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REPUBLIC OF SOUTH AFRICA

REPORT NO: P WMA 11/U10/00/3312/3/1/3

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

ENGINEERING FEASIBILITY DESIGN REPORT

SUPPORTING DOCUMENT 3:

OPTIMIZATION OF SCHEME CONFIGURATION

FINAL

SEPTEMBER 2014

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Sub-report title:	***Supporting Report 3: Optimisation of Scheme Configuration***
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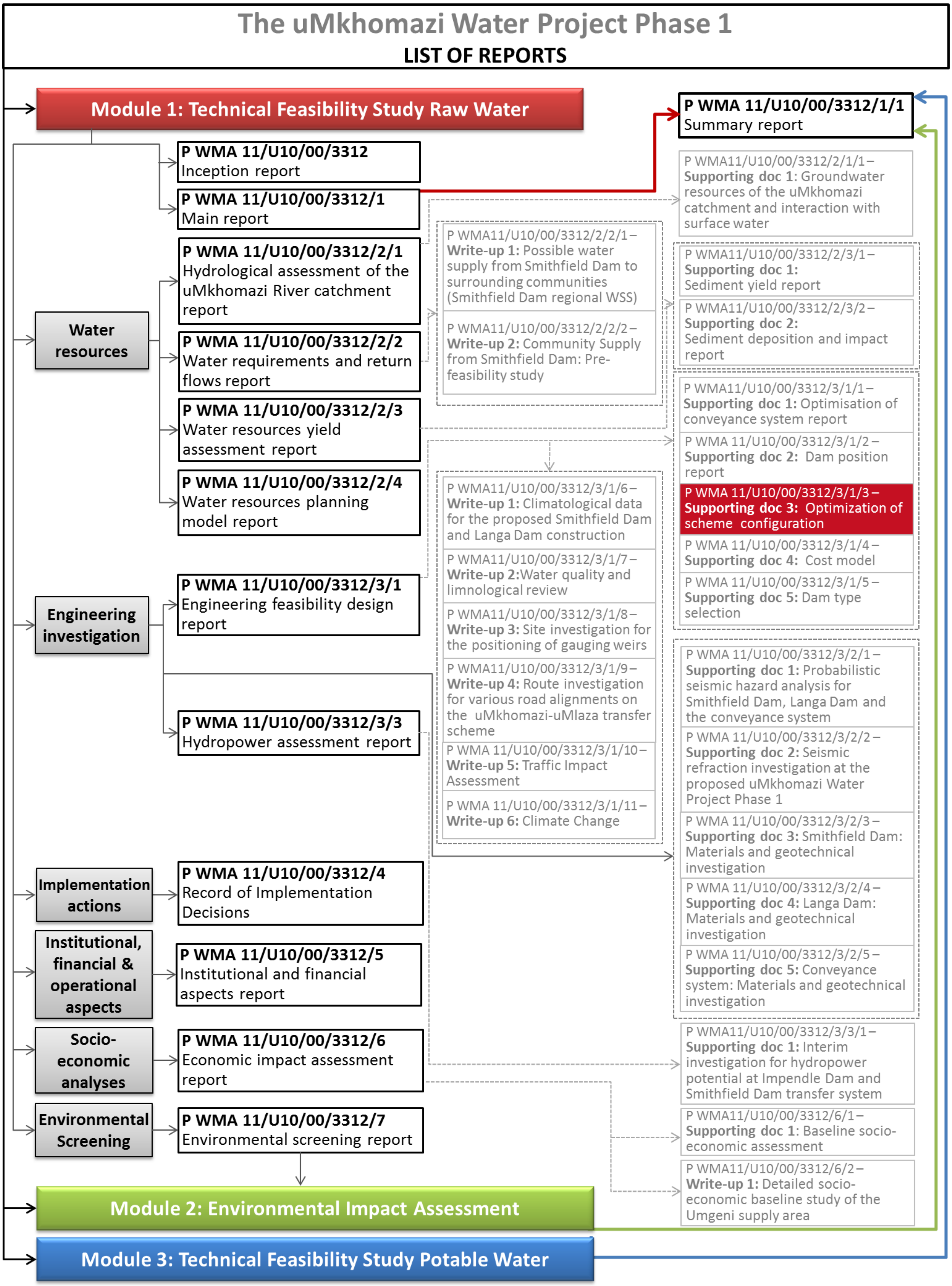
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PREAMBLE

Company name i.e. BKS vs AECOM

The Department of Water Affairs appointed **BKS (Pty) Ltd** in association with three sub-consultants **Africa Geo-Environmental Services, 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.

Subsequently, 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, a decision was made that all the final study reports will be published under the AECOM name.

However, as the first draft of this report (*P WMA 11/U10/00/3312/3/1/3 – Optimization of scheme configuration*) had already been published at the time, agreement was reached that the references to BKS, **especially on some of the figures within this report**, will remain within this report as is.

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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LIST OF ABBREVIATIONS

AADD	Average annual daily demand
DWA	Department of Water Affairs
EWR	Environmental water requirements
FSL	Full supply level
MAR	Mean annual runoff
MOL	Minimum operating level
M&E	Mechanical and Electrical
PV	Net present value
O&M	Operation and Maintenance
RBL	River bed level
RL	Reduced level
SDD	Summer daily demand
TBM	Tunnel boring machine
TOR	Terms of Reference
uMWP	uMkhomazi Water Project
WTW	Water Treatment works

LIST OF UNITS

m^3/a	cubic metres per annum
m^3/s	cubic metres per second
Mℓ/d	mega litre per day
Mℓ/d/a	mega litre per day per annum
masl	metres above sea level
m/km	metres per kilometre
kW	kilowatt
MW	mega watt
KWh	kilowatt hour
MWh	megawatt hour

1 INTRODUCTION

Engineering Investigations referred to as *Task 5* of the feasibility study consist of the following:

- Task 5.1 Optimisation of conveyance system
- Task 5.2 Dam position
- Task 5.3 Materials investigation
- Task 5.4 Geomorphologic and seismic investigation
- Task 5.5 Geotechnical investigation
- Task 5.6 Survey
- Task 5.7 Dam type selection
- Task 5.8 Establish required storage capacity for dam
- Task 5.9 Flood and backwater calculations for the final dam
- Task 5.10 Climatological data for the construction site
- Task 5.11 Water quality and limnological review
- Task 5.12 Sediment yield
- Task 5.13 Land requirements and associated costs
- **Task 5.14 Optimise scheme configuration**
- Task 5.15 Assessment of the potential for hydropower generation at dams
- Task 5.16 Feasibility design of selected scheme
- Task 5.17 Creating a cost model for the dam

This report covers *Task 5.14: Optimisation of scheme configuration*. The objective of this task is to identify and compare final options for the storage and conveyance of water from the proposed Smithfield Dam to the Umlaas Road Reservoir. The final option for feasibility design is identified.

Task 5.1 Optimization of conveyance system and *Task 5.2 Dam position* reports concluded that a Smithfield Dam at Site B and a pressure tunnel from dam Site A to the upper area of Baynesfield is the best storage and conveyance system. However, it did not include the pipeline conveyance systems from the tunnel outlet to Umlaas Road. This part is described in Module 2 of this feasibility study of the project and was carried out by Knight Piésold for Umgeni Water. Module 1 and Module 3 are distinguished in **Figure 1.1**.

This report covers the following:

- Summary of yields and cost details of Smithfield and Impendle Dams;
- Summary of water requirements;
- Definition of the scheme configuration of the complete storage and conveyance system, the comparison of options and the optimization of such options;
- Comparison of tunnel and pipeline conveyance structures from Smithfield Dam to the connection point to Module 3 (henceforth referred to as the inlet to the water treatment works);
- The required storage of Smithfield Dam as required in *Task 5.8*;
- Describing of the tunnel design philosophy;
- Consideration and optimization of the Langa Balancing Dam;
- The identification of the layout to be investigated regarding required materials and geotechnical investigations described in *Task 5.3* and *Task 5.5*;
- Consideration of the vertical alignment of the conveyance structure;
- The identification of the selected scheme layout for dam type selection conceptual design and costing using scheme unit reference values of options.

The final conceptual design and costing of the selected option are dealt with under *Task 5.16* and is described in *Supporting Document 6: Economic comparison of the uMkhomazi-uMlaza transfer scheme with desalination and re-use options*.

The layout of scheme components is shown in **Figure 1.1**.

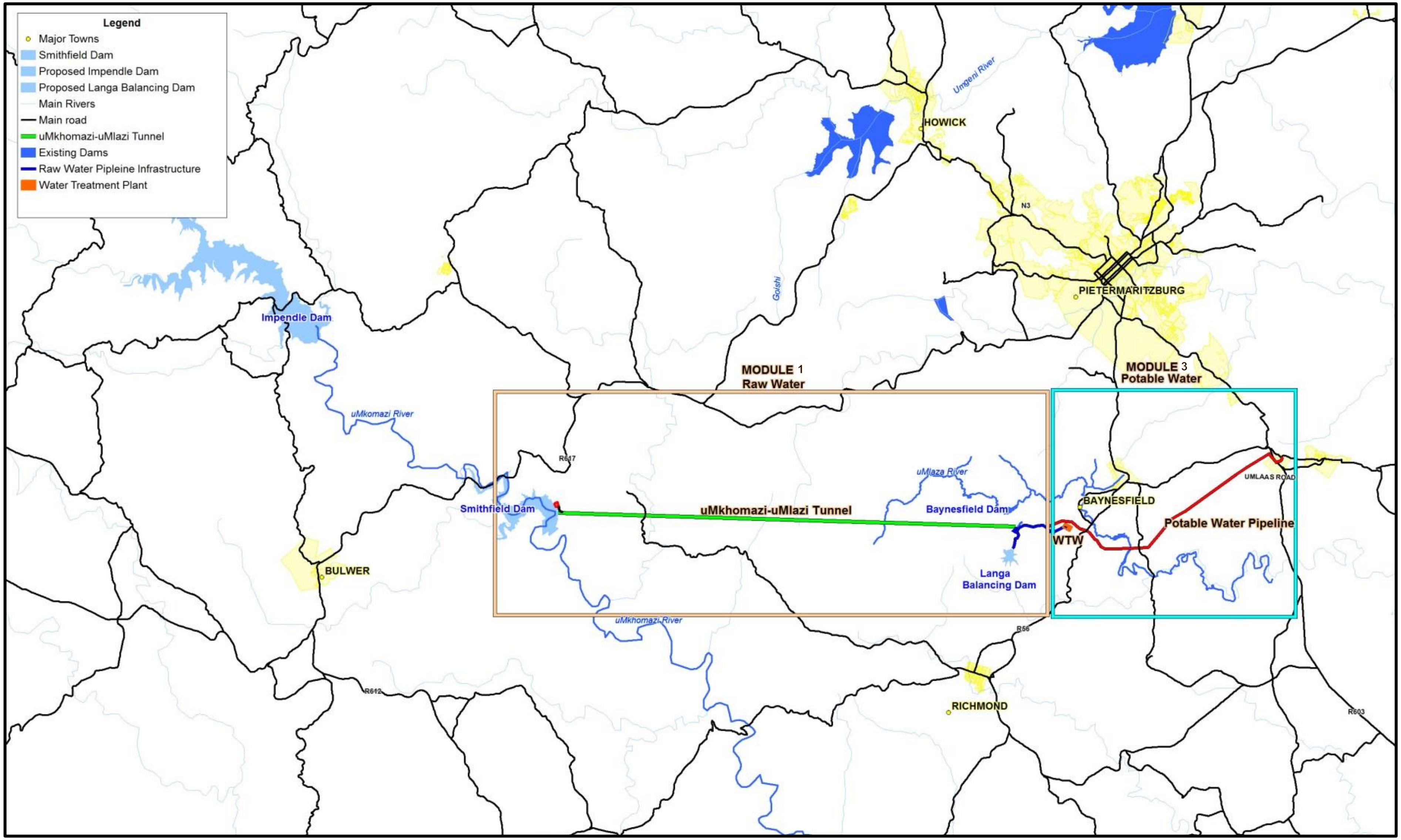

Figure 1.1: Layout of scheme components and phases

2 SMITHFIELD AND IMPENDLE DAM YIELD ANALYSIS RESULTS

2.1 YIELD RESULTS

2.1.1 Pre-feasibility Study

Long-term stochastic yield analyses were undertaken for the earlier *Mkomazi-Mgeni Transfer Scheme Pre-feasibility Study* [1] and the results are listed in **Table 2.1**. Yields are shown for a recurrence interval of failure of 1:100 years (annual reliability of supply of 99%) and analyses were undertaken for (i) the proposed Smithfield Phase 1 Scheme (Smithfield Dam only) and (ii) Smithfield Dam in combination with up to a 1.5 MAR upstream Impendle Dam. Furthermore, two scenarios were analysed, namely for the 1999 – and 2040 – development levels, taking into account the projected growth in catchment developments upstream of the dams over that period, including mainly irrigation and commercial forestry.

The analyses for the *Pre-feasibility Study* were based on the following characteristics for Smithfield Dam:

- Full supply level (FSL): 915 m masl
- Minimum operating level (MOL): 875 m masl
- Gross storage volume: 137 million m^3
- Live storage volume: 129 million m^3
- Mean annual runoff (MAR): 731.1 million m^3/a
- Incremental MAR downstream of Impendle Dam: 163.2 million m^3/a

Table 2.1: Summary of yield results from the *Pre-feasibility Study*

Phase	Description (dam and gross storage volume)		1:100-year yield, at indicated level of development					
	Smithfield Dam	Impendle Dam	1999			2040		
			million m^3/a	Mℓ/d	m^3/s	million m^3/a	Mℓ/d	m^3/s
1	19 % MAR(1)	-	177	485	5.61	147	402	4.66

(1) Based on natural MAR = 731 x 10^6 m^3

2.1.2 Feasibility Study

As part of this feasibility study, yield analyses were carried out for various current-day (2013) and future (2050) development levels. The natural mean annual runoff (MAR) at the Smithfield dam site is 725.9 million m^3 per annum. For the purposes of long term planning and calculating URVs, the future (2050) scenario was chosen. The yield for various sizes of Smithfield Dam on its own as well as in combination with Impendle Dam was assessed. This included up to five different sizes of Smithfield dam ranging from 0.14 to 0.36 MAR in storage capacity, in combination with three different sizes of Impendle, namely 0.5, 1.0 and 1.5 MAR storage capacities. The size of Smithfield is limited due to a physical topography constraint at the preferred dam site. The future 2050 scenario included:

- Projected future development and associated growth in demand for water in the uMkhomazi catchment, both upstream and downstream of the proposed dam sites;
- Preliminary ecological water requirements (EWRs) to be confirmed in the DWA Reserve Study (DWA, 2013);
- Updated catchment runoffs and other hydro-meteorological data;
- Updated dam basin characteristics for Smithfield Dam;
- A dead storage level for Smithfield Dam of 887.20 masl (this corresponds to the energy required in order to provide the minimum required flow within the tunnel and relates to a dead storage volume of 25.23 million m^3); and
- For the 2050-development level, sediment deposition within the Smithfield Dam reservoir was assumed to equal the 30-year future sediment volume, which has been estimated at 17.87 million m^3 at 90% confidence level (*Supporting Document 1: Sediment Yield Report*). Furthermore, it was assumed that approximately 80% of this sediment volume would be deposited within the live storage of the dam.

The yield results determined as part of this Feasibility Study are summarised in **Table 2.2** and **Figure 2.1**. More information in this regard is provided in the *Water Resources Yield Assessment Report (P WMA 11/U10/00/3312/2/3).* Based on **Figure 2.1**, it is clear that a diminishing return in yield with growing storage is recognised, as storage increases in the different scenario options. The increased 1:100 year yield for increasing Smithfield dam sizes with a 1.5 MAR Impendle is almost negligible. This follows the general theory trend of decreasing yield benefit for storage volumes greater than 1 MAR on the eastern parts of the country which have higher more consistent rainfall. The future 2050 water requirement projections for the uMWP supply area are in the order of 220 million m^3/a. More detail is available in the *Water Requirements and Return Flows Report (P WMA 11/U10/00/3312/2/3)*. A Smithfield Dam in the order of 30% MAR capacity with a FSL of 930 masl provides a yield of this magnitude. The results are shown in **Table 2.2**.

Table 2.2: Results of feasibility study yield analyses for Smithfield and Impendle Dams

<table>
<tr><th rowspan="4">Scenario Description</th><th>Impendle Dam</th><th colspan="5">Smithfield Dam</th><th colspan="2" rowspan="2">System Yield @2050</th></tr>
<tr><th rowspan="2">FSL</th><th rowspan="2">FSL</th><th colspan="4">Storage capacity[1]</th></tr>
<tr><th colspan="2">Gross</th><th colspan="2">Live[3]</th><th colspan="2">million m³/a</th></tr>
<tr><th>masl</th><th>masl</th><th>million m³</th><th>% MAR[2]</th><th>million m³</th><th>% MAR</th><th>Hist. firm</th><th>1:100</th></tr>
<tr><td rowspan="5">Smithfield Dam Only</td><td rowspan="5">-</td><td>915.0</td><td>136</td><td>19%</td><td>111</td><td>15%</td><td>103</td><td>163</td></tr>
<tr><td>920.0</td><td>169</td><td>23%</td><td>144</td><td>20%</td><td>122</td><td>181</td></tr>
<tr><td>925.0</td><td>207</td><td>29%</td><td>182</td><td>25%</td><td>145</td><td>200</td></tr>
<tr><td>**930.0**</td><td>**251**</td><td>**35%**</td><td>**226**</td><td>**31%**</td><td>**172**</td><td>**220**</td></tr>
<tr><td>935.0</td><td>301</td><td>41%</td><td>276</td><td>38%</td><td>204</td><td>247</td></tr>
<tr><td rowspan="3">Smithfield & 0.5 MAR Impendle Dam[4]</td><td rowspan="3">1 172.1</td><td>925.0</td><td>207</td><td>29%</td><td>182</td><td>25%</td><td>270</td><td>294</td></tr>
<tr><td>930.0</td><td>251</td><td>35%</td><td>226</td><td>31%</td><td>284</td><td>306</td></tr>
<tr><td>935.0</td><td>301</td><td>41%</td><td>276</td><td>38%</td><td>309</td><td>316</td></tr>
<tr><td rowspan="3">Smithfield & 1.0 MAR Impendle Dam</td><td rowspan="3">1 187.9</td><td>920.0</td><td>169</td><td>23%</td><td>144</td><td>20%</td><td>338</td><td>336</td></tr>
<tr><td>925.0</td><td>207</td><td>29%</td><td>182</td><td>25%</td><td>344</td><td>341</td></tr>
<tr><td>930.0</td><td>251</td><td>35%</td><td>226</td><td>31%</td><td>352</td><td>347</td></tr>
<tr><td rowspan="3">Smithfield & 1.5 MAR Impendle Dam</td><td rowspan="3">1 199.5</td><td>915.0</td><td>136</td><td>19%</td><td>111</td><td>15%</td><td>385</td><td>364</td></tr>
<tr><td>920.0</td><td>169</td><td>23%</td><td>144</td><td>20%</td><td>388</td><td>366</td></tr>
<tr><td>925.0</td><td>207</td><td>29%</td><td>182</td><td>25%</td><td>393</td><td>370</td></tr>
</table>

(1) Storage capacity at construction
(2) Natural mean annual runoff of 725.9 million m³/a at Smithfield dam site (over the period 1925 to 2008, hydrological years)
(3) Live storage is gross storage minus storage at the minimum operating level
(4) Live storage, with natural mean annual runoff of 571.4 million m³/a (over the period 1925 to 2008, hydrological years)

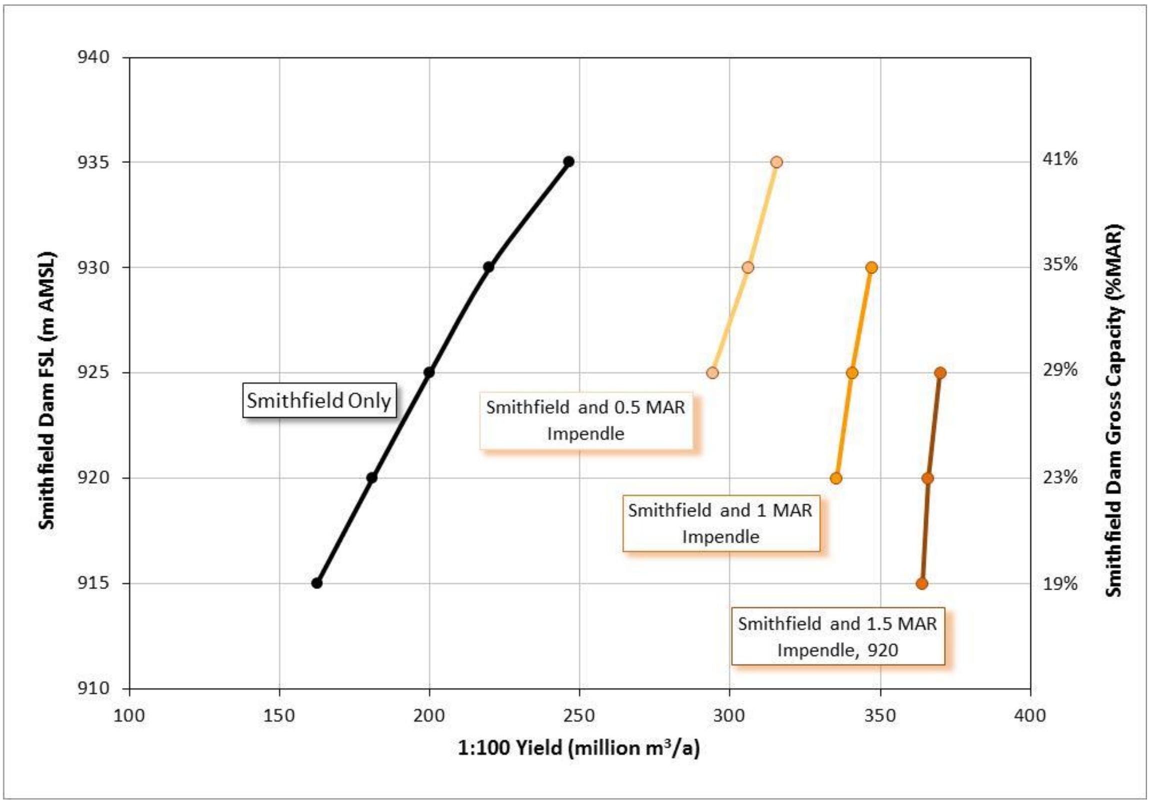

Figure 2.1: Future (2050) yields of Smithfield and Impendle Dam size options

3 SMITHFIELD AND IMPENDLE DAM COST ESTIMATES

3.1 LOCATION OF DAM EMBANKMENT AND CONSIDERED SIZES

The pre-feasibility study and *Task 5.2* report of this feasibility study concluded Site B as the optimal position for the Smithfield Dam. However, these reports only investigated the size of the Smithfield Dam up to a maximum of 35% MAR height with the pre-feasibility yields.

In order to determine the optimum embankment height by comparing yield and dam cost the maximum height of the dam is investigated in this feasibility study to 38% MAR storage volumes or up to a NOC level of 943 masl. The layout for dams at Site B is indicated in **Figure 3.1**.

3.2 COST COMPONENTS

A cost model was developed which included most activities that increase in quantity and cost with increasing heights of the embankment. These activities are:

- Rockfill, filters, transition zones and core material;
- Position and length of the side channel ogee spillway and chute;
- Intake structure to the transfer tunnel;
- Excavations;
- Diversion works with the increase of the tunnel lengths and portal excavation lengths for the different options;
- The relocation of road R617 above the reservoir footprints;
- The diversion of the transmission line around the footprint of the reservoir; and
- The percentage in increase on the above item included for, Landscaping, Miscellaneous items, Preliminary and General, Contingencies, and Planning and Supervision.

The costs of the items were priced in accordance with the average tendered rates from tenders obtained from the construction of Spring Grove Dam. Rates were, however, adjusted to reflect local conditions and quantities.

The cost of both of these components increase in relation to the embankment increase is marginal. However, these items are included when the unit reference values (URVs) are calculated as described in **Section 10** of this report (the unit reference value will allocate a unit value to each scheme as a cost per cubic metre of water over the total life-cycle of the scheme).

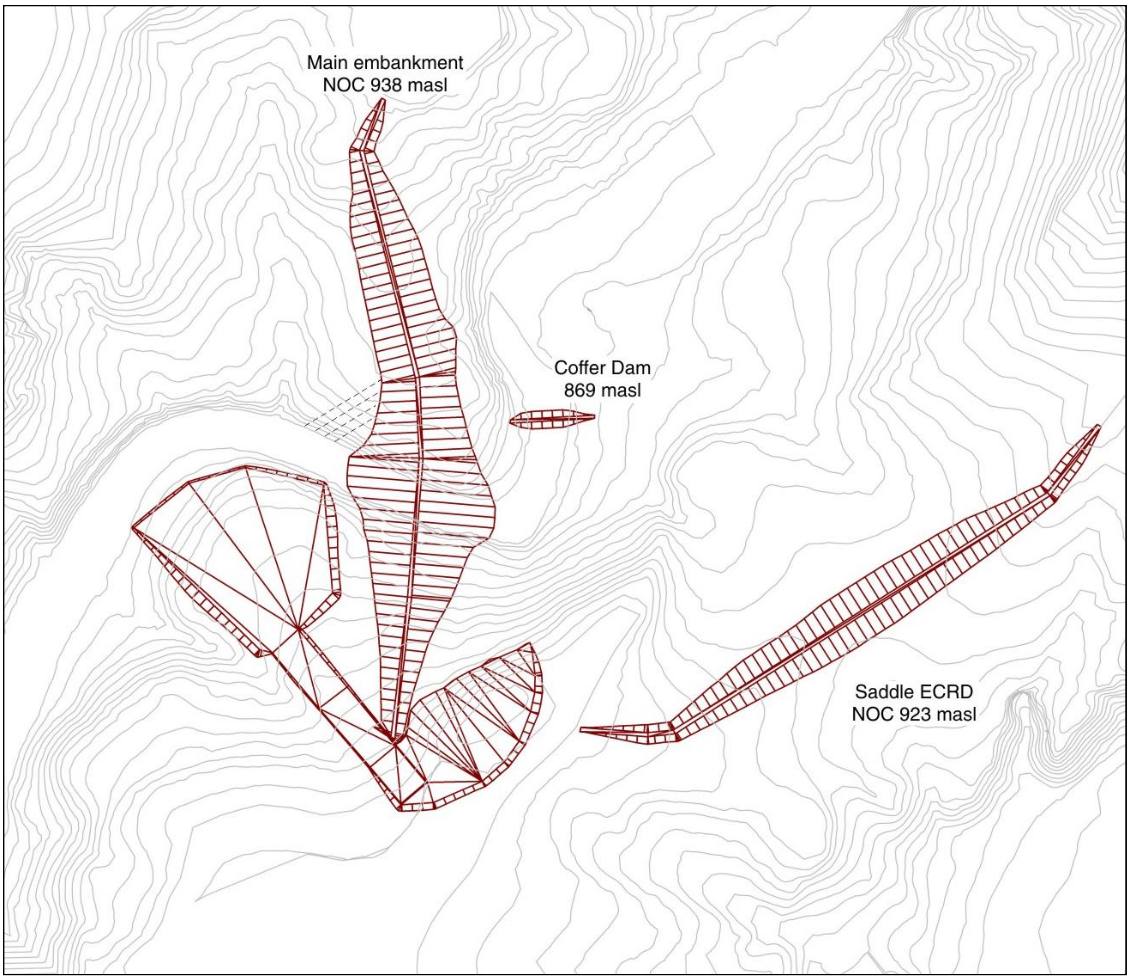

Figure 3.1: Layout of embankment at site B

3.2.1 Results

The detailed cost estimate for a 31% MAR Smithfield Dam is included in **Annexure B**.

Table 3.1: Results of the Smithfield Dam 2013 costs (excluding VAT)

Location	Cost of dam (R million) per percentage of MAR				
	15%	20%	25%	31%	38%
Site B	1561	1733	1948	2203	2517
Cost (R million) of dam embankment only					
Site B	286	358	442	538	655

Size refers to % of 2013 natural MAR

Figure 3.2 below graphically displays the costs in **Table 3.1**.

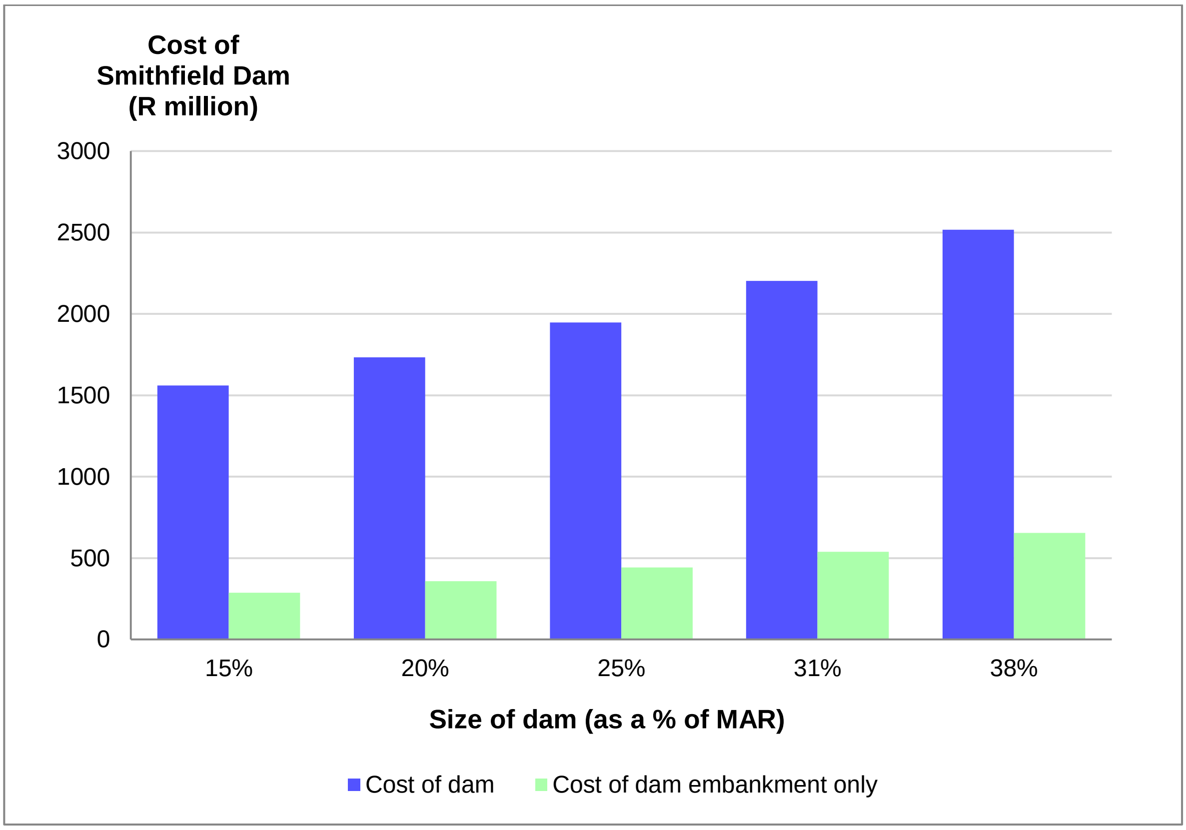

Figure 3.2: Smithfield Dam costs for various sizes

4 PROJECT WATER REQUIREMENTS

4.1 SUPPLY AREAS

The water requirements are based on the projections provided by Umgeni Water for the water supply area downstream of the Umlaas Road reservoir. The water supply areas are shown in **Figure 4.1**.

The water supply areas and reservoirs serviced are shown in **Table 4.1**.

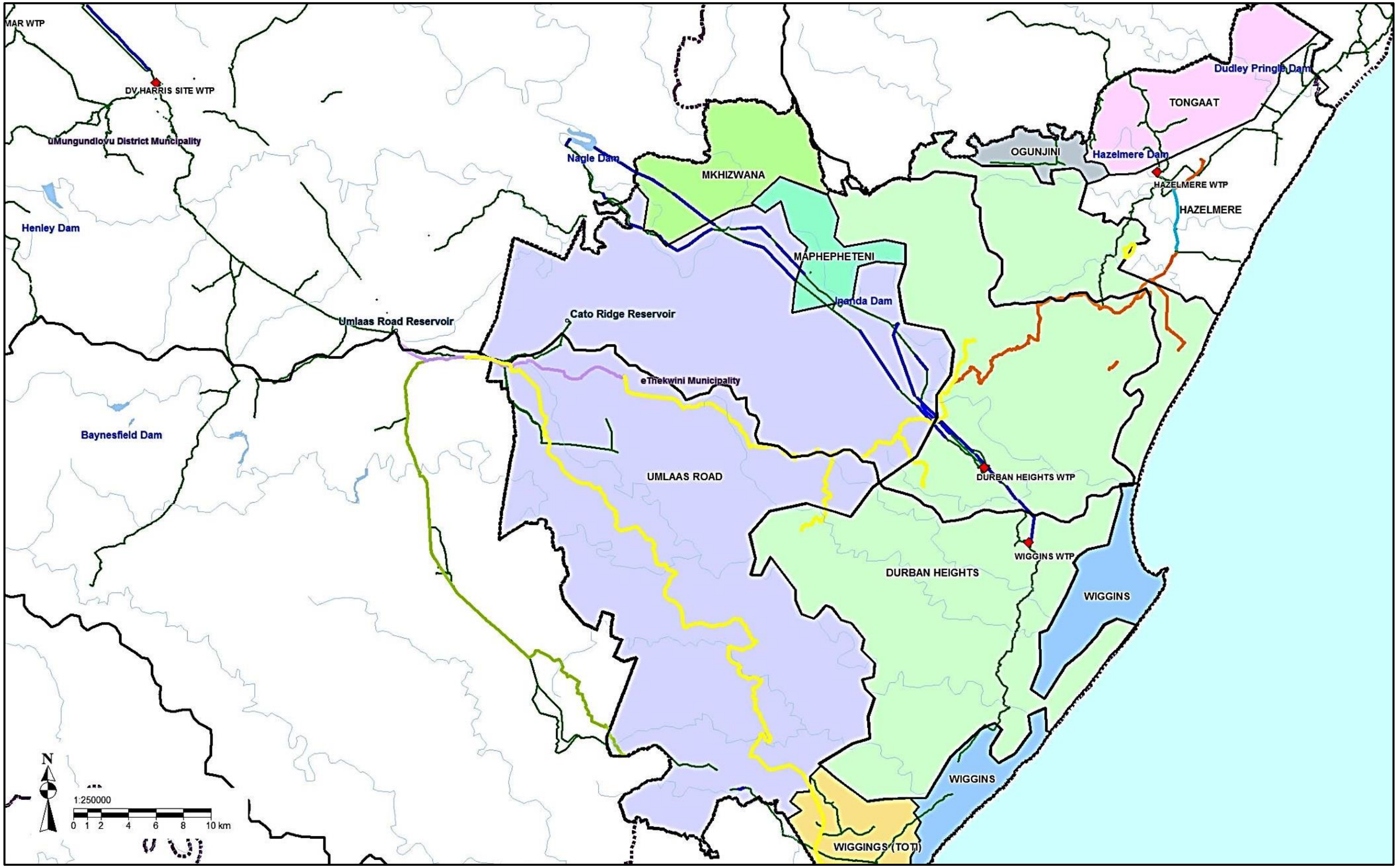

Figure 4.1: Water requirements areas included in demand studies

Table 4.1: uMkhomazi supply area

Supply Area	Names of included reservoirs	
Western	Abelia	Mpumalanga 1
	Alverstone Nek	Mpumalanga 2
	Bothas Hill	Mpumalanga 3
	Cato Ridge Abbattoir	Mpumalanga 4
	Cato Ridge	Mpumalanga 6
	Emberton	Ofudu
	Georgedale & Et	Pinkney Park
	Hammersdale Hl	Plateau Et
	Hammersdale_Ll_	Point M
	Hoyer (Ex Ctholme)	Salem
	Knlesby Pk	Shongweni
	Kwanqetho	Summerhills Et
	Molweni 1	Westriding
	Molweni 2	Zwelibomvu 2
	Monteseel Ps & Et	
Pinetown, Wyebank-Bershire Downs System	Berkshire Downs	Hocking Place
	Clermont 1, 2&4	Methven
	Clermont 5	Mountain Ridge
	Kwadabeka 5	Paradise Valley
	Clubhouse Place	Pinetown System
	Haygarth Road	Wybank
KwaDabeka	Kwadabeka 1 Bpt1 & Bpt2	Kwadabeka 3
	Kwadabeka 2	Kwadabeka 4
Tshelimnyama	Intake Road	Tshelimnyama 2
	Kwadengezi	Tshelimnyama 3
	Tshelimnyama 1	Washington Hts
Ntuzuma	Amaotana	Ntuzuma 4
	Etafuleni	Ntuzuma 5
	Kwasilwane	Ntuzuma 7
	Nr 5 Elevated Tank	Rural North West
	Ntuzuma 3	Sensokuhle
Northern Aquaduct	Cornubia	Phoenix 5
	Mount View	Umhlanga 2
	Phoenix 2	Umhlanga North
	Phoenix 4	Umhlanga South
iNyaninga	Ksia & Dube Tradeport	Inyaninga
Waterloo	Sibaya Nodes 1-5	Mt Moreland Township
	Sibaya West	Mt Moreland South
	Umdloti North	Mt Moreland North
LaMercy	La Mercy Beach	Zimbali South Banks / Westbrook
Mzinyathi	Nr5 To Mzinyathi	Ogunjini Waterworks Partial Demand

The water requirements are based on average annual daily figures, and allowance for phasing out of existing water treatment plants were made. The projections are shown with a 1.5% annual increase line coupled to a start date after phasing of supply systems had been completed in **Figure 4.2**.

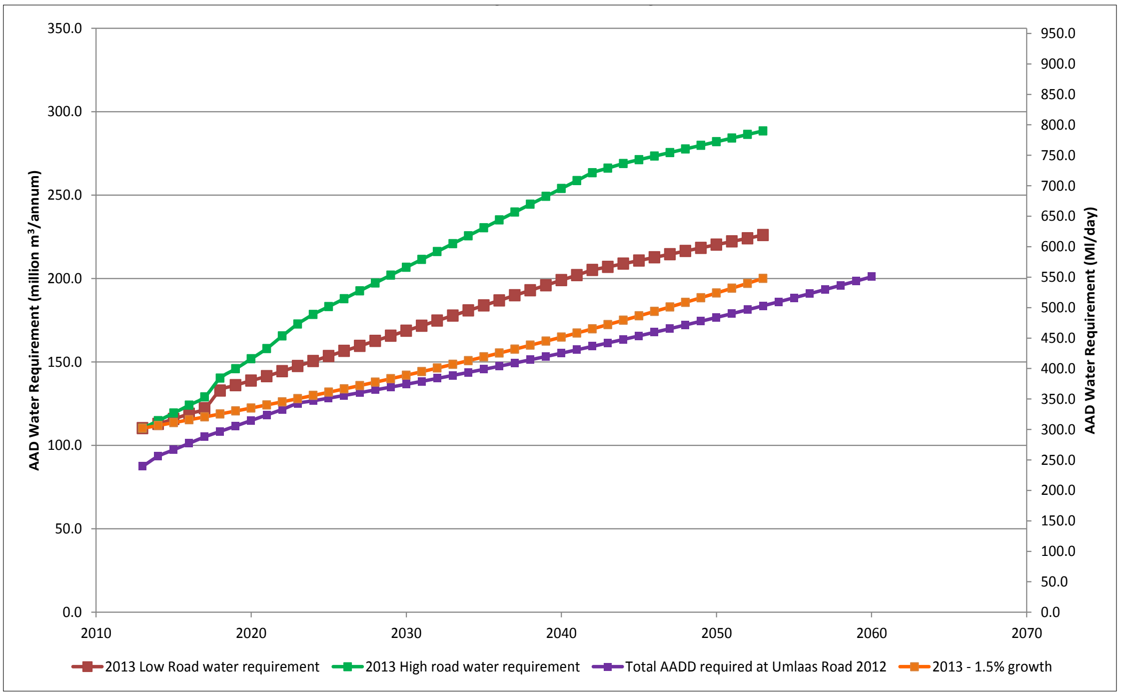

Figure 4.2: uMkhomazi Water Project direct supply area water requirement projections

The low road projection follows the annual growth of 1.5% per year. This projection follows the historic pattern as shown in **Figure 4.2**.

5 CONVEYANCE STRUCTURE TRANSFER CAPACITIES

5.1 DESIGN TRANSFER CAPACITIES OF PHASES

The design transfer capacities were based on a peak supply factor of 1.25 and the available yield from the dam.

No operational peak factors have been considered. This was agreed with Umgeni Water and will be added in the supply system downstream of the tunnel.

Sizing of the first tunnel, for Phase 1, was based on a flow rate of 8.65 m^3/s, which is associated with a 31% MAR Smithfield Dam.

The design transfer flow capacities for one maximum size transfer tunnel are shown in **Table 5.1**:

Table 5.1: Smithfield dam transfer design flow capacities

Dam Size (%)	Dam Yield		Transfer Design[(1)] Capacity
	(million m^3/yr)	(m^3/s)	(m^3/s)
15	163	5.17	6.46
20	181	5.74	7.17
25	200	6.34	7.93
31	220	6.98	8.65
38	247	7.83	9.79

(1) Including peak supply factor of 1.25

6 SIZING OF CONVEYANCE STRUCTURE

6.1 HYDRAULIC DESIGN

The longitudinal section of the tunnel and pipeline with the water energy line from Smithfield Dam to the Module 1 – Module 3 connection point (inlet to the WTW) is shown on Figure 6.1. A layout of the conveyance system is shown in **Figure 6.2**.

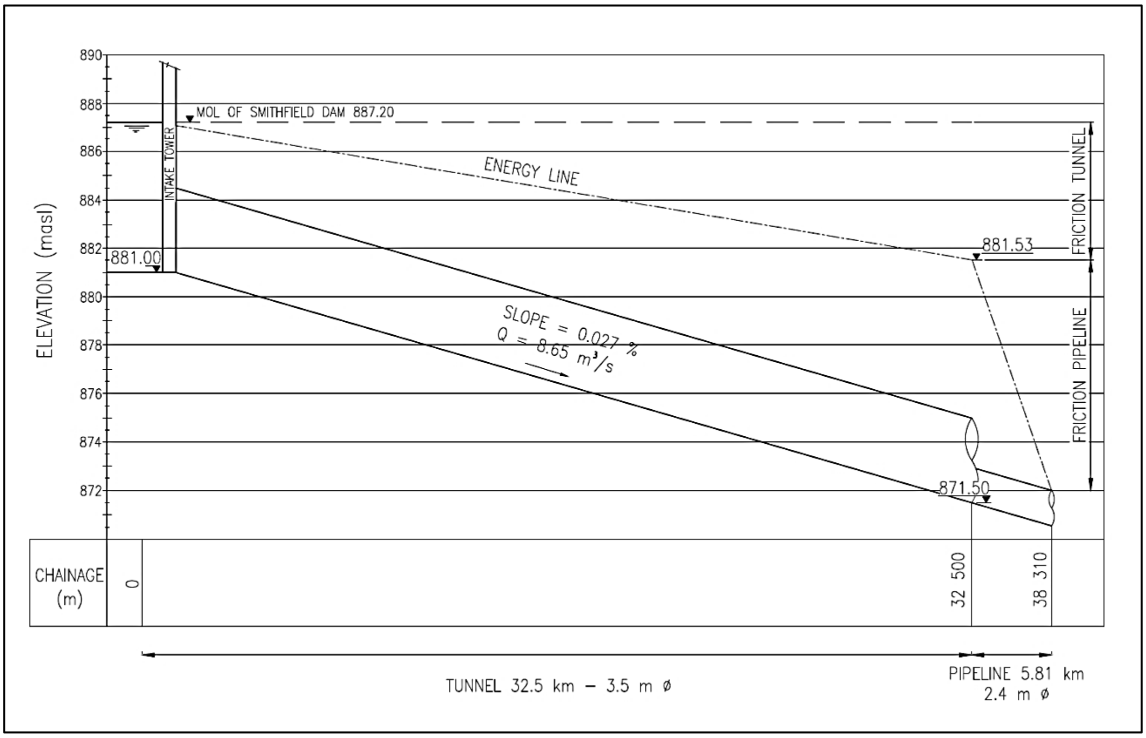

Figure 6.1: Schematic layout of conveyance system showing energy line

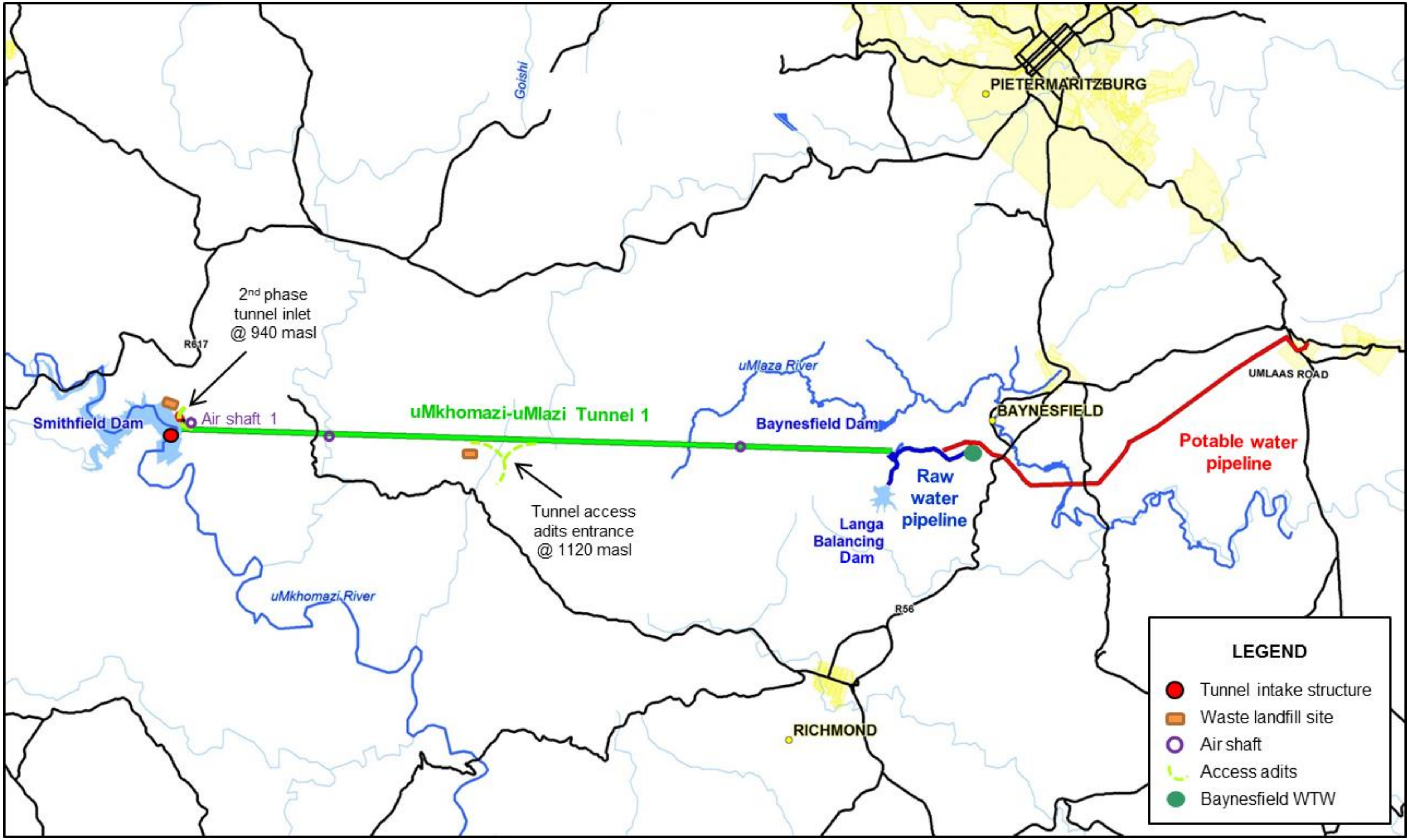

Figure 6.2: Proposed layout of the conveyance system

This layout is based on the following:

- The minimum operating level of Smithfield Dam is 887.2 masl, which is the head water level at the beginning of the tunnel. This head is required for the transfer of the required flow under gravity;
- The intake level of the lowest pipe at the Intake Structure is at 881 masl. This level is at the storage volume of the reservoir associated with the expected 50 year sediment volume at a confidence level of 80% (13.91 million m^3 – see sedimentation report), retained in the reservoir from the Smithfield Dam Embankment with a horizontal depositioning pattern. This assumption is not practical as most silt will be deposited in the upper reaches of the reservoir where the water velocity of flowing water decreases and where power allows. As a result, a sedimentation deposition study considering the longer than 100 year impact of sedimentation around the reservoir intake to the tunnel should be carried out. Furthermore, it is better to carry out this study during the feasibility stage than the design stages of the project in order to prevent changes to the vertical alignment of the tunnel during the design stages, which may have an effect on the yield of the system when the minimum operating level has to be raised. If this study is not carried out in any phase of the implementation of the project it may result in the tunnel entrance becoming blocked or sediment being drawn through the tunnel and supply pipelines in the future.

  Therefore the depositioning of silt is a study on its own using specific principles and must be done before the scheme is implemented;

- 3.5 m diameter tunnel with lengths as indicated in the figure;
- 2.4 m diameter pipe from the tunnel end to the connection point (connection point was later changed);
- Umlaas Road to be served at the end of the pipeline section from the connection point to the Umlaas Road Pipeline, which is designed by the Module 3 Consultants – Knight Piésold. The head water level required at the connection point meeting this demand is 871.5 masl, and
- Discharge design flow: 8.65 m^3/s.

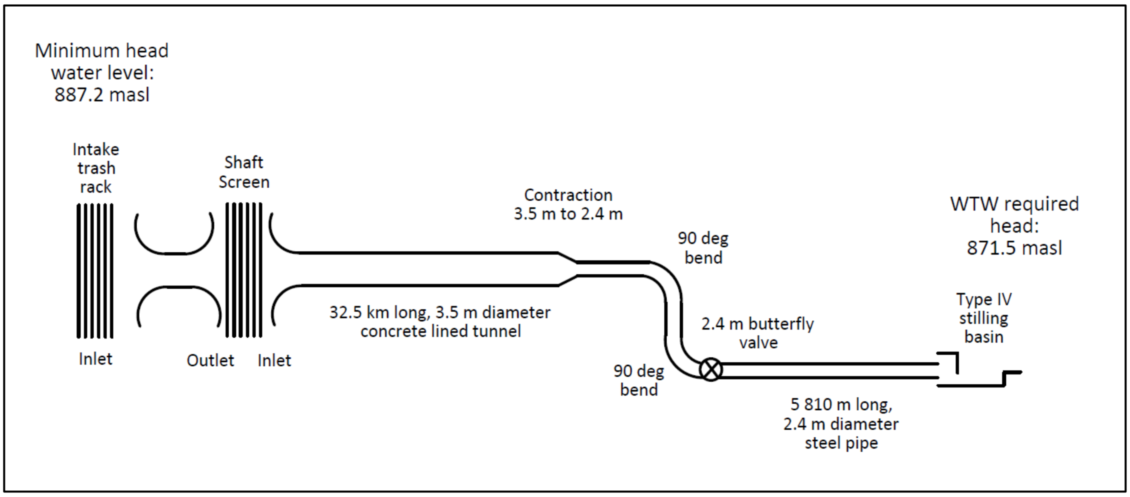

Figure 6.3: Layout of system showing components regarding hydraulic friction

The layout of the proposed conveyance system having effect on hydraulic friction consists of the following:

- A 3.5 x 3.5 m Trash Rack at the inlet of the Intake tower;
- A bellmouth intake at the tunnel inlet;
- A 3.5 x 3.5 m screen at the tunnel shaft;
- The 3.5 diameter tunnel for length 32 500 m;
- A reducer from the tunnel to the steel pipe of 3.5 to 2.4 m diameter;
- Two 90° bends;
- A 2.4 m diameter butterfly valve;
- A 2.4 m diameter steel pipe from the tunnel outlet to the WTW;
- A Type IV stilling basin at the outlet of the steel pipe; and
- The friction formula for the tunnel and the pipe is the Darcy-Weisbach friction loss **Equation 6.1**:

$$hf = \frac{\lambda L V^2}{2gD} \qquad (6.1)$$

Where:	h_f	=	Frictional head loss, m
	λ	=	Pipe friction factor
	L	=	Length of the pipe, m
	V	=	Average velocity in the pipe, m/s
	G	=	Gravitation constant, m/s²
	D	=	Diameter of the pipe, m

- The formula for determining the λ pipe friction factor is the Barr pipe friction factor **Equation 6.2**:

$$1/\sqrt{\lambda} = -2\log\left(\frac{ks}{3,7D} + \frac{2,51}{RE\sqrt{\lambda}}\right) \quad (6.2)$$

Where:

$$RE = \frac{DV}{v} \quad (6.3)$$

And:	λ	=	Pipe friction factor
	K_s	=	Absolute roughness of pipe, m
	RE	=	Reynolds number
	D	=	Pipe diameter
	V	=	Velocity in pipe, m/s
	v	=	Kinematic viscosity = 1.13×10^{-6} m²/s

The K_s value for a tunnel is estimated for this investigation as 1.5 mm and for a steel pipe as 0.5 mm. The minor losses in the tunnel are estimated as $0.5\frac{V^2}{2g}$ and for the steel pipe as $0.8\frac{V^2}{2g}$.

7 OPTIMIZATION OF TUNNEL AND PIPELINE SIZE

Hydraulic calculations showed for the complete conveyance system that the following options are possible for the tunnel and pipe system:

- Option A: A 3.5 m internal diameter tunnel combined with a 2.4 m diameter pipeline; or
- Option B: A 4 m internal diameter tunnel combined with a 2.1 m diameter pipeline

A cost comparison of these two options is indicated in **Table 7.1**:

Table 7.1: Cost comparison of two tunnel diameter layouts

Description	Option	
	A	B
Tunnel length (km)	32.50	32.50
Tunnel diameter (m)	3.50	4.00
Pipeline Length (km)	5.81	5.81
Pipeline diameter (m)	2.40	2.10
Unit cost for tunnel (R/m)(1)	71 000	78 000
Unit cost for pipeline (R/m)(2)	50 000	33 000
Total Tunnel cost (R million)	2 307 500	2 535 000
Total Pipeline cost (R million)	290 500	191 730
Additional 500 mm pipe to balancing Dam		
Total cost (R million)	**2 598 000**	**2 726 730**

(1) Supporting document 1
(2) Umgeni Water study

From **Table 7.1** it is clear that the 3.5 m internal diameter tunnel option with the 2.4 m diameter system is the cheapest. The selected tunnel diameter is therefore 3.5 m.

8 OPTIMIZATION OF CONVEYANCE STRUCTURE LAYOUT FROM SMITHFIELD DAM TO BAYNESFIELD ESTATE

8.1 INTRODUCTION

In this section the layout configuration regarding the horizontal and vertical alignments of the conveyance structure is addressed. This was based on the following criteria:

- The selected tunnel diameter of 3.5 m – see **Section 6**.
- The minimum operation level of Smithfield Dam of 887.5 masl for meeting the design flow requirement in the conveyance structure– see also previous sections;
- The conveyance structure includes the tunnel and the first section of the pipeline to the WTW as shown on **Figure 1.1**. The delivery level at this point is 875.6 masl as required by the pipeline infrastructure of Module 3. (Two levels have been considered in conjunction with Umgeni Water: 875.6 masl and 871.5 masl.)

8.2 HORIZONTAL ALIGNMENT OF TUNNEL AND PIPELINE

8.2.1 Introduction

Supporting documents 1 and 2 of the Engineering Investigation Task address the optimization of the Smithfield Dam and Smithfield Dam to Baynesfield Dam Tunnel as storage reservoir and conveyance structure. A recommendation for a pressure tunnel was adopted. This section investigates the optimal horizontal tunnel alignment from Smithfield Dam and the optimal pipe alignment from the tunnel exit to the inlet to the WTW.

8.2.2 Options

The options identified for comparison purposes are shown in **Figure 8.1**. The longitudinal sections along the pipeline routes are shown in **Figure 8.2**.

The options are as follows:

- Option A: Tunnel end at western side of Baynesfield Dam and pipeline connection on downstream side of dam;
- Option B: Tunnel ends in upper reaches of the Baynesfield Dam. Pipeline bypass is provided around Baynesfield Dam;
- Option C: Tunnel end at western side of Mbangweni Dam with short pipeline connection around Mbangweni Dam; and
- Option D: Same as Option C but the tunnel ends on the upper reaches of Mbangweni Dam.

In this comparison the balancing dam was not added as it is common to all options. A connection pipe to the dam was, however, included.

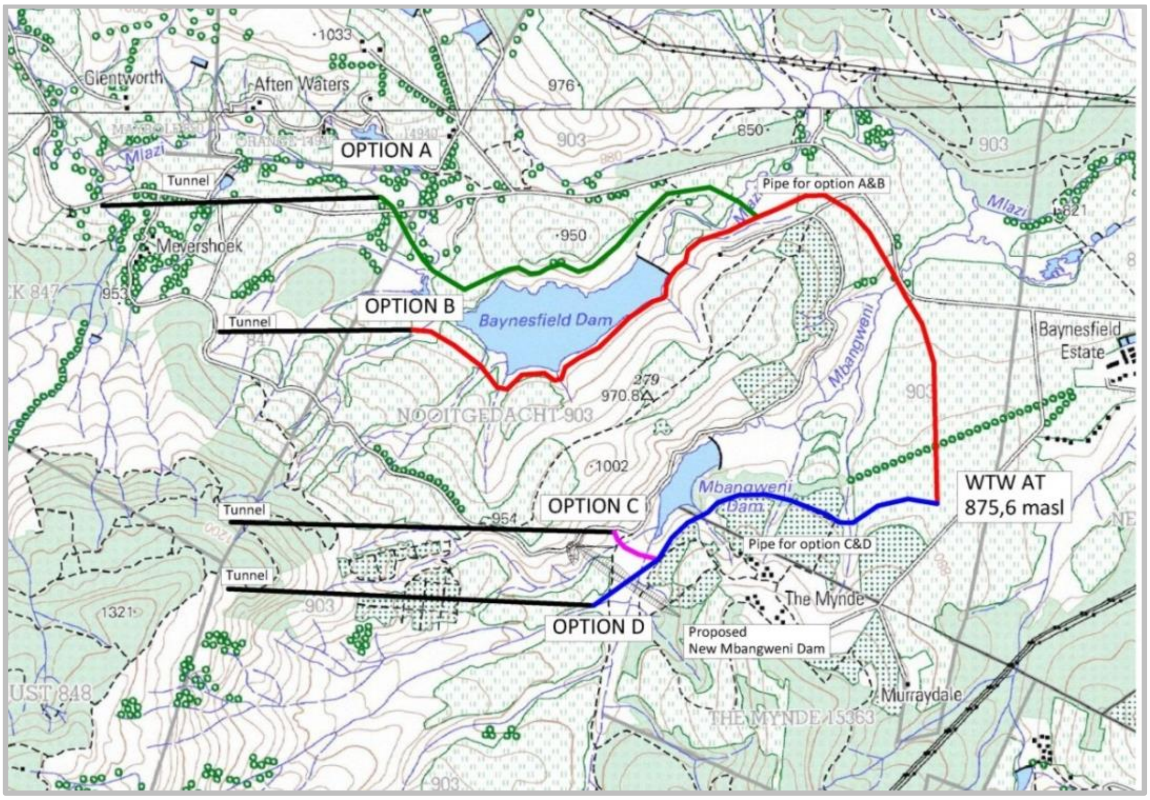

Figure 8.1: Layout of options

Sizing of the options was based on the *Supporting Document 1* assumptions regarding design transfer capacity, that is: 8.65 m^3/s. The characteristics and assumptions for the considered tunnels and pipelines are as shown in **Table 8.1**.

Table 8.1: Main characteristics and assumptions for considered pipelines

Component	Option			
	A	B	C	D
Tunnel length (m)	32 500	32 459	34 100	33 789
Ideal head level at end of tunnel (masl)	882.4	882.4	882.17	882.2
Pipeline length (m)	5 822	5 700	3 050	2 606
Pipeline required diameter (m)	2.1	2.1	1.9	1.8
Cost Estimate of pipe (R million)	134	132	64	52

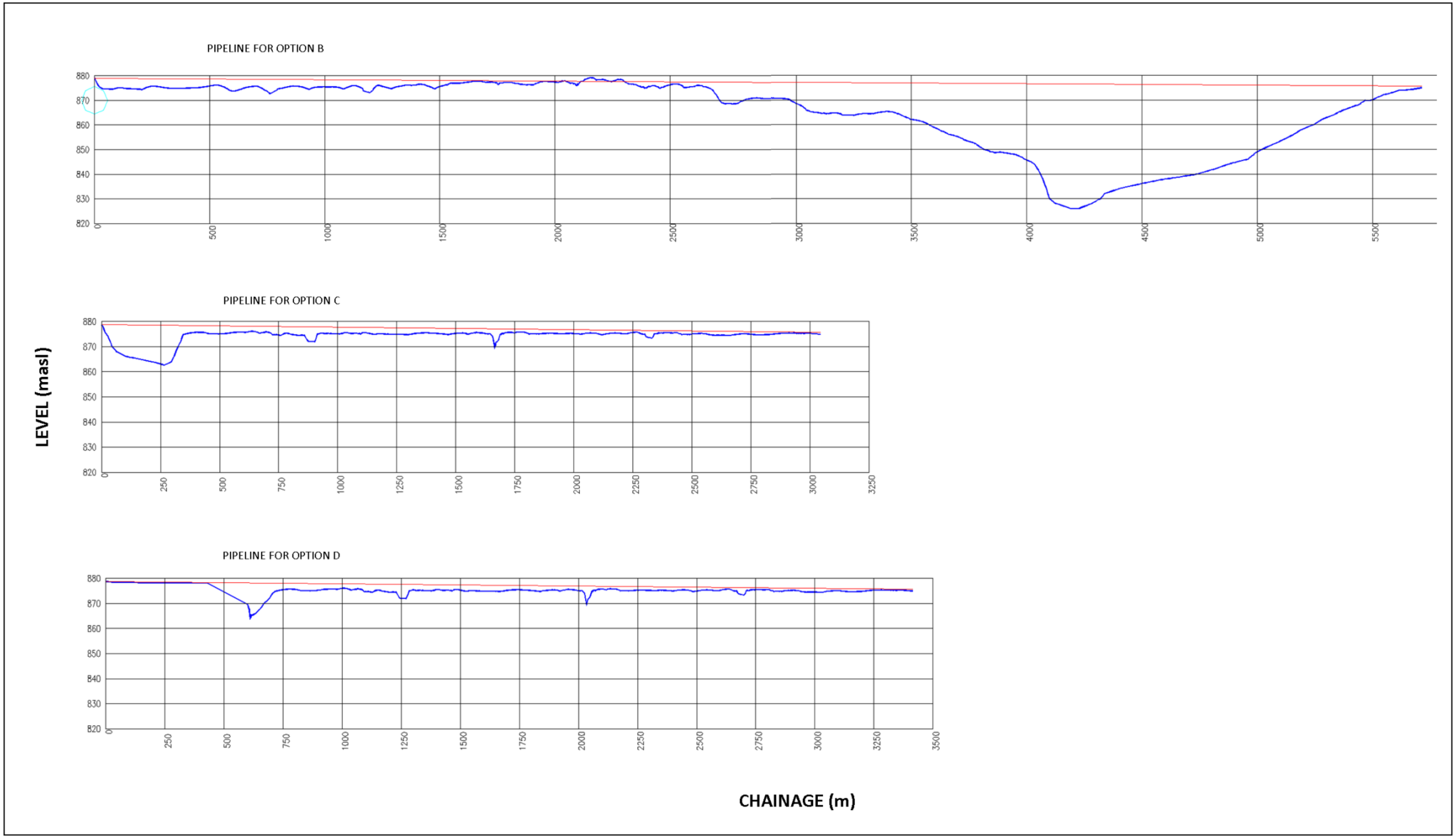

Figure 8.2: Long sections of pipelines for options

8.2.3 Comparison of options

The options are compared regarding dimensions, cost as well as other aspects as shown in **Table 8.2**:

Table 8.2: Cost comparison of tunnel and pipeline options

Component	Option			
	A	B	C	D
Tunnel length (km)	32.5	32.4	34.1	33.8
Unit cost for tunnel (R/m)	71 000	71 000	71 000	71 000
Total tunnel cost (R million)	2 308	2 305	2 421	2 399
Pipeline length (km)	5.82	5.70	3.05	2.6
Unit cost for pipeline (R/m)	23 320	23 320	20 900 (ND 1 900)	19 800
Total pipeline cost (R million)	136	132	63	52
Additional Excavation required (m^3)	85 127	85 127	0	0
Cost of excavation (Average Soft and hard rock) (R/m^3)	100	100	0	0
Total additional excavation cost (R million)	8.5	8.5	0	0
Additional pipe length from Balancing Dam (m)	2106	2106	100	NA
Unit cost for pipeline from balancing dam (R/m)	23 100 (ND 2 100)	23 100 (ND 2 100)	20 900 (ND 1 900)	NA
Total pipeline cost from Balancing Dam (R million)	49	49	2,1	NA
Total conveyance cost (R million)	2 502	2 494	2 486	NA
Other aspects	Actual tunnel length to end point: 34.3 km. Due to lack of rock cover the tunnel was ended at 32.5 km and a pipeline connected from there. However, roof cover still less than 10 m for last km.		Based on a TBM drilling rate of 130 m/week the construction programme for constructing relative to Option B additional 1.6 km will be 3.1 months longer	The tunnel end daylights below FSL of the proposed Balancing Dam Reservoir.

From **Table 8.2** the following is clear:

- The cost difference between the options are negligible;
- For Option A, a tunnel to chainage 34.3 km is not possible. A shorter tunnel with an extension pipeline was evaluated and is comparable in cost with Option B. The roof cover for the last 1 km is less than 10 m which may result in more excavation and time delays during construction;
- The pipeline from the tunnel outlet to the Water Treatment Works for Option B must be laid below ground level to ensure that it is below the hydraulic grade line as Baynesfield Dam prohibits the change in position of the pipeline. The excavation cost most probably does not clearly reflect the difficulties to excavate to a depth of 6 m on a cross incline of 22%;
- Option C will need about 3.1 months longer construction period than Options A and B due to the tunnel construction, which is on the critical path;
- A short section of the pipe to the WTW inlet of Option C will be constructed below the water table (Upstream of Mbangweni Dam);
- Although lower in cost, Option D is similar to Option C in requiring longer construction time; and
- Option B requires an additional 2 106 m long pipe excavation in saturated conditions from the balancing dam to the WTW inlet.

8.2.4 Conclusion

As the costs of Positions B and C are almost the same, Position C is favoured for the following reasons:

- The pipe to the connection point does not have to be lowered in order to be below the hydraulic grade line;
- Due to the shallower excavation depth the construction of the pipe will be easier at most sections (depth);
- Due to the shallower excavation depth, the excavation footprint will be much smaller and could favour environmental considerations;
- Option B has an additional pipe length of 2 106 m from the balancing dam, which increases the environmental impact; and
- The pipe to the WTW inlet for Option C has more space to be positioned, if required, than at Position B (Baynesfield Dam prohibits major position changes of the pipe).

From the above it is clear that Option C is favoured. This layout was selected for further analyses.

8.3 VERTICAL ALIGNMENT LAYOUT OF TUNNEL FROM SMITHFIELD DAM TO BAYNESFIELD ESTATE

The horizontal alignment of the tunnel and pipe to the WTW inlet was investigated and selected in the previous section. In this section the vertical alignment of the tunnel is optimised further focussing on local geological and potential high groundwater inflow conditions, construction methods, practical conditions as well as drainage aspects. Each of the following will be addressed:

- Engineering geology;
- Expected tunnel conditions;
- Excavation method;
- Size of tunnel;
- Advanced rates;
- Drainage during construction and operation of scheme;
- Access to the tunnel;
- Drainage during construction;
- Different alignment options;
- Position and level of the intake for the EWR, drainage and tunnel releases during the operation of the scheme; and
- Costs.

The selected plan layout of the tunnel/pipeline transfer system is shown in **Figure 8.3**. Background on tunnel techniques and general philosophy of tunnelling are included in **Annexure A**.

8.3.1 Engineering geology

The proposed ±32 km long tunnel is expected to be mainly driven within rocks of the Volksrust Formation (70%), which almost exclusively comprises predominantly siltstone, but will also intersect strata of the older Vryheid Formation (15%) which comprises sandstone with interbedded siltstone, and the Pietermaritzburg Formation (15%), a relatively homogeneous unit comprising siltstone with inter-bedded mica-rich horizons. These rocks all form part of the Ecca group of the Karoo sequence. These sedimentary strata have all been intruded by dolerites, in the form of dykes and sills.

The extent to which the dolerites are expected to intersect at tunnel invert level is unknown

8.3.2 Expected tunnel condition

With the exception of the areas close to the portals, the tunnel is expected to be excavated within an unweathered rock mass. Siltstone, shale, mudstone, sandstone and dolerite and combinations of these rock types will be encountered across the tunnel section. The dolerite intrusions could have a blocky structure which may lead to instability problems and certain of the sedimentary rocks are known to be susceptible to slaking. These problems can be overcome by installing the correct primary support.

Available geotechnical information indicates that tunnelling conditions should generally be favourable, but that the potential for high groundwater inflows exist, particularly at the dolerite contact zones.

8.3.3 Excavation method

After consideration of the advantages and disadvantages of various excavation methods as described in the tunnel design philosophy included in **Annexure A**, it is recommended that the main tunnel be excavated by means of Tunnel Boring Machine (TBM). The tunnel boring machine would be suited to the relatively uniform geology and the envisaged long drives. In addition, the TBM excavation would be suited to the required low grades. A minimum grade of 0.1% is normally used for gravity drainage of water inflow.

8.3.4 Size of tunnel

A 3.0 m diameter lined tunnel may well be acceptable, but will not be a practical solution due to the fact that for long drives the tunnel will be too small to accommodate train crossings, ventilation and conveyor belts. A minimum internal diameter of 3.5 m was utilized on this project. This conforms to the hydraulic requirements described in previous sections of this report.

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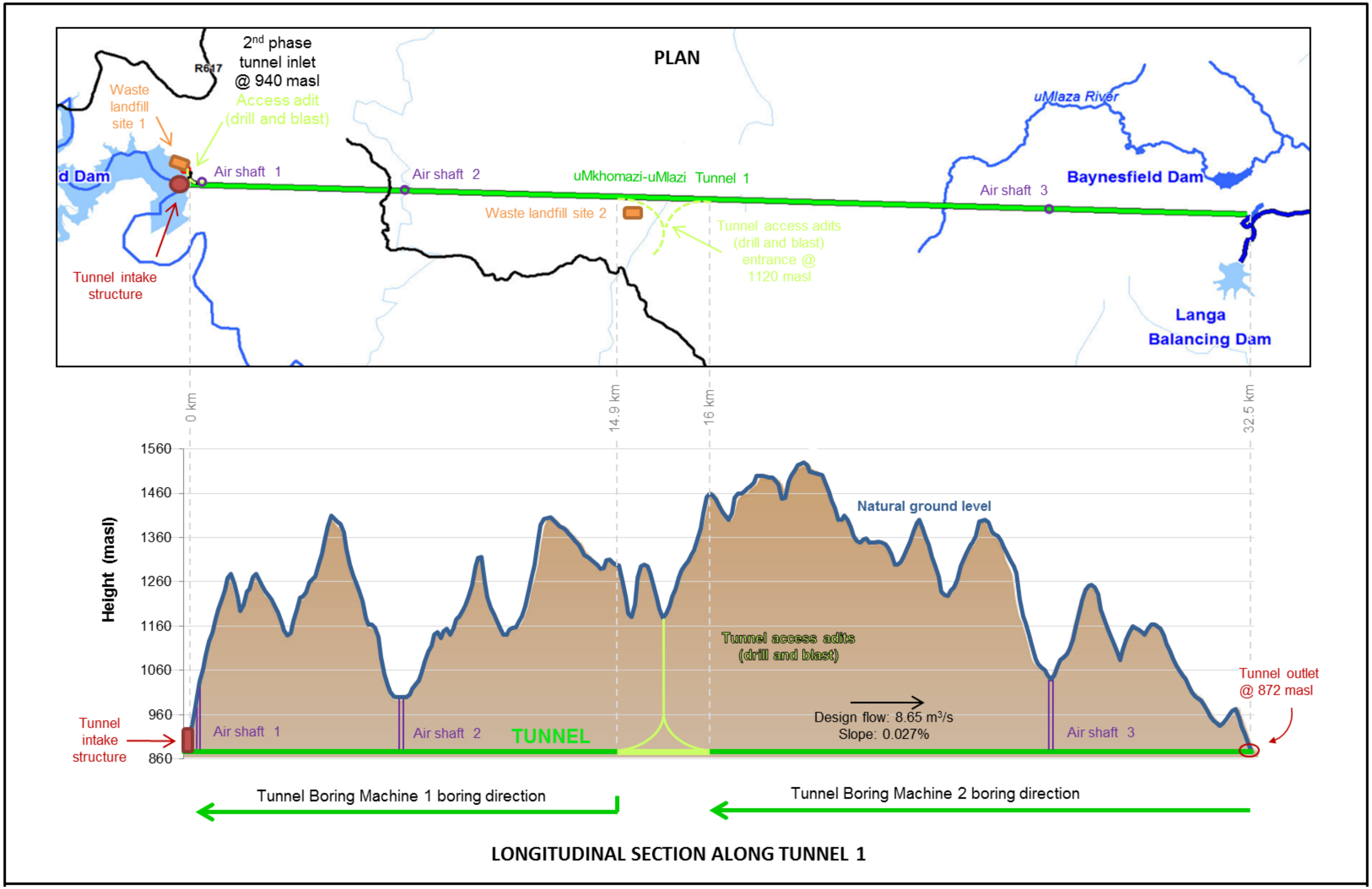


Figure 8.3: Proposed layout arrangement for tunnel

8.3.5 Economic tunnel drive lengths

A study conducted on the Mohale Tunnel of the Lesotho Highlands Project has shown that 15 km is the maximum economical length of drive achievable by a 3.5 m diameter TBM. Thus it is envisaged that at least two TBMs would be utilized on this project. Aspects such as access and ventilation can become problematic with longer drives.

As the tunnel(s) will operate under pressure it is assumed that the tunnel(s) will be fully concrete lined along the entire length. Waterproof membrane and steel liners have not been considered at this stage. The assumptions will be refined during the detailed design stage once more data is available.

8.3.6 Advance rates

Advance rates of TBM excavation and concrete lining are anticipated to be of the order of 130 m per week, per heading. This would equate to an excavation duration of approximately 123 weeks (or 2.4 years) for two TBMs. Coupled to this would be the lead time required to get a TBM on site. This varies from 9 to 12 months for a new machine from time of order, to perhaps 3 to 6 months for a refurbished machine. Once the machinery is on site, 3 to 6 weeks will be required for assembly. The start of boring operations rarely occurs with the full back-up system in place. Hence, decreased advance rates of the order of 50% less than for full production should be expected for the first 4 to 8 weeks of mining, as the back-up system is installed and the crew learns the ropes of system operation.

Experience indicates that tunnel depth has little impact on advance rates in civil projects, provided that the Contractor has installed adequate mucking capacity for non-delay operation. Therefore, tunnel depth should be chosen primarily by location of good rock. Portal access, as opposed to shafts, will facilitate mucking and material supply, but more importantly is that the staging area for either shaft or portal be adequate for contractor staging (such as precast yard if segmental lining is to be utilised). Confined surface space can have a severe impact on project schedule and costs.

8.3.7 Access during construction

For this long tunnel, intermediate access points are considered for ventilation and mucking exits.

It is proposed to drill and blast access tunnels which will facilitate demobilisation of the TBMs in the main tunnel. These access tunnels would be excavated at the mid-point of the main tunnel. The radius of the access tunnels should be at least 250 m with a vertical gradient of 12% to facilitate the access of TBM hauling equipment. The entrance of this adit is located at 1 120 masl. The ±500 m central portion of the tunnel is planned to be constructed with drill and blast techniques.

These access tunnels (adits) could be excavated during the lead time for the TBMs. Excavation rates for a 3.5 m to 4.0 m diameter tunnel can be expected to be of the order of 40 m per week per heading.

An adit is provided to the Intake structure of the tunnel to provide entrance to the second tunnel when this is constructed.

As it is envisaged that a second tunnel will be excavated around 2044, it is prudent to excavate the inlet **stub tunnel** during the initial contract to facilitate access to the second main tunnel as this inlet will be inundated at 2044 by the Smithfield reservoir. The inlet from the Inlet tower and shaft of this stub tunnel should be provided with stop-logs or an equivalent sealing system, as this would be necessary for the excavation of the second tunnel without interfering with the operation of the initial tunnel.

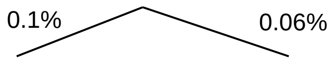
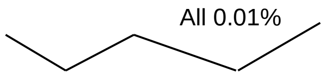
8.3.8 Drainage during construction and operation of scheme

The construction of a tunnel with a TBM requires the addition of water; additionally, water seeps into the tunnel boring. If excavation of a tunnel is carried out with free drainage away from the excavation head and no pumping of the water is required, the cost of excavation is approximately 10% less.

8.3.9 Alignment options

The alternatives with different alignment and drainage options shown in **Table 8.3** have been identified.

Table 8.3: Description of tunnel alignment options

Option	Configuration	Direction of excavation and drainage requirements during construction	Drainage requirements during operation
1	Slopes from centre towards downstream ends  Intake foundation level: 862 masl Outlet level: 875 masl	TBM accesses from the ends. No drainage requirements for free draining conditions	Pumping or drainage for inspection required for upstream half. Air shaft provided in centre.
2	One downstream slope  Intake foundation level: 883.87 masl Outlet level: 871.5 masl	Upstream half to be driven from centre in an upstream direction. Pumping of drainage water from centre.	Free draining: Air Shaft required at entrance
3	Slopes to meet the 0.1% criteria  Intake foundation level: 883.87 masl Outlet level: 871.5 masl	Drainage towards low points and pumping from these points	Pumping from lower points.

Cost comparisons of these options are shown in **Table 8.4**.

Table 8.4: Cost estimates for options

Activities	Quantity	Unit Cost	Amount (R million excluding VAT)		
			Option 1	Option 2	Option 3
Intake Tower	Sum		88.7	76.5	76.5
U/s part of tunnel(m)	15 000	71 000(1)	1065.0		
U/s part of tunnel(m)	15 000	74 100(2)		1 111.5	1 111.5
D/s part of tunnel(m)	19 100	71 000(1)	1 356.1	1 356.1	
D/s part of tunnel (m)	19 100	74 100(2)			1 415.3
Additional excavation cost at Intake Tower (m^3)	308 000	100	30.8		
Tunnel Drainage Pipe to Dam Outlet	3 500	20 000	70.0		
Additional Ventilation Shaft	SUM			2.0	
Total			2 611.6	2 546.1	2 603.3

(1) Boring uphill
(2) Boring downhill

For **Table 8.4**, the following has relevance:

- The unit cost for the tunnel was adjusted in accordance with the complexity of driving below water conditions;
- Vertical alignments of the tunnels are meeting the hydraulic and construction drainage requirements;
- Additional cost for the Intake Tower relates to a deeper foundation for Option 1 as compared to the others;
- The tunnel drainage pipe is necessary to drain the upstream part of Option 1 tunnel through the reservoir of the dam and through the outlet of the dam. This is, however, not favoured from a maintenance point of view. Draining of the tunnel can also be done by pumps from the bottom of the Intake Tower. This option is also not favoured due to pumps which will not be available for pumping when needed; and
- Option 2 is the option with lowest cost.

Option 2 suits the construction and operational requirements best.

8.3.10 Proposed layout of the tunnel

The proposed layout of the tunnel is shown in **Figure 8.3**. This layout is based on the following:

- One vertical slope;
- Excavations at both portals of the tunnel;
- A drill and blast access adit at the central part of the tunnel from chainage 14 750 m to 16 250 m;
- Two tunnel boring drives, both upward in a southerly direction;
- Four ventilation shafts;
- Three tunnel waste disposal landfill sites;
- An access adit at the entrance to facilitate access to tunnel number 2; and
- Construction of the first 100 m metre of the second tunnel to ensure access for full Smithfield Dam conditions.

8.3.11 Portal excavations

The tunnel portal excavations are shown in Figure 8.4 and **Figure 8.5**. The excavation material volumes are shown in **Table 8.5**.

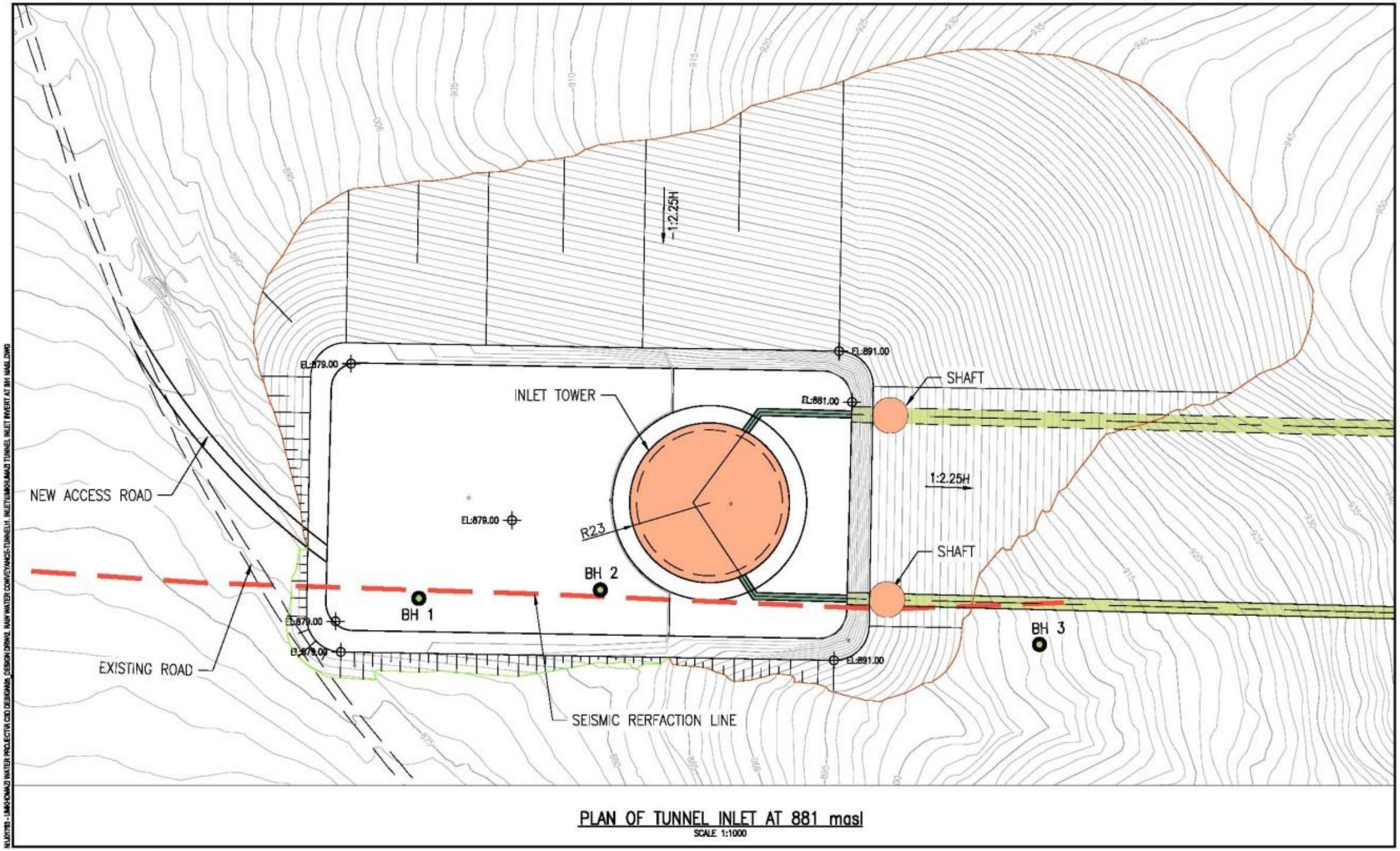


Figure 8.4: Tunnel inlet portal excavation

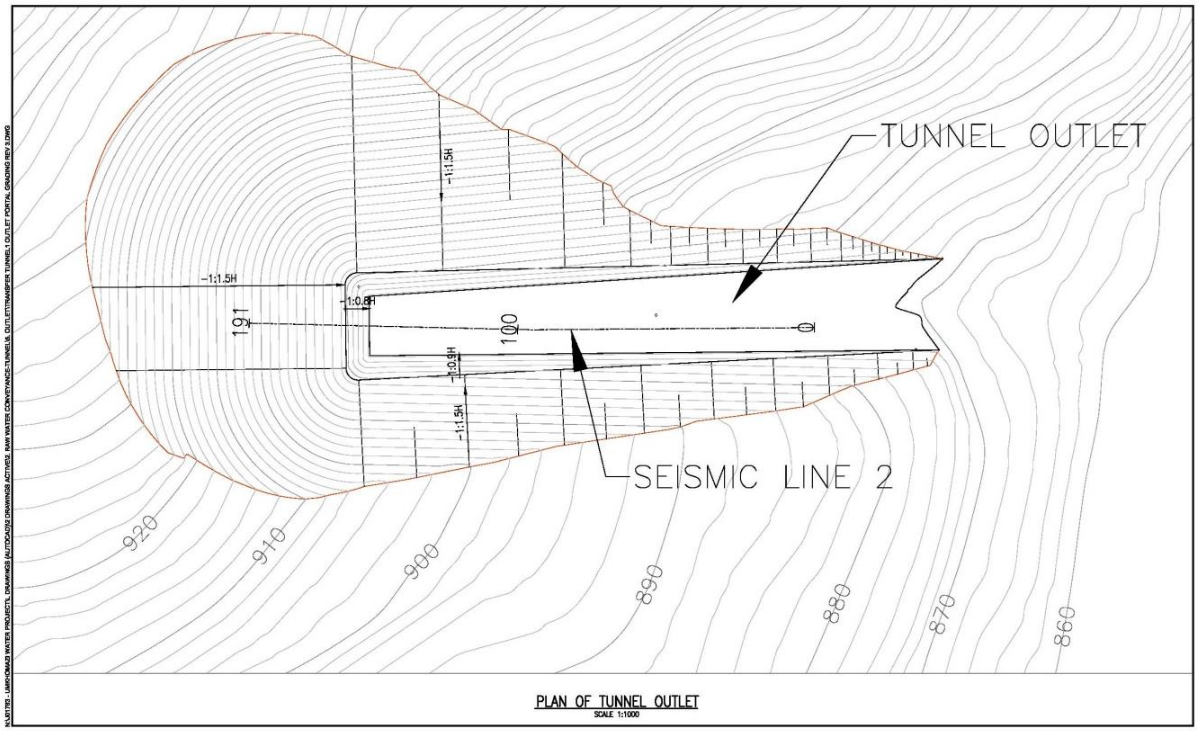


Figure 8.5: Tunnel outlet portal excavation

Table 8.5: Excavated volumes from tunnel portals

	Excavated material, in-situ volume (BCM(1))	Swell factor	Excavated material (LCM(2))
Inlet Portal	130 500 m^3	1.6	208 800 m^3
Outlet Portal	401 000 m^3	1.6	641 600 m^3

(1) Bank cubic metre
(2) Loose cubic metre

8.3.12 Tunnel spoil waste landfill site

The excavated material volumes from the tunnels are shown in **Table 8.6**.

Table 8.6: Excavated material volumes removed from tunnels

	Excavated material, in-situ volume (BCM)	Swell factor	Excavated material (LCM)
Inlet Portal	375 000 m^3	1.6	600 000 m^3
Outlet Portal	575 000 m^3	1.6	920 000 m^3
Central Portal	343 750 m^3	1.6	550 000 m^3

The landfills formed from excavated materials from the tunnel and excavations from the intake and the outlet of the tunnels are shown in **Figure 8.6**, **Figure 8.7** and **Figure 8.8**. Provision is recommended for landfill sites in the central and the upstream side of the tunnel to facilitate any of the two should the Contractor decide on either direction to carry out the tunnel boring activity.

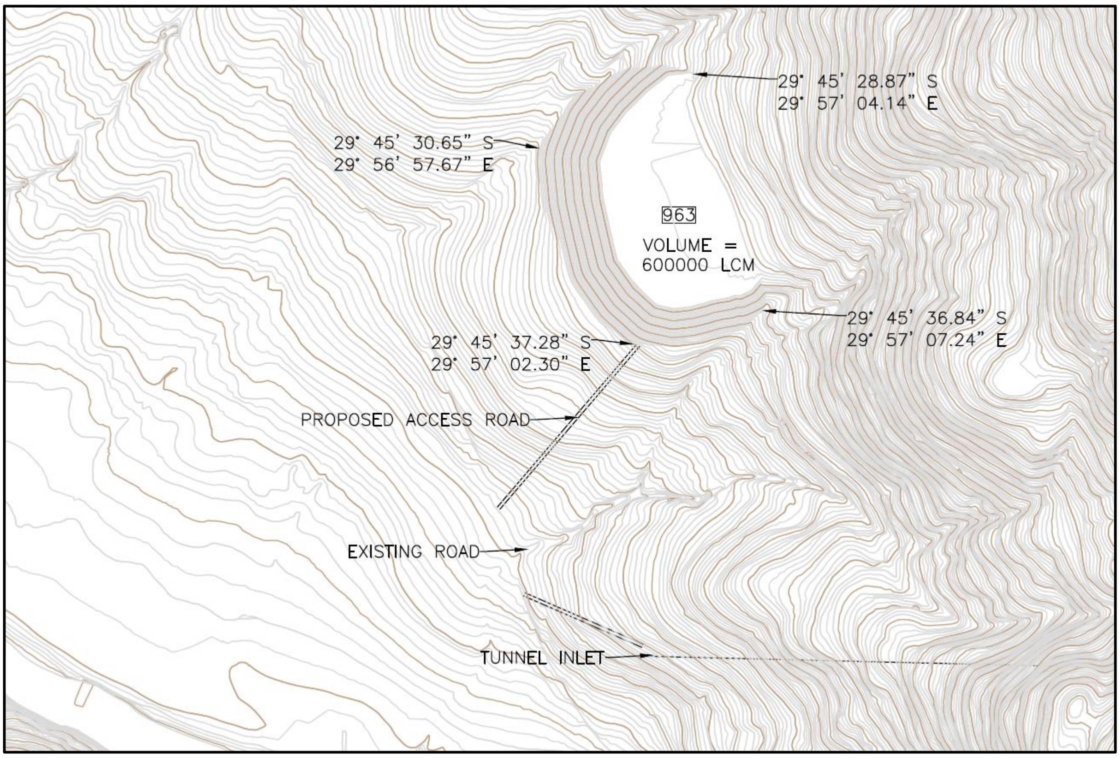


Figure 8.6: Upstream waste landfill site for tunnel spoil

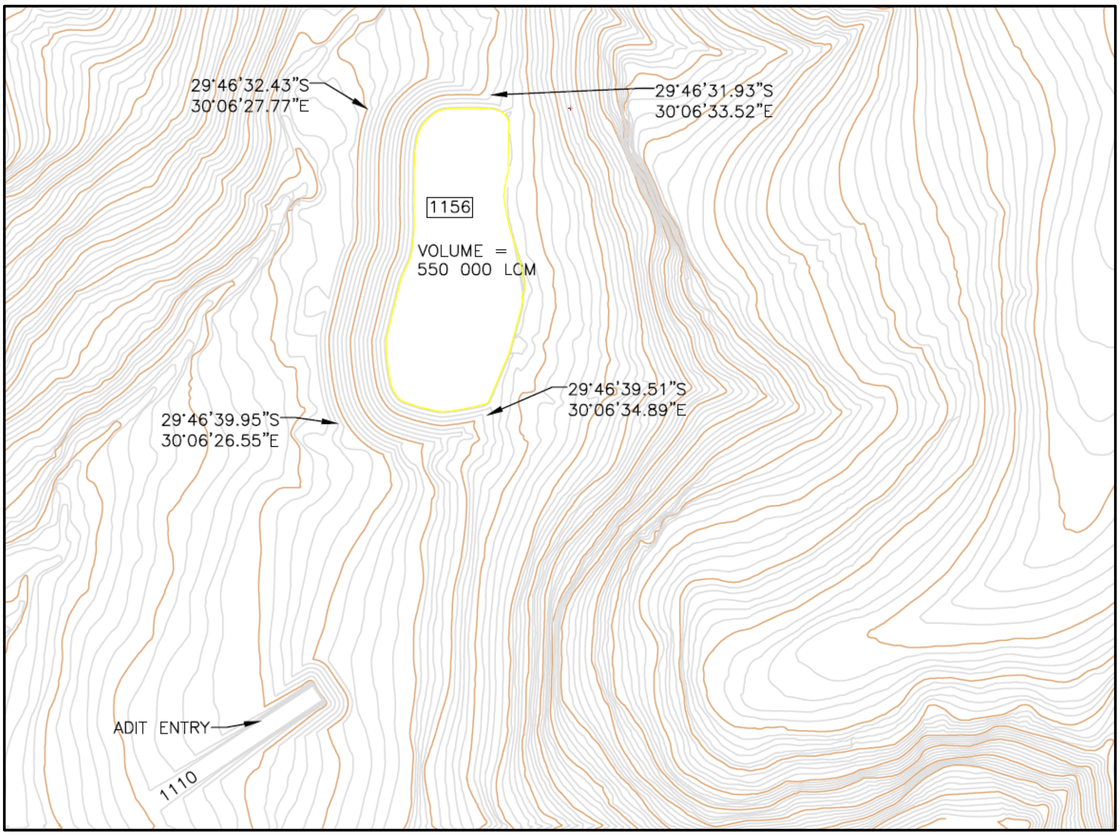


Figure 8.7: Central waste landfill site

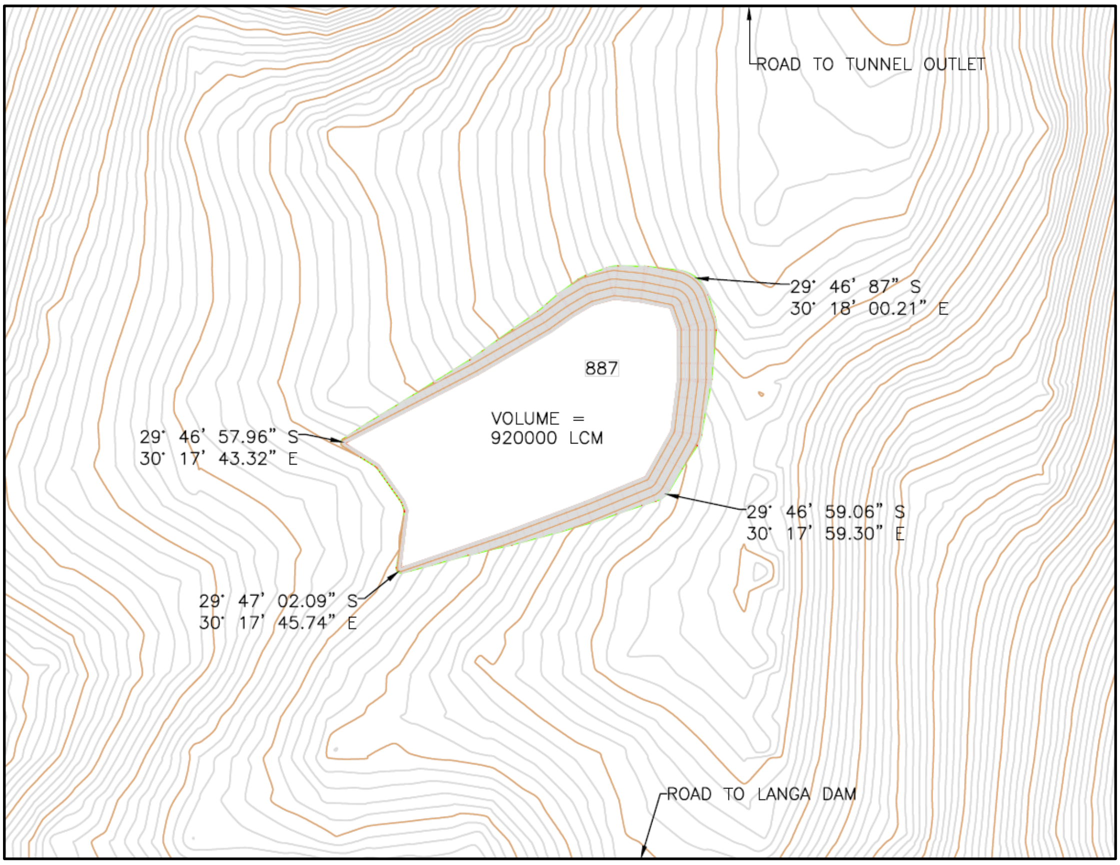


Figure 8.8: Downstream waste landfill site

9 BALANCING DAM

9.1 INTRODUCTION

Supporting Documents 1 and 2 describe investigations regarding Balancing Dams at Baynesfield or downstream of Baynesfield Dam. Due to the requirement that storage must be provided above the Umlaas Road commencement level and below the tunnel outlet and also taking into account local topographical conditions, this dam was large and very expensive. By locating a dam higher than the tunnel outlet and by not inundating the outlet, two options in the Mbangweni River upstream of the Mbangweni Dam were identified as shown in **Figure 9.1**. At both sites dams could be designed to meet the three week supply storage requirement with Full Supply levels below the Full Supply Level of Smithfield Dam. The required storage volume for a three-week period[1] is 12.5 million m³ and was determined with the following formula:

$$V = 1.8144 \times 10^6 Q/P_f \qquad (9.1)$$

Where:

V = required storage capacity of the balancing dam in m³

1.8144×10^6 = factor to convert m³/s to m³/21d

Q = design peak flow capacity required in m³/s (8.65 m³/s)

P_f = seasonal peaking factor of 1.25

This requirement was revisited and in the feasibility design report the dam was maximised to store as much as possible using available rockfill materials from the tunnel excavations.

9.2 BALANCING DAM SITES OPTIMISATION

A site visit to the dams indicated that the proposed dam, just upstream of Mbangweni Dam (New Mbangweni), has a wider marshy area (Vleiland) than an upstream dam (Langa Dam). The lower site is not considered further due to a wider valley within the river section and the deep foundation that will need to be excavated for any dam type

[1] *The three-week storage period was a requirement set by DWA.*

due to the marshy area. As a result, there will be higher associated costs for excavation and construction costs for the wider dam.

The required storage volume of water of 12.5 million m^3 is associated with the dam with a full supply level at 919 masl. A full supply level of 919 masl is more appropriate and is associated with 1 million m^3 of materials to be sourced from the dam. The New Mbangweni Dam site was therefore discarded and the upstream (Langa Dam site) site is therefore analysed in this optimisation study.

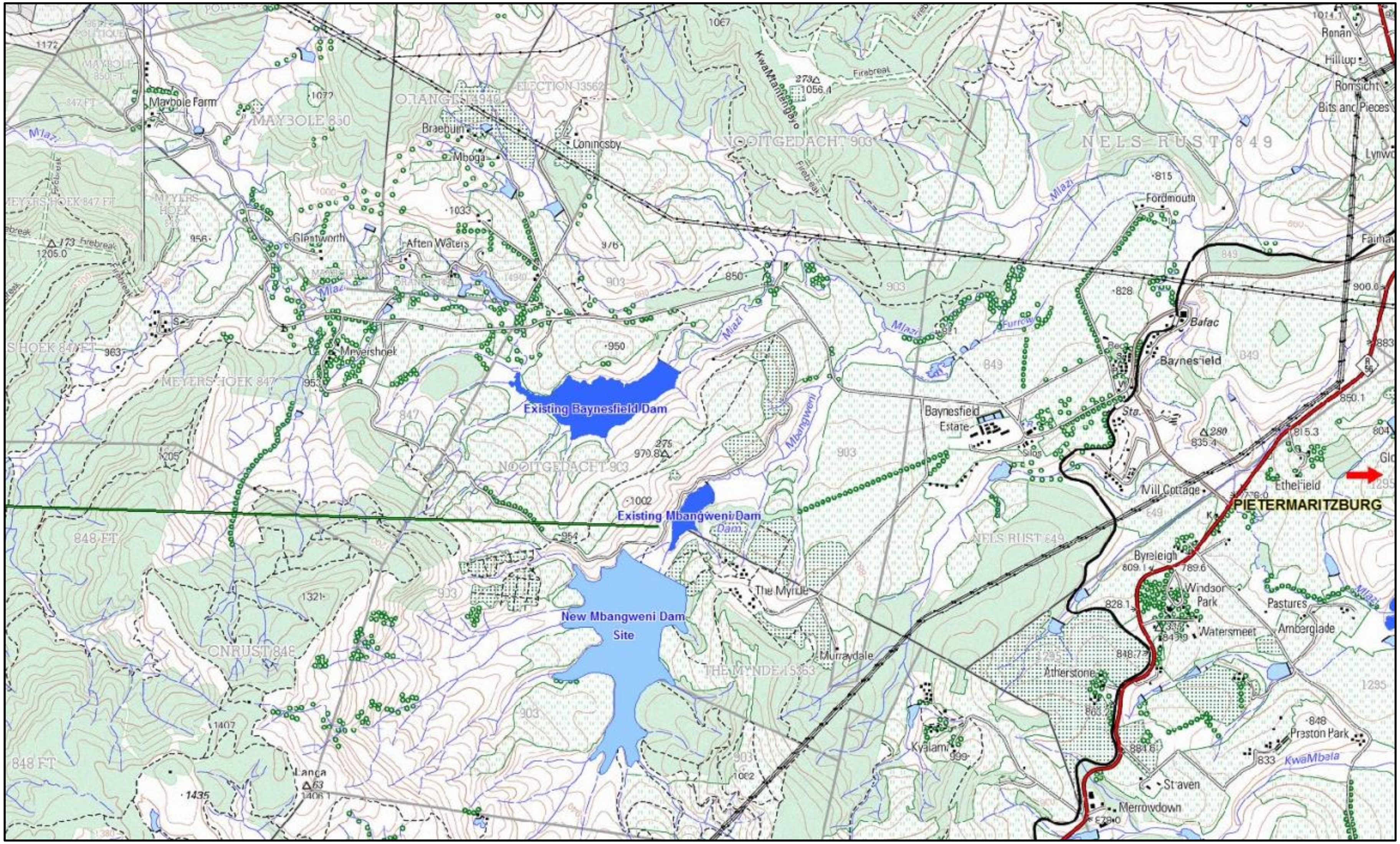


Figure 9.1: New Mbangweni Balancing Dam site

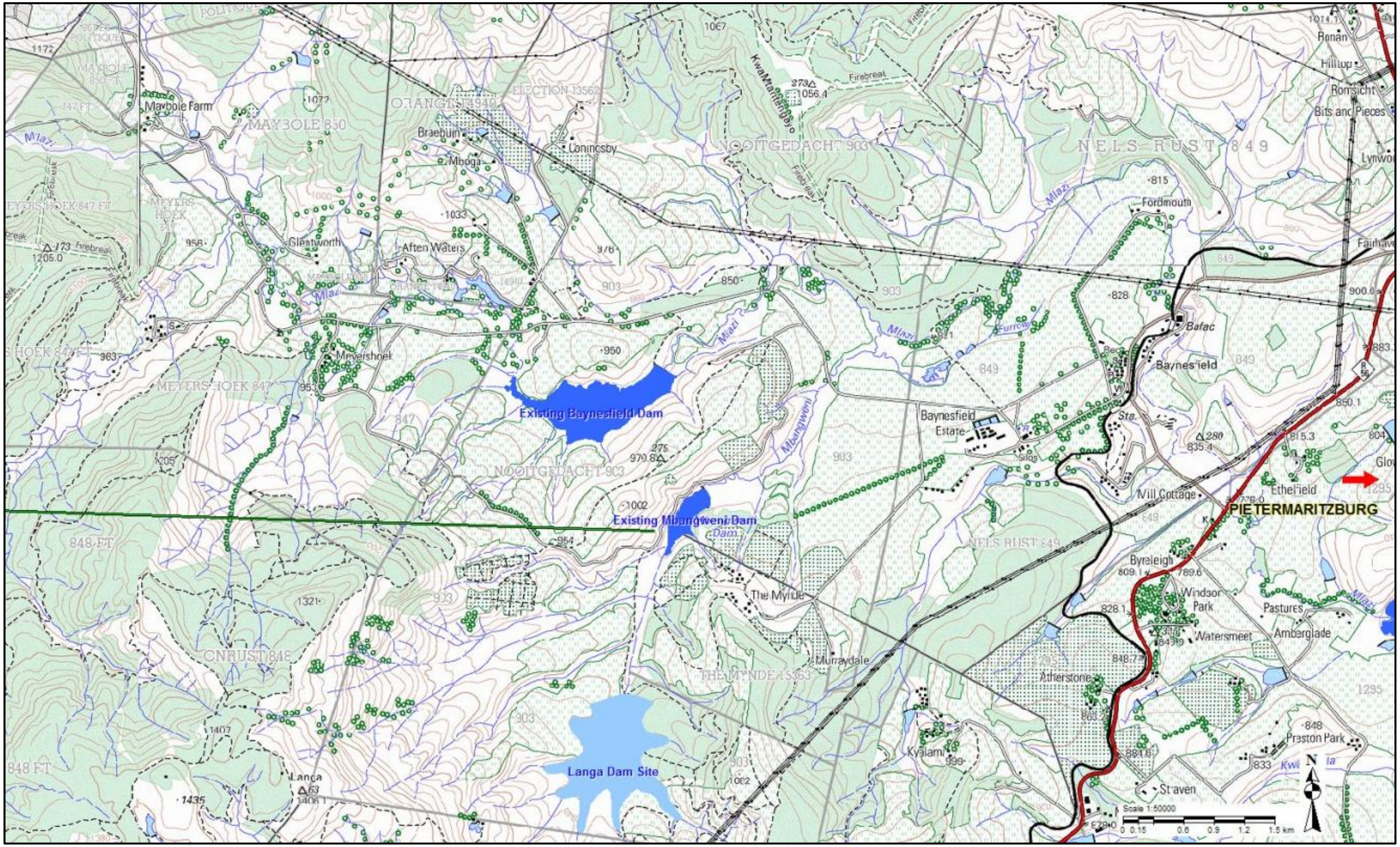


Figure 9.2: Langa Balancing Dam site

9.3 YIELD ANALYSES OF LANGA BALANCING DAM

Yield Analyses of the Langa Balancing Dam supporting Mbangweni Dam is described in the Water Resources report. The main findings of this study, which were based on stochastic generated flows considering assurance of supply, were:

- Langa Dam will fill from its own catchment area in 3 to 5 years; and
- Evaporation losses will be supplemented from rainfall and streamflows.

It must be noted that this dam can be filled with water from Smithfield Dam when the Smithfield Dam reservoir is at higher levels than the balancing dam.

9.4 DESIGN AND COST ESTIMATE

The cost estimate for this dam which is based on an earthcore rockfill dam is included in **Annexure D**. A cross-section of the layout is shown in **Figure 9.3**. A summary of the cost is shown in **Table 9.1**.

Table 9.1: Summary of cost estimate for Langa Dam

Size of dam (FSL)	Capacity (million m^3)	Cost (ZAR excluding VAT)
919 masl	12.5	453 million

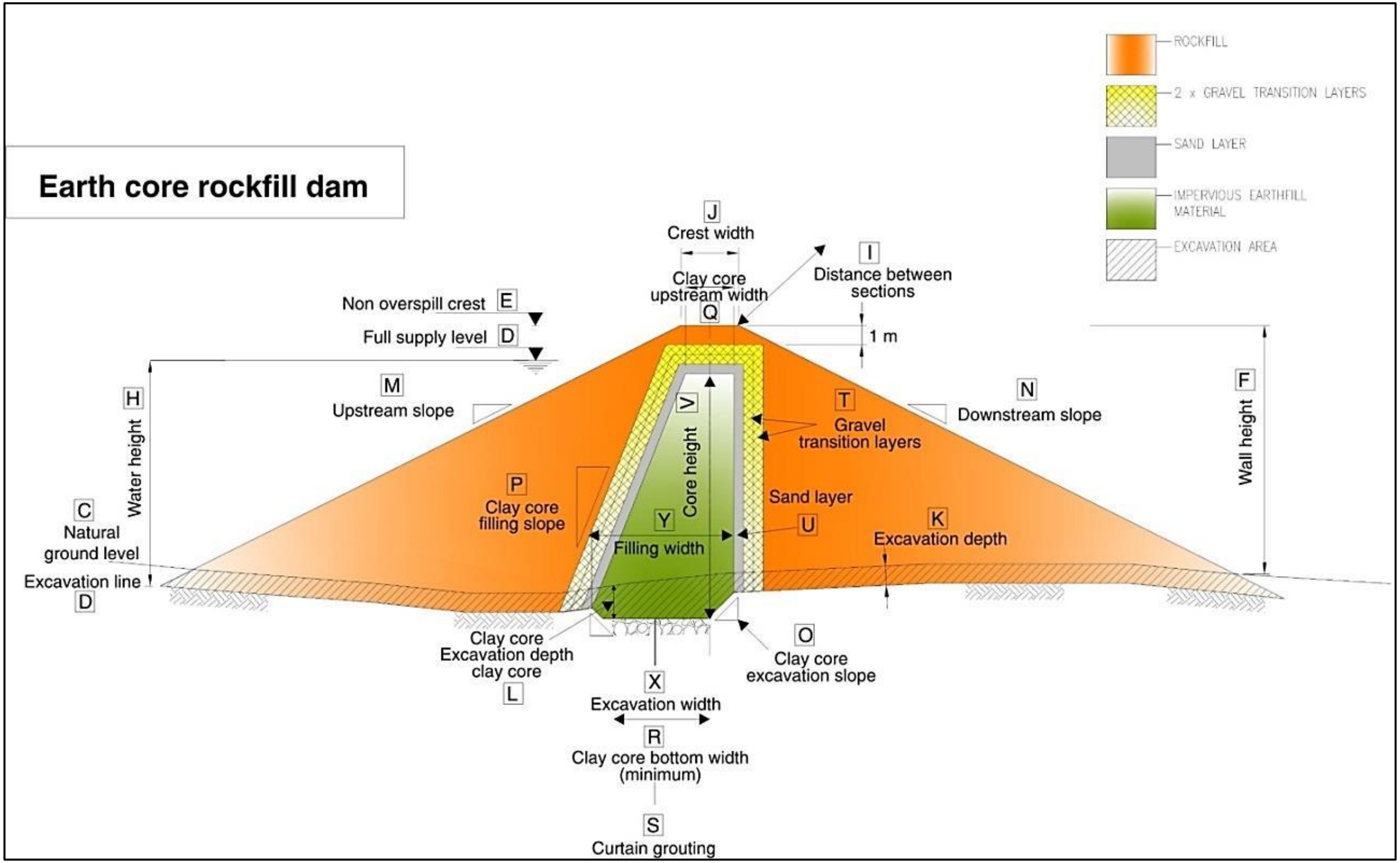


Figure 9.3: Layout of earthcore rockfill dam

10 OPTIMIZATION OF STORAGE VOLUME OF SMITHFIELD AND IMPENDLE DAMS

10.1 INTRODUCTION

The pre-feasibility study indicated a full supply level of 920 masl for Smithfield Dam. During this Feasibility Study yield analyses indicated that a Smithfield Dam at 925 masl would yield the same. This was based on new EWR figures and assumptions mentioned in **Section 2.1.2** as well as a higher MOL to accommodate the pressure tunnel.

This section describes using the unit reference value (URV) technique for the capital and operational costs of the complete scheme (including the conveyance system to Umlaas Road) and the low road water requirements as discussed in **Section 4** for various storage volumes of Smithfield and Impendle Dams to determine an optimum size for the project. It also covers the total Umgeni System available yields, especially Spring Grove Dam, and water requirements.

The purposes of the URV calculations are to:

- Determine the Smithfield Dam and Impendle Dam sizes, the timing of commencement of supply from Impendle Dam and the phasing of the conveyance systems; and
- Obtain an order of URV for comparison of alternative water supply schemes like desalination of seawater and supply to a common comparable point.

Tariff calculations for raw water delivered and distribution of the water will be determined once the conceptual designs have been completed. This will be described in a separate report.

10.2 Unit reference values of various Smithfield and Impendle Dam sizes based on the uMkhomazi Water Project

During this analysis capital costs for the following scheme components were determined:

- Impendle Dam for storage volumes of 50%, 100% and 150% of the Mean Annual Runoff volume;
- Smithfield Dam for storage volumes 15%, 20%, 25%, 31% and 38% of the Mean Annual Runoff volume at the site. This makes provision for road deviations around the reservoirs (especially the R617 road) as well as power line deviations;
- Two 3.5 m diameter pressure tunnels with an Intake Structure as well as two 2.4 m diameter steel pipelines from the tunnel to the WTW inlet (connection point between the Module 1 and Module 3 of the study) – the second tunnel and pipeline to be phased when required;
- Two pipelines from the connection point described above and the tie-in point to the Umlaas Road pipeline. These costs were supplied by Umgeni Water; and
- The WTW cost – also supplied by Umgeni Water.

Transfer capacities associated with 1.25 (peak factor) multiplied by the yield of the dam were taken to size the raw water conveyance system. The date at which the second phase of the uMWP is needed (i.e. Impendle Dam and a second tunnel), was determined based on when Phase 1 is projected to no longer have sufficient capacity. This date was based on when the 1:100 year yield of Smithfield Dam is insufficient to meet the growth in water requirements in the Mgeni. This date was also the similar to the date at which a second tunnel was needed, as the tunnel capacity is aligned with the 1:100 year yield of Smithfield Dam, as well as when the tunnel capacity becomes a limitation. Timing of supply through the second additional tunnel and from Impendle Dam was based on when Smithfield Dam 1:100 year stochastic yield and the first tunnel capacity (normal long term supply excluding peak factor) satisfies the water requirements downstream of Umlaas Road. Dam developments at the downstream end of the uMkhomazi River, including the South Coast water requirement, were not taken into consideration.

The low road water requirement projection for the uMWP supply area downstream of Umlaas Road received from Umgeni Water was used for the URV calculations. This projection does not include any further supply to the South Coast. In the calculations the following assumptions were used:

- The total water requirements for the Mgeni system where updated by including the new low road water requirements for the uMWP supply area downstream of Umlaas Road;
- This curve was assumed to be representative of the higher expected growth in demand in the uMWP supply areas. The water projections and water resources in system context are shown in **Figure 10.1**; and
- The growing water requirements to be supplied over and above the Spring Grove Dam yield were used in the calculations.

Two development options both including pumping from Spring Grove Dam when the yield from Smithfield Dam does not satisfy the water requirement were considered, namely:

- Option 1: Development of Smithfield Dam and one tunnel only; and
- Option 2: Development of combinations of Smithfield and Impendle Dam sizes and two conveyance systems. For this option the combinations of Smithfield and Impendle Dam sizes indicated in **Table 10.1** were considered.

Table 10.1: Smithfield Dam and Impendle Dam sizes or combinations considered

Impendle Dam Size	Smithfield Dam Size
1 (Impendle 0.5 MAR)	15% MAR (FSL 915 masl)
	20% MAR (FSL 920 masl)
	25% MAR (FSL 925 masl)
	31% MAR (FSL 930 masl)
	38% MAR (FSL 935 masl)
2 (Impendle 1.0 MAR)	15% MAR (FSL 915 masl)
	20% MAR (FSL 920 masl)
	25% MAR (FSL 925 masl)
	31% MAR (FSL 930 masl)
	38% MAR (FSL 935 masl)
3 (Impendle 1.5 MAR)	15% MAR (FSL 915 masl)
	20% MAR (FSL 920 masl)
	25% MAR (FSL 925 masl)
	31% MAR (FSL 930 masl)
	38% MAR (FSL 935 masl)

Spread sheets with assumptions for the options are included in **Annexure E** and **Annexure F**.

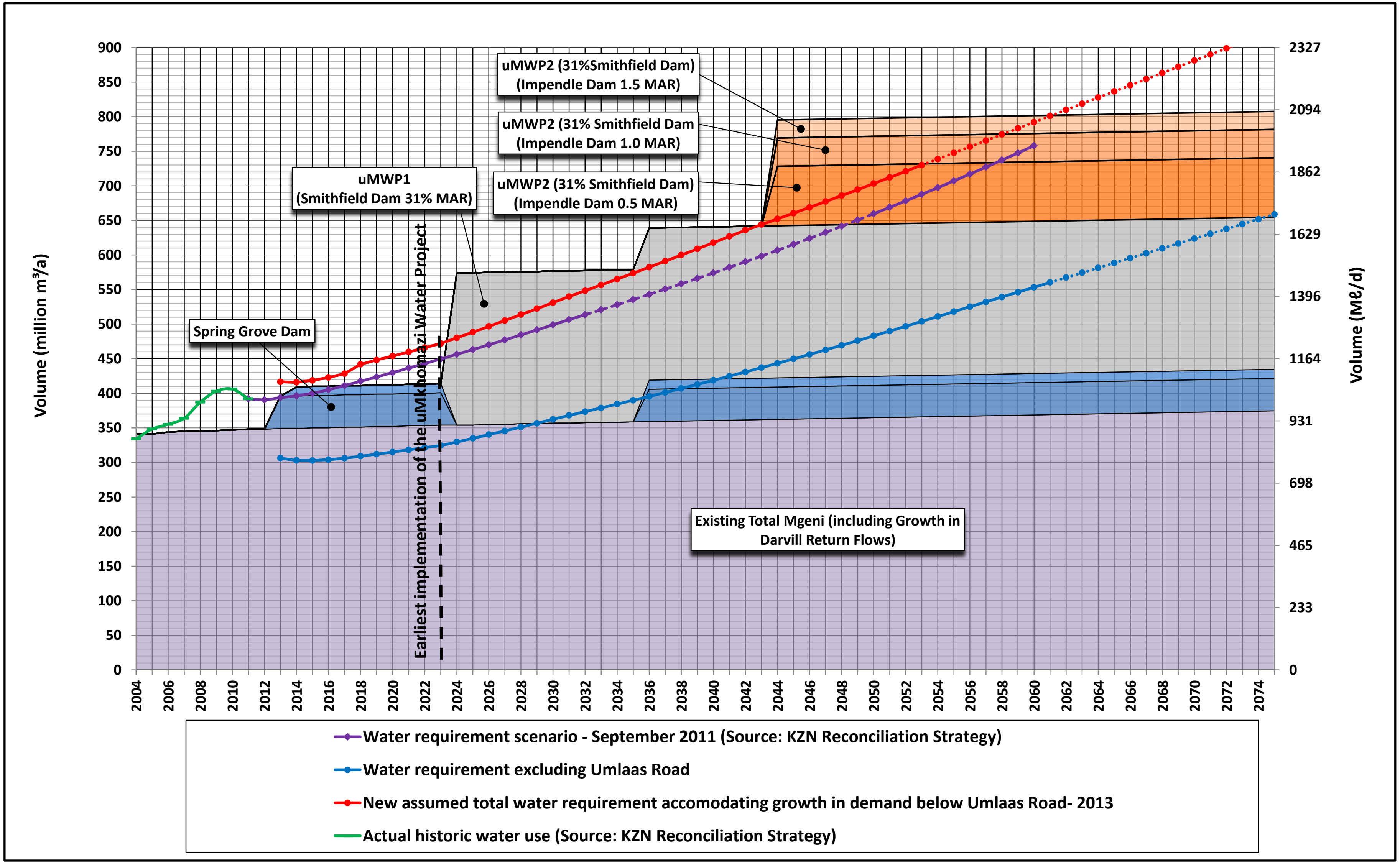


Figure 10.1: Water requirement projections and water yields for Mooi, Mgeni and uMkhomazi Systems

10.3 Unit Reference Values for Option 1: Smithfield Dam and One Tunnel Transfer Scheme

The results of this option are also included in **Annexure E**. A plot of unit reference values at 8% discount rate against FSLs of Smithfield Dam is shown in **Figure 10.2**. It also shows the years of supply from Smithfield Dam until water is required from another water resource.

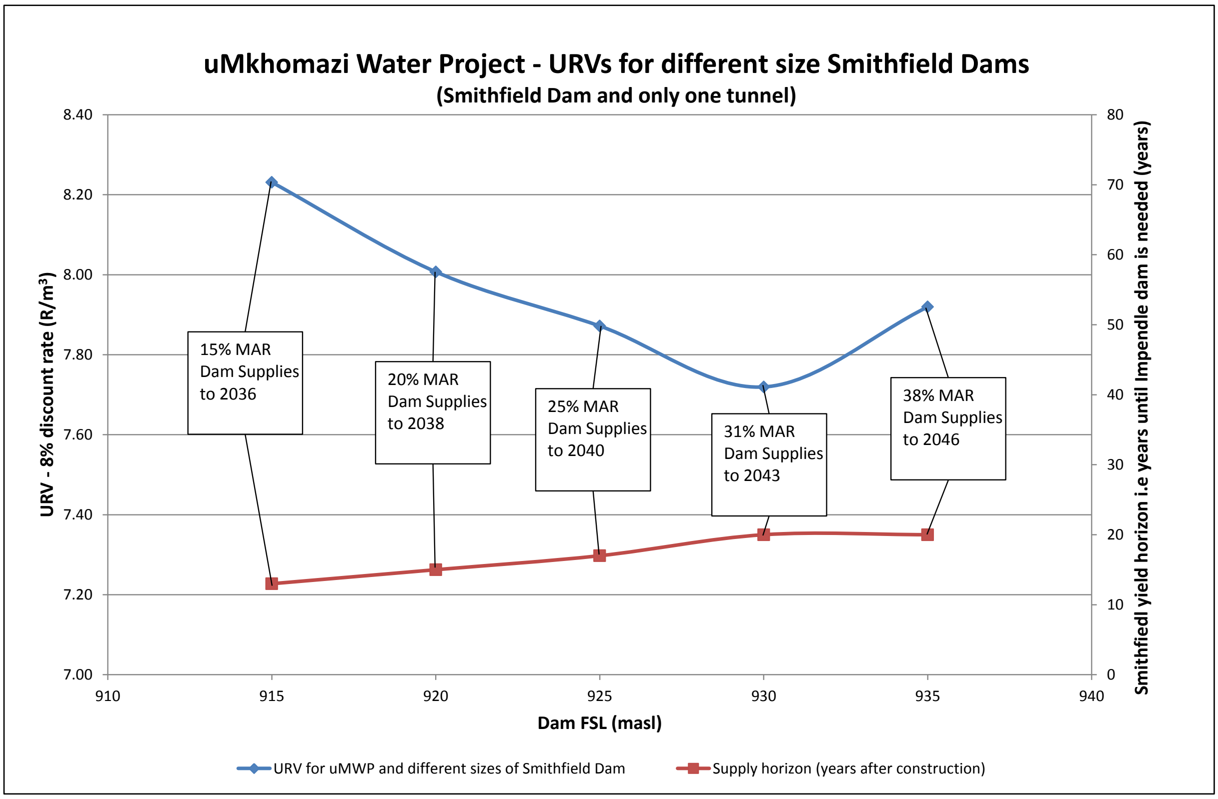


Figure 10.2: URV results for Option 1

10.4 UNIT REFERENCE VALUES FOR OPTION 2: TOTAL SCHEME

The results of this option are also included in **Annexure F**. A plot of unit reference values at 8% discount rate against FSLs of Smithfield Dams is shown in **Figure 10.3**. It also shows the years of supply from Smithfield Dam until water is required from Impendle Dam.

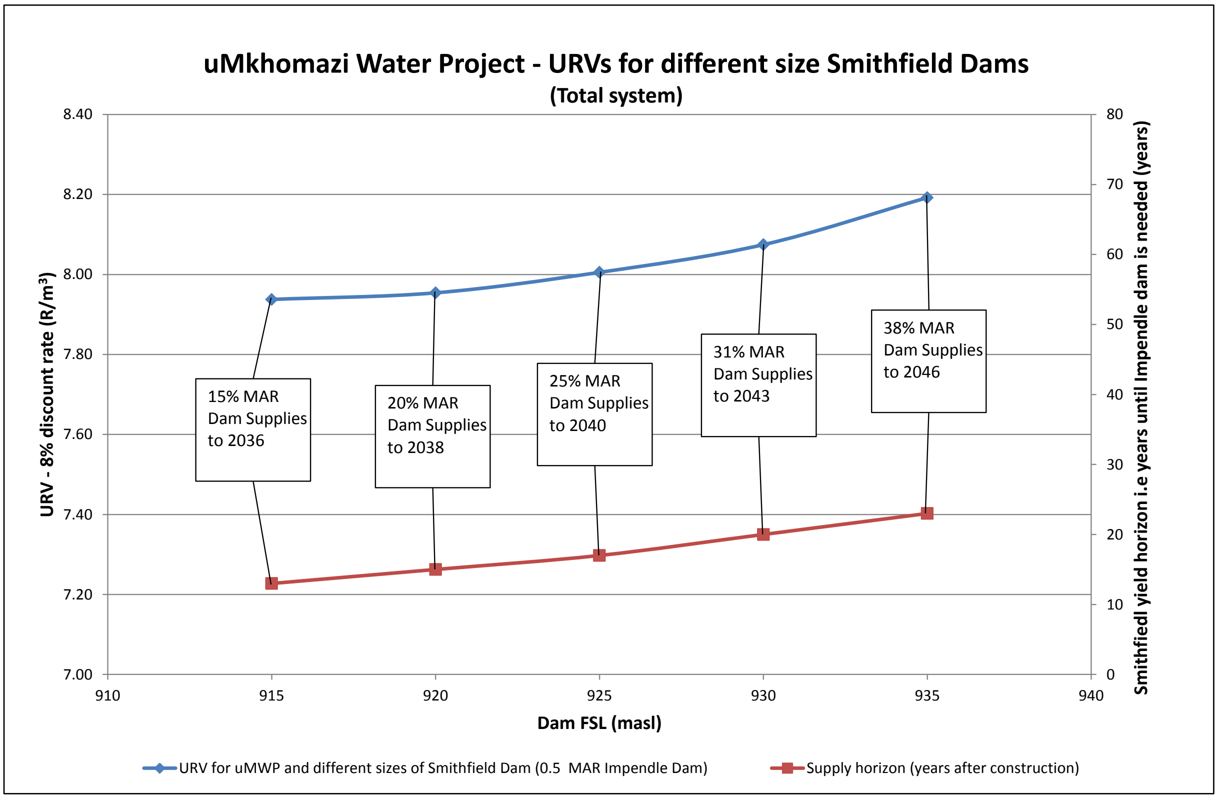


Figure 10.3: URV results for Option 2: 0.5 MAR Impendle Dam

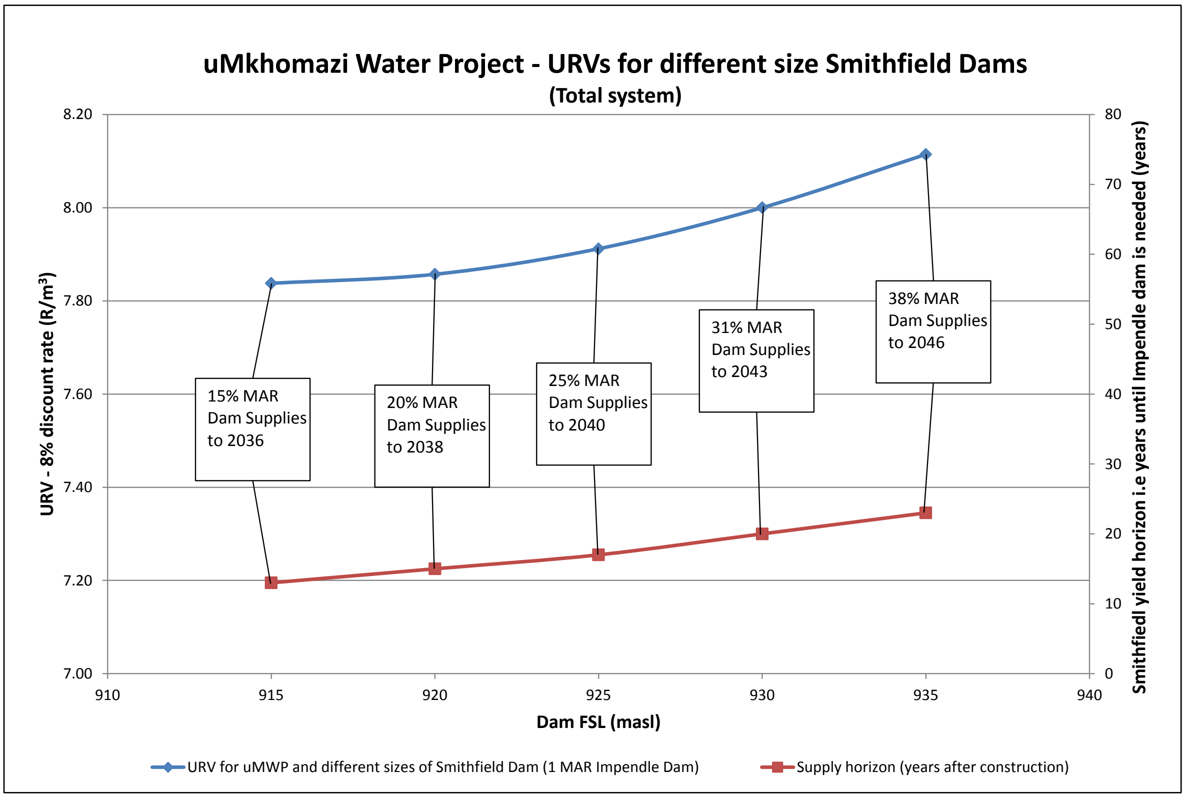


Figure 10.4: URV results for Option 2: 1.0 MAR Impendle Dam

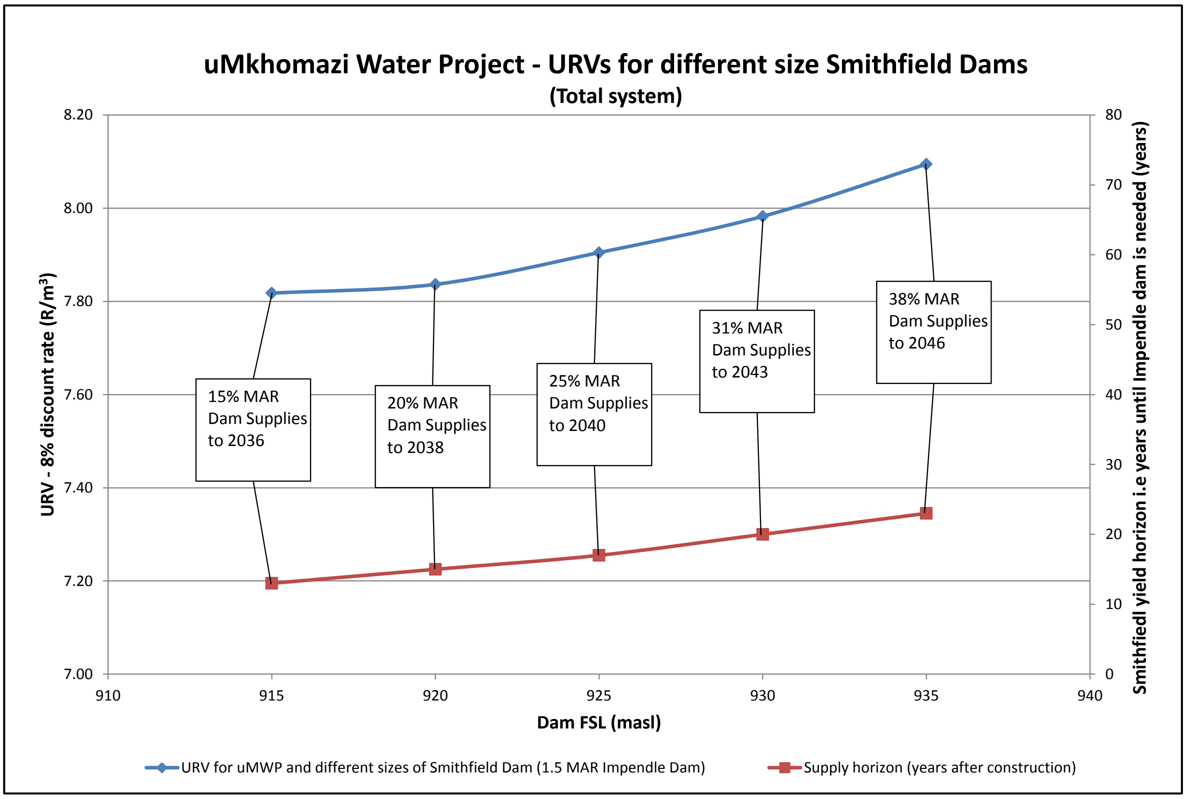


Figure 10.5: URV results for Option 2: 1.5 MAR Impendle Dam

10.5 SUMMARY OF SMITHFIELD DAM SIZE

The following summary can be made:

- For the option of a Smithfield Dam and one tunnel to be developed only as shown in Figure 10.2 it is clear that the 31% MAR Smithfield Dam has the lowest unit reference value. In case of Impendle Dam not being implemented, this dam size dam is the most economically favourable option.
- From **Figure 10.3**, **Figure 10.4** and **Figure 10.5** it is clear that the smallest Smithfield Dam has the lowest unit reference value.
- From **Figure 10.5** it is clear that the 15% MAR Smithfield Dam and 1.5 MAR Impendle Dam has the lowest unit reference value. For this case Impendle Dam should, however, be constructed in 2036 – which means that the next scheme should be implemented in 12 years' time. This is too short.
- From **Figure 10.3**, **Figure 10.4** and **Figure 10.5** it is clear that the 31% Smithfield Dam provides 21-year window before Impendle Dam would be required. The unit reference values increase only by about R 0.15, which is 2%. This is insignificant and within the margin of accuracy. (At 38% MAR Smithfield Dam the unit reference value increase is 6%.)
- The 1.5 MAR Impendle Dam and associated transfer scheme provides the lowest Unit reference values.
- The 8% discount rate used for the calculation of URV should be used in comparison analyses is R 7.80.

Based on:

- The optimum URV for the case where the Impendle Dam and second conveyance system are not developed;
- The insignificant difference in URV for a 31% Smithfield Dam with smaller dams;
- The timing of implementation of Impendle Dam to be 21 years after completion of Smithfield Dam (and not less); and
- Possible uncertainty in the water requirement projections;

It is recommended:

- To size the Smithfield Dam to a 31% MAR capacity during the feasibility design of the Dam; and

- Planning of implementation of a 1.5 MAR Impendle Dam should be considered for in the future.

11 OPTIMISATION OF UMKHOMAZI-UMLAZA TUNNEL SIZE

11.1 INTRODUCTION

This section describes the considerations taken into account for optimising the layout and size of the transfer tunnel from Smithfield Dam to Baynesfield WTW for Phase 1 of the uMWP. Three sizes of Impendle Dam were investigated, and for each of these options, two tunnel layouts were explored using different tunnel sizes.

11.2 METHODOLOGY

The methodology used to determine the optimal layout was, initially, to compare the unit reference values (URVs) of the various options (**Section 11.3**). The URV is the cost per cubic metre of water over the total life cycle of the scheme. After this, other aspects were considered for the optimisation of the complete system of Phases 1 and 2 of the uMWP (**Section 11.4**).

11.3 UNIT REFERENCE VALUES

11.3.1 Options

The options that were considered are summarised in **Table 11.1** below.

Table 11.1: Options for optimising uMWP Phase 2 layout

Impendle Dam size		Tunnel layout		
Option 1	0.5 MAR	Option 1a	Single tunnel	1 x 4.0 m internal diameter
		Option 1b	Twin tunnels	2 x 3.5 m internal diameter
Option 2	1.0 MAR	Option 2a	Single tunnel	1 x 4.5 m internal diameter
		Option 2b	Twin tunnels	2 x 3.5 m internal diameter
Option 3	1.5 MAR	Option 3a	Single tunnel	1 x 4.5 m internal diameter
		Option 3b	Twin tunnels	2 x 3.5 m internal diameter

The size of Smithfield Dam remained constant (31% MAR, with a yield of 220 million m³/a), based on the optimisation that had previously been done for the dam in the *Optimisation of scheme configuration report* (P WMA 11/U10/00/3312/3/1/3). Three sizes of Impendle Dam were considered, namely 0.5, 1.0 and 1.5 MAR. Both a single tunnel and twin tunnels were considered for each Impendle Dam size option. The tunnel sizes were calculated based on the total system yield for Smithfield and Impendle Dams, which differed based on the size of Impendle Dam under consideration. The calculation of these tunnel sizes is described in **Section 11.3.2**.

11.3.2 Assumptions

a) System yields

The transfer volumes and their timelines as per scenario 2 were assumed. Detailed transfer volumes and timelines are contained in **Annexure G**. For all Impendle Dam sizes, the water transfer volumes are the same until the total 1:100 yield for a 0.31 MAR Smithfield Dam in combination with Impendle Dam is reached. After this yield has been reached, the annual transfer volume remains constant. **Table 11.2** shows the dam yields that were considered for calculating the URVs, as well as the timelines in which they will be attained.

Table 11.2: Total system yield and year attained

Option	Impendle Dam size	Impendle Dam yield (million m³/a)	Smithfield Dam yield (million m³/a)	Total system yield (million m³/a)	Year in which total system yield is attained
1	0.5 MAR	83	220	**303**	2058
2	1.0 MAR	126	220	**346**	2065
3	1.5 MAR	155	220	**375**	2070

b) Tunnel sizes

The total system yields were used to determine an equivalent flow in the conveyance system. These flows were then used to determine the required tunnel diameter by using the Colebrook-White equation for pressurised flow in closed conduits. This involved determining the friction loss over the conveyance system, comprising the concrete tunnel and steel pipe, for different diameters, and ensuring that it was sufficiently low to convey the water.

At this stage, tunnel diameters were only determined for the larger single tunnel configuration, since the twin tunnel inner diameters were already previously determined to be 3.5 m to meet construction constraints (*Optimisation of conveyance system report*, P WMA 11/U10/00/3312/2/1/1). The flows and resulting required tunnel inner diameters for the single tunnel configuration are summarised in **Table 11.3**.

Table 11.3: Calculation of required tunnel diameters

Option	Flow (m^3/s)	Required tunnel diameter (m)
1a	9.9	4.0
2a	11.3	4.5
3a	12.3	4.5

c) Costs

Capital costs

To determine the URVs, the total cost of Impendle Dam and the transfer tunnel for each option was calculated. The following costs were used for the various Impendle Dam sizes, which were determined previously and are discussed in detail in the *Mkomazi-Mgeni Transfer Pre-feasibility Study* (PB1 U100-00-0499):

- 0.5 MAR: R 1 289 million
- 1.0 MAR: R 1 822 million
- 1.5 MAR: R 2 120 million

The unit costs for the tunnel construction, comprising excavation and lining costs, were used for the tunnel internal diameter sizes as follows:

- 3.5 m: R 71 000/m
- 4.0 m: R 77 000/m
- 4.5 m: R 83 000/m

It was assumed that the construction of the tunnel would be done over four years, starting in 2019 for the single tunnel, and in 2019 and 2040 for the twin tunnels. For Impendle Dam, the construction was assumed to be three years starting in 2041. The capital cost was distributed evenly over these years. Although the construction period would vary depending on the size of the dam, for the purpose of this optimisation the influence of this factor would not make a significant difference.

Operation and maintenance costs

The operation and maintenance (O&M) costs were assumed to be 0.25% of the total capital costs per year for the remainder of the project period for the tunnel and the dam. 50 years after the construction of the tunnel, a refurbishment cost of 25% of the capital cost was assumed.

Summary of costs

Table 11.4 below summarises the capital and annual O&M costs of each option. Detailed cost calculations and timelines are contained in **Annexure H**.

Table 11.4: Total cost of each option

Option		Costs (R million)				
		Capital costs			Annual O&M costs	
Number	Description	Impendle Dam	Tunnel	Total	Impendle Dam	Tunnel
1a	0.5 MAR Impendle Dam Single 4.0 m tunnel	1 289	2 464	**3 753**	3.22	6.16
1b	0.5 MAR Impendle Dam Twin 3.5 m tunnels	1 289	4 544	**5 833**	3.22	5.68 per tunnel
2a	1.0 MAR Impendle Dam Single 4.5 m tunnel	1 822	2 656	**4 478**	4.56	6.64
2b	1.0 MAR Impendle Dam Twin 3.5 m tunnels	1 822	4 544	**6 366**	4.56	5.68 per tunnel
3a	1.5 MAR Impendle Dam Single 4.5 m tunnel	2 120	2 656	**4 776**	5.30	6.64
3b	1.5 MAR Impendle Dam Twin 3.5 m tunnels	2 120	4 544	**6 664**	5.30	5.68 per tunnel

d) Results

By using the total transfer volumes and the years in which they will be attained, and the total costs of Impendle Dam and the transfer tunnel, the URVs were calculated. This was done by calculating the net present values (PV) of both the costs and water transfers, discounted at a variety of rates (6, 8 and 10%) until 2093. The URVs were then calculated by dividing the PV costs by the transfer volumes, resulting in a R/m^3 figure. These PV costs, transfers and URVs are summarised in **Table 11.5**.

Table 11.5: URVs of Phase 2 layout options

Discount rate	Option 1a	Option 1b	Option 2a	Option 2b	Option 3a	Option 3b
Costs (R million)						
PV 6%	1 812	2 111	2 031	2 208	2 072	2 249
PV 8%	1 459	1 597	1 617	1 652	1 642	1 677
PV 10%	1 204	1 256	1 323	1 287	1 338	1 302
Transfers (million m^3)						
PV 6%	1 630	1 630	1 666	1 666	1 681	1 681
PV 8%	936	936	947	947	952	952
PV 10%	580	580	584	584	586	586
URVs (R/m^3)						
PV 6%	1.11	1.30	1.22	1.33	1.23	1.34
PV 8%	1.56	1.71	1.71	1.74	1.72	1.76
PV 10%	2.07	2.17	2.26	2.20	2.28	2.22

These results indicate that for a discount rate of 8%, the optimal Phase 1 layout is a single tunnel of 4.0 m inner diameter, associated with a 1.5 MAR Impendle Dam. However, the variation in unit costs between the different Impendle Dam sizes is minimal, differing by approximately only 10%. This finding is in agreement with what was concluded by the optimisation of Smithfield Dam, which showed that the Impendle Dam size made insignificant difference.

Differences between a single tunnel and twin tunnels showed that for all Impendle Dam sizes, a single tunnel would be optimal. However, these unit cost differences show a negligible variance especially for a larger Impendle Dam.

e) Results if only the tunnels are compared

A decision on the size and timing of Impendle Dam need not be taken at this time. It is however necessary to decide whether a single 3.5 m, a single 4.0 m or a single 4.5 m tunnel is to be constructed as part of Phase 1. This decision can be informed by comparing twin 3.5 m tunnels with the other tunnel sizes.

If the cost and timing of Impendle Dam is ignored and only the tunnels are compared then the resulting PV costs are summarised in **Table 11.6**.

Table 11.6: PVs of the different tunnel options

Discount rate	2 X 3.5 m tunnels	4.0 m tunnel	4.5 m tunnel
Costs (R million)			
PV 6%	1 878	1 579	1 702
PV 8%	1 465	1 327	1 430
PV 10%	1 180	1 128	1 216

The timing of the second 3.5 m tunnel affects the PV of the double tunnel option but does not affect the cost of the other options. If it is required to construct the second 3.5 m tunnel either five years earlier or five years later, then the resulting PV costs would be as summarised in **Table 11.7**.

Table 11.7: PVs of the different tunnel options

Discount rate	2 X 3.5 m tunnels			4.0 m tunnel	4.5 m tunnel
	Second tunnel supplies in 2044	Second tunnel supplies in 2039	Second tunnel supplies in 2049		
Costs (R million)					
PV 6%	1 878	2 022	1 771	1 579	1 702
PV 8%	1 465	1 579	1 388	1 327	1 430
PV 10%	1 180	1 266	1 127	1 128	1 216
Size of Impendle Dam that can be served	No restriction	No restriction	No restriction	1.0 MAR	1.5 MAR

From **Table 11.7** it is clear that an earlier construction of a tunnel affects the PV. The effect is approximately 7.5%, which is negligible. Furthermore, **Table**

11.7 shows that the effect of a later 2049 construction of a tunnel compares well with any decision taken.

11.4 OTHER CONSIDERATIONS

In addition to the comparison of URVs and PVs, further considerations were taken into account for the optimisation of the Phase 2 layout. These included the following:

- The scarce water resource situation in South Africa;
- The need for flexibility of tunnel locations, possibly including Midmar Dam;
- The need to retain flexibility in deciding the size of Impendle Dam;
- The limit to the capital cost that can be used; and
- The effect of the residual value of a resource

These considerations, as well as the unit reference values, are weighed up with conclusions in **Section 11.5**.

11.5 OPTIMIZATION OF UMKHOMAZI-UMLAZA TUNNEL SIZE

The optimisation of the uMkhomazi scheme configuration is based on several factors, including economic sustainability and other practical considerations. The following are the determining factors, in order of decreasing priority:

- Economic sustainability
- Flexibility of tunnel locations
- Scarce water resource
- Capital cost required

11.5.1 Economic sustainability

Economic sustainability is the primary consideration for comparing scheme configuration options. The URV calculations show that for this consideration of transfer tunnel sizes at Smithfield Dam, Option 1a is the most economically viable option and Option 3b the least. However, the difference between these options is negligible, being approximately 13%.

11.5.2 Sensitivity on the timing of when the second tunnel would be required

At this stage it is not necessary to finally decide on the size of Impendle Dam. It is however necessary to decide whether a 3.5 m tunnel is to be constructed during the first phase with a view of constructing either a duplicate tunnel from Smithfield Dam or directly from Impendle Dam as a second phase; or whether a 4.0 m or 4.5 m tunnel should rather be constructed during the first phase and doing away with the need for a second tunnel when Impendle Dam is constructed.

PV Analysis shows that the timing of the second tunnel has a small impact on whether a double tunnel or single tunnel would be the economically cheaper option. A lower growth in water demand resulting in the later implementation of the second phase would favour two phased 3.5 m diameter tunnels while a steeper growth in water demand would favour a single larger tunnel.

Given the difficulty in accurately projecting the growth in water demand and the small difference in URVs, it appears that all options are economically similar and therefore the further considerations become decisive.

11.5.3 Capital cost required/tariff

Due to the challenges involved with obtaining capital funds, options requiring a smaller amount of capital expenditure required are attractive. According to this factor, Option 1a requires the least capital expenditure, and Option 3b requires the most. This factor, however, is not crucial, and would be used to differentiate between similarly suitable options.

A larger 4.5 m tunnel implemented during Phase 1 will increase the Umgeni Water bulk potable tariff by approximately 8.3 c more than would be the case with a 3.5 m diameter tunnel.

11.5.4 Flexibility of tunnel locations

In order to accommodate the possibility of linking Impendle Dam directly to Midmar in the future, and thereby utilizing the additional head of water of Impendle Dam as compared with Smithfield Dam, flexible tunnel options may be beneficial. Twin tunnel options are most suitable for this consideration, as one may be built now, with another tunnel built in the future. Options 1b, 2b and 3b take the future flexibility into account, while 1a, 2a and 3a may limit future development, if it happens upstream of Umlaas Road.

11.5.5 Scarce water resource and providing for flexibility in the sizing of Impendle Dam

Because of the scarcity of water resources in South Africa, the prioritisation of scheme configuration options which best address this water backlog (i.e. options with a larger Impendle Dam size) is necessary. However, optimisation of the Impendle Dam size cannot be concluded in this optimisation, as certain other parameters would need to be included in the comparison. These are as follows:

- The potential future water supply area, which could be the complete Umgeni water supply area, or at least the increased water supply area from Umlaas Road.
- The tunnel locations in 2044, which would potentially be to Midmar or to Umlaas Road.
- The implementation of a two phased tunnel approach with the first tunnel being 3.5 m in diameter will not restrict the sizing of Impendle Dam. A single 4.0 m tunnel would restrict the maximum size of Impendle Dam to 0.5 MAR while a single 4.5 m tunnel would accommodate an Impendle Dam size of 1.5 MAR.

Based on this optimisation, the following can be concluded:

- ***For this feasibility study***, the scheme configuration having twin tunnels with one 3.5 m tunnel installed initially is best. This would provide the most flexibility, both for the location of a second tunnel, either at Smithfield Dam or directly to Midmar Dam, as well as for the eventual size of Impendle Dam.
- With a 3.5 m first phase tunnel, the optimisation of the Impendle Dam size could be done in the future without being constrained by prior decisions.
- A 3.5 m first phase tunnel would be fully utilised by the 0.31 MAR Smithfield Dam.

12 CONCLUSION OF SELECTED RAW SCHEME FOR FEASIBILITY STUDY

The selected dam and raw conveyance scheme for Feasibility Design is therefore:

- A Smithfield Balancing Dam at Site B with storage volume equal to 31% of the MAR, FSL 930 masl;
- A Langa Balancing Dam with storage volume 12.5 million m^3 associated with a full supply level of 919 masl. To enable this dam to provide 3 weeks of down time supply, consideration should be given to the acquisition of earthfill and rockfill materials from excavations from the reservoir or from tunnel portal excavations.; and
- A single 3.5 m internal diameter uMkhomazi to uMlaza Tunnel and associated pipeline and water treatment plant system to Umlaas Road with a design (seasonal) transfer capacity of 8.65 m^3/s.

13 CONCLUSIONS AND RECOMMENDATIONS

13.1 SELECTED SCHEME

The recommended scheme will comprise of a Smithfield Dam at Site B with a storage volume equal to 31% of the MAR, a resultant FSL of 930 masl and a Langa Balancing Dam with a storage volume of 12.5 million m^3 with a resultant FSL of 919 masl. Water will be transferred through a single 3.5 m internal diameter uMkhomazi to uMlaza tunnel with associated pipeline to Umlaas road via a water treatment plant system.

13.2 SEDIMENT DEPOSITION STUDY

A sedimentation deposition study should be carried out during the feasibility stage and must consider a period of longer than 100 years for the impact of sedimentation around the reservoir intake to the tunnel. This should be done to prevent changes to the vertical alignment during the design stage and to ensure that the tunnel entrance does not become blocked during the operational stage of the tunnel.

13.3 LANGA BALANCING DAM

The Langa Balancing Dam should be optimised based on a 2-month requirement and using available materials from tunnel excavations.

14 REFERENCES

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Annexure A

Techniques and practices of tunnelling

A – 1 ANTICIPATED EXCAVATION METHOD

Tunnels may be excavated either by the use of tunnelling boring machines (TBM) which bore openings through the rock, or by the use of conventional drill and blast techniques. Both methods have their advantages and disadvantages, which have to be evaluated for each tunnel where the use of tunnelling machines is envisaged.

A – 2 Selection of the Excavation Method

The selection of the excavation method for any rock tunnel project is a major decision which influences all aspects of the tunnelling operation. The excavation method directly influences:

- The possible shape of the tunnel;
- The rate of advance of the excavation and, therefore, the overall rate of advance of the tunnel and the duration of the project;
- The muck handling problem, in terms of the type of muck, sequence of mucking operation, type and capacity of the muck-handling system;
- The quality of the tunnel opening in terms of smoothness of the tunnel walls, or amount of overbreak, extent of loosening of the surrounding rock, and stability of the unsupported tunnel;
- The rock support and lining system; and
- The effect of the tunnelling operation on the local environment.
  The choice of the excavation method may be influenced by specific conditions related to any of the above parameters. The proper selection of the excavation method is, therefore, of paramount importance in the design and construction of any tunnel.

A – 3 Drill and Blast Methods of Tunnelling

The drill and blast method of excavating tunnels is more than 100 years old. Because of its continued use, the drill and blast method is now well-known and quite reliable. It has been tested and has proven successful in nearly all rock conditions.

The excavation of a tunnel by the drill and blast method is a cyclic operation. Each cycle referred to as a "round", consists of three successive operations, i.e. drilling, blasting and mucking. Because of the cyclic operation, the rate of advance of a drill and blast excavation is dependent on the efficiency of each individual operation, i.e. drilling, blasting, ventilation, mucking and installation of the support system.

A – 4 Advantages of the Drill and Blast Method

Advantages of the drill and blast method may be summarised as follows:

a) The most obvious advantage of the drill and blast method is the experience gained by contractors and engineers from its very wide application in the past. Because of its continued use, well trained labour is easily available.

b) Another advantage of the method is the relatively low capital costs for the equipment. However, the drill and blast technique is more expensive in terms of consumables, and is less productive, so that it is advantageous only on short tunnel lengths (generally less than 2.5 km).

c) From a technical point of view, the drill and blast method is attractive because it can produce any shape of tunnel without special difficulties or costs.

d) Finally, the major advantage of the drill and blast method is its adaptability to practically all rock conditions. The drill and blast method is frequently used as the last remaining solution when other mining methods have failed.

A – 5 Disadvantages of the Drill and Blast Method

Disadvantages of the drill and blast method may be summarised as follows:

a) A significant problem with the method is related to the cyclic operation. To achieve high advance rates, each sequence of the operation has to be carried out in the minimum amount of time. To do so, high capacity equipment is essential, which is particularly obvious for ventilation and muck-handling. Capital costs for such equipment are, therefore, greater than would be required for a continuous operation.

b) Further, the equipment used in each sequence is left unproductive for the duration of other sequences, so that it is in operation only 30 to 50 percent of the time. The re-entry period, which repents about 10 percent of the time of the period of a round, is totally unproductive since neither man nor equipment can be utilised during this period.

c) Finally, unproductive time is spent in moving equipment and men in and out between the different sequences; this accounts for as much as 15 percent lost time.

d) Another problem associated with the drill and blast method is the lack of detailed control on the size and shape of the excavation. To eliminate so-called "tight spots" or underbreak, drill patterns are selected to produce overbreak. The amount of overbreak is governed by the blasting method and by the quality of the rock mass. It is a minimum for a tunnel excavated by the smooth wall technique in massive rock, where the increase in quantities over those assuming a "neat" tunnel opening are about 5 percent for muck and 20 percent for concrete. In blocky rock, increases can be as high as 20 percent for muck and 100 percent for concrete.

e) The drill and blast method also produces an unavoidable loosening of the rock surrounding the tunnel opening, hence additional rock support may be required to stabilize the opening (possibly as much as 20 percent).

f) The effects of blasting must also be considered. Blasting in rock generates vibrations which are transmitted through the surrounding ground to adjacent structure. Excessive vibration can result in damage to such structure.

A – 6 Full-Face Tunnel Boring Machines (TBM’s)

The use of tunnel-boring machines dates back to the late 1800’s, but it is only since the 1950’s that the use of TBM’s has become widespread. With this increasing use, major improvements have been achieved in the design of cutters and machines. As a result, TBM's can now be used in rocks with compressive strengths up to 275 MPa, and are extremely competitive when compared to other methods in softer rocks with compressive strengths less than 150 MPa.

When compared to the drill and blast method, TBM’s are still in their early stages of development, yet it is possible to achieve advance rates in excess of 300 metres per week, or about 2 to 3 times that for drilled and blasted tunnels.

A – 7 Operation of TBM's

A full-face tunnel boring machine (TBM) consists of a rotating head fitted with rock cutting tools or picks. The head is supported by a bearing on a structural support member that, in turn, is held in place by a hydraulically positioned wall-gripping mechanism. Both torque and thrust are applied to the cutting head, the machine thrust being provided by jacks reacting against the grippers, which are expanded laterally against the tunnel sidewalls. The rock cuttings fall to the invert at the tunnel face where they are removed by means of buckets or scoops that transfer the cuttings to a conveyor belt working immediately behind the cutting head. After advancing the cutting head through a pre-set boring stroke, the tunnelling machine is advanced by hydraulically pulling in the gripper mechanism from the tunnel walls, stroking forward, and edging the grippers to the new forward position on the wall; the machine is then set for the next advance stroke.

Although special machines have been designed to turn on a radius of 30 metres in both horizontal and vertical directions, the conveyors and back-up service equipment generally limit TBMs to turn with a radius of more than 100 metres.

The full-face rotary TBM's have provided the fastest and most reliable production of any excavation method or machine type. They can operate as "open" machines, or alternatively as "shielded" machines. The open machines have the advantage of allowing any type of ground support system to be installed as near to the tunnel face as possible. The shielded machines, on the other hand, are designed principally to allow the placing of pre-cast concrete segments. The shielded machines completely protect the equipment and personnel at the heading, but for reasons of economy are limited to permanent openings where full lining is required.

The following aspects need to be considered when choosing the type of TBM to be utilised on a project:

a) Cutting Tools

   Tunnelling machines utilise several different types of rock cutting tools or picks. There are three common types, i.e. the drag bit, the disc cutter and button cutter, which are utilised for specific geological and operational conditions. As cutting tool replacement costs are high, it is important to match tool type with machine type and operational and geological conditions.

b) Fracture Strength and Abrasion of Rock

The two mechanical characteristics of the rock which directly affect both pick replacement costs and excavation rates are, firstly, the ability of the rock to be fractured (which is generally measured in terms of the uni-axial compressive strength of the intact rock), and secondly the abrasiveness of the rock (for which no standard test exists, although the index of percentage silica is often used).

c) Personnel

A tunnelling machine is only as good as the personnel in charge of its operation. It is imperative therefore to have good organisation and supervision, and a thoroughly trained work force. In general, mechanical excavation requires more than twice the number of skilled operatives compared to conventional drill and blast techniques.

d) Ground support systems

With tunnel boring operations, a variety of ground support systems can be installed, including rock bolts, steel arches, pre-cast concrete members, etc. Where a significant proportion of the tunnel requires support, a reduction in the machine utilisation factor to around 50% to 60% can be expected, although this factor obviously depends upon the difficulty of the ground support.

Due to the significant reduced rock mass loosening and over-break experienced with tunnel boring machines compared to conventional drill and blast techniques, machine-bored tunnels generally require much less ground support. As one would expect, the factor is greater for small diameter tunnels than larger ones.

e) Line and grade control

Prior to the introduction of laser beam guidance, the maintenance of line and grade was always problematic. Adjustments of the grade and alignment of the machine can be made automatically or manually. Deviations can be easily kept within 25 mm.

f) Dust Control

The control of dust is a major factor in the operation of TBM’s. This is commonly achieved by installing ventilation ducts mounted on suction type blowers, as close to the face as possible. In addition, the face is frequently sprayed with water or a wetting agent.

e) Geotechnical Factors

To a great extent, the efficiency and economy of any tunnelling machine is dependent upon the rock and rock structure through which it bores. Problems of a geological nature found only during actual tunnelling operations result in very costly downtime and must be prevented at all costs.

h) Rates of Advance

Penetration rates for full-face TBM's vary from 2 to 3 m/hr with the minimum rate required for economic machine boring operations being approximately 1 m/hr.

A – 8 Advantages of TBM's

Advantages of Tunnel Boring Machines may be summarised as follows:

a) A negative feature of the drill and blast method is the delay caused by cyclic operation. In contrast, TBM's can operate on an almost continuous basis, the only unproductive time in the cycle is that required to advance the reaction frame at the end of each "stroke". The continuous advance results in higher hourly rates of advance and in optimum use of ancillary tunnelling equipment such as muck handling and ventilation systems.

b) TBM’s have the great advantage that in good rock they produce a smooth bore with a diameter equal to the design diameter. Consequently, overbreak is practically eliminated, which results in a reduction in the quantities of muck to be handled and the amount of concrete used in the lining.

c) A further benefit, resulting from the smooth bore and from the elimination of blasting vibration, is that loosening of the rock is considerably reduced, so that the rock has a better self-supporting capacity. This in turn, means that the support requirements for machine excavated tunnels are significantly less than for drilled and blasted tunnels. This effects the economics not only in terms of reduced quantities of support, but also in terms of shorter installation time for rock support and consequent faster rates of advance of the entire tunnelling operation.

d) A further advantage is that due to the absence of blast induced vibrations, TBM's are not as damaging to the local environment, hence special precautions need not be taken with regard to the effect of tunnelling vibrations on nearby structures.

A – 9 Disadvantages of TBM's

Tunnel-boring machines pent some important disadvantages that may reduce their potential use under some conditions.

a) Geometric Constraints

Full-face TBM's can only excavate circular tunnel sections and a given TBM can bore only one size of tunnel.

A further geometric constraint in the use of TBM's is related to the minimum radius of curvature, the tightest practical curve which can be negotiated by a TBM is in the order of 100 metres. For maximum tunnel grades, the limitations are generally similar to those for the material handling system and, as such; do not introduce additional constraints to the alignment.

b) Limitations due to Rock Conditions

The limitations of TBM use are uniquely related to variations in the quality of the rock mass. Since TBM's are custom built for local rock conditions (i.e. their design is based on the strength and hardness of the rock expected), if the rock conditions are variable over the length of the tunnel, the operation of any TBM will be very difficult. The incapacity of TBM's to adapt to changes in rock quality can be even more severe and may force the contractor to use classical mining methods to overcome the difficulty.

A – 10 Mechanised Tunnelling verses Drilling and Blasting

Full-face rock tunnelling machines produce a very smooth opening which reduces rock support requirements, and minimises overbreak and the distance to the flow of ventilation. In addition, the smooth tunnel makes support installation much faster, gives improved support, and is much more cost effective. Rock sts concentrations are also reduced. The smooth tunnel and the absence of explosives make machine tunnelling operations safer and less unpleasant.

On the other hand, the drill and blast technique has a wealth of experience, and is frequently used as the last remaining solution when other methods have failed. For identical projects, tunnelling machines can develop at 3 to 10 times the rate of conventional drill and blast techniques.

Rules of thumb can sometimes be misleading but the following are pented as a list of the items to be evaluated when considering the use of tunnel boring techniques:

- The required tunnel length should be at least 2.0 km, with the tunnel diameter greater than 3.0m for full-face machines;
- The uni-axial compressive strength of the intact rock should be less than 275 MPa, with a geological structure that is preferably jointed or bedded;
- Tunnel curves should have a radius of at least 100m with the tunnel grade varying from -9% to +14%;
- The rate of water inflow at the tunnel face should not exceed 0.017 m^3/second (i.e. 17 ℓ/second) per metre of tunnel diameter. The maximum water pressure should be less than 1.5 MPa;
- The muck handling system must be capable of disposing of broken rock at the sustained production rate of the tunnelling machine; and
- The rock sts must not exceed the equivalent of two tunnel diameters.

Annexure B

Detailed cost estimate of 31% MAR Smithfield Dam

(DATA INCLUDED ON CD)

Annexure C

Determination of energy line sheet

Smithfield conveyance

First order calculations

Z	887.200	m	Minimum Draw Down Level
Z	872.000	m	Required Water Level at the WTW
H	15.200	m	Available head
Q	8.650	m³/s	Design flow
kp	0.5	mm	Pipe hydraulic roughness
kt	1.5	mm	Tunnel hydraulic roughness
v	1.14E-06	m²/s	Kinematic viscosity

Trashrack loss			
a_n	5.04	m²	Net area through the rack bars
a_g	12.25	m²	Gross area of bars and supports
k	1.0955837		Minor loss coeficient (Small dams, USBR)
V	1.716	m/s	Velocity through net area
hl	0.329	m	Minor head loss through 2 x trash rack

Inlet tower minor losses

k	D_1 (m)	D_2 (m)	V_1 (m/s)	V_2 (m/s)	hl (m)	Description
0.100	3.5	-	0.9	-	0.004	Entrance - bellmouth fully rounded, r/D>0.15 (Small dams, US
0.100	3.5	-	0.9	-	0.004	Entrance - bellmouth fully rounded, r/D>0.15 (Small dams, US
0.500	3.5	-	0.9	-	0.021	Entrance -second trash rack
0.500	3.5	-	0.9	-	0.021	Exit loss -second trash rack
				Sub T	0.049	

Friction losses through tunnel

l (m)	D (m)	V (m/s)	λ		hf (m)
34100	3.500	0.899	0.01636		6.566

Re	λ	Left	Right
3411045.1	0.016359	7.81846	7.83025222

Tunnel minor losses

k	D_1 (m)	D_2 (m)	V_1 (m/s)	V_2 (m/s)	hl (m)
0.5	3.5		0.899063		0.702434211
				Sub T	7.269

Friction losses through pipe to WTW

l (m)	D (m)	V (m/s)	λ		hf (m)
3285	2.400	1.912	0.01455		3.711
				Sub T	3.711

Re	λ	Left	Right
4974440.8	0.014548	8.290695	8.436638292

Pipe minor losses

k	D_1 (m)	D_2 (m)	V_1 (m/s)	V_2 (m/s)	hl (m)	Description
0.800	0.0	2.4	-	1.91	0.49	Coefficient of 1/km of pipe
0.300	3.5	2.4	0.899	1.91	0.04	Contraction, 10° flare angle (Small dams, USBR)
0.750	0.0	2.4	-	1.91	0.140	90° elbow (Manual of British Water Engineering Practice)
0.750	0.0	2.4	-	1.91	0.140	90° elbow (Manual of British Water Engineering Practice)
0.300	0.0	2.4	-	1.91	0.056	Butterfly valve (Manual of British Water Engineering Practice)
1.000	0.0	2.4	-	1.91	0.186	Outlet loss
				Sub T	1.06	

TOTAL LOSSES	12.4	m
AVAILABLE HEAD	15.2	m

Annexure D

Detailed cost estimate of Langa Balancing Dam at 919

(DATA INCLUDED ON CD)

Annexure E

URV information option: Smithfield Dam and one tunnel only

uMkhomazi URVs

				Supply horizon (years after construction)	Limiting date for scheme	NPV Costs			NPV water			URV		
						6%	8%	10%	6%	8%	10%	6%	8%	10%
(Impendle 0 MAR)	15%MAR (915masl)	915	2036	13	2036	7 609	6 090	4 986	1 196	742	484	6.36	8.21	10.30
	20%MAR (920masl)	920	2038	15	2038	7 718	6 182	5 064	1 258	774	501	6.13	7.98	10.10
	25%MAR (925masl)	925	2040	17	2040	7 853	6 296	5 161	1 314	802	516	5.98	7.85	10.01
	31%MAR (930masl)	930	2043	20	2043	8 014	6 432	5 276	1 383	836	532	5.79	7.70	9.91
	38%MAR (935masl)	935	2043	20	2043	8 212	6 599	5 418	1 383	836	532	5.94	7.90	10.18

uMkhomazi Water Project: Phase 1
Sizing of Smithfield Dam
Options for analyses

Option	Smithfield Dam size	Smithfield Dam Yield (m^3)	Total System Yield with 1*MAR Impendle Dam (m^3)	Transfer yield Phase 1 (m^3)	Transfer yield Phase 2 (m^3)	Phase 1 Size of tunnel (m diameter)	Size of Pipe for phase 1(m diameter)	Phase 2 Size of tunnel (m diameter)	Size of Pipe for phase 2 (m diameter)	Transfer capacity of tunnel Phase 1	Transfer capacity of tunnel Phase 2	Year of commencement of supply for second tunnel	Year of Impendle supply commencement (Total system)	Year of Impendle supply commencement (Umlaas Road)	Limiting date for scheme	Cost Smithfield Dam R (million)	Cost Smithfield Dam Saddle Wall R (million)	Cost Impendle Dam R (million)	Cost Langa Balancing Dam R (million)	Cost Mkhomazi-uMlazi Tunnel (Single tunnel) R (million)	Cost Tunnel end -M1/M3 connection pipeline R (million)	Cost M1/M3 Connection - Umlaas Road R (million)	Cost Raw water reservoirs R (million)	Cost WTW R (million)	Cost Potable water reservoirs R (million)
3 (Impendle 0,5MAR)	15%MAR (915masl)	163 000 000	273 000 000	163 000 000	273 000 000	3.5		2 x 3.5		6.46	10.82	2044	2036	2028	2050	1520	41	1289	419	3895	152	812	360	2695	270
	20%MAR (920masl)	181 000 000	284 000 000	181 000 000	284 000 000	3.5		2 x 3.5		7.17	11.26	2044	2038	2034	2051	1659	74	1289	419	3895	152	812	360	2695	270
	25%MAR (925masl)	200 000 000	294 000 000	200 000 000	294 000 000	3.5		2 x 3.5		7.93	11.65	2044	2040	2040	2052	1823	125	1289	419	3895	152	812	360	2695	270
	31%MAR (930masl)	220 000 000	306 000 000	220 000 000	306 000 000	3.5		2 x 3.5		8.72	12.13	2044	2043	2049	2053	2009	194	1289	419	3895	152	812	360	2695	270
	38%MAR (935masl)	247 000 000	316 000 000	247 000 000	316 000 000	3.5		2 x 3.5		9.79	12.53	2044	2046	2064	2054	2234	283	1289	419	3895	152	812	360	2695	270
1 (Impendle 1MAR)	15%MAR (915masl)	163 000 000	329 000 000	163 000 000	329 000 000	3.5		2 x 3.5		6.46	13.04	2044	2036	2028	2056	1520	41	1822	419	3895	152	812	360	2695	270
	20%MAR (920masl)	181 000 000	336 000 000	181 000 000	336 000 000	3.5		2 x 3.5		7.17	13.32	2044	2038	2034	2057	1659	74	1822	419	3895	152	812	360	2695	270
	25%MAR (925masl)	200 000 000	341 000 000	200 000 000	341 000 000	3.5		2 x 3.5		7.93	13.52	2044	2040	2040	2058	1823	125	1822	419	3895	152	812	360	2695	270
	31%MAR (930masl)	220 000 000	347 000 000	220 000 000	347 000 000	3.5		2 x 3.5		8.72	13.75	2044	2043	2049	2058	2009	194	1822	419	3895	152	812	360	2695	270
	38%MAR (935masl)	247 000 000	353 000 000	247 000 000	353 000 000	3.5		2 x 3.5		9.79	13.99	2044	2046	2064	2059	2234	283	1822	419	3895	152	812	360	2695	270
2 (Impendle 1.5MAR)	15%MAR (915masl)	163 000 000	364 000 000	163 000 000	364 000 000	3.5		2 x 3.5		6.46	14.43	2044	2036	2028	2060	1520	41	2120	419	3895	152	812	360	2695	270
	20%MAR (920masl)	181 000 000	366 000 000	181 000 000	366 000 000	3.5		2 x 3.5		7.17	14.51	2044	2038	2034	2061	1659	74	2120	419	3895	152	812	360	2695	270
	25%MAR (925masl)	200 000 000	370 000 000	200 000 000	370 000 000	3.5		2 x 3.5		7.93	14.67	2044	2040	2040	**2061**	1823	125	2120	419	3895	152	812	360	2695	270
	31%MAR (930masl)	220 000 000	373 000 000	220 000 000	373 000 000	3.5		2 x 3.5		8.72	14.78	2044	2043	2049	**2061**	2009	194	2120	419	3895	152	812	360	2695	270
	38%MAR (935masl)	247 000 000	376 000 000	247 000 000	376 000 000	3.5		2 x 3.5		9.79	14.90	2044	2046	2064	**2062**	2234	283	2120	419	3895	152	812	360	2695	270

NPV date	2013
End of analysis	2073
Interest rate	6%

15% MAR Smithfield and 0 MAR Impendle	Capital Cost				Life span	Operating cost %	Replacement date			Remaining life			NPV Factors Capital			NPV Factor Operations			NPV Factor Replacement			NPV Factor Residual			NPV Capital				NPV Operations				NPV Replacement				NPV Residual				NPV Total			
	End of Year						End of Year			End of Year			End of Year			End of Year			End of Year			End of Year			End of Year				End of Year				End of Year				End of Year				End of Year			
	2023	2044	2036																																									
Component	R(million)																																											
Environmental, admin and social																																												
Impendle Dam					50	0.25%	0	0	0	0	21	13	1.64	5.59	3.51	0.11	0.45	0.26	0.00	0.00	0.00	32.99	32.99	32.99			0.00				0.00		0.00	0.00	0.00				0.00				0.00	
Smithfield Dam	1561				50	0.25%	0	0	0	0	21	13	1.64	5.59	3.51	0.11	0.45	0.26	0.00	0.00	0.00	32.99	32.99	32.99	949.25				34.35				0.00	0.00	0.00		0.00				983.60			
uMkhomazi - uMlazi tunnel	3895				50	0.25%	0	0	0	0	21	13	1.64	5.59	3.51	0.11	0.45	0.26	0.00	0.00	0.00	32.99	32.99	32.99	2368.57	0.00			85.70	0.00			0.00	0.00	0.00		0.00	0.00			2 454.27	0.00		
Tunnel end -M1/M3 connection	152				30	0.40%	2053	0	2066	10	1	23	1.69	5.75	3.61	0.11	0.45	0.26	10.29	0.00	21.94	32.99	32.99	32.99	89.87	0.00			5.35	0.00			14.78	0.00	0.00		1.54	0.00			108.46	0.00		
Langa Balancing dam	419				50	0.25%	0	0	0	0	21	13	1.69	5.75	3.61	0.11	0.45	0.26	0.00	0.00	0.00	32.99	32.99	32.99	247.73				9.22				0.00	0.00	0.00		0.00				256.94			
M1/M3 Connection - Umlaas Road Pipeline	812				30	0.40%	2053	0	2066	10	1	23	1.69	5.75	3.61	0.11	0.45	0.26	10.29	0.00	21.94	32.99	32.99	32.99	480.08	0.00			28.59	0.00			78.94	0.00	0.00		8.21	0.00			579.40	0.00		
Raw water reservoirs	360.0				30	0.40%	2053	0	2066	10.0	1	23	1.69	5.75	3.61	0.11	0.45	0.26	10.29	0.00	21.94	32.99	32.99	32.99	212.84	0.00			12.67	0.00			35.00	0.00	0.00		3.64	0.00			256.88	0.00		
WTW	2 695.0				30	4.00%	2053	0	2066	10.0	1	23	1.69	5.75	3.61	0.11	0.45	0.26	10.29	0.00	21.94	32.99	32.99	32.99	1593.36	0.00			948.78	0.00			262.01	0.00	0.00		27.23	0.00			2 776.93	0.00		
Potable water reservoirs	270.0				30	0.40%	2053	0	2066	10.0	1	23	1.69	5.75	3.61	0.11	0.45	0.26	10.29	0.00	21.94	32.99	32.99	32.99	159.63	0.00			9.51	0.00			26.25	0.00	0.00		2.73	0.00			192.66	0.00		
Total Capital	10 164.0	0.0	0.0	10 164.0																					6 101.3	0.0	0.0	6 101.3	1 134.2	0.0	0.0	1 134.2	417.0	0.0	0.0	417.0	43.3	0.0	0.0	43.3	7 609.1	0.0	0.0	7 609.1

20% MAR Smithfield and 0 MAR Impendle	Capital Cost				Life span	Operating cost %	Replacement date			Remaining life			NPV Factors Capital			NPV Factor Operations			NPV Factor Replacement			NPV Factor Residual			NPV Capital				NPV Operations				NPV Replacement				NPV Residual				NPV Total			
	End of Year						End of Year			End of Year			End of Year			End of Year			End of Year			End of Year			End of Year				End of Year				End of Year				End of Year				End of Year			
	2023	2044	2038																																									
Component	R(million)																																											
Environmental, admin and social																																												
Impendle Dam					50	0.25%	0	0	0	0	21	15	1.64	5.59	3.94	0.11	0.45	0.30	0.00	0.00	0.00	32.99	32.99	32.99			0.00				0.00		0.00	0.00	0.00				0.00				0.00	
Smithfield Dam	1733				50	0.25%	0	0	0	0	21	15	1.64	5.59	3.94	0.11	0.45	0.30	0.00	0.00	0.00	32.99	32.99	32.99	1053.85				38.13				0.00	0.00	0.00		0.00				1 091.98			
uMkhomazi - uMlazi tunnel	3895				50	0.25%	0	0	0	0	21	15	1.64	5.59	3.94	0.11	0.45	0.30	0.00	0.00	0.00	32.99	32.99	32.99	2368.57	0.00			85.70	0.00			0.00	0.00	0.00		0.00	0.00			2 454.27	0.00		
Tunnel end -M1/M3 connection	152				30	0.40%	2053	0	2068	10	1	25	1.69	5.75	4.05	0.11	0.45	0.30	10.29	0.00	24.65	32.99	32.99	32.99	89.87	0.00			5.35	0.00			14.78	0.00	0.00		1.54	0.00			108.46	0.00		
Langa Balancing dam	419				50	0.25%	0	0	0	0	21	15	1.69	5.75	4.05	0.11	0.45	0.30	0.00	0.00	0.00	32.99	32.99	32.99	247.73				9.22				0.00	0.00	0.00		0.00				256.94			
M1/M3 Connection - Umlaas Road Pipeline	812				30	0.40%	2053	0	2068	10	1	25	1.69	5.75	4.05	0.11	0.45	0.30	10.29	0.00	24.65	32.99	32.99	32.99	480.08	0.00			28.59	0.00			78.94	0.00	0.00		8.21	0.00			579.40	0.00		
Raw water reservoirs	360.0				30	0.40%	2 053.0	0	2068	10.0	1	25	1.69	5.75	4.05	0.11	0.45	0.30	10.29	0.00	24.65	32.99	32.99	32.99	212.84	0.00			12.67	0.00			35.00	0.00	0.00		3.64	0.00			256.88	0.00		
WTW	2 695.0				30	4.00%	2 053.0	0	2068	10.0	1	25	1.69	5.75	4.05	0.11	0.45	0.30	10.29	0.00	24.65	32.99	32.99	32.99	1593.36	0.00			948.78	0.00			262.01	0.00	0.00		27.23	0.00			2 776.93	0.00		
Potable water reservoirs	270.0				30	0.40%	2 053.0	0	2068	10.0	1	25	1.69	5.75	4.05	0.11	0.45	0.30	10.29	0.00	24.65	32.99	32.99	32.99	159.63	0.00			9.51	0.00			26.25	0.00	0.00		2.73	0.00			192.66	0.00		
Total Capital	10 336.0	0.0	0.0	10 336.0																					6 205.9	0.0	0.0	6 205.9	1 138.0	0.0	0.0	1 138.0	417.0	0.0	0.0	417.0	43.3	0.0	0.0	43.3	7 717.5	0.0	0.0	7 717.5

25% MAR Smithfield and 0 MAR Impendle	Capital Cost				Life span	Operating cost %	Replacement date			Remaining life			NPV Factors Capital			NPV Factor Operations			NPV Factor Replacement			NPV Factor Residual			NPV Capital				NPV Operations				NPV Replacement				NPV Residual				NPV Total			
	End of Year						End of Year			End of Year			End of Year			End of Year			End of Year			End of Year			End of Year				End of Year				End of Year				End of Year				End of Year			
	2023	2044	2040																																									
Component	R(million)																																											
Environmental, admin and social																																												
Impendle Dam					50	0.25%	0	0	0	0	21	17	1.64	5.59	4.43	0.11	0.45	0.34	0.00	0.00	0.00	32.99	32.99	32.99			0.00				0.00		0.00	0.00	0.00				0.00				0.00	
Smithfield Dam	1948				50	0.25%	0	0	0	0	21	17	1.64	5.59	4.43	0.11	0.45	0.34	0.00	0.00	0.00	32.99	32.99	32.99	1184.59				42.86				0.00	0.00	0.00		0.00				1 227.45			
uMkhomazi - uMlazi tunnel	3895				50	0.25%	0	0	0	0	21	17	1.64	5.59	4.43	0.11	0.45	0.34	0.00	0.00	0.00	32.99	32.99	32.99	2368.57	0.00			85.70	0.00			0.00	0.00	0.00		0.00	0.00			2 454.27	0.00		
Tunnel end -M1/M3 connection	152				30	0.40%	2053	0	2070	10	1	27	1.69	5.75	4.55	0.11	0.45	0.34	10.29	0.00	27.70	32.99	32.99	32.99	89.87	0.00			5.35	0.00			14.78	0.00	0.00		1.54	0.00			108.46	0.00		
Langa Balancing dam	419				50	0.25%	0	0	0	0	21	17	1.69	5.75	4.55	0.11	0.45	0.34	0.00	0.00	0.00	32.99	32.99	32.99	247.73				9.22				0.00	0.00	0.00		0.00				256.94			
M1/M3 Connection - Umlaas Road Pipeline	812				30	0.40%	2053	0	2070	10	1	27	1.69	5.75	4.55	0.11	0.45	0.34	10.29	0.00	27.70	32.99	32.99	32.99	480.08	0.00			28.59	0.00			78.94	0.00	0.00		8.21	0.00			579.40	0.00		
Raw water reservoirs	360.0				30	0.40%	2 053.0	0	2070	10.0	1	27	1.69	5.75	4.55	0.11	0.45	0.34	10.29	0.00	27.70	32.99	32.99	32.99	212.84	0.00			12.67	0.00			35.00	0.00	0.00		3.64	0.00			256.88	0.00		
WTW	2 695.0				30	4.00%	2 053.0	0	2070	10.0	1	27	1.69	5.75	4.55	0.11	0.45	0.34	10.29	0.00	27.70	32.99	32.99	32.99	1593.36	0.00			948.78	0.00			262.01	0.00	0.00		27.23	0.00			2 776.93	0.00		
Potable water reservoirs	270.0				30	0.40%	2 053.0	0	2070	10.0	1	27	1.69	5.75	4.55	0.11	0.45	0.34	10.29	0.00	27.70	32.99	32.99	32.99	159.63	0.00			9.51	0.00			26.25	0.00	0.00		2.73	0.00			192.66	0.00		
Total Capital	10 551.0	0.0	0.0	10 551.0																					6 336.7	0.0	0.0	6 336.7	1 142.7	0.0	0.0	1 142.7	417.0	0.0	0.0	417.0	43.3	0.0	0.0	43.3	7 853.0	0.0	0.0	7 853.0

31% MAR Smithfield and 0 MAR Impendle	Capital Cost				Life span	Operating cost %	Replacement date			Remaining life			NPV Factors Capital			NPV Factor Operations			NPV Factor Replacement			NPV Factor Residual			NPV Capital				NPV Operations				NPV Replacement				NPV Residual				NPV Total			
	End of Year						End of Year			End of Year			End of Year			End of Year			End of Year			End of Year			End of Year				End of Year				End of Year				End of Year				End of Year			
	2023	2044	2043																																									
Component	R(million)																																											
Environmental, admin and social																																												
Impendle Dam					50	0.25%	0	0	0	0	21	20	1.64	5.59	5.27	0.11	0.45	0.42	0.00	0.00	0.00	32.99	32.99	32.99			0.00				0.00		0.00	0.00	0.00				0.00				0.00	
Smithfield Dam	2203				50	0.25%	0	0	0	0	21	20	1.64	5.59	5.27	0.11	0.45	0.42	0.00	0.00	0.00	32.99	32.99	32.99	1339.66				48.47				0.00	0.00	0.00		0.00				1 388.13			
uMkhomazi - uMlazi tunnel	3895				50	0.25%	0	0	0	0	21	20	1.64	5.59	5.27	0.11	0.45	0.42	0.00	0.00	0.00	32.99	32.99	32.99	2368.57	0.00			85.70	0.00			0.00	0.00	0.00		0.00	0.00			2 454.27	0.00		
Tunnel end -M1/M3 connection pipeline	152				30	0.40%	2053	0	0	10	1	0	1.69	5.75	5.42	0.11	0.45	0.42	10.29	0.00	0.00	32.99	32.99	32.99	89.87	0.00			5.35	0.00			14.78	0.00	0.00		1.54	0.00			108.46	0.00		
Langa Balancing dam	419				50	0.25%	0	0	0	0	21	20	1.69	5.75	5.42	0.11	0.45	0.42	0.00	0.00	0.00	32.99	32.99	32.99	247.73				9.22				0.00	0.00	0.00		0.00				256.94			
M1/M3 Connection - Umlaas Road Pipeline	812				30	0.40%	2053	0	0	10	1	0	1.69	5.75	5.42	0.11	0.45	0.42	10.29	0.00	0.00	32.99	32.99	32.99	480.08	0.00			28.59	0.00			78.94	0.00	0.00		8.21	0.00			579.40	0.00		
Raw water reservoirs	360.0				30	0.40%	2 053.0	0	0	10.0	1	0	1.69	5.75	5.42	0.11	0.45	0.42	10.29	0.00	0.00	32.99	32.99	32.99	212.84	0.00			12.67	0.00			35.00	0.00	0.00		3.64	0.00			256.88	0.00		
WTW	2 695.0				30	4.00%	2 053.0	0	0	10.0	1	0	1.69	5.75	5.42	0.11	0.45	0.42	10.29	0.00	0.00	32.99	32.99	32.99	1593.36	0.00			948.78	0.00			262.01	0.00	0.00		27.23	0.00			2 776.93	0.00		
Potable water reservoirs	270.0				30	0.40%	2 053.0	0	0	10.0	1	0	1.69	5.75	5.42	0.11	0.45	0.42	10.29	0.00	0.00	32.99	32.99	32.99	159.63	0.00			9.51	0.00			26.25	0.00	0.00		2.73	0.00			192.66	0.00		
Total Capital	10 806.0	0.0	0.0	10 806.0																					6 491.7	0.0	0.0	6 491.7	1 148.3	0.0	0.0	1 148.3	417.0	0.0	0.0	417.0	43.3	0.0	0.0	43.3	8 013.7	0.0	0.0	8 013.7

38% MAR Smithfield and 0 MAR Impendle	Capital Cost				Life span	Operating cost %	Replacement date			Remaining life			NPV Factors Capital			NPV Factor Operations			NPV Factor Replacement			NPV Factor Residual			NPV Capital				NPV Operations				NPV Replacement				NPV Residual				NPV Total			
	End of Year						End of Year			End of Year			End of Year			End of Year			End of Year			End of Year			End of Year				End of Year				End of Year				End of Year				End of Year			
	2023	2044	2046																																									
Component	R(million)																																											
Environmental, admin and social																																												
Impendle Dam					50	0.25%	0	0	0	0	21	23	1.64	5.59	6.28	0.11	0.45	0.52	0.00	0.00	0.00	32.99	32.99	32.99			0.00				0.00		0.00	0.00	0.00				0.00				0.00	
Smithfield Dam	2517				50	0.25%	0	0	0	0	21	23	1.64	5.59	6.28	0.11	0.45	0.52	0.00	0.00	0.00	32.99	32.99	32.99	1530.60				55.38				0.00	0.00	0.00		0.00				1 585.98			
uMkhomazi - uMlazi tunnel	3895				50	0.25%	0	0	0	0	21	23	1.64	5.59	6.28	0.11	0.45	0.52	0.00	0.00	0.00	32.99	32.99	32.99	2368.57	0.00			85.70	0.00			0.00	0.00	0.00		0.00	0.00			2 454.27	0.00		
Tunnel end -M1/M3 connection pipeline	152				30	0.40%	2053	0	0	10	1	3	1.69	5.75	6.46	0.11	0.45	0.52	10.29	0.00	0.00	32.99	32.99	32.99	89.87	0.00			5.35	0.00			14.78	0.00	0.00		1.54	0.00			108.46	0.00		
Langa Balancing dam	419				50	0.25%	0	0	0	0	21	23	1.69	5.75	6.46	0.11	0.45	0.52	0.00	0.00	0.00	32.99	32.99	32.99	247.73				9.22				0.00	0.00	0.00		0.00				256.94			
M1/M3 Connection - Umlaas Road Pipeline	812				30	0.40%	2053	0	0	10	1	3	1.69	5.75	6.46	0.11	0.45	0.52	10.29	0.00	0.00	32.99	32.99	32.99	480.08	0.00			28.59	0.00			78.94	0.00	0.00		8.21	0.00			579.40	0.00		
Raw water reservoirs	360.0				30	0.40%	2 053.0	0	0	10.0	1	3	1.69	5.75	6.46	0.11	0.45	0.52	10.29	0.00	0.00	32.99	32.99	32.99	212.84	0.00			12.67	0.00			35.00	0.00	0.00		3.64	0.00			256.88	0.00		
WTW	2 695.0				30	4.00%	2 053.0	0	0	10.0	1	3	1.69	5.75	6.46	0.11	0.45	0.52	10.29	0.00	0.00	32.99	32.99	32.99	1593.36	0.00			948.78	0.00			262.01	0.00	0.00		27.23	0.00			2 776.93	0.00		
Potable water reservoirs	270.0				30	0.40%	2 053.0	0	0	10.0	1	3	1.69	5.75	6.46	0.11	0.45	0.52	10.29	0.00	0.00	32.99	32.99	32.99	159.63	0.00			9.51	0.00			26.25	0.00	0.00		2.73	0.00			192.66	0.00		
Total Capital	11 120.0	0.0	0.0	11 120.0																					6 682.7	0.0	0.0	6 682.7	1 155.2	0.0	0.0	1 155.2	417.0	0.0	0.0	417.0	43.3	0.0	0.0	43.3	8 211.5	0.0	0.0	8 211.5

NPV date 2013
End of analysis 2073
Interest rate 8%

15% MAR Smithfield and 0 MAR Impendle	Capital Cost				Life span	Operating cost %	Replacement date			Remaining life			NPV Factors Capital			NPV Factor Operations			NPV Factor Replacement			NPV Factor Residual			NPV Capital				NPV Operations				NPV Replacement				NPV Residual				NPV Total			
	End of Year						End of Year			End of Year			End of Year			End of Year			End of Year			End of Year			End of Year				End of Year				End of Year				End of Year				End of Year			
	2023	2044	2036																																									
Component		R(million)																																										
Environmental, admin and social																																												
Impendle Dam					50	0.25%	0	0	0	0	21	13	1.93	9.72	5.25	0.18	0.97	0.50	0.00	0.00	0.00	101.26	101.26	101.26			0.00				0.00		0.00	0.00	0.00				0.00				0.00	
Smithfield Dam	1561				50	0.25%	0	0	0	0	21	13	1.93	9.72	5.25	0.18	0.97	0.50	0.00	0.00	0.00	101.26	101.26	101.26	808.53				22.11				0.00	0.00	0.00		0.00				830.64			
uMkhomazi - uMlazi tunnel	3895				50	0.25%	0	0	0	0	21	13	1.93	9.72	5.25	0.18	0.97	0.50	0.00	0.00	0.00	101.26	101.26	101.26	2017.43	0.00			55.18	0.00			0.00	0.00	0.00		0.00	0.00			2 072.61	0.00		
Tunnel end -M1/M3 connection	152				30	0.40%	2053	0	2066	10	1	23	2.00	10.08	5.45	0.18	0.97	0.50	21.72	0.00	59.08	101.26	101.26	101.26	75.89	0.00			3.45	0.00			7.00	0.00	0.00		0.50	0.00			85.83	0.00		
Langa Balancing dam	419				50	0.25%	0	0	0	0	21	13	2.00	10.08	5.45	0.18	0.97	0.50	0.00	0.00	0.00	101.26	101.26	101.26	209.19				5.94				0.00	0.00	0.00		0.00				215.13			
M1/M3 Connection - Umlaas Road	812				30	0.40%	2053	0	2066	10	1	23	2.00	10.08	5.45	0.18	0.97	0.50	21.72	0.00	59.08	101.26	101.26	101.26	405.40	0.00			18.40	0.00			37.38	0.00	0.00		2.67	0.00			458.51	0.00		
Raw water reservoirs	360.0				30	0.40%	2053	0	2066	10.0	1	23	2.00	10.08	5.45	0.18	0.97	0.50	21.72	0.00	59.08	101.26	101.26	101.26	179.73	0.00			8.16	0.00			16.57	0.00	0.00		1.19	0.00			203.28	0.00		
WTW	2 695.0				30	4.00%	2053	0	2066	10.0	1	23	2.00	10.08	5.45	0.18	0.97	0.50	21.72	0.00	59.08	101.26	101.26	101.26	1345.51	0.00			610.85	0.00			124.05	0.00	0.00		8.87	0.00			2 071.54	0.00		
Potable water reservoirs	270.0				30	0.40%	2053	0	2066	10.0	1	23	2.00	10.08	5.45	0.18	0.97	0.50	21.72	0.00	59.08	101.26	101.26	101.26	134.80	0.00			6.12	0.00			12.43	0.00	0.00		0.89	0.00			152.46	0.00		
Total Capital	10 164.0	0.0	0.0	10 164.0																					5 176.5	0.0	0.0	5 176.5	730.2	0.0	0.0	730.2	197.4	0.0	0.0	197.4	14.1	0.0	0.0	14.1	6 090.0	0.0	0.0	6 090.0

20% MAR Smithfield and 0 MAR Impendle	Capital Cost				Life span	Operating cost %	Replacement date			Remaining life			NPV Factors Capital			NPV Factor Operations			NPV Factor Replacement			NPV Factor Residual			NPV Capital				NPV Operations				NPV Replacement				NPV Residual				NPV Total			
	End of Year						End of Year			End of Year			End of Year			End of Year			End of Year			End of Year			End of Year				End of Year				End of Year				End of Year				End of Year			
	2023	2044	2038																																									
Component		R(million)																																										
Environmental, admin and social																																												
Impendle Dam					50	0.25%	0	0	0	0	21	15	1.93	9.72	6.12	0.18	0.97	0.59	0.00	0.00	0.00	101.26	101.26	101.26			0.00				0.00		0.00	0.00	0.00				0.00				0.00	
Smithfield Dam	1733				50	0.25%	0	0	0	0	21	15	1.93	9.72	6.12	0.18	0.97	0.59	0.00	0.00	0.00	101.26	101.26	101.26	897.62				24.55				0.00	0.00	0.00		0.00				922.17			
uMkhomazi - uMlazi tunnel	3895				50	0.25%	0	0	0	0	21	15	1.93	9.72	6.12	0.18	0.97	0.59	0.00	0.00	0.00	101.26	101.26	101.26	2017.43	0.00			55.18	0.00			0.00	0.00	0.00		0.00	0.00			2 072.61	0.00		
Tunnel end -M1/M3 connection	152				30	0.40%	2053	0	2068	10	1	25	2.00	10.08	6.35	0.18	0.97	0.59	21.72	0.00	68.91	101.26	101.26	101.26	75.89	0.00			3.45	0.00			7.00	0.00	0.00		0.50	0.00			85.83	0.00		
Langa Balancing dam	419				50	0.25%	0	0	0	0	21	15	2.00	10.08	6.35	0.18	0.97	0.59	0.00	0.00	0.00	101.26	101.26	101.26	209.19				5.94				0.00	0.00	0.00		0.00				215.13			
M1/M3 Connection - Umlaas Road	812				30	0.40%	2053	0	2068	10	1	25	2.00	10.08	6.35	0.18	0.97	0.59	21.72	0.00	68.91	101.26	101.26	101.26	405.40	0.00			18.40	0.00			37.38	0.00	0.00		2.67	0.00			458.51	0.00		
Raw water reservoirs	360.0				30	0.40%	2 053.0	0	2068	10.0	1	25	2.00	10.08	6.35	0.18	0.97	0.59	21.72	0.00	68.91	101.26	101.26	101.26	179.73	0.00			8.16	0.00			16.57	0.00	0.00		1.19	0.00			203.28	0.00		
WTW	2 695.0				30	4.00%	2 053.0	0	2068	10.0	1	25	2.00	10.08	6.35	0.18	0.97	0.59	21.72	0.00	68.91	101.26	101.26	101.26	1345.51	0.00			610.85	0.00			124.05	0.00	0.00		8.87	0.00			2 071.54	0.00		
Potable water reservoirs	270.0				30	0.40%	2 053.0	0	2068	10.0	1	25	2.00	10.08	6.35	0.18	0.97	0.59	21.72	0.00	68.91	101.26	101.26	101.26	134.80	0.00			6.12	0.00			12.43	0.00	0.00		0.89	0.00			152.46	0.00		
Total Capital	10 336.0	0.0	0.0	10 336.0																					5 265.6	0.0	0.0	5 265.6	732.6	0.0	0.0	732.6	197.4	0.0	0.0	197.4	14.1	0.0	0.0	14.1	6 181.5	0.0	0.0	6 181.5

25% MAR Smithfield and 0 MAR Impendle	Capital Cost				Life span	Operating cost %	Replacement date			Remaining life			NPV Factors Capital			NPV Factor Operations			NPV Factor Replacement			NPV Factor Residual			NPV Capital				NPV Operations				NPV Replacement				NPV Residual				NPV Total			
	End of Year						End of Year			End of Year			End of Year			End of Year			End of Year			End of Year			End of Year				End of Year				End of Year				End of Year				End of Year			
	2023	2044	2040																																									
Component		R(million)																																										
Environmental, admin and social																																												
Impendle Dam					50	0.25%	0	0	0	0	21	17	1.93	9.72	7.14	0.18	0.97	0.69	0.00	0.00	0.00	101.26	101.26	101.26			0.00				0.00		0.00	0.00	0.00				0.00				0.00	
Smithfield Dam	1948				50	0.25%	0	0	0	0	21	17	1.93	9.72	7.14	0.18	0.97	0.69	0.00	0.00	0.00	101.26	101.26	101.26	1008.98				27.60				0.00	0.00	0.00		0.00				1 036.57			
uMkhomazi - uMlazi tunnel	3895				50	0.25%	0	0	0	0	21	17	1.93	9.72	7.14	0.18	0.97	0.69	0.00	0.00	0.00	101.26	101.26	101.26	2017.43	0.00			55.18	0.00			0.00	0.00	0.00		0.00	0.00			2 072.61	0.00		
Tunnel end -M1/M3 connection pipeline	152				30	0.40%	2053	0	2070	10	1	27	2.00	10.08	7.41	0.18	0.97	0.69	21.72	0.00	80.38	101.26	101.26	101.26	75.89	0.00			3.45	0.00			7.00	0.00	0.00		0.50	0.00			85.83	0.00		
Langa Balancing dam	419				50	0.25%	0	0	0	0	21	17	2.00	10.08	7.41	0.18	0.97	0.69	0.00	0.00	0.00	101.26	101.26	101.26	209.19				5.94				0.00	0.00	0.00		0.00				215.13			
M1/M3 Connection - Umlaas Road Pipeline	812				30	0.40%	2053	0	2070	10	1	27	2.00	10.08	7.41	0.18	0.97	0.69	21.72	0.00	80.38	101.26	101.26	101.26	405.40	0.00			18.40	0.00			37.38	0.00	0.00		2.67	0.00			458.51	0.00		
Raw water reservoirs	360.0				30	0.40%	2 053.0	0	2070	10.0	1	27	2.00	10.08	7.41	0.18	0.97	0.69	21.72	0.00	80.38	101.26	101.26	101.26	179.73	0.00			8.16	0.00			16.57	0.00	0.00		1.19	0.00			203.28	0.00		
WTW	2 695.0				30	4.00%	2 053.0	0	2070	10.0	1	27	2.00	10.08	7.41	0.18	0.97	0.69	21.72	0.00	80.38	101.26	101.26	101.26	1345.51	0.00			610.85	0.00			124.05	0.00	0.00		8.87	0.00			2 071.54	0.00		
Potable water reservoirs	270.0				30	0.40%	2 053.0	0	2070	10.0	1	27	2.00	10.08	7.41	0.18	0.97	0.69	21.72	0.00	80.38	101.26	101.26	101.26	134.80	0.00			6.12	0.00			12.43	0.00	0.00		0.89	0.00			152.46	0.00		
Total Capital	10 551.0	0.0	0.0	10 551.0																					5 376.9	0.0	0.0	5 376.9	735.7	0.0	0.0	735.7	197.4	0.0	0.0	197.4	14.1	0.0	0.0	14.1	6 295.9	0.0	0.0	6 295.9

31% MAR Smithfield and 0 MAR Impendle	Capital Cost				Life span	Operating cost %	Replacement date			Remaining life			NPV Factors Capital			NPV Factor Operations			NPV Factor Replacement			NPV Factor Residual			NPV Capital				NPV Operations				NPV Replacement				NPV Residual				NPV Total			
	End of Year						End of Year			End of Year			End of Year			End of Year			End of Year			End of Year			End of Year				End of Year				End of Year				End of Year				End of Year			
	2023	2044	2043																																									
Component		R(million)																																										
Environmental, admin and social																																												
Impendle Dam					50	0.25%	0	0	0	0	21	20	1.93	9.72	9.00	0.18	0.97	0.89	0.00	0.00	0.00	101.26	101.26	101.26			0.00				0.00		0.00	0.00	0.00				0.00				0.00	
Smithfield Dam	2203				50	0.25%	0	0	0	0	21	20	1.93	9.72	9.00	0.18	0.97	0.89	0.00	0.00	0.00	101.26	101.26	101.26	1141.05				31.21				0.00	0.00	0.00		0.00				1 172.26			
uMkhomazi - uMlazi tunnel	3895				50	0.25%	0	0	0	0	21	20	1.93	9.72	9.00	0.18	0.97	0.89	0.00	0.00	0.00	101.26	101.26	101.26	2017.43	0.00			55.18	0.00			0.00	0.00	0.00		0.00	0.00			2 072.61	0.00		
Tunnel end -M1/M3 connection pipeline	152				30	0.40%	2053	0	0	10	1	0	2.00	10.08	9.34	0.18	0.97	0.89	21.72	0.00	0.00	101.26	101.26	101.26	75.89	0.00			3.45	0.00			7.00	0.00	0.00		0.50	0.00			85.83	0.00		
Langa Balancing dam	419				50	0.25%	0	0	0	0	21	20	2.00	10.08	9.34	0.18	0.97	0.89	0.00	0.00	0.00	101.26	101.26	101.26	209.19				5.94				0.00	0.00	0.00		0.00				215.13			
M1/M3 Connection - Umlaas Road Pipeline	812				30	0.40%	2053	0	0	10	1	0	2.00	10.08	9.34	0.18	0.97	0.89	21.72	0.00	0.00	101.26	101.26	101.26	405.40	0.00			18.40	0.00			37.38	0.00	0.00		2.67	0.00			458.51	0.00		
Raw water reservoirs	360.0				30	0.40%	2 053.0	0	0	10.0	1	0	2.00	10.08	9.34	0.18	0.97	0.89	21.72	0.00	0.00	101.26	101.26	101.26	179.73	0.00			8.16	0.00			16.57	0.00	0.00		1.19	0.00			203.28	0.00		
WTW	2 695.0				30	4.00%	2 053.0	0	0	10.0	1	0	2.00	10.08	9.34	0.18	0.97	0.89	21.72	0.00	0.00	101.26	101.26	101.26	1345.51	0.00			610.85	0.00			124.05	0.00	0.00		8.87	0.00			2 071.54	0.00		
Potable water reservoirs	270.0				30	0.40%	2 053.0	0	0	10.0	1	0	2.00	10.08	9.34	0.18	0.97	0.89	21.72	0.00	0.00	101.26	101.26	101.26	134.80	0.00			6.12	0.00			12.43	0.00	0.00		0.89	0.00			152.46	0.00		
Total Capital	10 806.0	0.0	0.0	10 806.0																					5 509.0	0.0	0.0	5 509.0	739.3	0.0	0.0	739.3	197.4	0.0	0.0	197.4	14.1	0.0	0.0	14.1	6 431.6	0.0	0.0	6 431.6

38% MAR Smithfield and 0 MAR Impendle	Capital Cost				Life span	Operating cost %	Replacement date			Remaining life			NPV Factors Capital			NPV Factor Operations			NPV Factor Replacement			NPV Factor Residual			NPV Capital				NPV Operations				NPV Replacement				NPV Residual				NPV Total			
	End of Year						End of Year			End of Year			End of Year			End of Year			End of Year			End of Year			End of Year				End of Year				End of Year				End of Year				End of Year			
	2023	2044	2046																																									
Component		R(million)																																										
Environmental, admin and social																																												
Impendle Dam					50	0.25%	0	0	0	0	21	23	1.93	9.72	11.34	0.18	0.97	1.16	0.00	0.00	0.00	101.26	101.26	101.26			0.00				0.00		0.00	0.00	0.00				0.00				0.00	
Smithfield Dam	2517				50	0.25%	0	0	0	0	21	23	1.93	9.72	11.34	0.18	0.97	1.16	0.00	0.00	0.00	101.26	101.26	101.26	1303.69				35.66				0.00	0.00	0.00		0.00				1 339.35			
uMkhomazi - uMlazi tunnel	3895				50	0.25%	0	0	0	0	21	23	1.93	9.72	11.34	0.18	0.97	1.16	0.00	0.00	0.00	101.26	101.26	101.26	2017.43	0.00			55.18	0.00			0.00	0.00	0.00		0.00	0.00			2 072.61	0.00		
Tunnel end -M1/M3 connection pipeline	152				30	0.40%	2053	0	0	10	1	3	2.00	10.08	11.76	0.18	0.97	1.16	21.72	0.00	0.00	101.26	101.26	101.26	75.89	0.00			3.45	0.00			7.00	0.00	0.00		0.50	0.00			85.83	0.00		
Langa Balancing dam	419				50	0.25%	0	0	0	0	21	23	2.00	10.08	11.76	0.18	0.97	1.16	0.00	0.00	0.00	101.26	101.26	101.26	209.19				5.94				0.00	0.00	0.00		0.00				215.13			
M1/M3 Connection - Umlaas Road Pipeline	812				30	0.40%	2053	0	0	10	1	3	2.00	10.08	11.76	0.18	0.97	1.16	21.72	0.00	0.00	101.26	101.26	101.26	405.40	0.00			18.40	0.00			37.38	0.00	0.00		2.67	0.00			458.51	0.00		
Raw water reservoirs	360.0				30	0.40%	2 053.0	0	0	10.0	1	3	2.00	10.08	11.76	0.18	0.97	1.16	21.72	0.00	0.00	101.26	101.26	101.26	179.73	0.00			8.16	0.00			16.57	0.00	0.00		1.19	0.00			203.28	0.00		
WTW	2 695.0				30	4.00%	2 053.0	0	0	10.0	1	3	2.00	10.08	11.76	0.18	0.97	1.16	21.72	0.00	0.00	101.26	101.26	101.26	1345.51	0.00			610.85	0.00			124.05	0.00	0.00		8.87	0.00			2 071.54	0.00		
Potable water reservoirs	270.0				30	0.40%	2 053.0	0	0	10.0	1	3	2.00	10.08	11.76	0.18	0.97	1.16	21.72	0.00	0.00	101.26	101.26	101.26	134.80	0.00			6.12	0.00			12.43	0.00	0.00		0.89	0.00			152.46	0.00		
Total Capital	11 120.0	0.0	0.0	11 120.0																					5 671.7	0.0	0.0	5 671.7	743.7	0.0	0.0	743.7	197.4	0.0	0.0	197.4	14.1	0.0	0.0	14.1	6 598.7	0.0	0.0	6 598.7

NPV date 2013
End of analysis 2073
Interest rate 10%

15% MAR Smithfield and 0 MAR Impendle	Capital Cost				Life span	Operating cost %	Replacement date			Remaining life			NPV Factors Capital			NPV Factor Operations			NPV Factor Replacement			NPV Factor Residual			NPV Capital				NPV Operations				NPV Replacement				NPV Residual				NPV Total			
	End of Year						End of Year			End of Year			End of Year			End of Year			End of Year			End of Year			End of Year				End of Year				End of Year				End of Year				End of Year			
	2023	2044	2036																																									
Component	R(million)																																											
Environmental, admin and social																																												
Impendle Dam					50	0.25%	0	0	0	0	21	13	2.26	16.73	7.81	0.26	2.05	0.92	0.00	0.00	0.00	304.48	304.48	304.48			0.00				0.00		0.00	0.00	0.00				0.00				0.00	
Smithfield Dam	1561				50	0.25%	0	0	0	0	21	13	2.26	16.73	7.81	0.26	2.05	0.92	0.00	0.00	0.00	304.48	304.48	304.48	690.40				14.92				0.00	0.00	0.00		0.00				705.32			
uMkhomazi - uMlazi tunnel	3895				50	0.25%	0	0	0	0	21	13	2.26	16.73	7.81	0.26	2.05	0.92	0.00	0.00	0.00	304.48	304.48	304.48	1722.69	0.00			37.22	0.00			0.00	0.00	0.00		0.00	0.00			1 759.91	0.00		
Tunnel end -M1/M3 connection	152				30	0.40%	2053	0	2066	10	1	23	2.37	17.50	8.16	0.26	2.05	0.92	45.26	0.00	156.25	304.48	304.48	304.48	64.27	0.00			2.32	0.00			3.36	0.00	0.00		0.17	0.00			69.78	0.00		
Langa Balancing dam	419				50	0.25%	0	0	0	0	21	13	2.37	17.50	8.16	0.26	2.05	0.92	0.00	0.00	0.00	304.48	304.48	304.48	177.16				4.00				0.00	0.00	0.00		0.00				181.16			
M1/M3 Connection - Umlaas Road Pipeline	812				30	0.40%	2053	0	2066	10	1	23	2.37	17.50	8.16	0.26	2.05	0.92	45.26	0.00	156.25	304.48	304.48	304.48	343.33	0.00			12.42	0.00			17.94	0.00	0.00		0.89	0.00			372.79	0.00		
Raw water reservoirs	360.0				30	0.40%	2053	0	2066	10.0	1	23	2.37	17.50	8.16	0.26	2.05	0.92	45.26	0.00	156.25	304.48	304.48	304.48	152.21	0.00			5.50	0.00			7.95	0.00	0.00		0.39	0.00			165.28	0.00		
WTW	2 695.0				30	4.00%	2053	0	2066	10.0	1	23	2.37	17.50	8.16	0.26	2.05	0.92	45.26	0.00	156.25	304.48	304.48	304.48	1139.49	0.00			412.08	0.00			59.55	0.00	0.00		2.95	0.00			1 608.16	0.00		
Potable water reservoirs	270.0				30	0.40%	2053	0	2066	10.0	1	23	2.37	17.50	8.16	0.26	2.05	0.92	45.26	0.00	156.25	304.48	304.48	304.48	114.16	0.00			4.13	0.00			5.97	0.00	0.00		0.30	0.00			123.96	0.00		
Total Capital	10 164.0	0.0	0.0	10 164.0																					4 403.7	0.0	0.0	4 403.7	492.6	0.0	0.0	492.6	94.8	0.0	0.0	94.8	4.7	0.0	0.0	4.7	4 986.4	0.0	0.0	4 986.4

20% MAR Smithfield and 0 MAR Impendle	Capital Cost				Life span	Operating cost %	Replacement date			Remaining life			NPV Factors Capital			NPV Factor Operations			NPV Factor Replacement			NPV Factor Residual			NPV Capital				NPV Operations				NPV Replacement				NPV Residual				NPV Total			
	End of Year						End of Year			End of Year			End of Year			End of Year			End of Year			End of Year			End of Year				End of Year				End of Year				End of Year				End of Year			
	2023	2044	2038																																									
Component	R(million)																																											
Environmental, admin and social																																												
Impendle Dam					50	0.25%	0	0	0	0	21	15	2.26	16.73	9.44	0.26	2.05	1.12	0.00	0.00	0.00	304.48	304.48	304.48			0.00				0.00		0.00	0.00	0.00				0.00				0.00	
Smithfield Dam	1733				50	0.25%	0	0	0	0	21	15	2.26	16.73	9.44	0.26	2.05	1.12	0.00	0.00	0.00	304.48	304.48	304.48	766.48				16.56				0.00	0.00	0.00		0.00				783.04			
uMkhomazi - uMlazi tunnel	3895				50	0.25%	0	0	0	0	21	15	2.26	16.73	9.44	0.26	2.05	1.12	0.00	0.00	0.00	304.48	304.48	304.48	1722.69	0.00			37.22	0.00			0.00	0.00	0.00		0.00	0.00			1 759.91	0.00		
Tunnel end -M1/M3 connection	152				30	0.40%	2053	0	2068	10	1	25	2.37	17.50	9.88	0.26	2.05	1.12	45.26	0.00	189.06	304.48	304.48	304.48	64.27	0.00			2.32	0.00			3.36	0.00	0.00		0.17	0.00			69.78	0.00		
Langa Balancing dam	419				50	0.25%	0	0	0	0	21	15	2.37	17.50	9.88	0.26	2.05	1.12	0.00	0.00	0.00	304.48	304.48	304.48	177.16				4.00				0.00	0.00	0.00		0.00				181.16			
M1/M3 Connection - Umlaas Road Pipeline	812				30	0.40%	2053	0	2068	10	1	25	2.37	17.50	9.88	0.26	2.05	1.12	45.26	0.00	189.06	304.48	304.48	304.48	343.33	0.00			12.42	0.00			17.94	0.00	0.00		0.89	0.00			372.79	0.00		
Raw water reservoirs	360.0				30	0.40%	#####	0	2068	10.0	1	25	2.37	17.50	9.88	0.26	2.05	1.12	45.26	0.00	189.06	304.48	304.48	304.48	152.21	0.00			5.50	0.00			7.95	0.00	0.00		0.39	0.00			165.28	0.00		
WTW	2 695.0				30	4.00%	#####	0	2068	10.0	1	25	2.37	17.50	9.88	0.26	2.05	1.12	45.26	0.00	189.06	304.48	304.48	304.48	1139.49	0.00			412.08	0.00			59.55	0.00	0.00		2.95	0.00			1 608.16	0.00		
Potable water reservoirs	270.0				30	0.40%	#####	0	2068	10.0	1	25	2.37	17.50	9.88	0.26	2.05	1.12	45.26	0.00	189.06	304.48	304.48	304.48	114.16	0.00			4.13	0.00			5.97	0.00	0.00		0.30	0.00			123.96	0.00		
Total Capital	10 336.0	0.0	0.0	10 336.0																					4 479.8	0.0	0.0	4 479.8	494.2	0.0	0.0	494.2	94.8	0.0	0.0	94.8	4.7	0.0	0.0	4.7	5 064.1	0.0	0.0	5 064.1

25% MAR Smithfield and 0 MAR Impendle	Capital Cost				Life span	Operating cost %	Replacement date			Remaining life			NPV Factors Capital			NPV Factor Operations			NPV Factor Replacement			NPV Factor Residual			NPV Capital				NPV Operations				NPV Replacement				NPV Residual				NPV Total			
	End of Year						End of Year			End of Year			End of Year			End of Year			End of Year			End of Year			End of Year				End of Year				End of Year				End of Year				End of Year			
	2023	2044	2040																																									
Component	R(million)																																											
Environmental, admin and social																																												
Impendle Dam					50	0.25%	0	0	0	0	21	17	2.26	16.73	11.43	0.26	2.05	1.37	0.00	0.00	0.00	304.48	304.48	304.48			0.00				0.00		0.00	0.00	0.00				0.00				0.00	
Smithfield Dam	1948				50	0.25%	0	0	0	0	21	17	2.26	16.73	11.43	0.26	2.05	1.37	0.00	0.00	0.00	304.48	304.48	304.48	861.57				18.62				0.00	0.00	0.00		0.00				880.18			
uMkhomazi - uMlazi tunnel	3895				50	0.25%	0	0	0	0	21	17	2.26	16.73	11.43	0.26	2.05	1.37	0.00	0.00	0.00	304.48	304.48	304.48	1722.69	0.00			37.22	0.00			0.00	0.00	0.00		0.00	0.00			1 759.91	0.00		
Tunnel end -M1/M3 connection pipeline	152				30	0.40%	2053	0	2070	10	1	27	2.37	17.50	11.95	0.26	2.05	1.37	45.26	0.00	228.76	304.48	304.48	304.48	64.27	0.00			2.32	0.00			3.36	0.00	0.00		0.17	0.00			69.78	0.00		
Langa Balancing dam	419				50	0.25%	0	0	0	0	21	17	2.37	17.50	11.95	0.26	2.05	1.37	0.00	0.00	0.00	304.48	304.48	304.48	177.16				4.00				0.00	0.00	0.00		0.00				181.16			
M1/M3 Connection - Umlaas Road Pipeline	812				30	0.40%	2053	0	2070	10	1	27	2.37	17.50	11.95	0.26	2.05	1.37	45.26	0.00	228.76	304.48	304.48	304.48	343.33	0.00			12.42	0.00			17.94	0.00	0.00		0.89	0.00			372.79	0.00		
Raw water reservoirs	360.0				30	0.40%	#####	0	2070	10.0	1	27	2.37	17.50	11.95	0.26	2.05	1.37	45.26	0.00	228.76	304.48	304.48	304.48	152.21	0.00			5.50	0.00			7.95	0.00	0.00		0.39	0.00			165.28	0.00		
WTW	2 695.0				30	4.00%	#####	0	2070	10.0	1	27	2.37	17.50	11.95	0.26	2.05	1.37	45.26	0.00	228.76	304.48	304.48	304.48	1139.49	0.00			412.08	0.00			59.55	0.00	0.00		2.95	0.00			1 608.16	0.00		
Potable water reservoirs	270.0				30	0.40%	#####	0	2070	10.0	1	27	2.37	17.50	11.95	0.26	2.05	1.37	45.26	0.00	228.76	304.48	304.48	304.48	114.16	0.00			4.13	0.00			5.97	0.00	0.00		0.30	0.00			123.96	0.00		
Total Capital	10 551.0	0.0	0.0	10 551.0																					4 574.9	0.0	0.0	4 574.9	496.3	0.0	0.0	496.3	94.8	0.0	0.0	94.8	4.7	0.0	0.0	4.7	5 161.2	0.0	0.0	5 161.2

31% MAR Smithfield and 0 MAR Impendle	Capital Cost				Life span	Operating cost %	Replacement date			Remaining life			NPV Factors Capital			NPV Factor Operations			NPV Factor Replacement			NPV Factor Residual			NPV Capital				NPV Operations				NPV Replacement				NPV Residual				NPV Total			
	End of Year						End of Year			End of Year			End of Year			End of Year			End of Year			End of Year			End of Year				End of Year				End of Year				End of Year				End of Year			
	2023	2044	2043																																									
Component	R(million)																																											
Environmental, admin and social																																												
Impendle Dam					50	0.25%	0	0	0	0	21	20	2.26	16.73	15.21	0.26	2.05	1.85	0.00	0.00	0.00	304.48	304.48	304.48			0.00				0.00		0.00	0.00	0.00				0.00				0.00	
Smithfield Dam	2203				50	0.25%	0	0	0	0	21	20	2.26	16.73	15.21	0.26	2.05	1.85	0.00	0.00	0.00	304.48	304.48	304.48	974.35				21.05				0.00	0.00	0.00		0.00				995.40			
uMkhomazi - uMlazi tunnel	3895				50	0.25%	0	0	0	0	21	20	2.26	16.73	15.21	0.26	2.05	1.85	0.00	0.00	0.00	304.48	304.48	304.48	1722.69	0.00			37.22	0.00			0.00	0.00	0.00		0.00	0.00			1 759.91	0.00		
Tunnel end -M1/M3 connection pipeline	152				30	0.40%	2053	0	0	10	1	0	2.37	17.50	15.91	0.26	2.05	1.85	45.26	0.00	0.00	304.48	304.48	304.48	64.27	0.00			2.32	0.00			3.36	0.00	0.00		0.17	0.00			69.78	0.00		
Langa Balancing dam	419				50	0.25%	0	0	0	0	21	20	2.37	17.50	15.91	0.26	2.05	1.85	0.00	0.00	0.00	304.48	304.48	304.48	177.16				4.00				0.00	0.00	0.00		0.00				181.16			
M1/M3 Connection - Umlaas Road Pipeline	812				30	0.40%	2053	0	0	10	1	0	2.37	17.50	15.91	0.26	2.05	1.85	45.26	0.00	0.00	304.48	304.48	304.48	343.33	0.00			12.42	0.00			17.94	0.00	0.00		0.89	0.00			372.79	0.00		
Raw water reservoirs	360.0				30	0.40%	#####	0	0	10.0	1	0	2.37	17.50	15.91	0.26	2.05	1.85	45.26	0.00	0.00	304.48	304.48	304.48	152.21	0.00			5.50	0.00			7.95	0.00	0.00		0.39	0.00			165.28	0.00		
WTW	2 695.0				30	4.00%	#####	0	0	10.0	1	0	2.37	17.50	15.91	0.26	2.05	1.85	45.26	0.00	0.00	304.48	304.48	304.48	1139.49	0.00			412.08	0.00			59.55	0.00	0.00		2.95	0.00			1 608.16	0.00		
Potable water reservoirs	270.0				30	0.40%	#####	0	0	10.0	1	0	2.37	17.50	15.91	0.26	2.05	1.85	45.26	0.00	0.00	304.48	304.48	304.48	114.16	0.00			4.13	0.00			5.97	0.00	0.00		0.30	0.00			123.96	0.00		
Total Capital	10 806.0	0.0	0.0	10 806.0																					4 687.7	0.0	0.0	4 687.7	498.7	0.0	0.0	498.7	94.8	0.0	0.0	94.8	4.7	0.0	0.0	4.7	5 276.5	0.0	0.0	5 276.5

38% MAR Smithfield and 0 MAR Impendle	Capital Cost				Life span	Operating cost %	Replacement date			Remaining life			NPV Factors Capital			NPV Factor Operations			NPV Factor Replacement			NPV Factor Residual			NPV Capital				NPV Operations				NPV Replacement				NPV Residual				NPV Total			
	End of Year						End of Year			End of Year			End of Year			End of Year			End of Year			End of Year			End of Year				End of Year				End of Year				End of Year				End of Year			
	2023	2044	2046																																									
Component	R(million)																																											
Environmental, admin and social																																												
Impendle Dam					50	0.25%	0	0	0	0	21	23	2.26	16.73	20.25	0.26	2.05	2.51	0.00	0.00	0.00	304.48	304.48	304.48			0.00				0.00		0.00	0.00	0.00				0.00				0.00	
Smithfield Dam	2517				50	0.25%	0	0	0	0	21	23	2.26	16.73	20.25	0.26	2.05	2.51	0.00	0.00	0.00	304.48	304.48	304.48	1113.22				24.05				0.00	0.00	0.00		0.00				1 137.28			
uMkhomazi - uMlazi tunnel	3895				50	0.25%	0	0	0	0	21	23	2.26	16.73	20.25	0.26	2.05	2.51	0.00	0.00	0.00	304.48	304.48	304.48	1722.69	0.00			37.22	0.00			0.00	0.00	0.00		0.00	0.00			1 759.91	0.00		
Tunnel end -M1/M3 connection pipeline	152				30	0.40%	2053	0	0	10	1	3	2.37	17.50	21.18	0.26	2.05	2.51	45.26	0.00	0.00	304.48	304.48	304.48	64.27	0.00			2.32	0.00			3.36	0.00	0.00		0.17	0.00			69.78	0.00		
Langa Balancing dam	419				50	0.25%	0	0	0	0	21	23	2.37	17.50	21.18	0.26	2.05	2.51	0.00	0.00	0.00	304.48	304.48	304.48	177.16				4.00				0.00	0.00	0.00		0.00				181.16			
M1/M3 Connection - Umlaas Road Pipeline	812				30	0.40%	2053	0	0	10	1	3	2.37	17.50	21.18	0.26	2.05	2.51	45.26	0.00	0.00	304.48	304.48	304.48	343.33	0.00			12.42	0.00			17.94	0.00	0.00		0.89	0.00			372.79	0.00		
Raw water reservoirs	360.0				30	0.40%	#####	0	0	10.0	1	3	2.37	17.50	21.18	0.26	2.05	2.51	45.26	0.00	0.00	304.48	304.48	304.48	152.21	0.00			5.50	0.00			7.95	0.00	0.00		0.39	0.00			165.28	0.00		
WTW	2 695.0				30	4.00%	#####	0	0	10.0	1	3	2.37	17.50	21.18	0.26	2.05	2.51	45.26	0.00	0.00	304.48	304.48	304.48	1139.49	0.00			412.08	0.00			59.55	0.00	0.00		2.95	0.00			1 608.16	0.00		
Potable water reservoirs	270.0				30	0.40%	#####	0	0	10.0	1	3	2.37	17.50	21.18	0.26	2.05	2.51	45.26	0.00	0.00	304.48	304.48	304.48	114.16	0.00			4.13	0.00			5.97	0.00	0.00		0.30	0.00			123.96	0.00		
Total Capital	11 120.0	0.0	0.0	11 120.0																					4 826.5	0.0	0.0	4 826.5	501.7	0.0	0.0	501.7	94.8	0.0	0.0	94.8	4.7	0.0	0.0	4.7	5 418.3	0.0	0.0	5 418.3

Water demand

	Benchmark supplies	Existing with Springrove	Marginal Requirement	PV Water		
	(million m³/a)	(million m³/a)	(million m³/a)	6%	8%	10%
2013			0	0.00	0.00	0.00
2014			0	0.00	0.00	0.00
2015			0	0.00	0.00	0.00
2016			0	0.00	0.00	0.00
2017			0	0.00	0.00	0.00
2018			0	0.00	0.00	0.00
2019			0	0.00	0.00	0.00
2020			0	0.00	0.00	0.00
2021			0	0.00	0.00	0.00
2022			0	0.00	0.00	0.00
2023	472	410	58	32.34	26.83	22.33
2024			66	34.83	28.36	23.18
2025			74	36.97	29.54	23.71
2026			82	38.33	30.06	23.68
2027			90	39.89	30.71	23.75
2028			98	40.77	30.80	23.39
2029			106	41.85	31.03	23.14
2030			114	42.34	30.81	22.56
2031			123	43.02	30.73	22.09
2032			131	43.21	30.30	21.38
2033			139	43.27	29.78	20.63
2034			147	43.21	29.18	19.85
2035	574	410	155	43.03	28.53	19.05
2036			163	42.76	27.82	18.24
2037			172	42.39	27.07	17.43
2038			180	41.95	26.29	16.62
2039			189	41.44	25.49	15.82
2040			197	40.87	24.67	15.03
2041			206	40.25	23.85	14.27
2042			214	39.58	23.02	13.52
2043	644	410	222	38.68	22.08	12.73
2044			230	37.77	21.16	11.98
2045			238	36.85	20.26	11.26
2046			246	35.93	19.39	10.58
2047			254	35.01	18.54	9.94
2048			262	34.09	17.72	9.32
2049			270	33.17	16.92	8.74
2050			279	32.26	16.15	8.19
2051			287	31.35	15.41	7.67
2052			296	30.46	14.69	7.18
2053	730	410	304	29.58	14.00	6.72
2054			312	28.65	13.32	6.28
2055			321	27.77	12.66	5.86
2056			329	26.89	12.04	5.47
2057			338	26.02	11.43	5.10
2058	774	410	346	25.17	10.85	4.75
2059			355	24.32	10.29	4.43
2060			363	23.50	9.76	4.12
2061	801	410	372	22.68	9.25	3.83
2062			380	21.89	8.76	3.56
2063			389	21.11	8.29	3.31
2064			397	20.35	7.85	3.08
2065			406	19.61	7.42	2.86
2066			414	18.89	7.01	2.65
2067			423	18.18	6.63	2.46
2068			431	17.50	6.26	2.28
2069			440	16.83	5.91	2.12
2070			448	16.19	5.58	1.96
2071			457	15.56	5.26	1.82
2072			465	14.95	4.96	1.68
2073			474	14.36	4.68	1.56

Start analysis	2013
Analysis period	2073

		Limiting date for scheme	NPV water			
			6%	8%	10%	
(Impendle 0 MAR)	15%MAR (915masl)	2036	1196.02	742.06	484.02	
	20%MAR (920masl)	2038	1258.42	774.25	501.28	
	25%MAR (925masl)	2040	1314.11	802.09	515.73	
	31%MAR (930masl)	2043	1383.47	835.50	532.41	
	38%MAR (935masl)	2043	1383.47	835.50	532.41	Limiting date if tunnel not doublec

Annexure F

URV information option: Combinations of Smithfield and Impendle Dams and conveyance systems

(DATA INCLUDED ON CD)

Annexure G

Transfer volumes and timelines

Year	Transfer volume (Scenario 3 phased)	Transfer volume (Scenario 2)	Linear Growth		Option 1	Option 2	Option 3
	(million m^3/a)	(million m^3/a)	(million m3/a)		0.5 MAR Impendle	1.0 MAR Impendle	1.5 MAR Impendle
2013				0	0.0	0.0	0.0
2014				0	0.0	0.0	0.0
2015				0	0.0	0.0	0.0
2016				0	0.0	0.0	0.0
2017				0	0.0	0.0	0.0
2018				0	0.0	0.0	0.0
2019				0	0.0	0.0	0.0
2020				0	0.0	0.0	0.0
2021				0	0.0	0.0	0.0
2022				0	0.0	0.0	0.0
2023	115.3	93.8		93.8	93.8	93.8	93.8
2024	116.3	99.5		99.5	99.5	99.5	99.5
2025	117.3	105.3		105.3	105.3	105.3	105.3
2026	118.3	111.1		111.1	111.1	111.1	111.1
2027	119.3	116.9		116.9	116.9	116.9	116.9
2028	120.3	122.7		122.7	122.7	122.7	122.7
2029	121.3	128.6		128.6	128.6	128.6	128.6
2030	155.2	134.4		134.4	134.4	134.4	134.4
2031	156.7	140.3		140.3	140.3	140.3	140.3
2032	158.2	146.3		146.3	146.3	146.3	146.3
2033	159.6	152.2		152.2	152.2	152.2	152.2
2034	161.1	158.2		158.2	158.2	158.2	158.2
2035	162.5	164.2		164.2	164.2	164.2	164.2
2036	164.0	170.2		170.2	170.2	170.2	170.2
2037	165.5	176.2		176.2	176.2	176.2	176.2
2038	211.1	182.3		182.3	182.3	182.3	182.3
2039	212.8	188.4		188.4	188.4	188.4	188.4
2040	214.5	194.5		194.5	194.5	194.5	194.5
2041	216.2	200.7		200.7	200.7	200.7	200.7
2042	217.8	206.9		206.9	206.9	206.9	206.9
2043	219.5	213.0		213.0	213.0	213.0	213.0
2044	221.2	219.1		219.1	219.1	219.1	219.1
2045	222.9	225.3		225.3	225.3	225.3	225.3
2046	224.6	231.4		231.4	231.4	231.4	231.4
2047	226.2	237.6		237.6	237.6	237.6	237.6
2048	227.9	243.7		243.7	243.7	243.7	243.7
2049	229.6	249.8		249.8	249.8	249.8	249.8
2050	231.3	255.9	6.12	255.9	255.9	255.9	255.9
2051		262.0	6.12	262.1	262.1	262.1	262.1
2052		268.2	6.12	268.2	268.2	268.2	268.2
2053		274.3	6.12	274.3	274.3	274.3	274.3
2054			6.12	280.4	280.4	280.4	280.4

2055			6.12	286.5	286.5	286.5	286.5
2056			6.12	292.7	292.7	292.7	292.7
2057			6.12	298.8	298.8	298.8	298.8
2058			6.12	304.9	303.0	304.9	304.9
2059			6.12	311.0	303.0	311.0	311.0
2060			6.12	317.1	303.0	317.1	317.1
2061			6.12	323.3	303.0	323.3	323.3
2062			6.12	329.4	303.0	329.4	329.4
2063			6.12	335.5	303.0	335.5	335.5
2064			6.12	341.6	303.0	341.6	341.6
2065			6.12	347.7	303.0	346.0	347.7
2066			6.12	353.9	303.0	346.0	353.9
2067			6.12	360.0	303.0	346.0	360.0
2068			6.12	366.1	303.0	346.0	366.1
2069			6.12	372.2	303.0	346.0	372.2
2070			6.12	378.3	303.0	346.0	375.0
2071			6.12	384.5	303.0	346.0	375.0
2072			6.12	390.6	303.0	346.0	375.0
2073			6.12	396.7	303.0	346.0	375.0
2074			6.12	402.8	303.0	346.0	375.0
2075			6.12	409.0	303.0	346.0	375.0
2076			6.12	415.1	303.0	346.0	375.0
2077			6.12	421.2	303.0	346.0	375.0
2078			6.12	427.3	303.0	346.0	375.0
2079			6.12	433.4	303.0	346.0	375.0
2080			6.12	439.6	303.0	346.0	375.0
2081			6.12	445.7	303.0	346.0	375.0
2082			6.12	451.8	303.0	346.0	375.0
2083			6.12	457.9	303.0	346.0	375.0
2084			6.12	464.0	303.0	346.0	375.0
2085			6.12	470.2	303.0	346.0	375.0
2086			6.12	476.3	303.0	346.0	375.0
2087			6.12	482.4	303.0	346.0	375.0
2088			6.12	488.5	303.0	346.0	375.0
2089			6.12	494.6	303.0	346.0	375.0
2090			6.12	500.8	303.0	346.0	375.0
2091			6.12	506.9	303.0	346.0	375.0
2092			6.12	513.0	303.0	346.0	375.0
2093			6.12	519.1	303.0	346.0	375.0
				TRANSFERS	**Option 1**	**Option 2**	**Option 3**
				NPV 6%	1629.70	1665.58	1681.42
				NPV 8%	935.53	947.30	952.05
				NPV 10%	580.01	584.05	585.53

Annexure H

Capital and O&M costs and timelines

	TUNNELS				IMPENDLE DAM		
	Option 1b, 2b, 3b		Opion 1a	Option 2a, 3a	Option 1	Option 2	Option 3
	First 3.5m Dia Tunnel	Second 3.5m Dia Tunnel	Single 4.0m Dia Tunnel	Single 4.5m Dia Tunnel	0.5 MAR	1.0 MAR	1.5 MAR
Capital cost	2 272	2 272	2 464	2 656	1 289	1 822	2 120
Year	Cost						
2013	0	0	0	0	0	0	0
2014	0	0	0	0	0	0	0
2015	0	0	0	0	0	0	0
2016	0	0	0	0	0	0	0
2017	0	0	0	0	0	0	0
2018	0	0	0	0	0	0	0
2019	568.00	0	616.00	664.00	0	0	0
2020	568.00	0	616.00	664.00	0	0	0
2021	568.00	0	616.00	664.00	0	0	0
2022	568.00	0	616.00	664.00	0	0	0
2023	5.68	0.00	6.16	6.64	0	0	0
2024	5.68	0.00	6.16	6.64	0	0	0
2025	5.68	0.00	6.16	6.64	0	0	0
2026	5.68	0.00	6.16	6.64	0	0	0
2027	5.68	0.00	6.16	6.64	0	0	0
2028	5.68	0.00	6.16	6.64	0	0	0
2029	5.68	0.00	6.16	6.64	0	0	0
2030	5.68	0.00	6.16	6.64	0	0	0
2031	5.68	0.00	6.16	6.64	0	0	0
2032	5.68	0.00	6.16	6.64	0	0	0
2033	5.68	0.00	6.16	6.64	0	0	0
2034	5.68	0.00	6.16	6.64	0	0	0
2035	5.68	0.00	6.16	6.64	0	0	0
2036	5.68	0.00	6.16	6.64	0	0	0
2037	5.68	0.00	6.16	6.64	0	0	0
2038	5.68	0.00	6.16	6.64	0	0	0
2039	5.68	0.00	6.16	6.64	0	0	0
2040	5.68	568.00	6.16	6.64	0	0	0
2041	5.68	568.00	6.16	6.64	429.67	607.33	706.67
2042	5.68	568.00	6.16	6.64	429.67	607.33	706.67
2043	5.68	568.00	6.16	6.64	429.67	607.33	706.67
2044	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2045	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2046	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2047	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2048	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2049	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2050	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2051	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2052	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2053	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2054	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2055	5.68	5.68	6.16	6.64	3.22	4.56	5.30

2056	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2057	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2058	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2059	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2060	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2061	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2062	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2063	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2064	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2065	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2066	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2067	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2068	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2069	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2070	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2071	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2072	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2073	568.00	5.68	616.00	664.00	3.22	4.56	5.30
2074	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2075	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2076	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2077	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2078	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2079	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2080	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2081	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2082	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2083	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2084	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2085	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2086	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2087	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2088	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2089	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2090	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2091	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2092	5.68	5.68	6.16	6.64	3.22	4.56	5.30
2093	5.68	5.68	6.16	6.64	3.22	4.56	5.30
NPV 6%	**1 455.59**	**422.84**	**1 578.60**	**1 701.60**	**233.02**	**329.38**	**383.25**
NPV 8%	**1 223.42**	**241.91**	**1 326.81**	**1 430.20**	**131.98**	**186.55**	**217.06**
NPV 10%	**1 039.88**	**140.27**	**1 127.76**	**1 215.63**	**75.76**	**107.09**	**124.60**