction sizes. **Table B.1** provides the name of the sample and the location where the samples was obtained. Some of the samples were collected downstream of the dam site for a study on the impact of the dam on the coastal sediment budget which was reported on in another report of this study. Geotechnical laboratory data on the samples are given below the table.

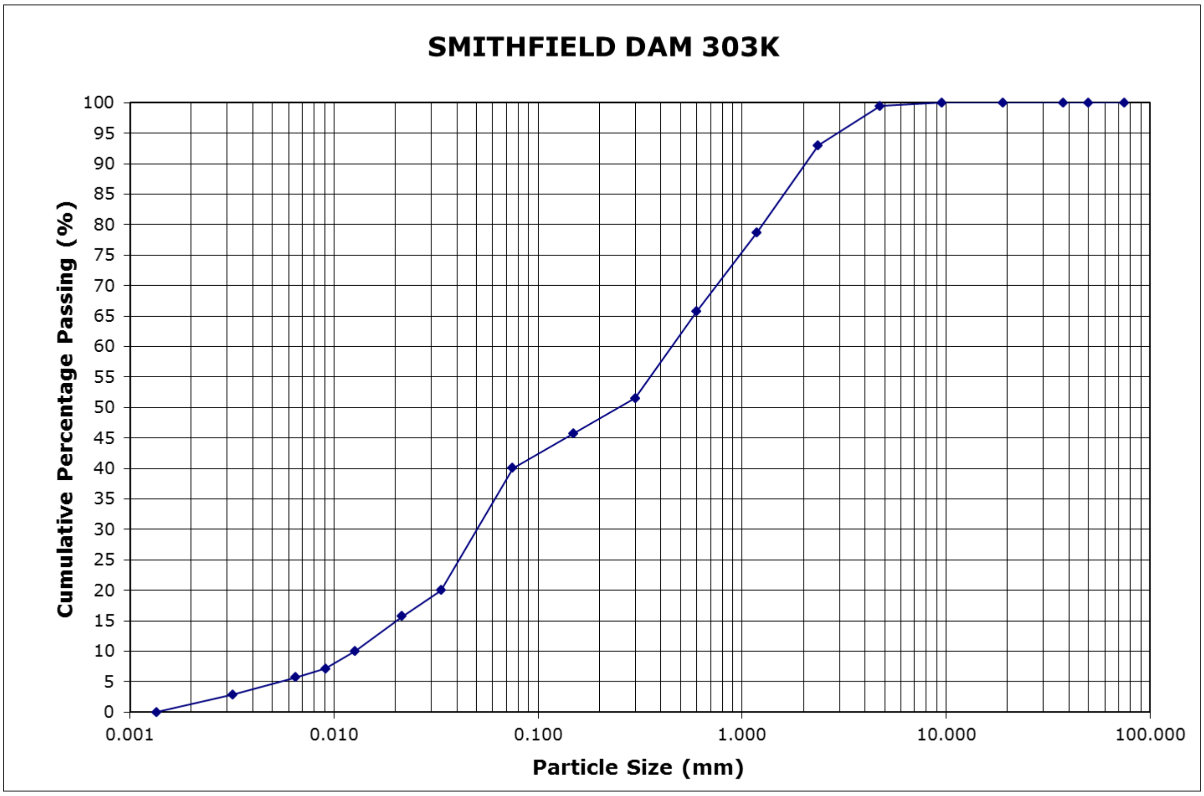
Table B.1: Soil Samples along the uMkhomazi River

Sample nr.	UTM	Location			Position Relative to Dam wall
		X	Y	Description	
287	36 J	288470	6656905	Mouth - Low Tide	Downstream
288	36 J	288502	6656905	Mouth- High Tide	Downstream
289	36 J	288610	6657161	Coast North - Low Tide	Downstream
290	36 J	288593	6657188	Coast North - High Tide	Downstream
291 M	36 J	284967	6658988	Middle of River	Downstream
291 K	36 J	284967	6658988	Bank of River	Downstream
292 M	36 J	276329	6663214	Middle of River	Downstream
292 K	36 J	276329	6663214	Bank of River	Downstream
293 M	36 J	234077	6677100	Middle of River	Downstream
293 K	36 J	234077	6677100	Bank of River	Downstream
294 (293K)	36 J	234080	6677070	Bank of River	Downstream
295 K	36 J	219377	6687949	Bank of River	Downstream
301 K	35 J	785228	6703332	Bank of River	Dam basin
297 M	35 J	780777	6705844	Middle of River	Dam basin
297 K	35 J	780777	6705844	Bank of River	Dam basin
298 K	35 J	779363	6706178	Bank of River	Dam basin
299 M	35 J	765212	6719271	Middle of River	Upstream
300 K	35 J	754030	6721325	Bank of River	Upstream
296 M	35 J	746869	6724661	Middle of River	Upstream
296 K	35 J	746869	6724661	Bank of River	Upstream
302 M	35 J	744381	6725624	Middle of River	Upstream
302 K	35 J	744381	6725624	Bank of River	Upstream

Sample nr.	UTM	Location			Position Relative to Dam wall
		X	Y	Description	
303 M	35 J	744066	6726314	Middle of River	Upstream
303 K	35 J	744066	6726314	Bank of River	Upstream

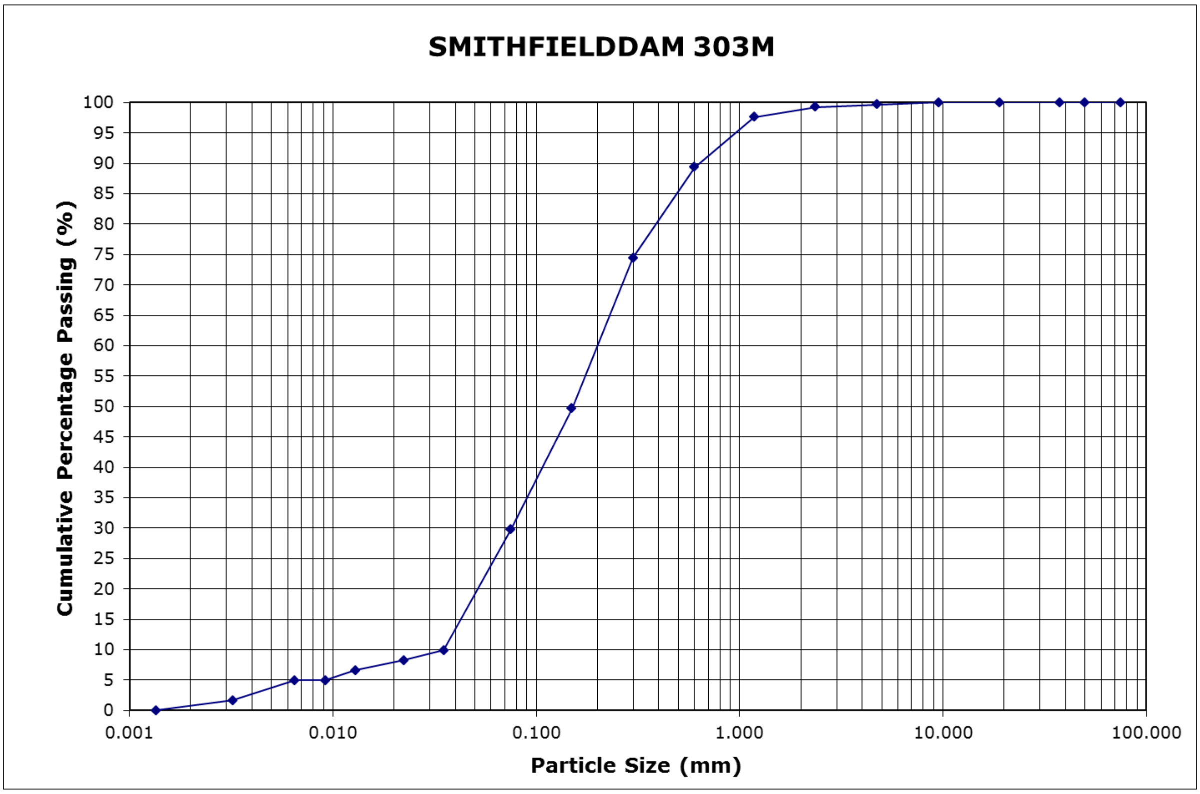
a) Grab Sample Nr 303K – Location: UTM 35J X: 744066; Y: 6726314;

% Passing	Diameter (mm)
100.00	75
100.00	50
100.00	37.5
100.00	19
100.00	9.5
99.46	4.75
92.96	2.36
78.66	1.18
65.79	0.6
51.49	0.3
45.77	0.15
40.04	0.075
20.02	0.0334
15.73	0.0215
10.01	0.0127
7.15	0.0091
5.72	0.0065
2.86	0.0032
0.00	0.0013



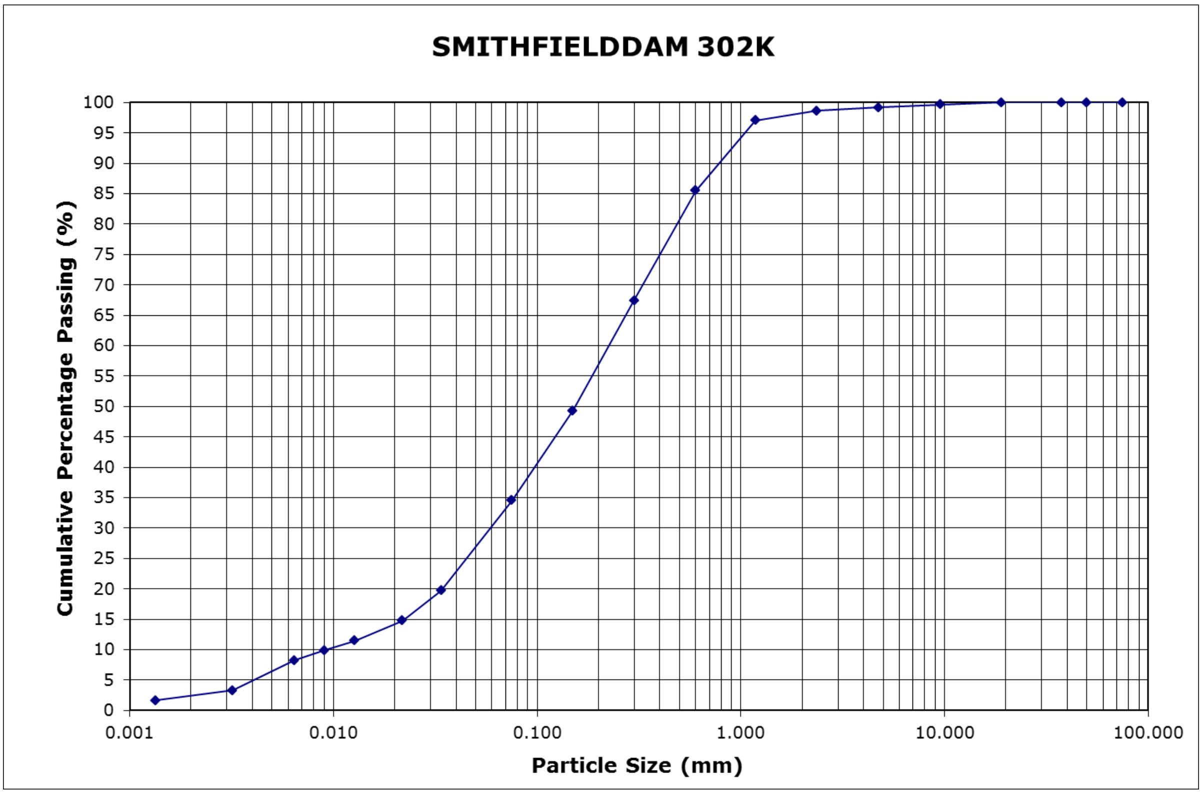
b) Grab Sample Nr 303M – Location: UTM 35J X: 744066; Y: 6726314;

% Passing	Diameter (mm)
100.00	75
100.00	50
100.00	37.5
100.00	19
100.00	9.5
99.63	4.75
99.26	2.36
97.60	1.18
89.33	0.6
74.44	0.3
49.63	0.15
29.78	0.075
9.93	0.0350
8.27	0.0223
6.62	0.0129
4.96	0.0092
4.96	0.0065
1.65	0.0032
0.00	0.0013



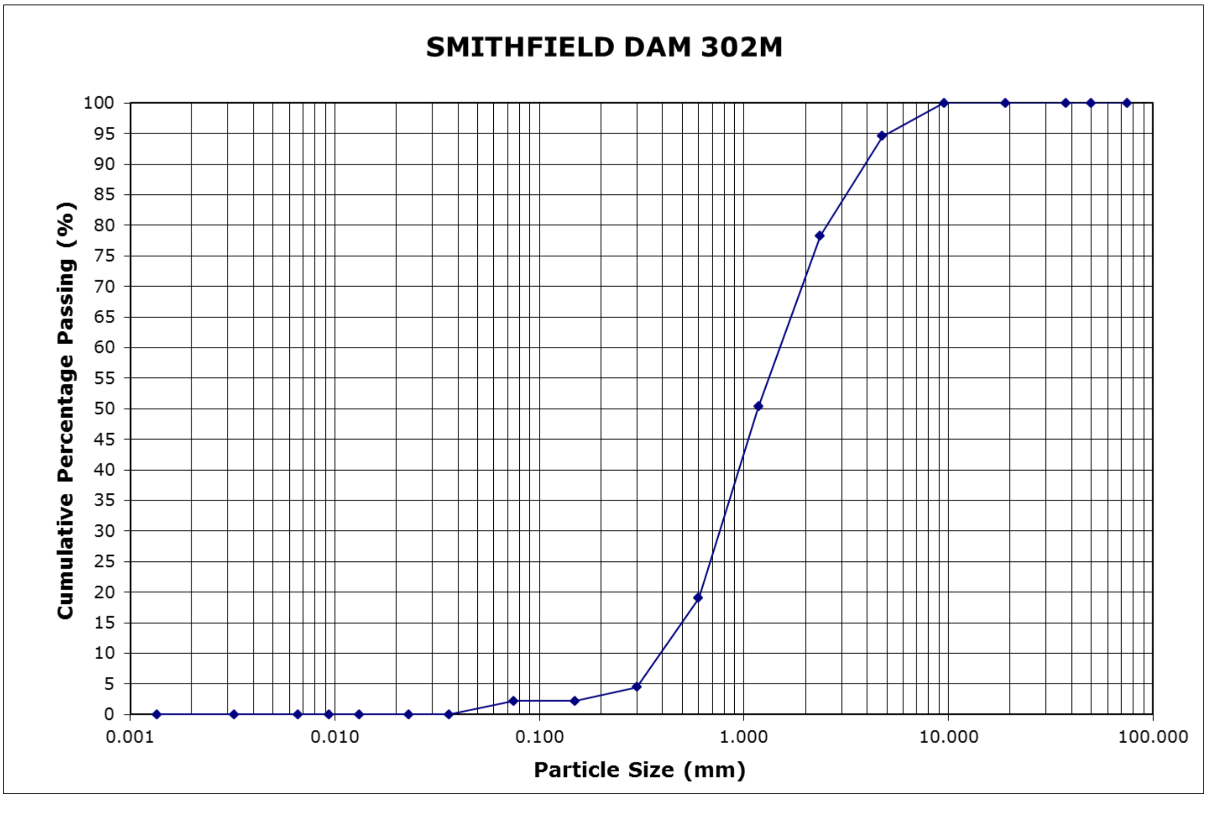
c) Grab Sample Nr 302K – Location: UTM 35J X: 744381; Y: 6725624;

% Passing	Diameter (mm)
100.00	75
100.00	50
100.00	37.5
100.00	19
99.66	9.5
99.16	4.75
98.65	2.36
97.01	1.18
85.50	0.6
67.41	0.3
49.33	0.15
34.53	0.075
19.73	0.0338
14.80	0.0218
11.51	0.0127
9.87	0.0090
8.22	0.0064
3.29	0.0032
1.64	0.0013



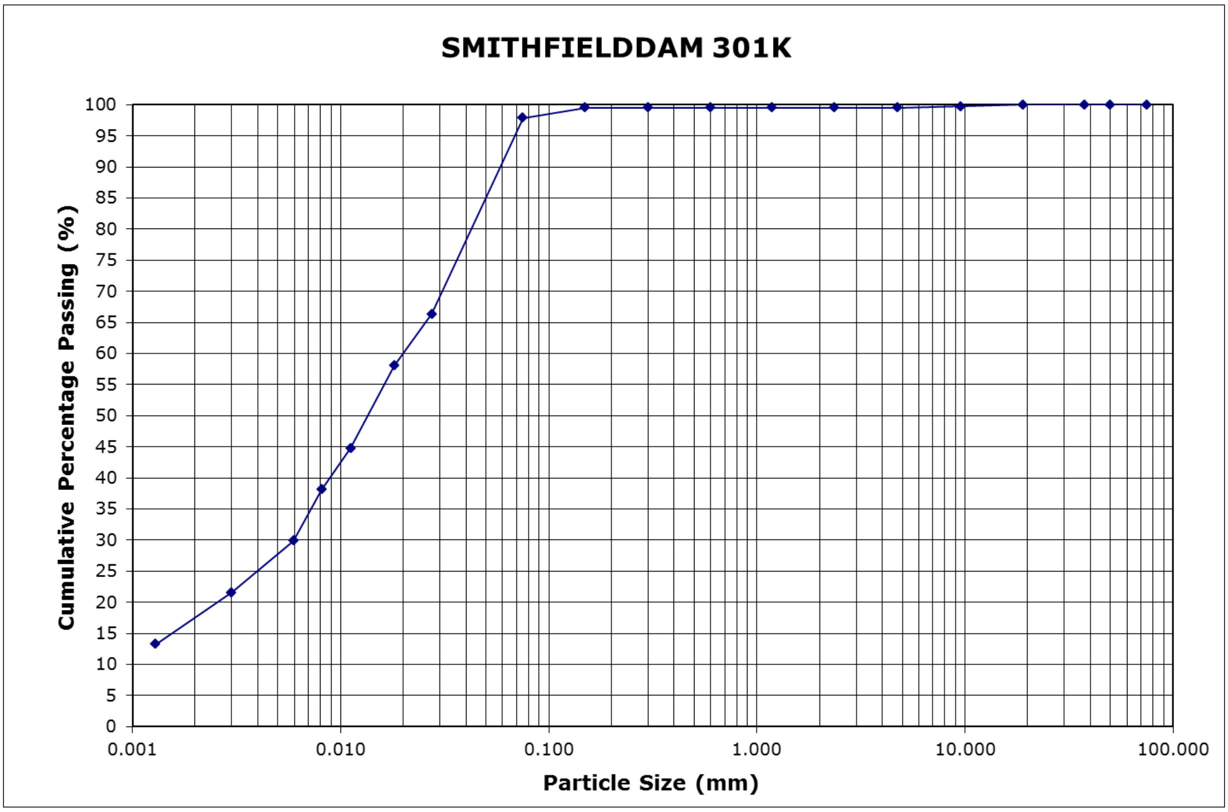
d) Grab Sample Nr 302M – Location: UTM 35J X: 744381; Y: 6725624;

% Passing	Diameter (mm)
100.00	75
100.00	50
100.00	37.5
100.00	19
100.00	9.5
94.57	4.75
78.29	2.36
50.33	1.18
19.01	0.6
4.47	0.3
2.24	0.15
2.24	0.075
0.00	0.0362
0.00	0.0229
0.00	0.0132
0.00	0.0094
0.00	0.0066
0.00	0.0032
0.00	0.0013



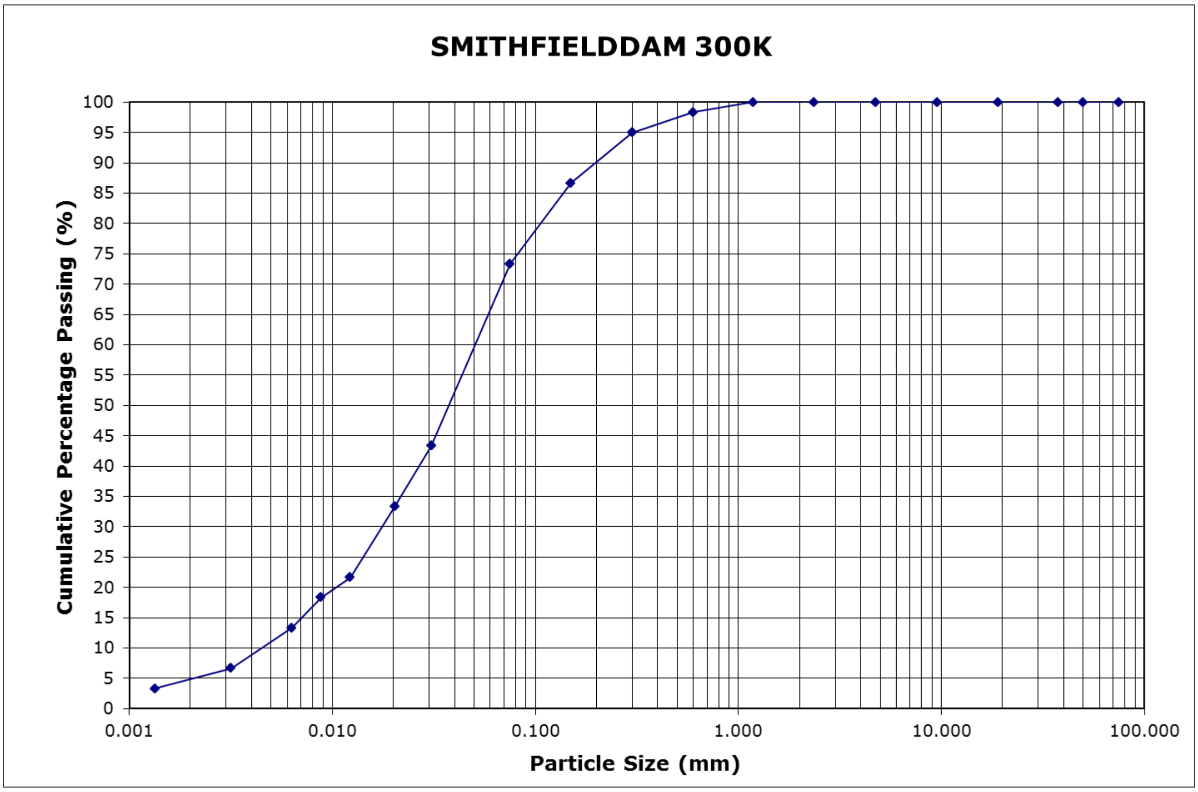
e) Grab Sample Nr 301K – Location: UTM 35J X: 785228; Y: 6703332;

% Passing	Diameter (mm)
100.00	75
100.00	50
100.00	37.5
100.00	19
99.69	9.5
99.49	4.75
99.49	2.36
99.49	1.18
99.49	0.6
99.49	0.3
99.49	0.15
97.83	0.075
66.33	0.0274
58.03	0.0181
44.77	0.0112
38.14	0.0081
29.85	0.0059
21.56	0.0030
13.27	0.0013



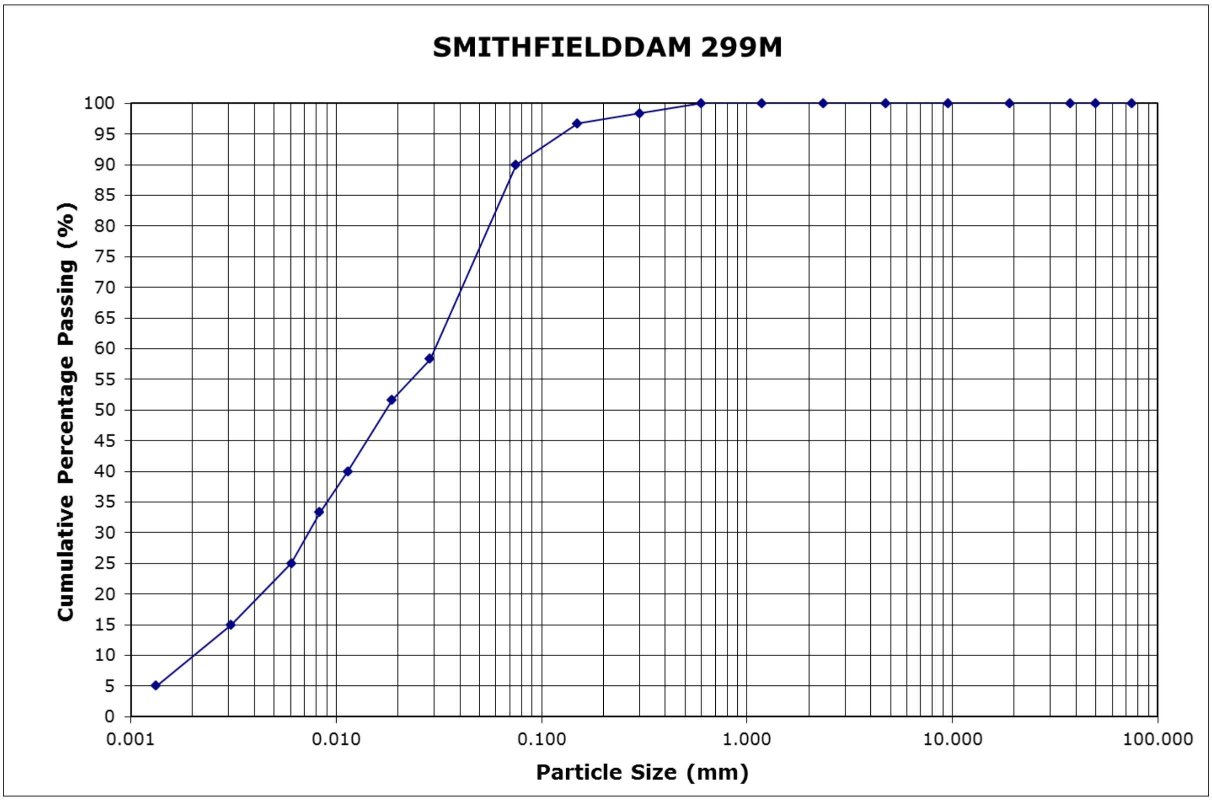
f) Grab Sample Nr 300K – Location: UTM 35J X: 754030; Y: 6721325;

% Passing	Diameter (mm)
100.00	75
100.00	50
100.00	37.5
100.00	19
100.00	9.5
100.00	4.75
100.00	2.36
100.00	1.18
98.33	0.6
95.00	0.3
86.67	0.15
73.33	0.075
43.33	0.0308
33.33	0.0203
21.67	0.0123
18.33	0.0088
13.33	0.0063
6.67	0.0032
3.33	0.0013



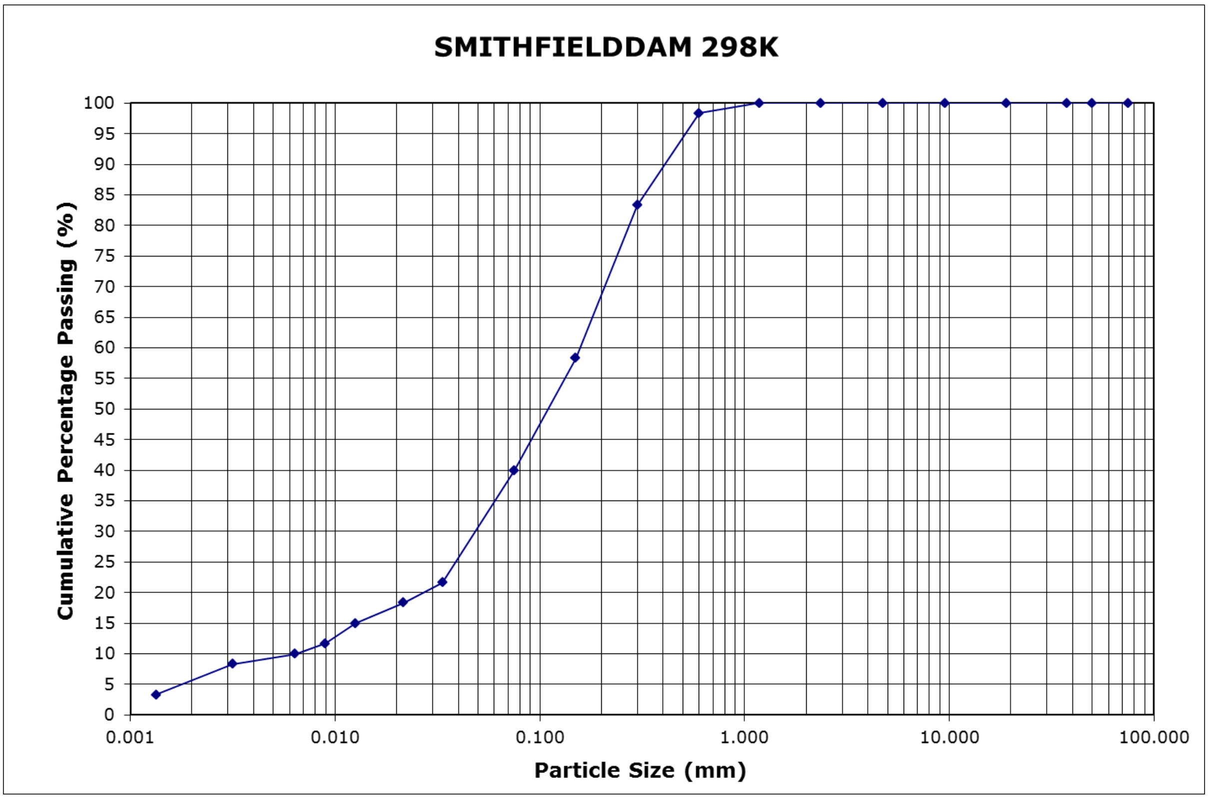
g) Grab Sample Nr 299M – Location: UTM 35J X: 765212; Y: 6719271;

% Passing	Diameter (mm)
100.00	75
100.00	50
100.00	37.5
100.00	19
100.00	9.5
100.00	4.75
100.00	2.36
100.00	1.18
100.00	0.6
98.33	0.3
96.67	0.15
90.00	0.075
58.33	0.0287
51.67	0.0188
40.00	0.0114
33.33	0.0083
25.00	0.0061
15.00	0.0031
5.00	0.0013



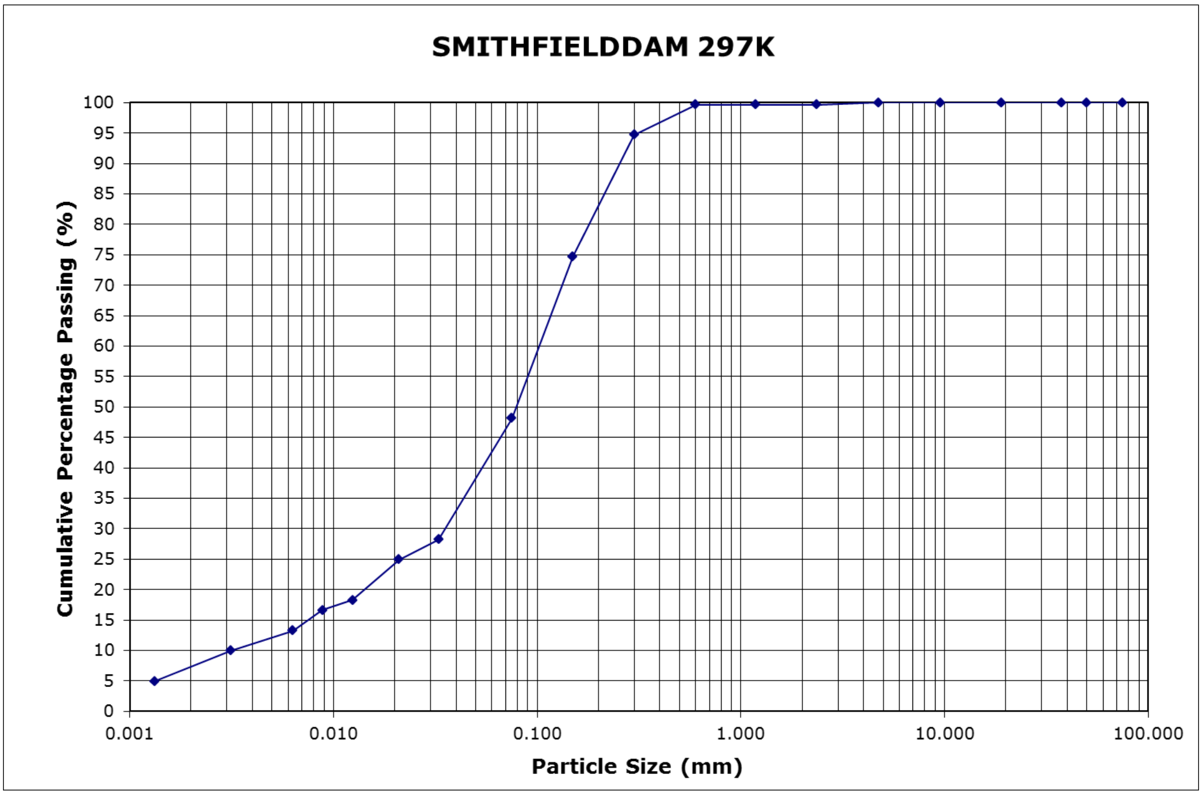
h) Grab Sample Nr 298K – Location: UTM 35J X: 779363; Y: 6706178;

% Passing	Diameter (mm)
100.00	75
100.00	50
100.00	37.5
100.00	19
100.00	9.5
100.00	4.75
100.00	2.36
100.00	1.18
98.33	0.6
83.33	0.3
58.33	0.15
40.00	0.075
21.67	0.0335
18.33	0.0215
15.00	0.0126
11.67	0.0090
10.00	0.0064
8.33	0.0032
3.33	0.0013



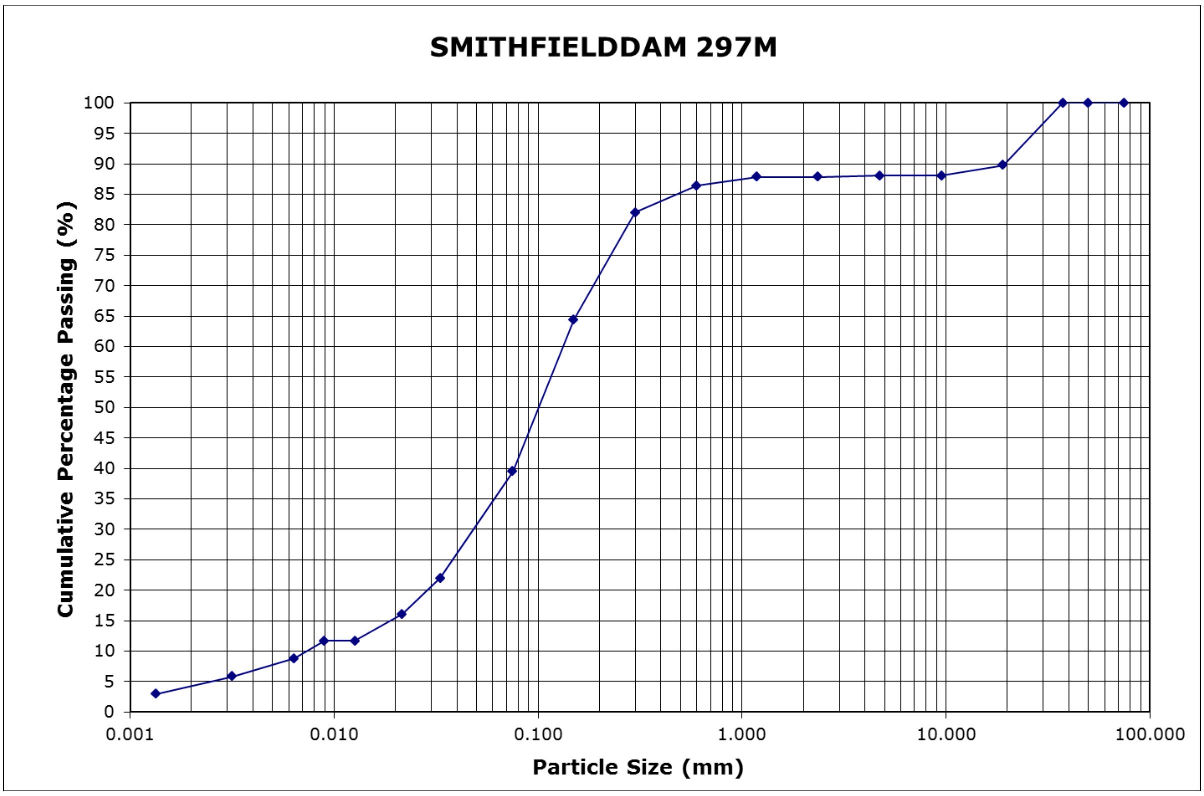
i) Grab Sample Nr 297K – Location: UTM 35J X: 780777; Y: 6705844;

% Passing	Diameter (mm)
100.00	75
100.00	50
100.00	37.5
100.00	19
100.00	9.5
100.00	4.75
99.66	2.36
99.66	1.18
99.66	0.6
94.67	0.3
74.74	0.15
48.17	0.075
28.24	0.0328
24.91	0.0210
18.27	0.0124
16.61	0.0088
13.29	0.0063
9.97	0.0031
4.98	0.0013



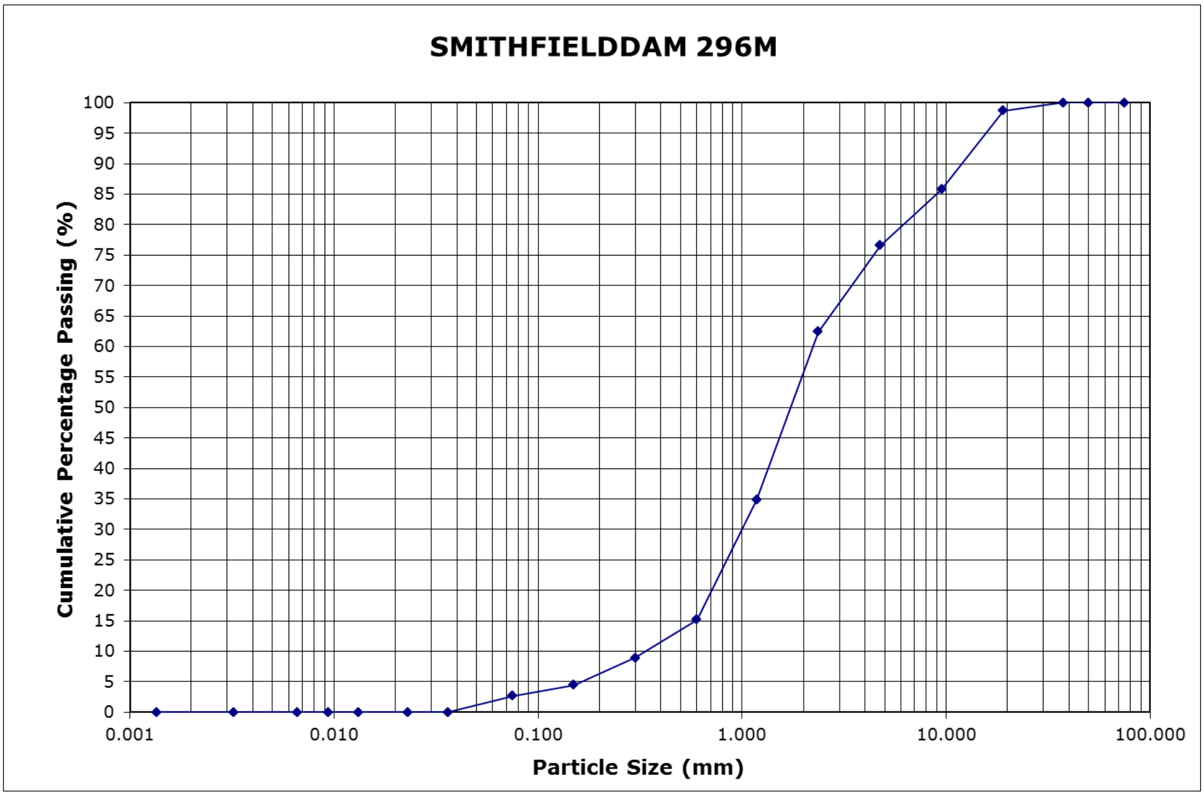
j) Grab Sample Nr 297M – Location: UTM 35J X: 780777; Y: 6705844;

% Passing	Diameter (mm)
100.00	75
100.00	50
100.00	37.5
89.73	19
88.02	9.5
88.02	4.75
87.83	2.36
87.83	1.18
86.37	0.6
81.98	0.3
64.41	0.15
39.52	0.075
21.96	0.0332
16.10	0.0215
11.71	0.0127
11.71	0.0090
8.78	0.0064
5.86	0.0032
2.93	0.0013



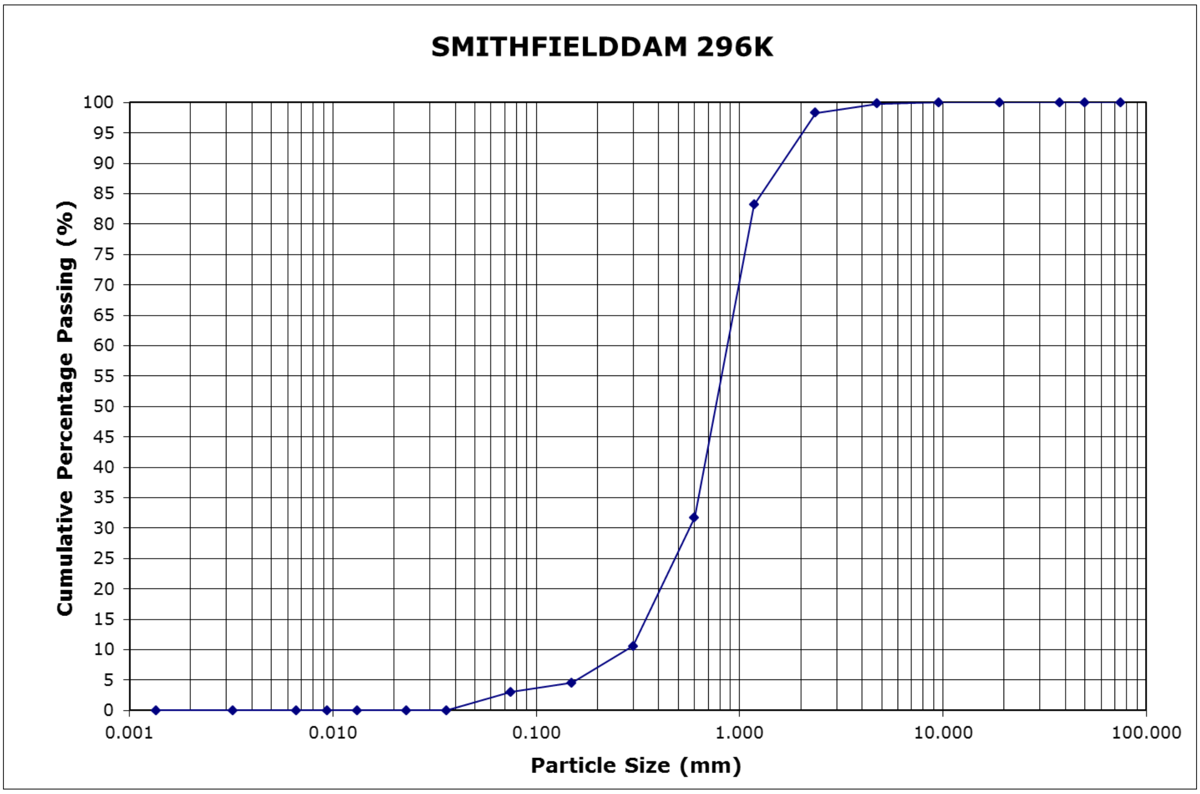
k) Grab Sample Nr 296M – Location: UTM 35J X: 746869; Y: 6724661;

% Passing	Diameter (mm)
100.00	75
100.00	50
100.00	37.5
98.68	19
85.77	9.5
76.55	4.75
62.45	2.36
34.79	1.18
15.17	0.6
8.92	0.3
4.46	0.15
2.68	0.075
0.00	0.0362
0.00	0.0229
0.00	0.0132
0.00	0.0094
0.00	0.0066
0.00	0.0032
0.00	0.0013



l) Grab Sample Nr 296K – Location: UTM 35J X: 746869; Y: 6724661;

% Passing	Diameter (mm)
100.00	75
100.00	50
100.00	37.5
100.00	19
100.00	9.5
99.80	4.75
98.28	2.36
83.16	1.18
31.75	0.6
10.58	0.3
4.54	0.15
3.02	0.075
0.00	0.0362
0.00	0.0229
0.00	0.0132
0.00	0.0094
0.00	0.0066
0.00	0.0032
0.00	0.0013



A total of 24 soil samples were collected along the uMkhomazi River. **Figure B-2** indicates the locations where the soil samples were obtained upstream of the dam site.

Figure B-2: Sites where sediment was sampled upstream of the dam site

From the grading analysis of river bed samples, 4 representative sediment size fractions had to be determined for the hydrodynamic reservoir model. Grading analysis tests were conducted for each sample to investigate the representative fraction sizes. The average sieve test results, for each soil sample group, are shown in **Table B.2**.

The investigation included dividing the soil groups into fractions, namely: Large, Mid, Small and Cohesive fractions. A percentage of the fraction was chosen for each fraction. The percentage of sediment passing was determined by considering the percentage of fraction and a chosen interval. The sediment size, was interpolated from the grading analysis results in this appendix. A settling velocity was calculated, using the sediment size and kinematic viscosity of water as inputs to the settling velocity formula. A weighted settling velocity is obtained for the fraction. This weighted settling velocity is used for the calculation of the representative (effective) sediment size of the particular fraction.

From the sieve test results, it was found that the soil samples within the Smithfield Dam basin possessed the finest sediment. The results of the 4 representative fraction sizes and their corresponding percentages of the sample are shown on **Table B.2**.

Table B.2: Representative fraction size results for samples in Smithfield Dam basin

Fraction	% in bed specified as initial condition in reservoir	Interval %	Sieve % passing	Particle diameter d (mm)	Settling velocity Vss (m/s)	Effective Vss (m/s)	Weighted d eff (mm)
Large Fraction	16	85.0%	98.28	22.603	0.605	0.409	**10.35**
		50.0%	94.25	8.448	0.369		
		15.0%	90.23	3.996	0.252		
Mid Fraction	35	85.0%	84.68	2.236	0.187	0.143	**1.37**
		50.0%	75.75	1.303	0.139		
		15.0%	66.83	0.786	0.103		
Small Fraction	48	85.0%	57.75	0.422	0.066	0.0319	**0.212**
		50.0%	45.5	0.172	0.024		
		15.0%	33.25	0.077	0.0058		
Cohesive Fraction	1	85.0%	23.8	0.046	0.002	0.00083	**0.033**
		50.0%	14	0.018	0		
		15.0%	4.2	0.00292	0		

Figure B-3 graphically represents the results presented on **Table B.2**. After several attempts of estimating the representative fraction sizes, it was found that 10.35 mm, 1.37 mm, 0.212 mm and 0.033 mm represent gravel, coarse sand, fine sand and cohesive fractions, respectively. These results were used as inputs in the 2D hydrodynamic reservoir model.

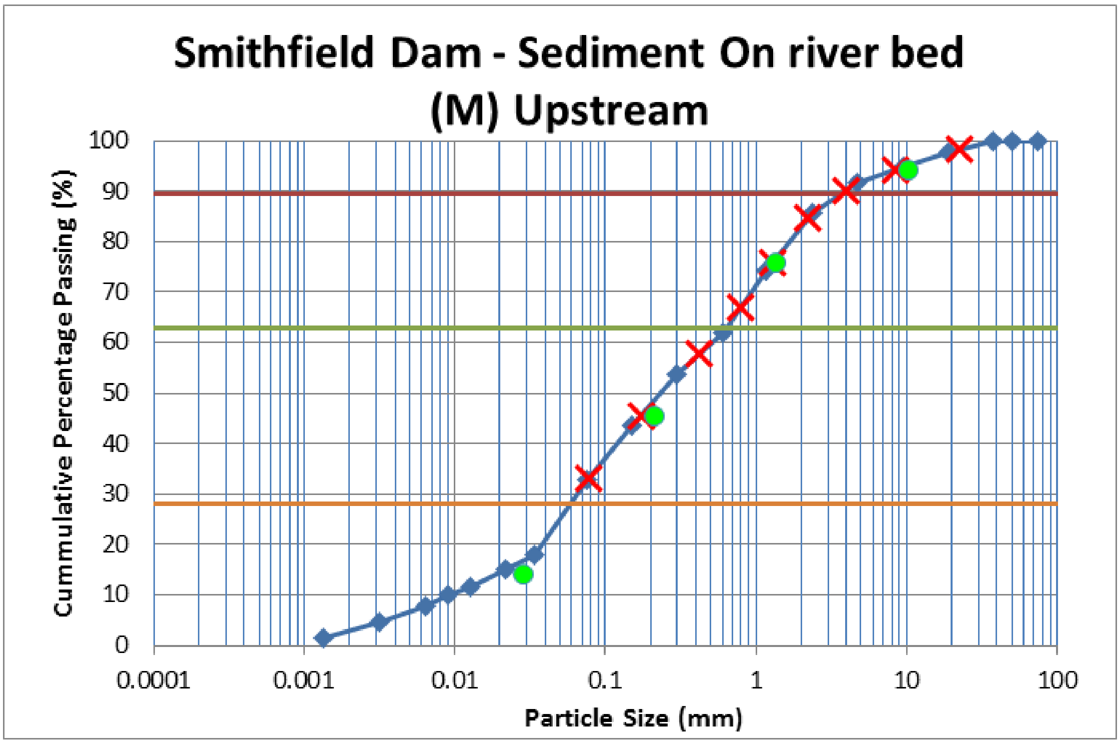


Figure B-3 Average Sieve Test Results

Appendix C

Hydrodynamic Modelling of the Reservoir Sedimentation with a Cohesive Fraction of 11 Micron

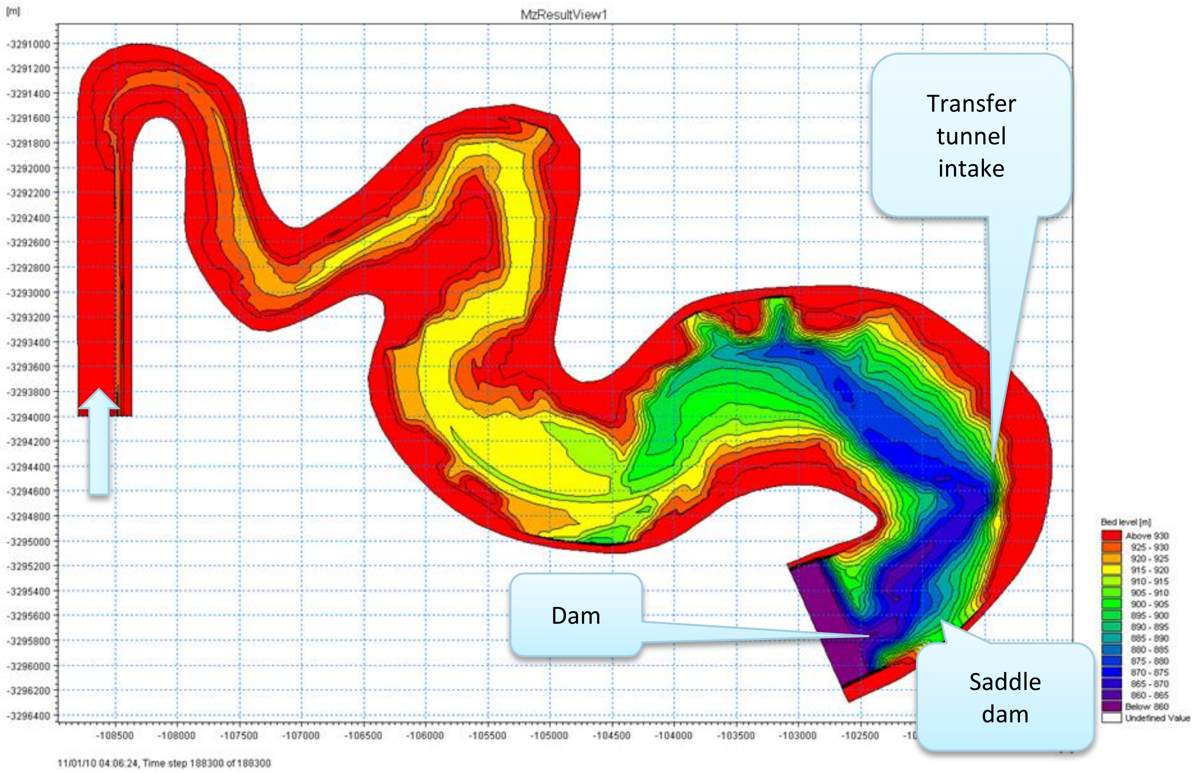


Figure C-1 Reservoir bed levels after 50 years (d=0.011mm, 90% cohesive sediment)

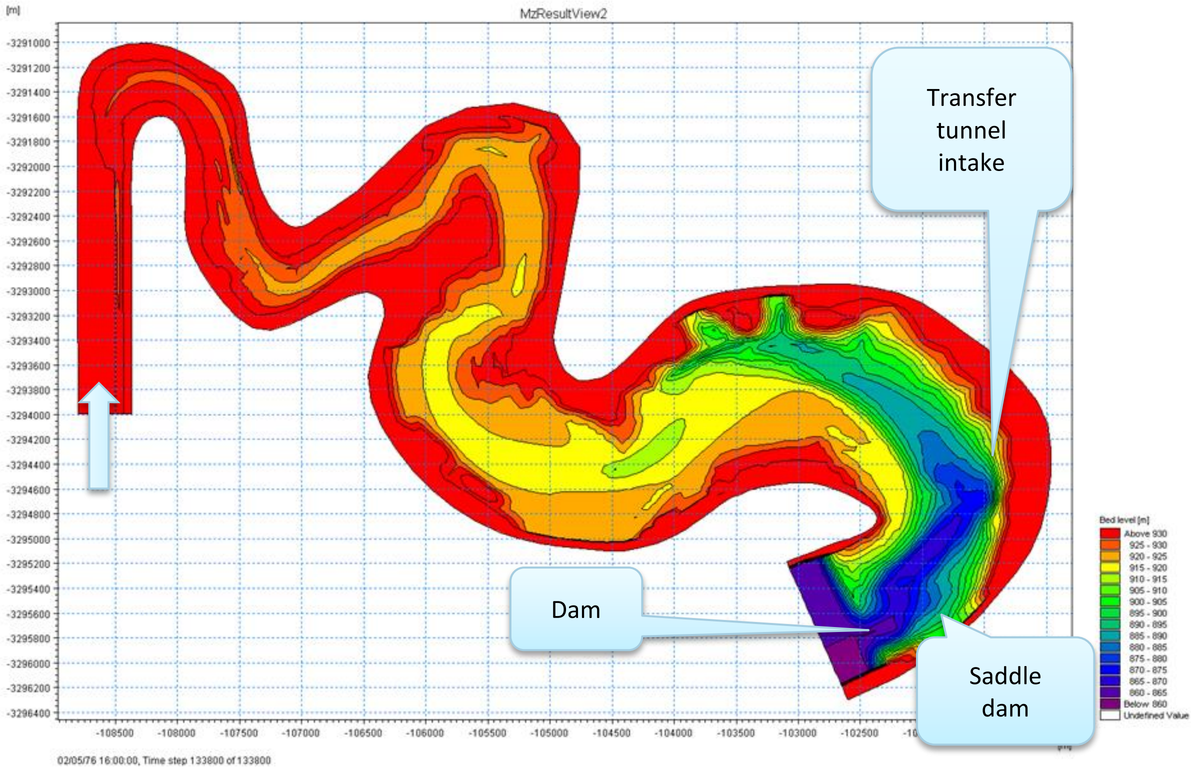


Figure C-2 Reservoir bed levels after 100 years (d=0.011mm, 90% cohesive sediment)

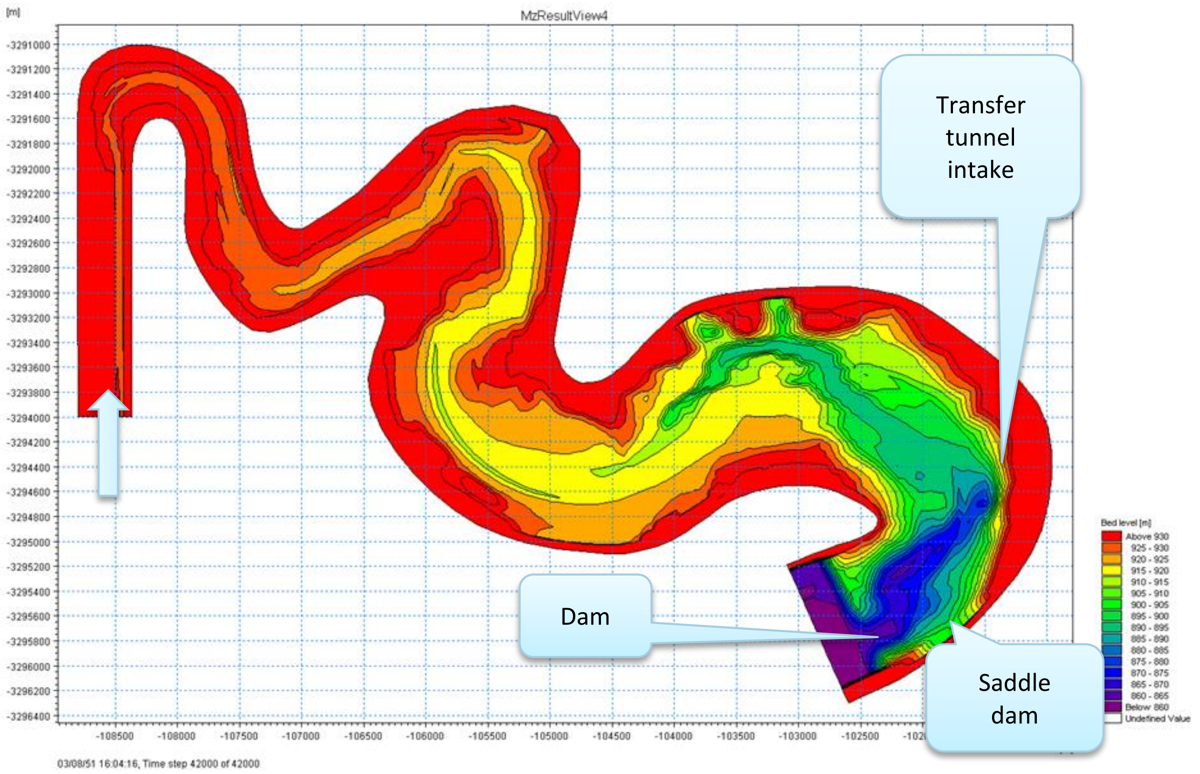


Figure C-3 Reservoir bed levels after 50 years (d=0.033 mm, 2 times of sediment concentration, 90% cohesive sediment)

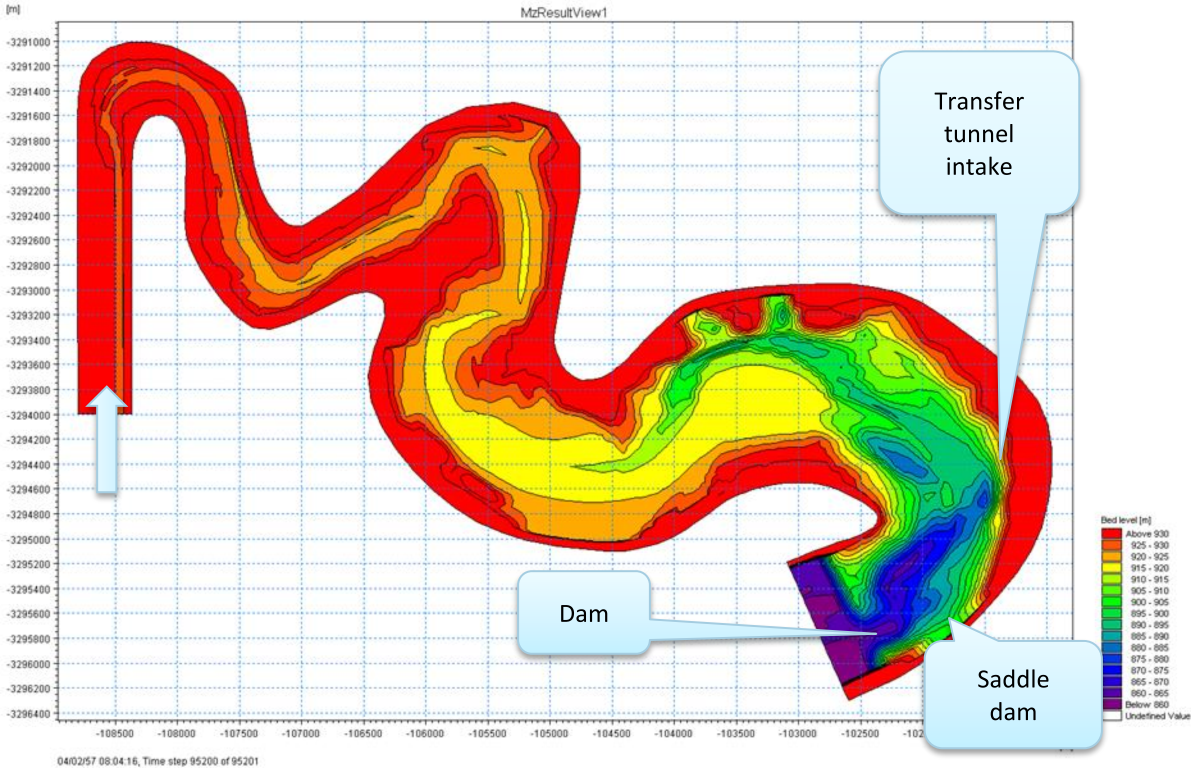


Figure C-4 Reservoir bed levels after 50 years (d=0.011 mm, 2 times of sediment concentration, 90% cohesive sediment)

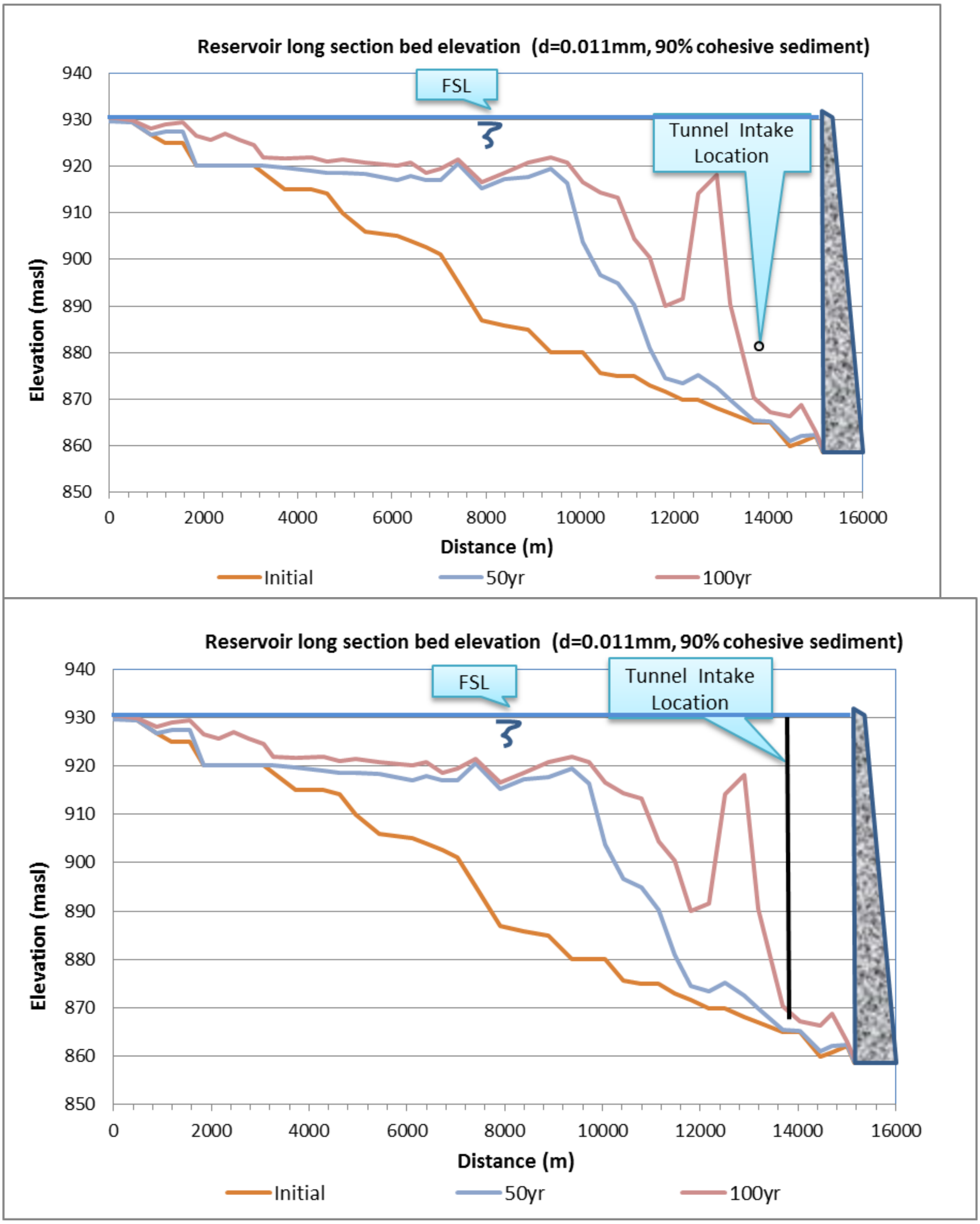
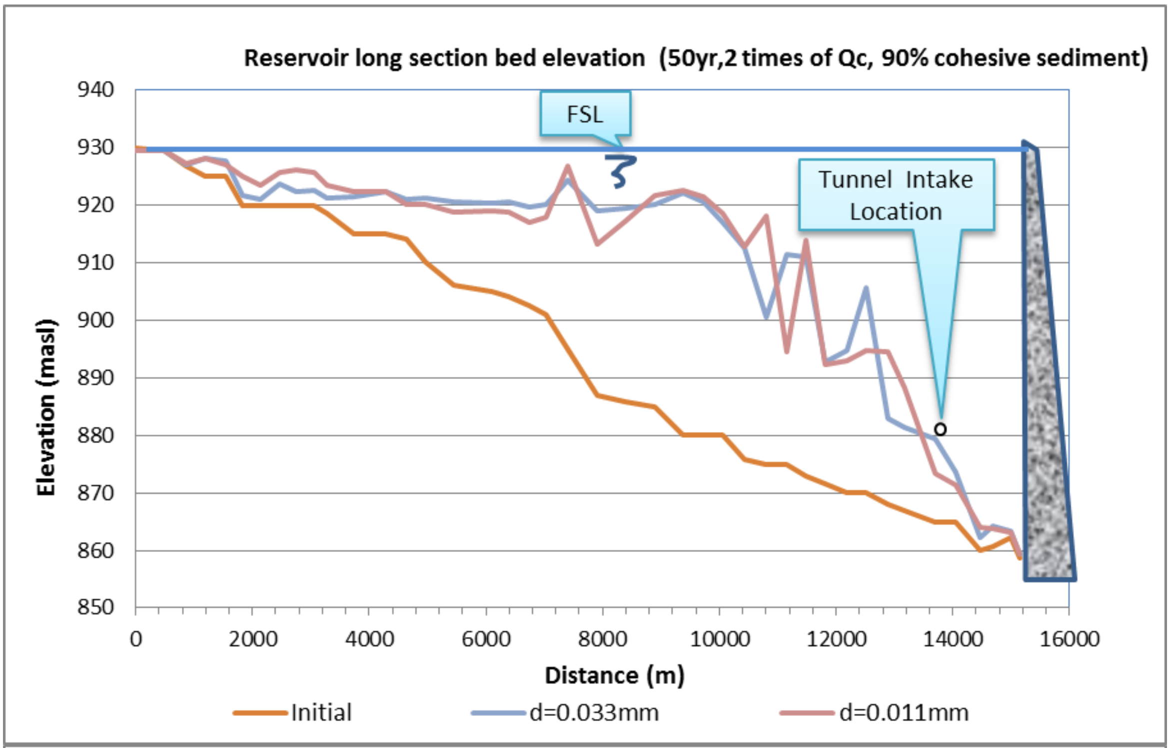


Figure C-5 Longitudinal profile of the simulated lowest bed levels in the reservoir for the current sediment yield (d=0.011mm, 90% cohesive sediment)



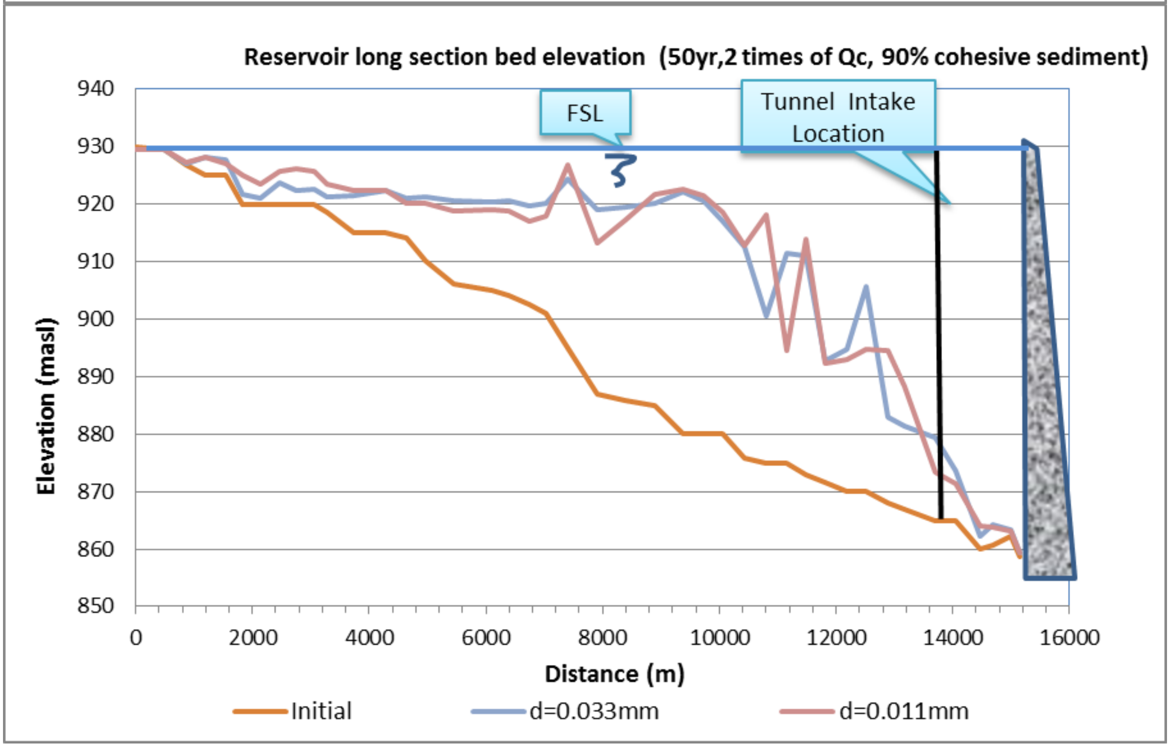


Figure C-6 Longitudinal profile of the simulated 50 years lowest bed levels in the reservoir for the doubled sediment yield (Doubled sediment concentration, 90% cohesive sediment)

Table C.1 Future reservoir sedimentation impacts on storage capacity and surface area versus water levels for different scenarios-1.

Contour (masl)	New reservoir storage capacity (million m3)	This report Surface Area of new reservoir (km²)	Old reservoir capacity after 50 years at current sediment yield-cohesive fraction size=0.011mm, 90% of cohesive concentration (Mm3)	Surface Area after 50 years at current sediment yield-cohesive fraction size=0.011mm, 90% of cohesive concentration (km²)	Old reservoir capacity after 100 years at current sediment yield-cohesive fraction size=0.011mm, 90% of cohesive concentration (Mm3)	Surface Area after 100 years at current sediment yield-cohesive fraction size=0.011mm, 90% of cohesive concentration (km²)
854.75	0.00	0.00	0.00	0.00	0.00	0.00
856	0.0	0.00	0.0	0.00	0.0	0.00
857	0.0	0.01	0.0	0.01	0.0	0.00
858	0.0	0.01	0.0	0.01	0.0	0.01
859	0.0	0.01	0.0	0.01	0.0	0.01
860	0.1	0.02	0.1	0.01	0.0	0.01
864	0.4	0.10	0.3	0.09	0.2	0.04
865	0.5	0.16	0.4	0.11	0.3	0.05
870	2.2	0.49	1.9	0.34	1.1	0.19
875	5.8	0.97	4.6	0.64	2.9	0.35
880	12.0	1.47	9.4	1.01	5.6	0.52
885	20.7	1.98	15.9	1.35	9.1	0.70
890	32.4	2.57	24.2	1.67	14.0	1.08
895	47.0	3.07	34.2	2.04	21.1	1.46
900	64.3	3.66	46.5	2.60	29.9	1.82
905	85.3	4.50	62.1	3.13	40.9	2.15

Contour (masl)	New reservoir storage capacity (million m3)	This report Surface Area of new reservoir (km²)	Old reservoir capacity after 50 years at current sediment yield-cohesive fraction size=0.011mm, 90% of cohesive concentration (Mm3)	Surface Area after 50 years at current sediment yield-cohesive fraction size=0.011mm, 90% of cohesive concentration (km²)	Old reservoir capacity after 100 years at current sediment yield-cohesive fraction size=0.011mm, 90% of cohesive concentration (Mm3)	Surface Area after 100 years at current sediment yield-cohesive fraction size=0.011mm, 90% of cohesive concentration (km²)
910	110.2	5.22	80.2	3.60	53.5	2.43
915	138.9	6.01	101.0	4.23	67.9	2.88
920	171.8	6.81	127.9	6.31	87.5	4.74
925	209.3	7.85	164.9	7.65	121.1	7.39
930*	251.5	9.55	207.4	9.42	162.5	8.88

*Note: * FSL*

Table C.2 Future reservoir sedimentation impacts on storage capacity and surface area versus water levels for different scenarios-2

Contour (masl)	New reservoir storage capacity (million m3)	This report Surface Area of new reservoir (km²)	Old reservoir capacity after 50 years at current sediment yield-cohesive fraction size=0.011mm, 2 times of sediment concentration, 90% of cohesive concentration (Mm3)	Surface Area after 50 years at current sediment yield-cohesive fraction size=0.011mm, 2 times of sediment concentration, 90% of cohesive concentration (km²)	Old reservoir capacity after 50 years at current sediment yield-cohesive fraction size=0.033mm, 2 times of sediment concentration, 90% of cohesive concentration (Mm3)	Surface Area after 50 years at current sediment yield-cohesive fraction size=0.033mm, 2 times of sediment concentration, 90% of cohesive concentration (km²)
854.75	0.00	0.00	0.00	0.00	0.00	0.00
856	0.0	0.00	0.0	0.00	0.0	0.00
857	0.0	0.01	0.0	0.00	0.0	0.00

Contour (masl)	New reservoir storage capacity (million m3)	This report Surface Area of new reservoir (km²)	Old reservoir capacity after 50 years at current sediment yield-cohesive fraction size=0.011mm, 2 times of sediment concentration, 90% of cohesive concentration (Mm3)	Surface Area after 50 years at current sediment yield-cohesive fraction size=0.011mm, 2 times of sediment concentration, 90% of cohesive concentration (km²)	Old reservoir capacity after 50 years at current sediment yield-cohesive fraction size=0.033mm, 2 times of sediment concentration, 90% of cohesive concentration (Mm3)	Surface Area after 50 years at current sediment yield-cohesive fraction size=0.033mm, 2 times of sediment concentration, 90% of cohesive concentration (km²)
858	0.0	0.01	0.0	0.01	0.0	0.01
859	0.0	0.01	0.0	0.01	0.0	0.01
860	0.1	0.02	0.1	0.01	0.1	0.01
864	0.4	0.10	0.2	0.04	0.2	0.05
865	0.5	0.16	0.3	0.06	0.3	0.06
870	2.2	0.49	1.1	0.17	1.2	0.17
875	5.8	0.97	2.6	0.30	2.8	0.33
880	12.0	1.47	4.8	0.41	5.1	0.44
885	20.7	1.98	7.7	0.56	8.0	0.57
890	32.4	2.57	11.7	0.81	11.8	0.75
895	47.0	3.07	17.5	1.33	17.4	1.37
900	64.3	3.66	26.1	1.80	26.7	1.93
905	85.3	4.50	37.1	2.13	38.2	2.20
910	110.2	5.22	50.0	2.57	51.3	2.53
915	138.9	6.01	65.5	3.16	66.7	3.24
920	171.8	6.81	86.4	5.13	87.7	5.18

Contour (masl)	New reservoir storage capacity (million m3)	This report Surface Area of new reservoir (km²)	Old reservoir capacity after 50 years at current sediment yield-cohesive fraction size=0.011mm, 2 times of sediment concentration, 90% of cohesive concentration (Mm3)	Surface Area after 50 years at current sediment yield-cohesive fraction size=0.011mm, 2 times of sediment concentration, 90% of cohesive concentration (km²)	Old reservoir capacity after 50 years at current sediment yield-cohesive fraction size=0.033mm, 2 times of sediment concentration, 90% of cohesive concentration (Mm3)	Surface Area after 50 years at current sediment yield-cohesive fraction size=0.033mm, 2 times of sediment concentration, 90% of cohesive concentration (km²)
925	209.3	7.85	119.9	7.51	120.6	7.19
930*	251.5	9.55	161.7	9.40	160.9	9.24

*Note: * FSL*

Appendix D

Hydrodynamic modelling of the reservoir sedimentation over a 100 year period for a future high sediment yield of double the current yield

Table D.1 Future reservoir sedimentation impacts on storage capacity and surface area versus water levels*

Contour (masl)	Old reservoir capacity after 50 years at double sediment yield-cohesive fraction size=0.033mm (million m3)	Surface Area after 50 years at double sediment yield-cohesive fraction size=0.033mm (km²)	Old reservoir capacity after 100 years at double sediment yield-cohesive fraction size=0.033mm (million m3)	Surface Area after 100 years at double sediment yield-cohesive fraction size=0.033mm (km²)
854.75	0.00	0.00	0.00	0.00
856	0.0	0.00	0.00	0.00
857	0.0	0.00	0.00	0.00
858	0.0	0.01	0.00	0.00
859	0.0	0.01	0.00	0.00
860	0.1	0.01	0.00	0.00
864	0.2	0.05	0.00	0.00
865	0.3	0.06	0.00	0.00
870	1.2	0.17	0.02	0.01
875	2.8	0.33	0.07	0.01
880	5.1	0.44	0.13	0.01
885	8.0	0.57	0.24	0.03
890	11.8	0.75	0.49	0.07
895	17.4	1.37	1.11	0.17
900	26.7	1.93	2.06	0.23
905	38.2	2.20	3.38	0.33
910	51.3	2.53	5.71	0.61
915	66.7	3.24	10.28	1.22
920	87.7	5.18	20.90	3.71
925	120.6	7.19	48.22	6.59
930	160.9	9.24	86.45	9.17

Notes: Cohesive fraction 33 micron size; Sediment yield double the current sediment yield over 100 years; simulation carried out for 100 year period

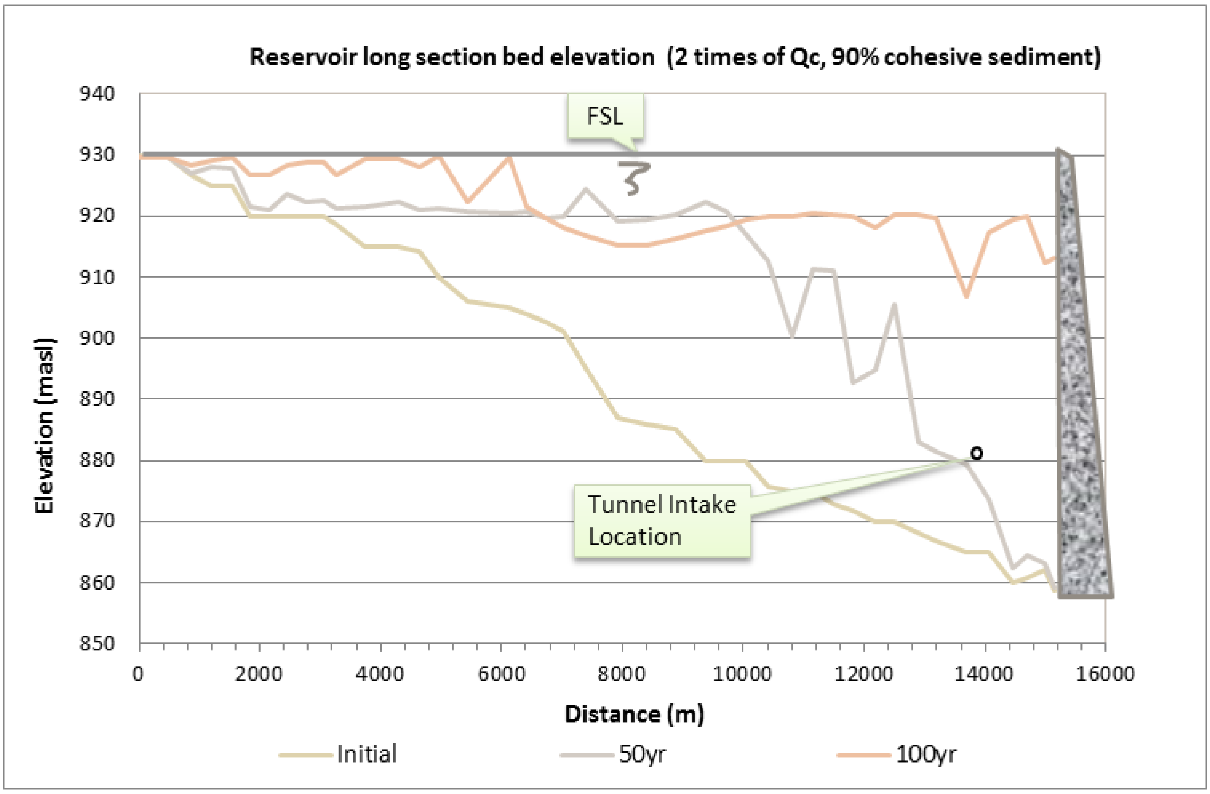


Figure D.1 Longitudinal profile of the simulated lowest bed elevations in the reservoir based on a future higher sediment yield of twice the current sediment yield (33 micron cohesive fraction)

Figure D.1 Simulated bed levels in the reservoirs after 100 years for the future sediment yield of double the current yield (cohesive fraction 0.033 mm)

Table D.2 Long term simulated reservoir storage capacity at FSL as well as bed levels at the tunnel intake and the dam for the future sediment yield of twice the current yield (33 micron cohesive fraction)

Years	Full supply storage capacity (million m³)	Full supply capacity loss (%)	Reservoir sediment trap efficiency (%)	Bed level at tunnel intake location (masl)	Lowest bed level at dam wall (masl)
0	252.0	-	97	881.0	854.8
50	161.0	36	97	893.8	859.3
100	86.5	66	88	909.5	913.2

Appendix E

Three dimensional views of the reservoir

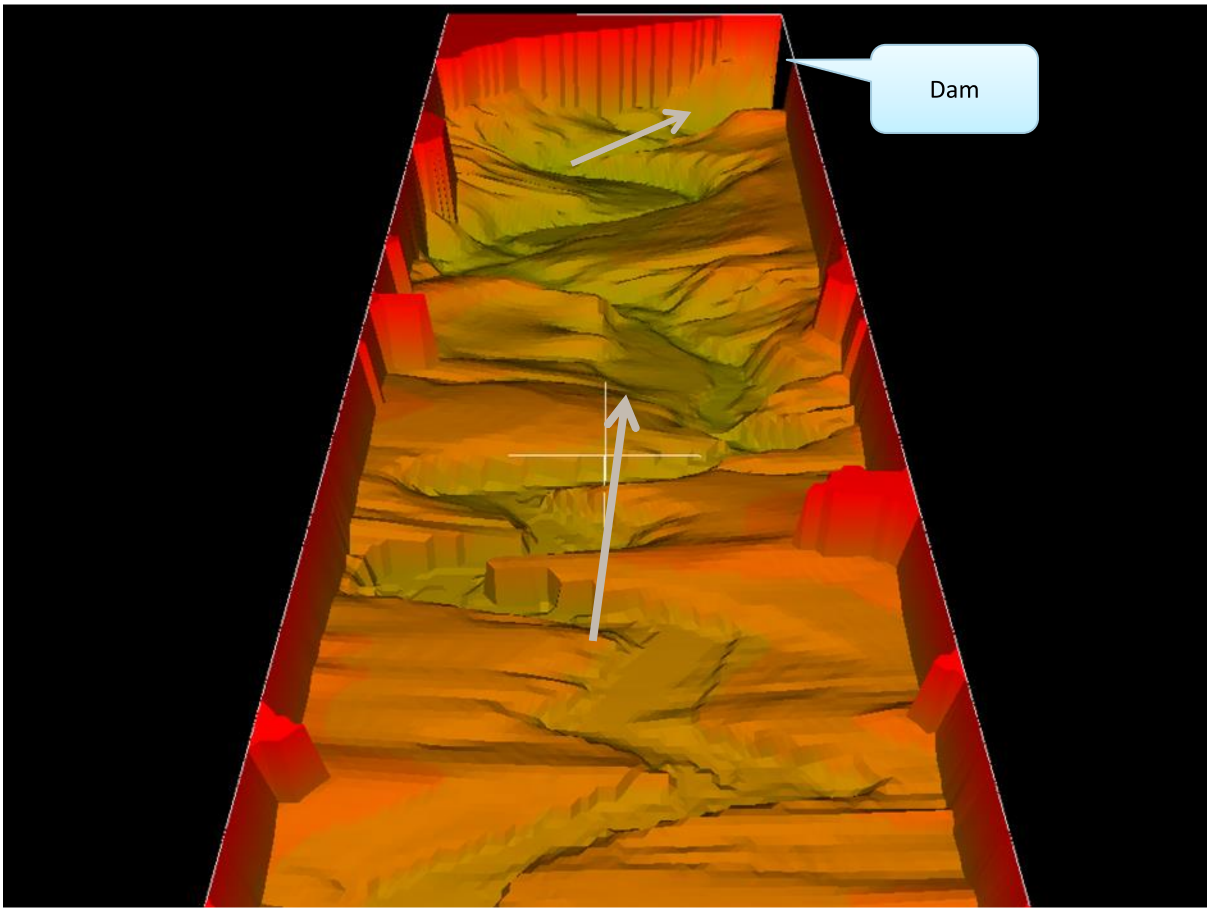


Figure E.1: Initial Bed level –3D view from upstream

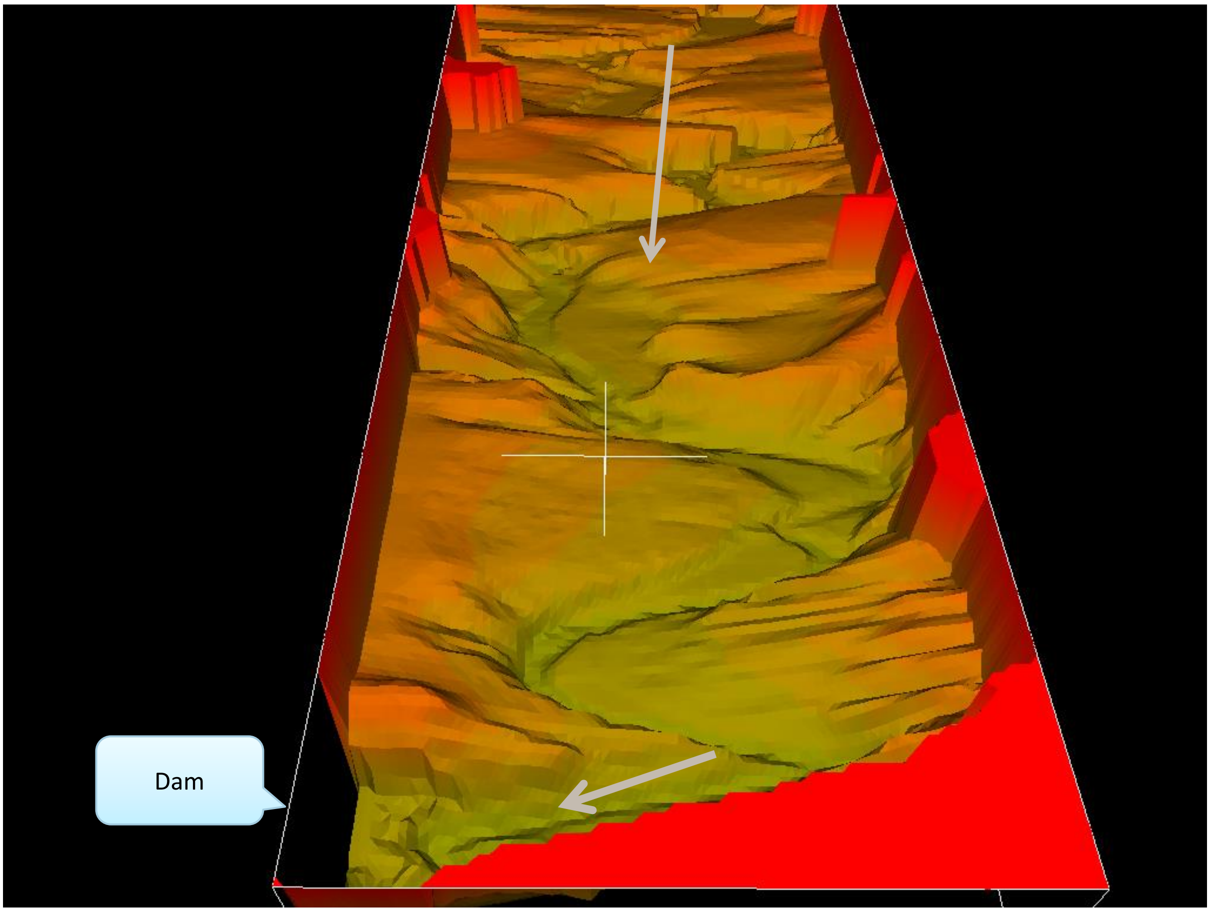


Figure E.2: Initial Bed level –3D view from downstream

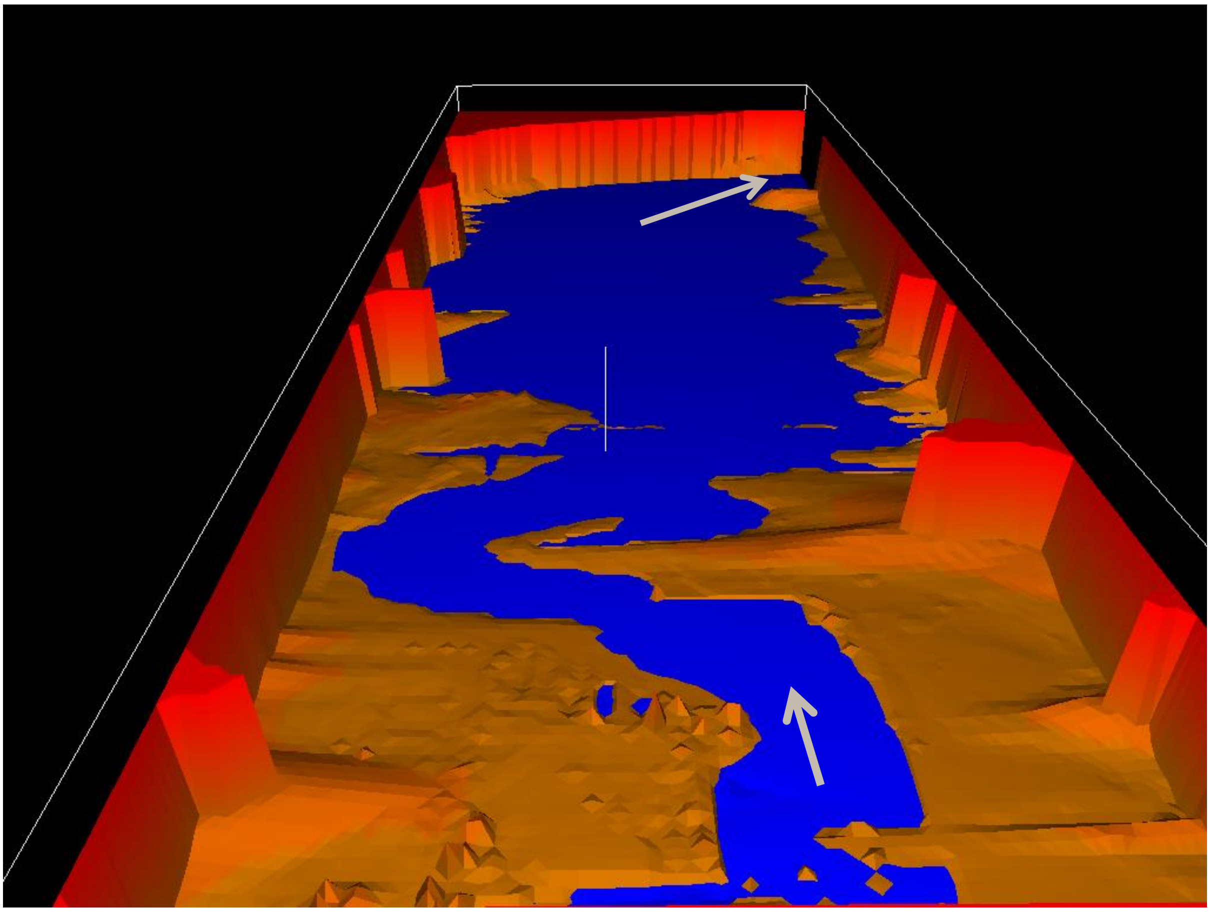


Figure E.3: Initial Bed level with FSL 930masl –3D view from upstream

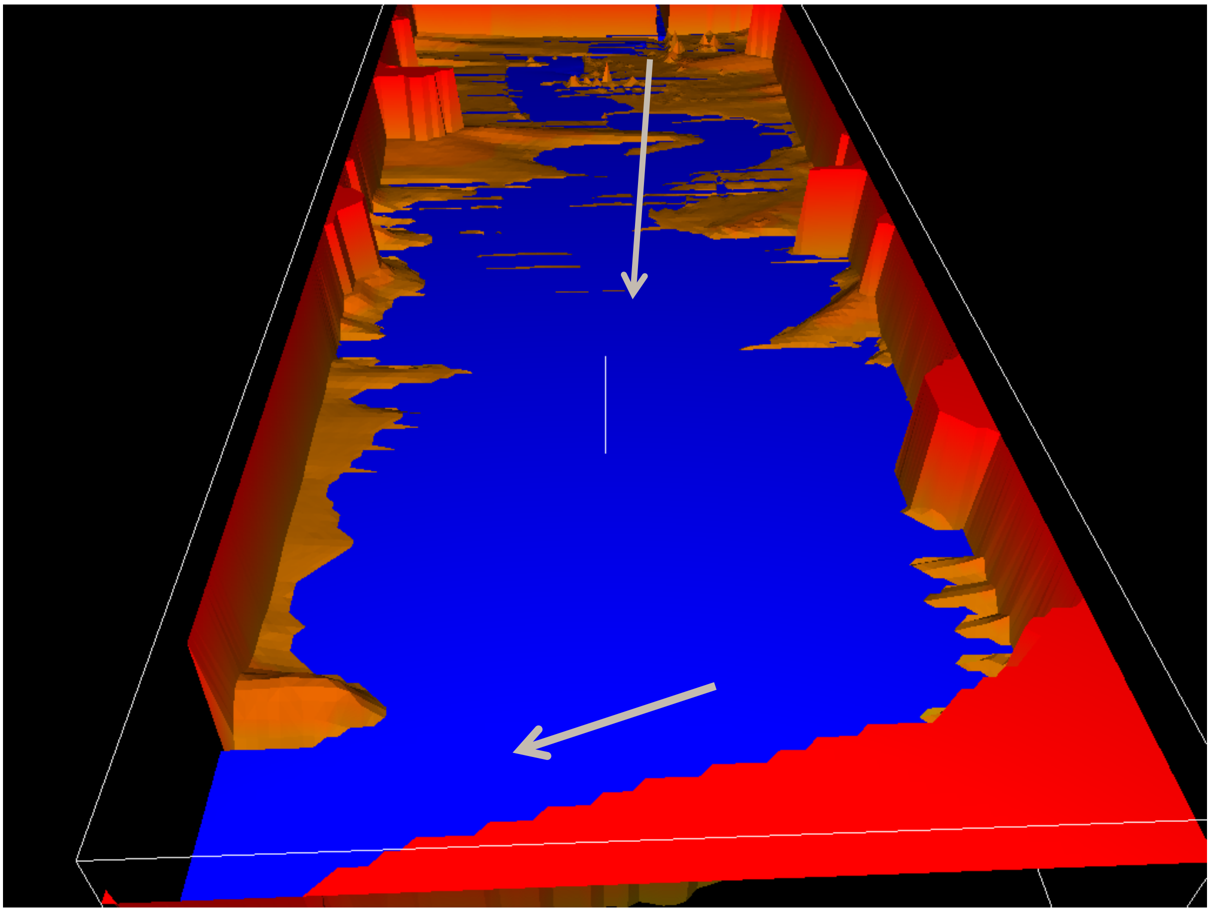


Figure E.4: Initial Bed level with FSL 930masl –3D view from downstream

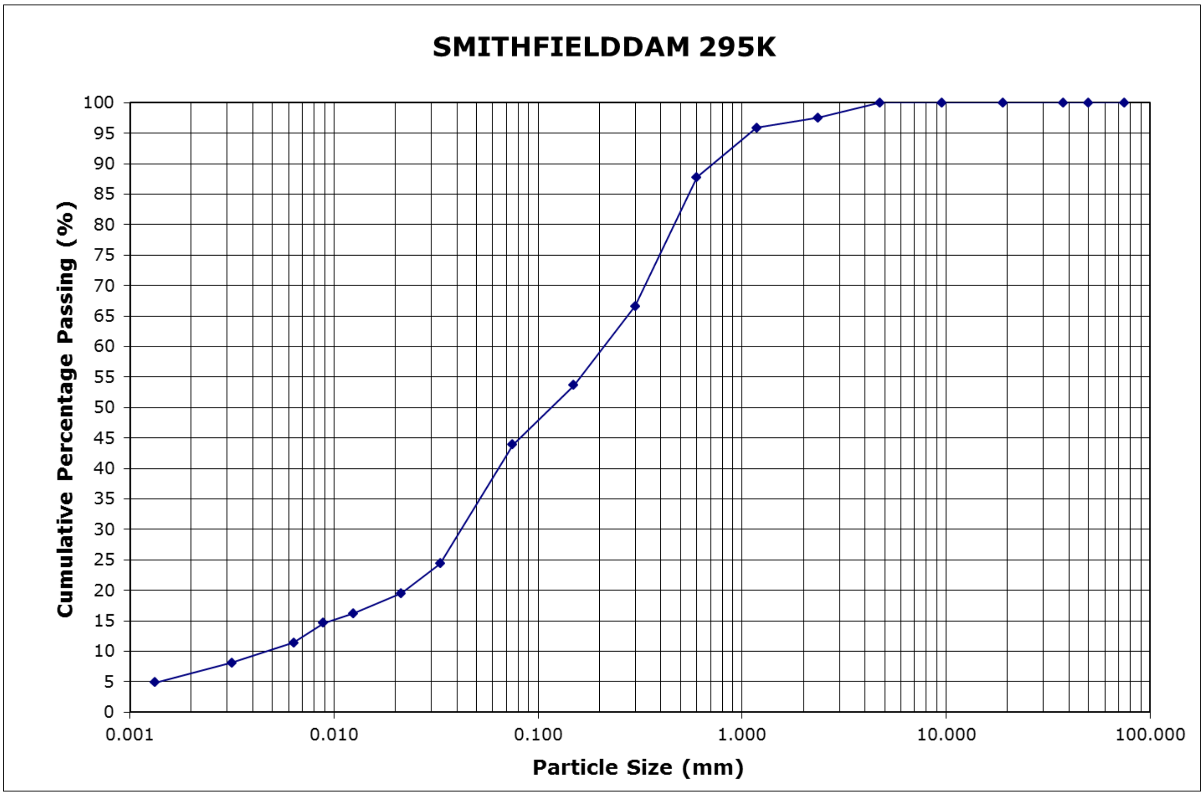
Appendix F

Sediment gradings of river and beach sediment grab samples collected during this study

F.1 uMkhomazi River Downstream of Smithfield Dam

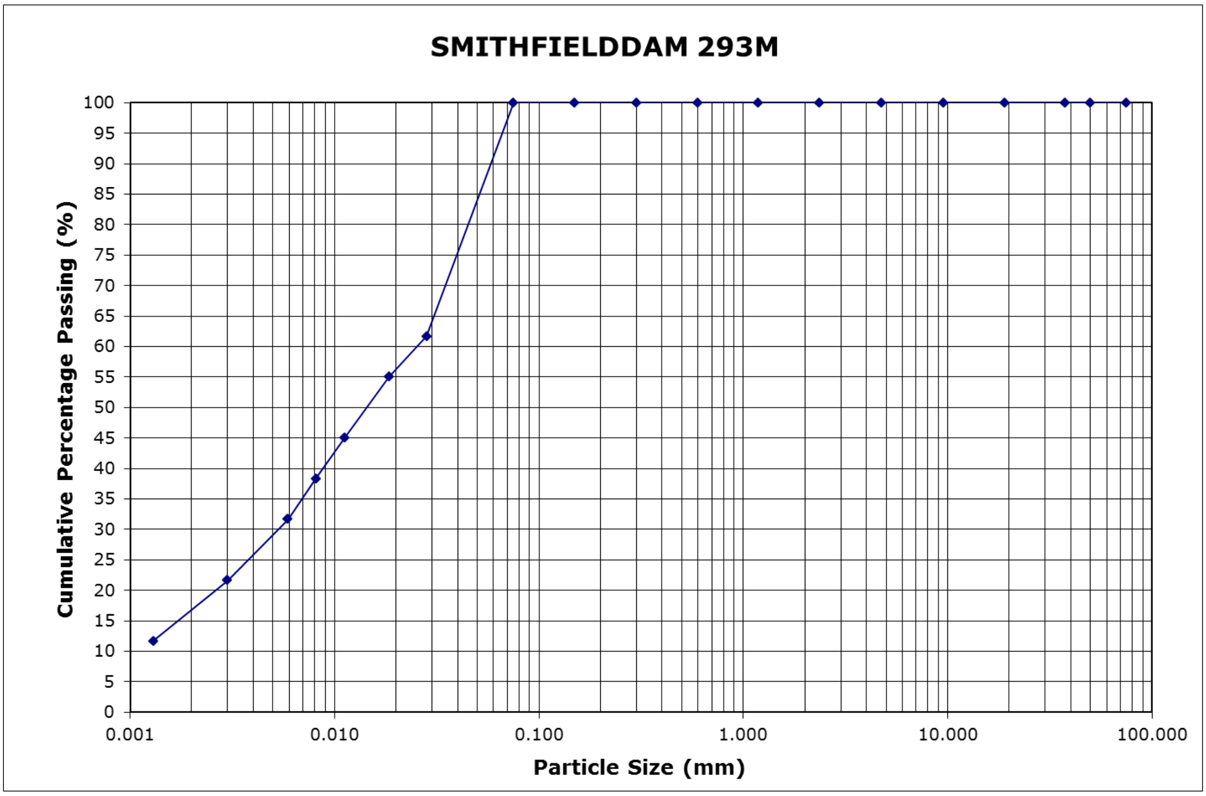
a) Grab Sample Nr 295K – Location: UTM 36J X: 219377; Y: 6687949;

% Passing	Diameter (mm)
100.00	75
100.00	50
100.00	37.5
100.00	19
100.00	9.5
100.00	4.75
97.49	2.36
95.86	1.18
87.74	0.6
66.62	0.3
53.62	0.15
43.87	0.075
24.37	0.0332
19.50	0.0214
16.25	0.0125
14.62	0.0089
11.37	0.0064
8.12	0.0032
4.87	0.0013



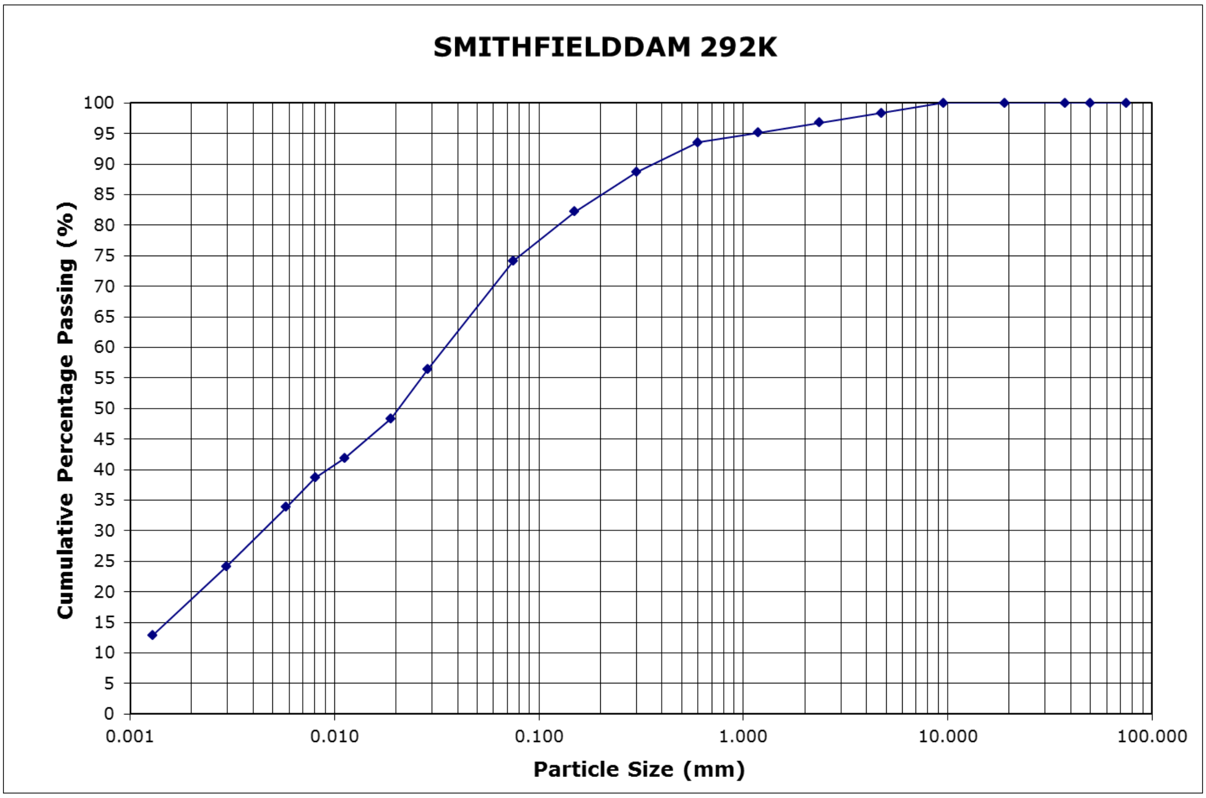
b) Grab Sample Nr 293M – Location: UTM 36J X: 234077; Y: 6677100;

% Passing	Diameter (mm)
100.00	75
100.00	50
100.00	37.5
100.00	19
100.00	9.5
100.00	4.75
100.00	2.36
100.00	1.18
100.00	0.6
100.00	0.3
100.00	0.15
100.00	0.075
61.67	0.0282
55.00	0.0185
45.00	0.0112
38.33	0.0081
31.67	0.0059
21.67	0.0030
11.67	0.0013



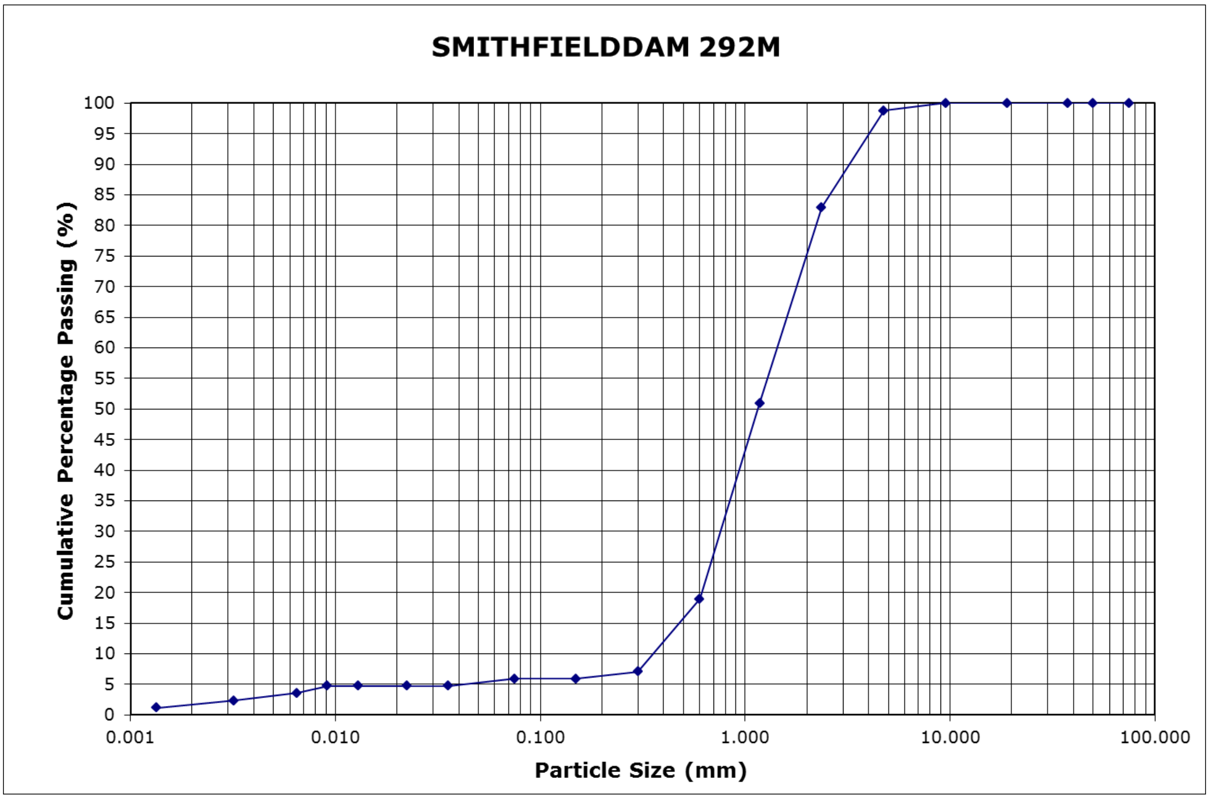
c) Grab Sample Nr 292K – Location: UTM 36J X: 276329; Y: 6663214;

% Passing	Diameter (mm)
100.00	75
100.00	50
100.00	37.5
100.00	19
100.00	9.5
98.37	4.75
96.73	2.36
95.12	1.18
93.51	0.6
88.67	0.3
82.22	0.15
74.16	0.075
56.43	0.0287
48.37	0.0189
41.92	0.0112
38.69	0.0081
33.86	0.0058
24.18	0.0030
12.90	0.0013



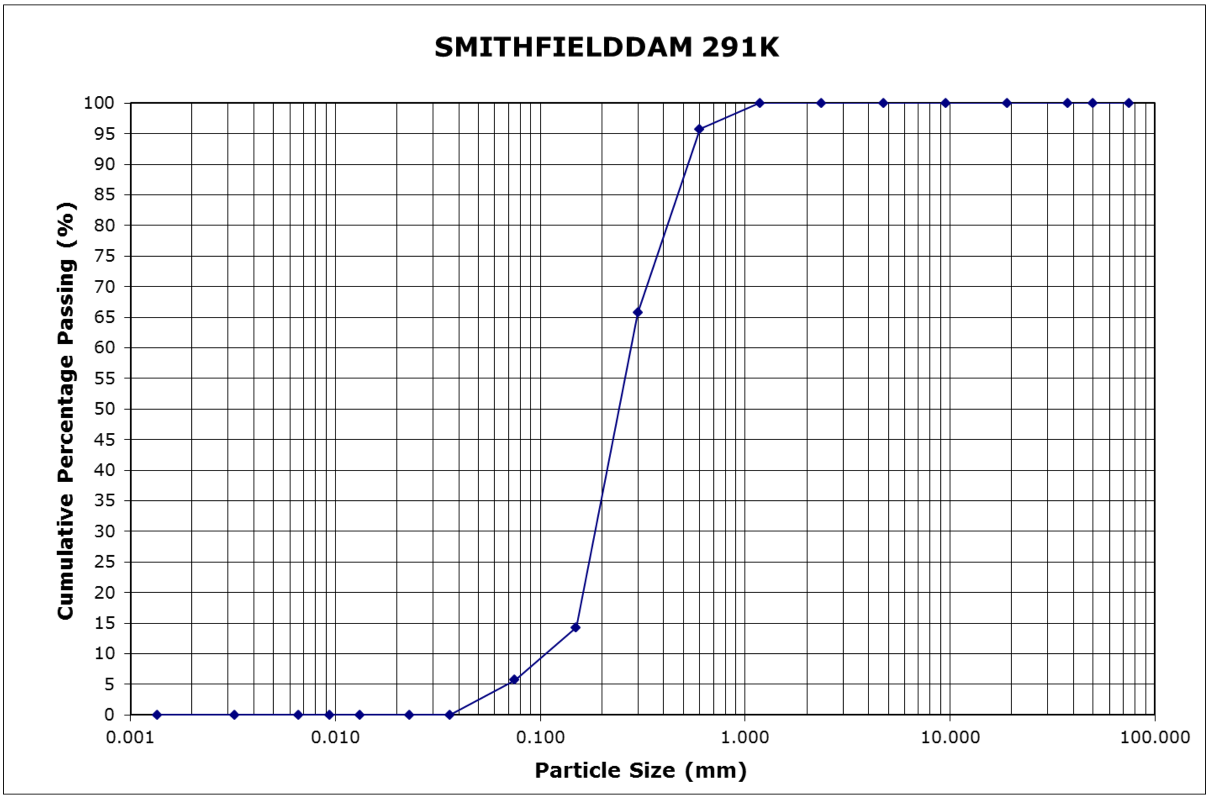
d) Grab Sample Nr 292M – Location: UTM 36J X: 276329; Y: 6663214;

% Passing	Diameter (mm)
100.00	75
100.00	50
100.00	37.5
100.00	19
100.00	9.5
98.74	4.75
82.97	2.36
50.97	1.18
18.97	0.6
7.11	0.3
5.93	0.15
5.93	0.075
4.74	0.0354
4.74	0.0224
4.74	0.0129
4.74	0.0091
3.56	0.0065
2.37	0.0032
1.19	0.0013



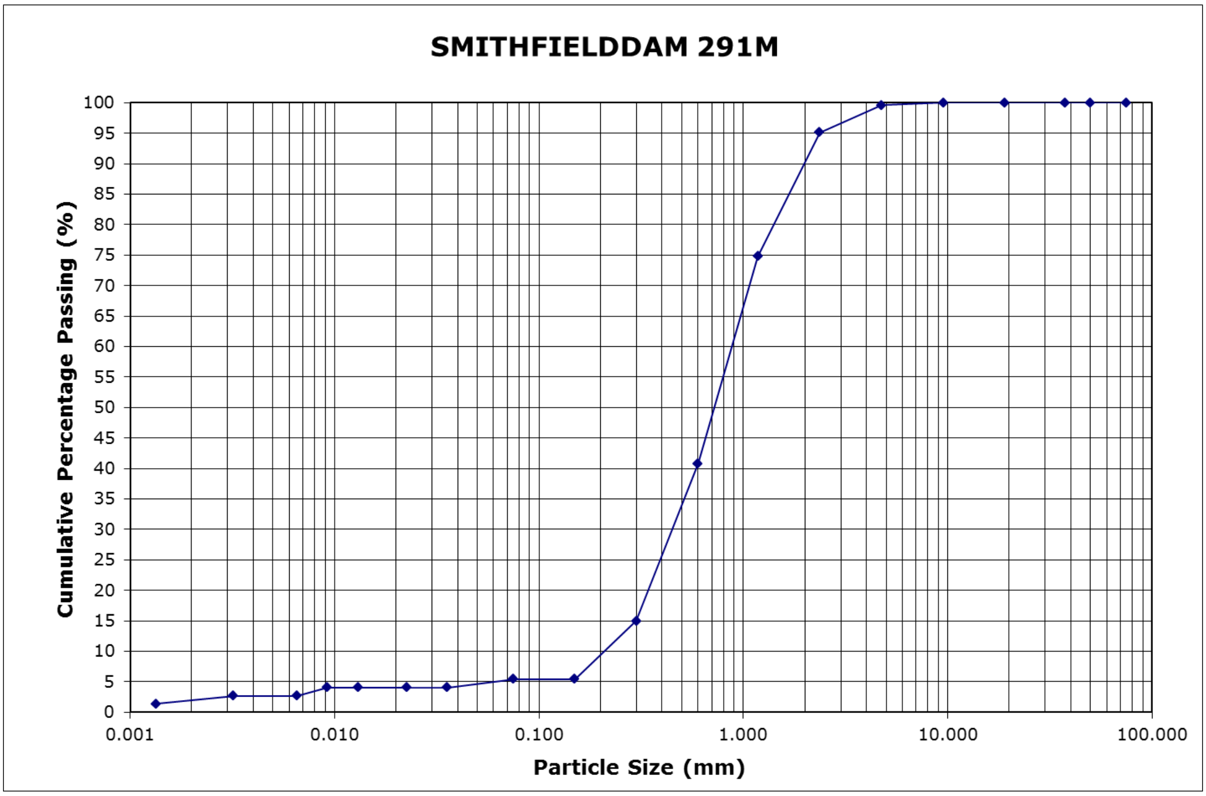
e) Grab Sample Nr 291K – Location: UTM 36J X: 284967; Y: 6658988;

% Passing	Diameter (mm)
100.00	75
100.00	50
100.00	37.5
100.00	19
100.00	9.5
100.00	4.75
100.00	2.36
100.00	1.18
95.71	0.6
65.71	0.3
14.29	0.15
5.71	0.075
0.00	0.0362
0.00	0.0229
0.00	0.0132
0.00	0.0094
0.00	0.0066
0.00	0.0032
0.00	0.0013



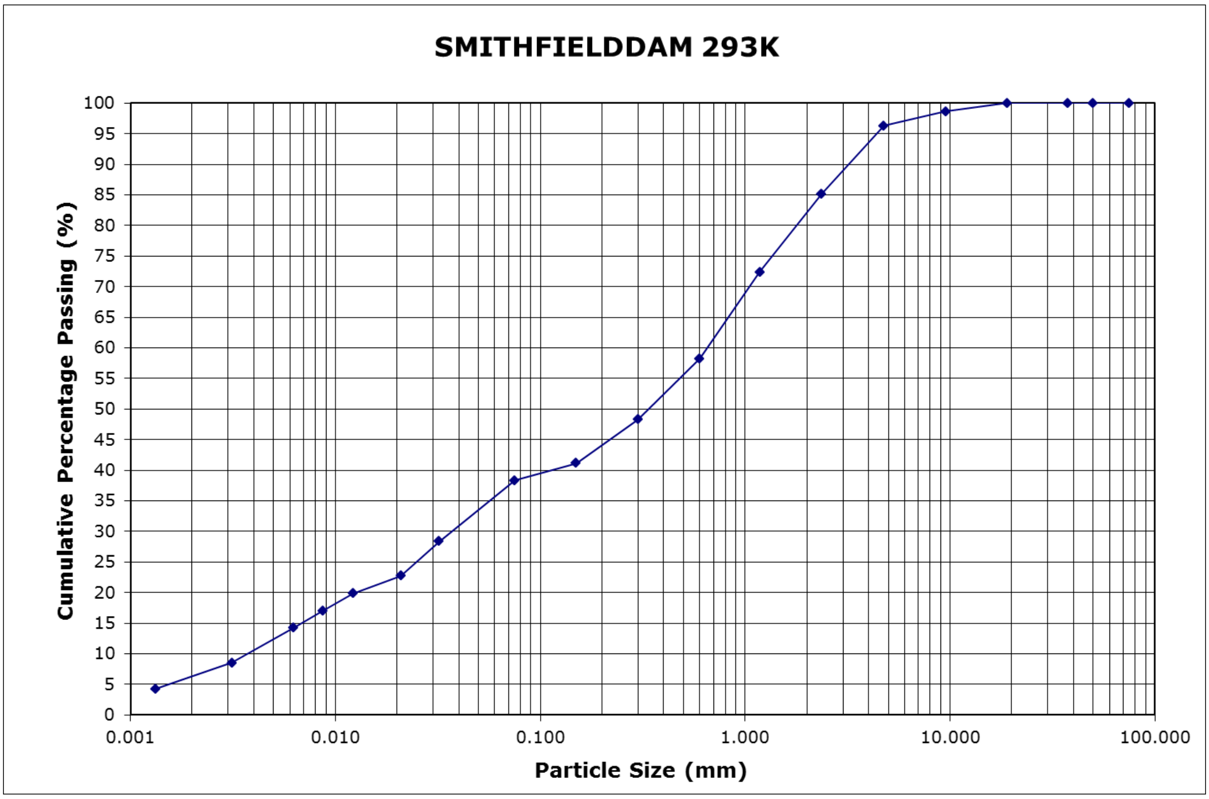
f) Grab Sample Nr 191M – Location: 36J X: 284967; Y: 6658988;

% Passing	Diameter (mm)
100.00	75
100.00	50
100.00	37.5
100.00	19
100.00	9.5
99.56	4.75
95.15	2.36
74.76	1.18
40.78	0.6
14.95	0.3
5.44	0.15
5.44	0.075
4.08	0.0356
4.08	0.0225
4.08	0.0130
4.08	0.0092
2.72	0.0065
2.72	0.0032
1.36	0.0013



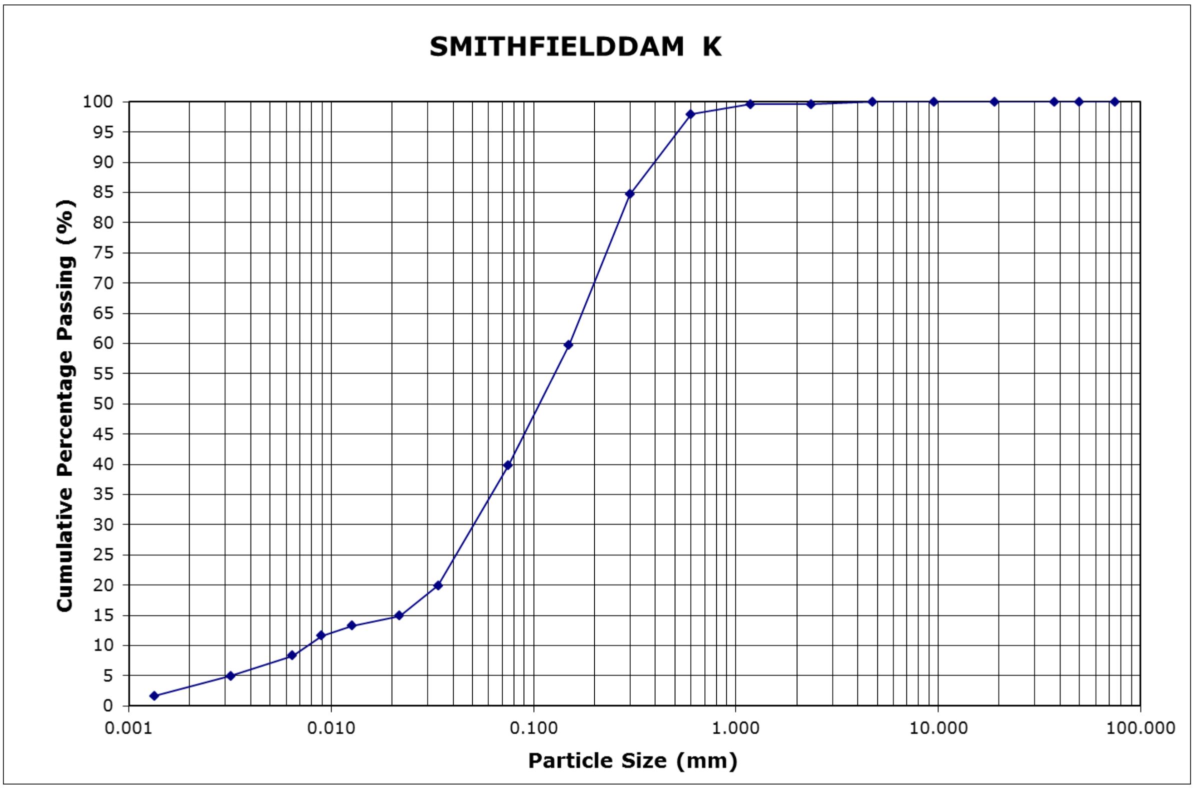
g) Grab Sample Nr 293K – Location: UTM 36J X: 234077; Y: 6677100;

% Passing	Diameter (mm)
100.00	75
100.00	50
100.00	37.5
100.00	19
98.64	9.5
96.30	4.75
85.19	2.36
72.41	1.18
58.21	0.6
48.27	0.3
41.17	0.15
38.33	0.075
28.40	0.0321
22.72	0.0209
19.88	0.0122
17.04	0.0087
14.20	0.0062
8.52	0.0031
4.26	0.0013



h) Grab Sample Nr 294K – Location: UTM 36J X: 234080; Y: 6677070;

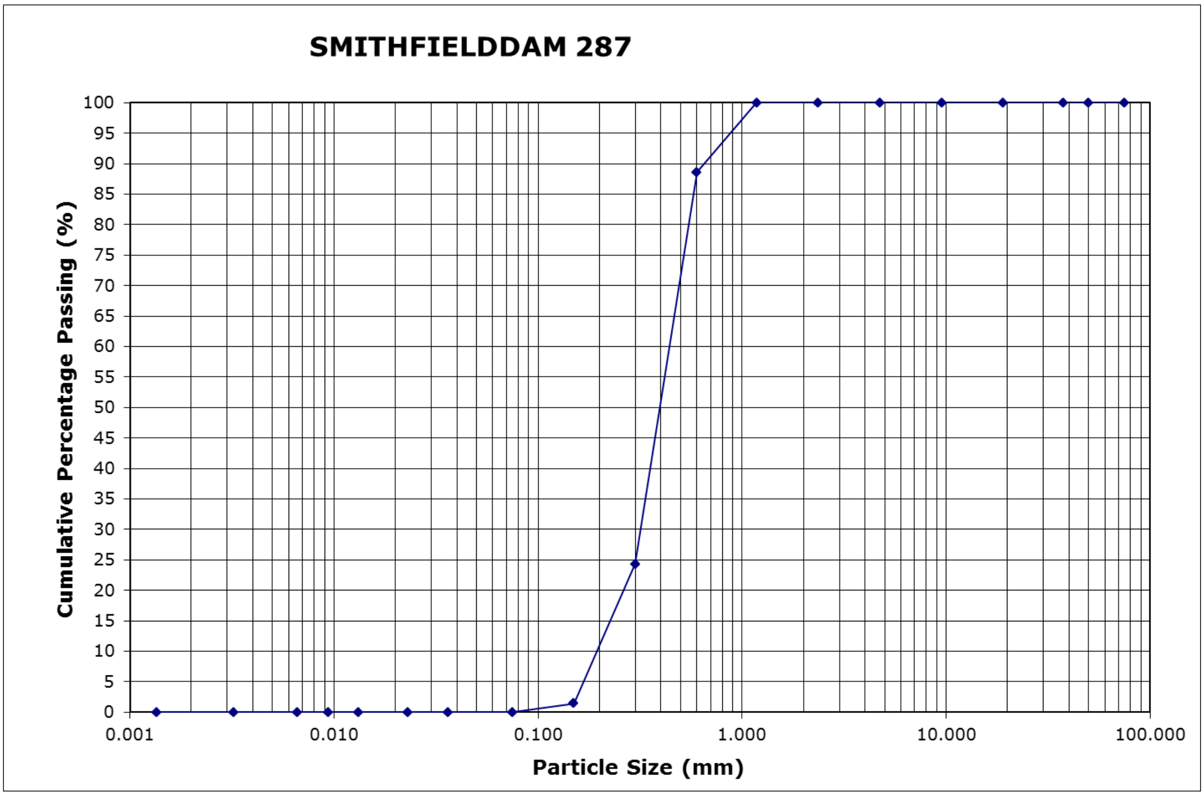
% Passing	Diameter (mm)
100.00	75
100.00	50
100.00	37.5
100.00	19
100.00	9.5
100.00	4.75
99.61	2.36
99.61	1.18
97.95	0.6
84.67	0.3
59.76	0.15
39.84	0.075
19.92	0.0338
14.94	0.0218
13.28	0.0127
11.62	0.0090
8.30	0.0064
4.98	0.0032
1.66	0.0013



F.2 Coastal Beach Samples

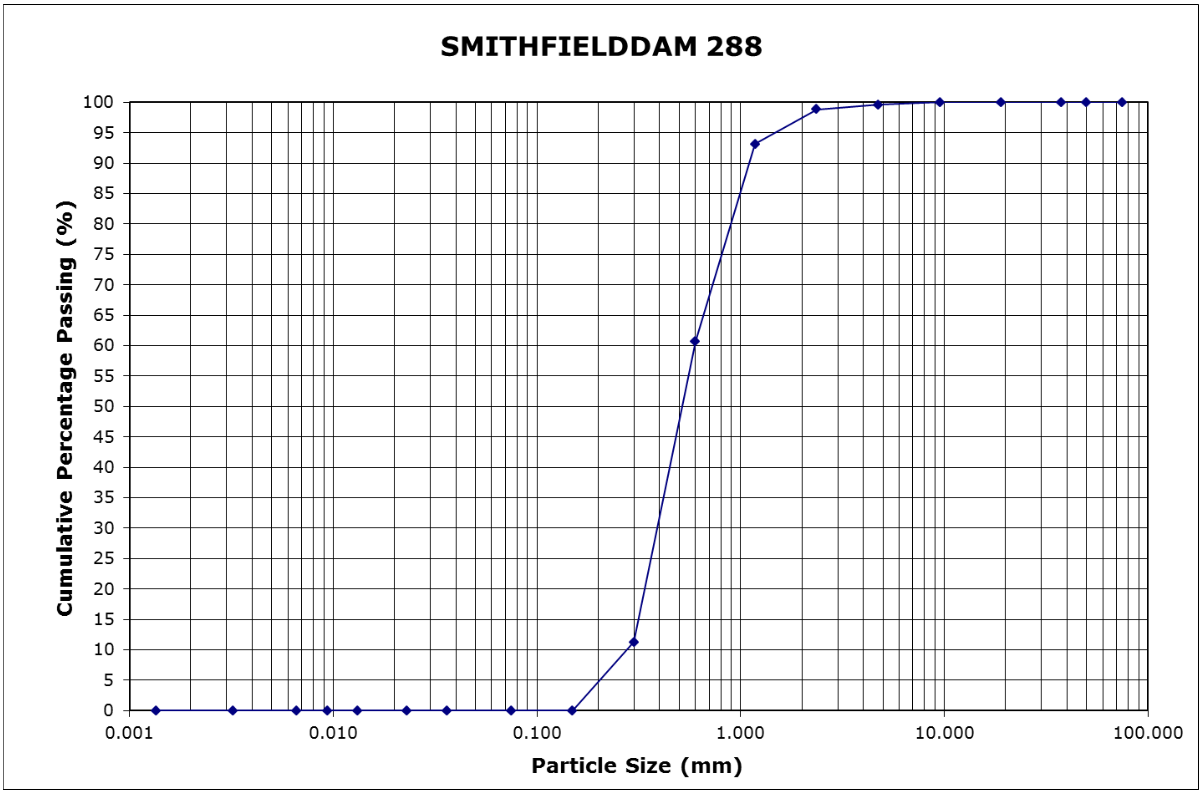
a) Grab Sample Nr 287 – Location: UTM 36J X: 288470; Y: 6656905;

% Passing	Diameter (mm)
100.00	75
100.00	50
100.00	37.5
100.00	19
100.00	9.5
100.00	4.75
100.00	2.36
100.00	1.18
88.57	0.6
24.29	0.3
1.43	0.15
0.00	0.075
0.00	0.0362
0.00	0.0229
0.00	0.0132
0.00	0.0094
0.00	0.0066
0.00	0.0032
0.00	0.0013



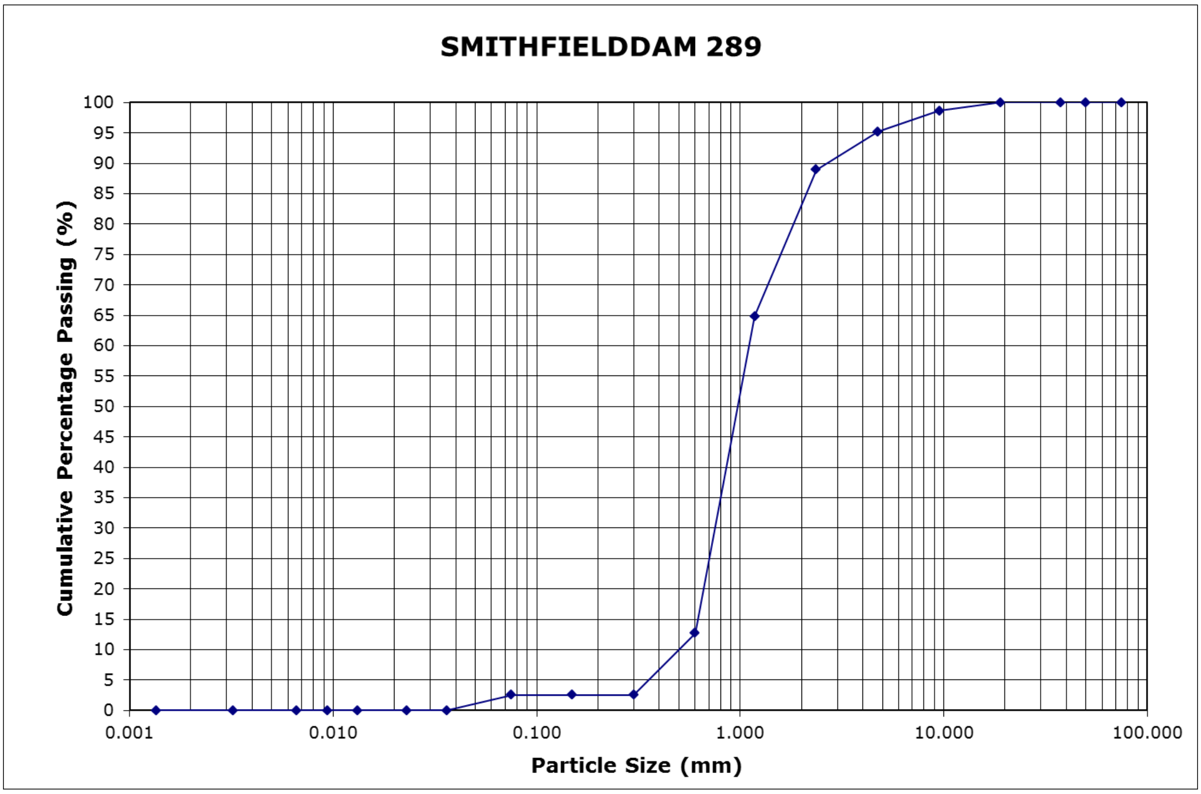
b) Grab Sample Nr 288 – Location: UTM 36J X: 288502; Y: 6656905;

% Passing	Diameter (mm)
100.00	75
100.00	50
100.00	37.5
100.00	19
100.00	9.5
99.55	4.75
98.79	2.36
93.15	1.18
60.69	0.6
11.29	0.3
0.00	0.15
0.00	0.075
0.00	0.0362
0.00	0.0229
0.00	0.0132
0.00	0.0094
0.00	0.0066
0.00	0.0032
0.00	0.0013



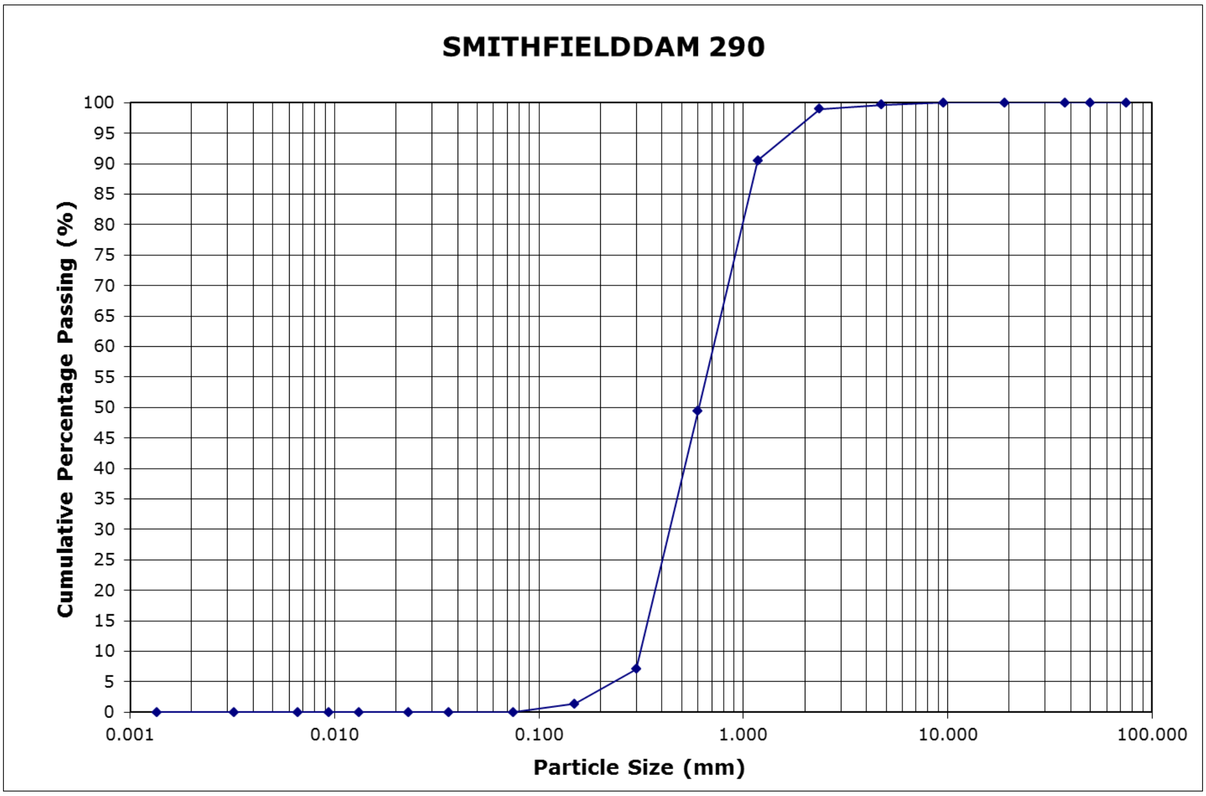
c) Grab Sample Nr 289 – Location: UTM 36J X: 288610; Y: 6657161;

% Passing	Diameter (mm)
100.00	75
100.00	50
100.00	37.5
100.00	19
98.62	9.5
95.17	4.75
88.95	2.36
64.81	1.18
12.71	0.6
2.54	0.3
2.54	0.15
2.54	0.075
0.00	0.0362
0.00	0.0229
0.00	0.0132
0.00	0.0094
0.00	0.0066
0.00	0.0032
0.00	0.0013



d) Grab Sample Nr 290 – Location: UTM 36J X: 288593; Y: 6657188;

% Passing	Diameter (mm)
100.00	75
100.00	50
100.00	37.5
100.00	19
100.00	9.5
99.66	4.75
98.97	2.36
90.48	1.18
49.48	0.6
7.07	0.3
1.41	0.15
0.00	0.075
0.00	0.0362
0.00	0.0229
0.00	0.0132
0.00	0.0094
0.00	0.0066
0.00	0.0032
0.00	0.0013



Appendix G

Sediment bypass tunnel

G-1 Introduction

This write-up emanates from the conclusion and recommendations stated in **Section 8.2** of the *Sediment Deposition and Impact Report*. The purpose of this write-up is to investigate the feasibility of implementing a sediment bypass tunnel at the proposed Smithfield Dam to mitigate the impact on sediment deposition in the uMkhomazi River downstream of the dam and at the river mouth.

This write-up includes the following:

- An overview of the purpose of a sediment bypass tunnel, sediment transportation calculations and design principles of the tunnel;
- The impact of the sediment bypass tunnel on the water supply potential (yield) of Smithfield Dam; and
- The preliminary costing of the sediment bypass tunnel.

G-2 Overview

A sediment tunnel is proposed to allow coarse sediment to bypass the Smithfield Dam reservoir to limit the impacts of the dam on the downstream river morphology and on the sediment loads at the uMkhomazi River mouth.

The tunnel was sized to divert floods equal to the 1:2 and 1:5-year recurrence interval floods under free flow conditions. An airshaft is provided on the upstream side to allow air to be entrained into the tunnel. The intake of the tunnel is located in the upper reservoir. A weir just downstream of the tunnel intake, with a height of 10 m and a length of 400 m, diverts water from the dam into the tunnel during the 1:2 and 1:5-year floods by opening the vertical gates, situated at the tunnel inlet. These vertical gates are closed during normal operating conditions to allow runoff to enter the reservoir.

The proposed tunnel route and weir location is illustrated in **Figure G.1**. The tunnel is approximately 5.8 km long and has a slope of 1.24% or approximately 1V:80H. The invert level of the tunnel is at 917 masl and the floor level at the outlet is at 845 masl. An 8 m internal diameter tunnel is proposed with 500 mm thick concrete lining and 50 mm thick shotcrete above the springline. The tunnel passes underneath the dam reservoir for a distance of 400 m. The minimum natural roof cover for this section is approximately 8 m and thus additional reinforcing and sealing will be required. The tunnel profile and cross-section are illustrated in **Figure G.2** and **Figure G.3** respectively.

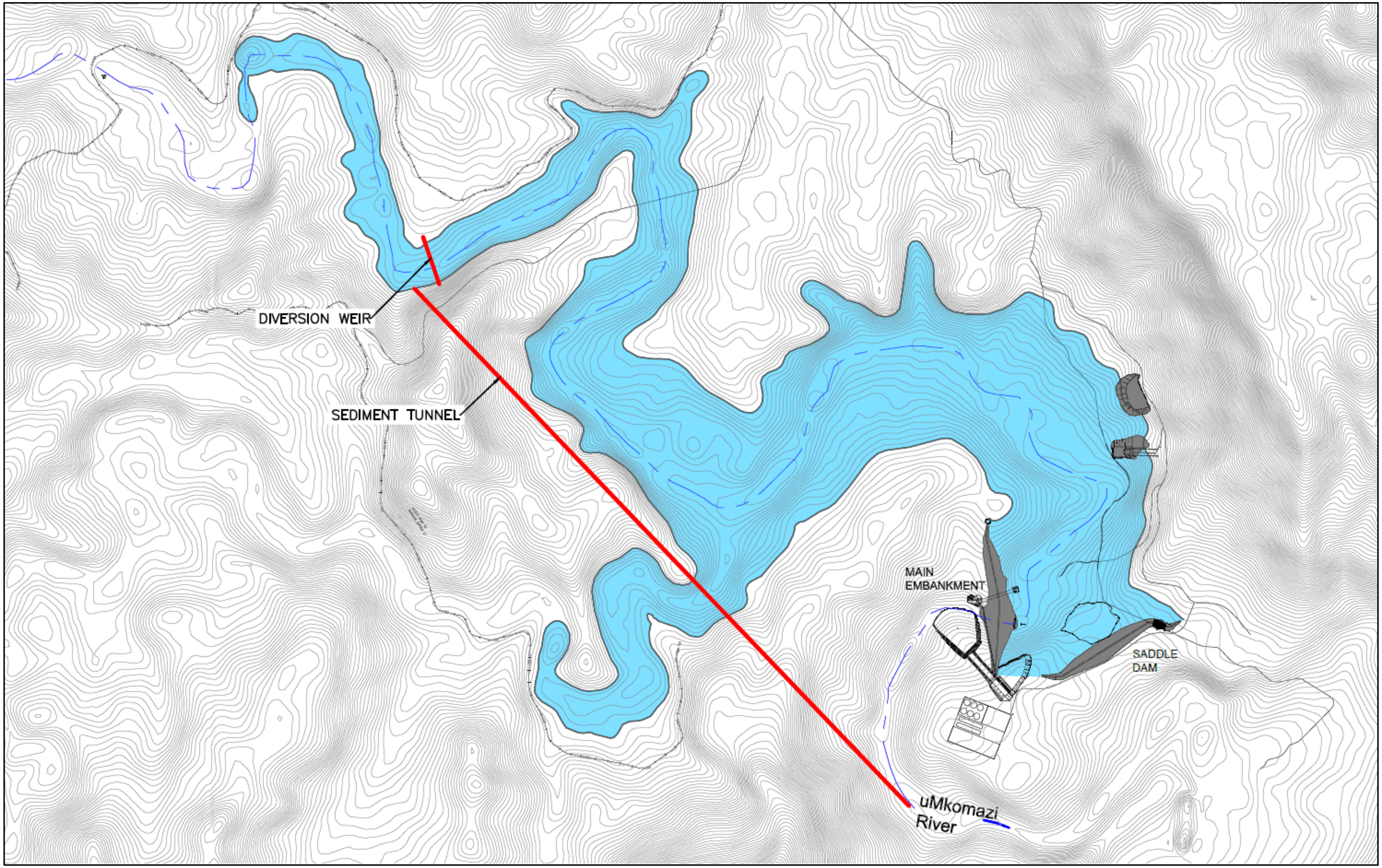


Figure G.1: Sediment tunnel and weir layout

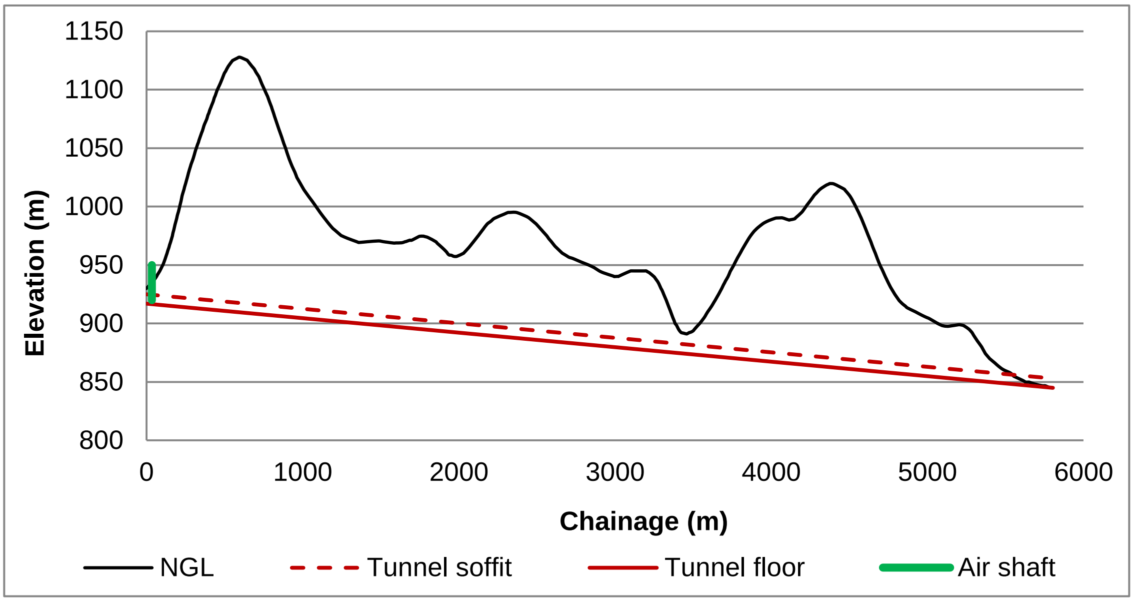


Figure G.2: Tunnel profile

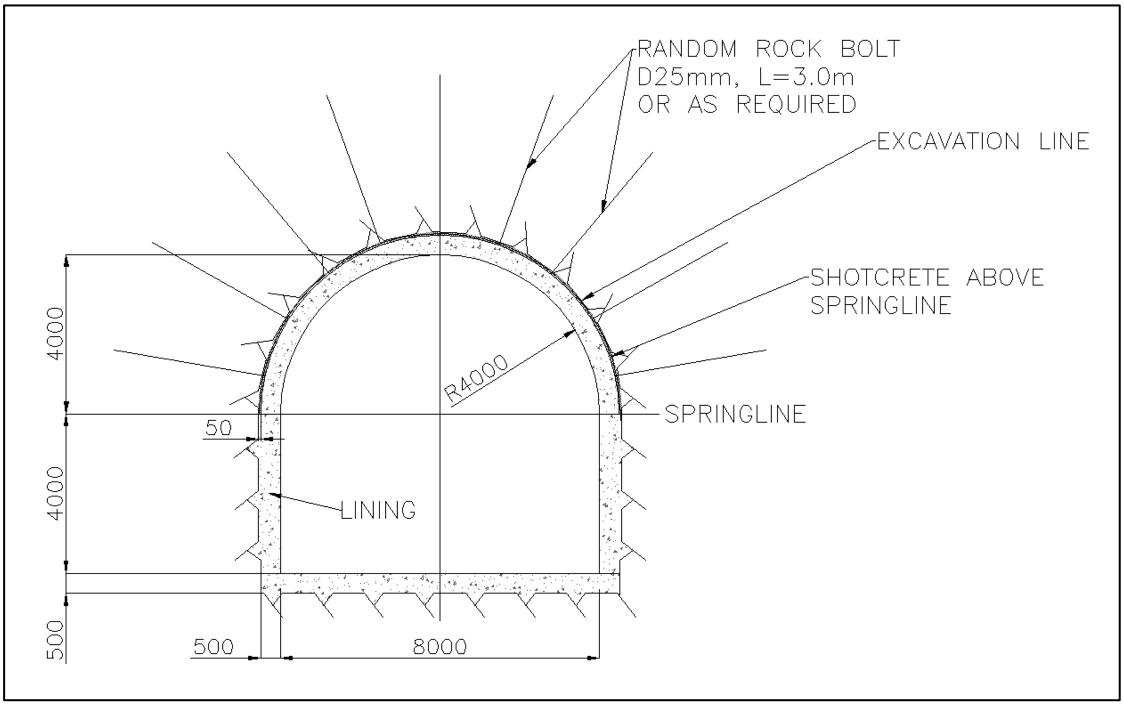


Figure G.3: Tunnel cross-section

The Manning equation was used to determine the maximum flow depth and velocity within the tunnel for the 1:2 and 1:5 year floods. The equation is given below:

$$Q = \frac{1}{n}\frac{A^{\frac{5}{3}}}{P^{\frac{2}{3}}} S^{1/2}$$

Where:

Q = Flow (m^3/s)

N = Manning N-value (0.015 $s/m^{1/3}$)

A = Cross-sectional flow area (m^2)

P = Wetted perimeter (m)

The flow depths and velocities for the 1:2 and 1:5 year floods diverted through the tunnel are given in **Table G.1**. The flow will be supercritical for all flow capacities and the high flow velocity will prevent sediment from depositing in the tunnel. However, measures have to be taken to avoid excessive scouring of the tunnel floor.

Table G.1: Flow depth and velocity within the tunnel

Recurrence interval (years)	Flood peak (m^3/s)	Flow depth (m)	Freeboard available (m)	Velocity (m/s)
1:2	336	3.85	4.15	10.91
1:5	585	6.04	1.96	12.29

Other tunnel routes were considered but were rejected due to the following reasons:

- Routes are too long;
- Insufficient roof cover; and
- Routes contain bends which is not ideal for supercritical flow conditions.

G-3 Effective Sediment Transport Checks

The critical flow velocity (minimum velocity required to avoid sediment deposition) has been by using the following set of equations:

- Sediment settling velocity:

$$w = \frac{(p_s - p) g {D_{50}}^2}{18\vartheta}$$

Where:

w = Sediment settling velocity (m/s)
p_s = Sediment density (assumed at 2 400 kg/m^3)
p = Water density (1 000 kg/m^3)
g = Gravitational acceleration (m/s^2)
D_{50} = Mean particle diameter (0.25 mm as determined by sediment sampling)
ϑ = Dynamic viscosity (taken as 0.00102)

- Critical velocity:

$$V_{cr} = 10\, w\ R^{1/6}$$

Where:

V_{cr} = Critical flow velocity to prevent sediment deposition (m/s)
w = Sediment settling velocity (m/s)
R = Hydraulic radius (m)

The critical settling velocity was calculated as 0.57 m/s – significantly less that the expected velocity within the sediment tunnel of 15 m/s.

As an additional check, the bed shear stress and the associated critical shear stress were calculated to verify if sediment that might have deposited in the tunnel will be scoured during the next flood. The following equations were used:

- Shear stress:

$$\tau_0 = pgRS$$

Where:

τ_0 = Shear stress (m/s)
p = Water density (1 000 kg/m^3)
g = Gravitational acceleration (m/s^2)

R = Hydraulic radius (m)

S = Slope of the tunnel (m/m)

- Critical shear stress:

$$\tau_{\mathrm{cr}} = 0.056(p_s - p)gD_{50}$$

Where:

τ_{cr} = Critical shear stress (m/s)

p_s = Sediment density (assumed at 2 400 kg/m^3)

p = Water density (1 000 kg/m^3)

g = Gravitational acceleration (m/s^2)

D_{50} = Mean particle diameter (0.25 mm as determined by sediment sampling)

For sediment movement to occur the shear stress should be more than the critical shear stress. In the case of the sediment tunnel, the shear stress is 394 N/m^2 compared to the critical shear stress of 193 N/m^2 – implying that sediment transport will occur.

G-4 Yield Impact Assessment

(a) Approach

The proposed implementation of a sediment bypass tunnel to divert 1:2 and 1:5-year floods around Smithfield Dam raised concern over the possible impact of this option on the long-term water supply potential (or "yield") of the dam. Within this context, water resources system analyses were undertaken to assess the possible impact. This involved analysing two scenarios as outlined below:

- **Scenario 1**: Smithfield Dam without the bypass tunnel.
- **Scenario 2**: Smithfield Dam including the bypass tunnel.

Furthermore, **Scenario 2** was repeated for two options, namely (i) where flows diverted through the bypass tunnel contribute to the supply of downstream ecological water requirements (EWRs) in the uMkhomazi River; and (ii) where diverted flows do not contribute to downstream EWRs. The second option was considered based on the fact that the 1:2 and 1:5-year floods are short in duration (approximately two days) and that these events would therefore not necessarily correspond (both in timing and magnitude) with the EWRs that may be required within the month in question.

(b) Modelling methodology

The analysis was undertaken using Version 3.2.8 of the *Water Resources Yield Model Information Management System* (WRYM-IMS) which was configured as part of this study for the uMkhomazi River System (as described in *Water Resources Yield Assessment Report (P WMA 11/U10/00/3312/2/3)*). The WRYM is a sophisticated model used to analyse complex multi-reservoir water resource systems for a variety of operating policies and is designed for the purpose of assessing a system's long- and short-term yields.

All scenarios were analysed on the following basis:

- An analysis period of 84 years from the 1925 to the 2008 hydrological year (i.e. October 1925 to September 2009).
- Both *historical* and *long-term stochastic* yield analyses were undertaken, with the latter based on 201 84-year stochastically generated stream flow sequences.
- A constant 2050-development level.

- With Smithfield Dam at the selected dam size, namely with a full supply level (FSL) of 930 masl. This corresponds to a live storage capacity of 226.20 million m^3 (or 31% of the natural mean annual runoff of the Smithfield Dam catchment).

(c) Results

All scenarios analysed yielded identical results, and these are summarised in **Table G.2**.

Table G.2: Summary of yield results for all scenarios analysed

Historical firm yield (million m^3/a)	Stochastic yield, at indicated RI[(1)] (annual assurance of supply)			
	1:20 (95%)	1:50 (98%)	1:100 (99%)	1:200 (99.5%)
172	260	237	220	210

Notes: (1) Recurrence interval of failure (years).

The above results imply that **the implementation of a sediment bypass tunnel to divert 1:2 and 1:5 year floods around Smithfield Dam will have no impact on the long-term yield of the dam**. While this finding may appear counter-intuitive it can be explained by the fact that the flood events in question would typically not occur during dry periods. This is clearly illustrated in **Figure G.4**, showing the modelled water volumes in Smithfield Dam (blue line) and the corresponding modelled flows in the sediment bypass tunnel (red line). The longest dry period (or "critical period") covers approximately 2 years from early-1981 to late-1982 and no bypass tunnel flows are required over this period.

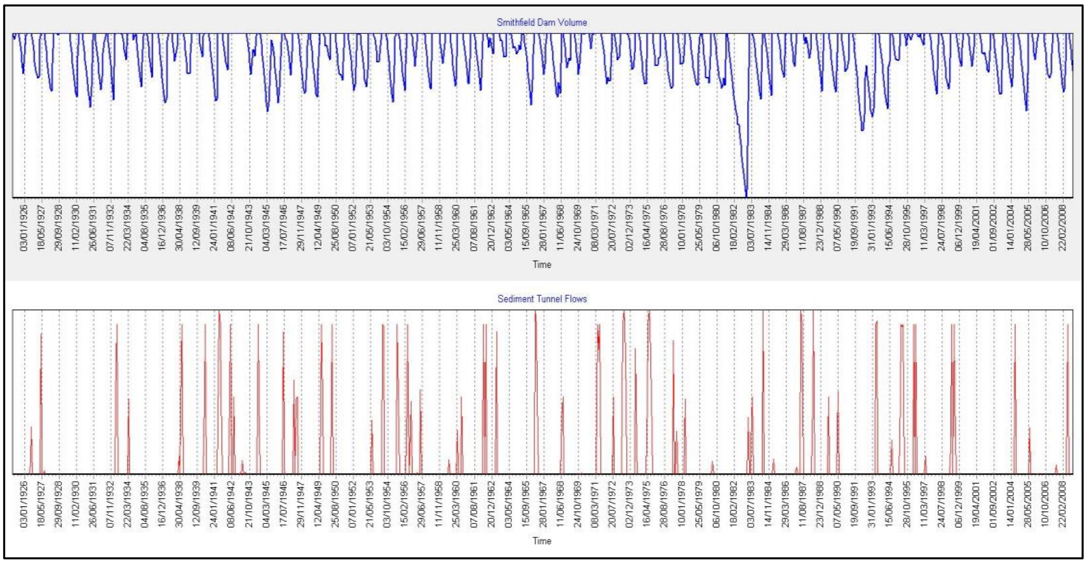


Figure G.4: Modelled dam water volumes and bypass tunnel flows

G-5 Cost Estimate

A preliminary cost estimate for the sediment tunnel and weir is provided in below Table G.3, with a total of approximately **R1.3 billion**.

Table G.3: Sediment tunnel cost estimate

DESCRIPTION	Unit	Quantity	Rate	Amount
TUNNEL				
Excavation of tunnel	m^3	426 452	1290	R 550 122 821.96
Construction of tunnel				
Rock bolts	m	95 253	285	R 27 147 111.14
Concrete (tunnel floor)				
Lining and tunnel floor	m^3	96 172	2775	R 266 877 377.57
Reinforcing	t	3 764	15000	R 56 456 534.83
Over break concrete	m^3	19 200	2245	R 43 104 000.00
Formwork	m^2	165 813	500	R 82 906 477.74
Grouting	m^2	45 000	485	R 21 825 000.00
Additional grouting (reinforcing under reservoir)	Lump sum			R 5 000 000
Sluice gate	Lump sum			R 6 400 000
Sub-total tunnel				**R 1 059 839 323.23**
INLET AND OUTLET PORTALS				
Excavation of inlet and outlet portals and airshaft				
Normal	Lump sum			R 5 000 000.00
Hard rock	Lump sum			R 300 000.00
Construction of portals				
Formwork	Lump sum			R 4 593 000.00
Concrete and shotcrete	Lump sum			R 10 000 000.00
Unformed surfaces	Lump sum			R 24 700.00
Reinforcement	Lump sum			R 8 000 000.00
Sub-total tunnel inlet and outlet portal				**R 27 917 700.00**
DIVERSION WEIR				
Earthworks				
Site clearance	m^2	3 800	20	R 76 000.00

DESCRIPTION	Unit	Quantity	Rate	Amount
Bulk excavation	m^3	11 400	110	R 1 254 000.00
River diversion	Lump sum			R 1 000 000.00
Construction of weir				
Formwork	Lump sum			
Vertical - Rough	m^2	12 400	380	R 4 712 000.00
Vertical - Smooth	m^2	4 799	650	R 3 119 350.00
Reinforcement				
High tensile reinforcement	t	4.7	10700	R 50 290.00
100 x 100 x 8 mm Stainless Steel angle welded to dowel at weir crest	m	4 000	930	R 3 720 000.00
Concrete				
Blinding layer	m^2	4 000	1900	R 7 600 000.00
Strength	m^3	38 070	2160	R 82 231 200.00
Finishing	m^2	6 857	290	R 1 988 530.00
Sub-total diversion weir				**R 105 751 370.00**
SUB-TOTAL (CONSTRUCTION COSTS)				**R 1 193 508 393.23**
Contingencies (15%)				R 179 026 258.99
TOTAL				**R 1 372 534 652.22**