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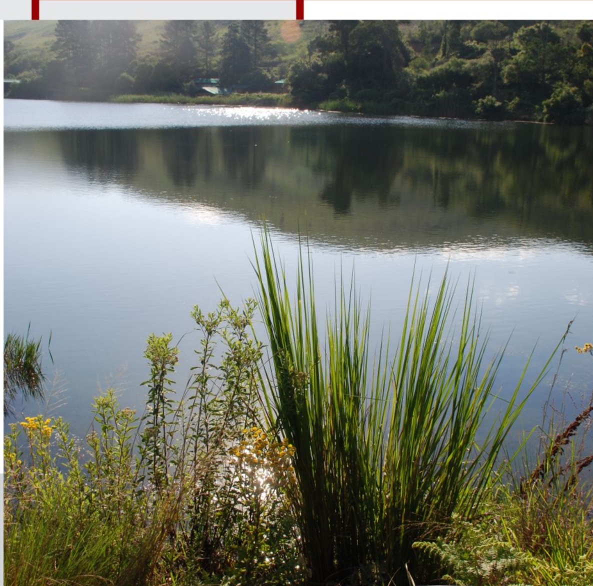
REPUBLIC OF SOUTH AFRICA

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

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

ENGINEERING FEASIBILITY DESIGN REPORT

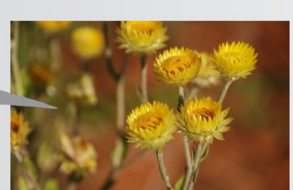


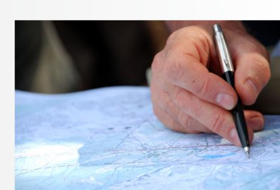
SUPPORTING DOCUMENT 1:

OPTIMISATION OF CONVEYANCE SYSTEM REPORT

FINAL

OCTOBER 2012





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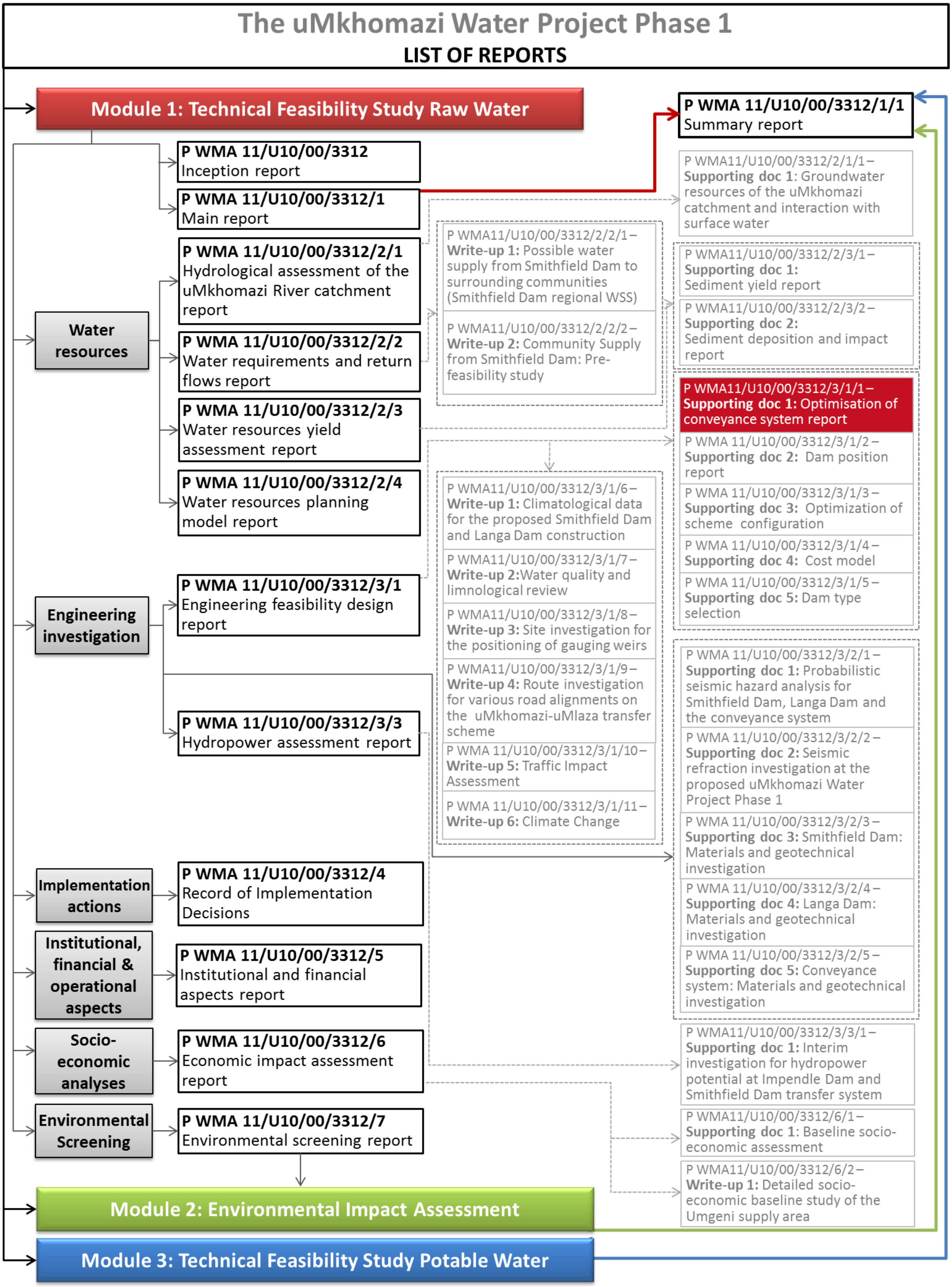
PREAMBLE

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

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

LIST OF ACRONYMS AND 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
NPV	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

LIST OF MEASUREMENTS UNITS

m^3/a	Cubic metres per annum
m^3/s	Cubic metres per second
Mℓ/d	Mega litres per day
Mℓ/d/a	Mega litres per day per annum
masl	Metres above sea level
m/km	Metres per kilometre
kw	Kilo watt
Mw	Mega watt
KWh	Kilo watt hour
MWh	Megawatt hour

1 INTRODUCTION

The Engineering Investigations referred to as *Task 5* 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
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- 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 5.1: Optimisation of conveyance system*. The objective of this task is to identify and compare different options for the conveyance of water from the proposed Smithfield Dam to the Baynesfield Waterworks. Water will be conveyed from the Baynesfield Waterworks by pipelines under gravity (if possible) to Umlaas Road.

The pre-feasibility study by Ninham Shand concluded that pumping at the Smithfield Dam to the intake of a free-flow tunnel was the preferred transfer option. The outlet level (885 masl) considered made it impossible to transfer the water under gravity or by means of a pressure tunnel.

It has been found, as described in this report, that the invert level of the tunnel outlet can be positioned lower than 885 masl. The head available to overcome friction losses differs for the different dam positions addressed under *Task 5.2 (Dam Position Report)*, with the higher heads facilitating the provision of a pressure tunnel. Considering the above, a pressure tunnel is an option. In addition, it is possible to lengthen the rising main with a shorter tunnel for the pumping option.

The following three transfer options were thus evaluated and compared:

- Option 1: Pumping via a free flow tunnel (similar to the preferred option from the pre-feasibility study)
- Option 2: Pressure tunnel
- Option 3: Pumping via a combination of longer rising mains and a shorter free flow tunnel.

Preliminary analyses showed that the cost of the tunnel dominates the net present value analyses. The shortest tunnel route was thus selected for both dam sites A and B defined under *Task 5.2* and as shown in **Figure 1.1**. A similar route was also used for Option 3 as shown in **Figure 1.1**. This evaluation is based on information (e.g. yields of dams) from previous studies, which still needs to be verified and confirmed through the other tasks under this feasibility study.

The layouts and cost estimates of the Smithfield Dam and the Balancing Dams are described in *Task 5.2, Dam Position Report*.

This report deals with the required transfer capacities and the conditions and limitations at the intake and outlet of the tunnel or pipelines. The options are then described in more detail and evaluated economically.

The final conceptual design and costing of the selected option are dealt with under *Tasks 5.14, 5.15* and *5.16*.

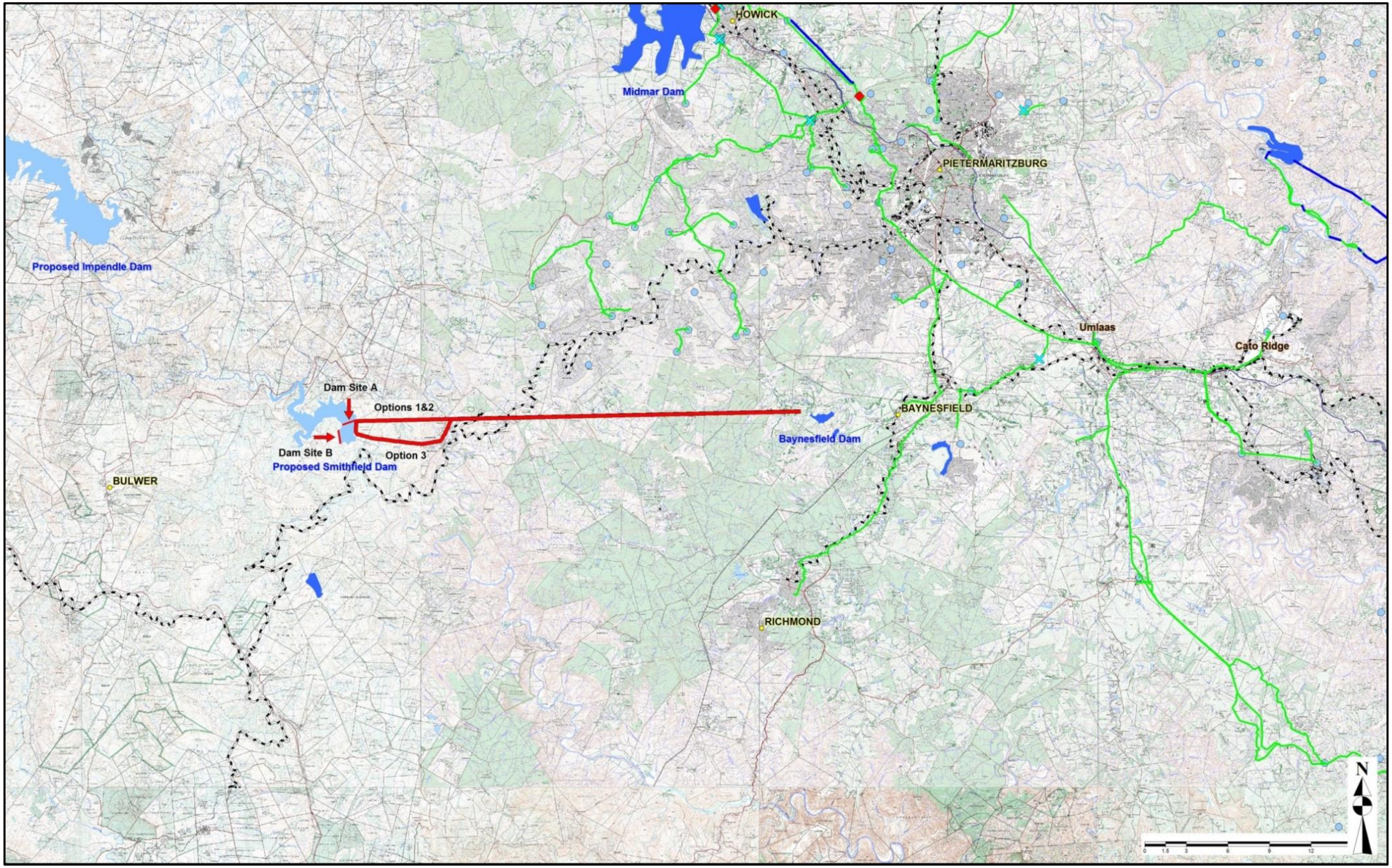


Figure 1.1: Transfer routes

2 TRANSFER CAPACITIES

2.1 FIRM YIELDS

Long-term stochastic yield analyses carried out in the prefeasibility study provided the firm yields listed in **Table 2.1** for a recurrence interval of 100 years.

Phase 1 of the uMWP comprises only the Smithfield Dam. The analyses in the pre-feasibility study were based on the following features for the Smithfield Dam:

- Full supply level (FSL) : 915 masl
- Minimum operating level (MOL) : 875 masl
- Gross storage : 137 million m³
- Live storage : 129 million m³
- Mean annual runoff (MAR) : 731,1 million m³
- Incremental MAR downstream of Impendle Dam : 163,2 million m³

The gross storage at the Smithfield dam is equal to about 19% of the MAR and 84% of the incremental MAR. (In the TOR and other reports, the storage volume is referred to as 25% of the MAR). The above storage volume for the Smithfield Dam needs to be re-addressed (refer also to the *Dam Position Report, Task 5.2*) particularly in the light of the large Impendle Dam given as 150% MAR.

Table 2.1: Stochastic Firm Yields (100-Recurrence Interval)

Phase/Description	Present Development (1999)	Future Development (2040)
1 Smithfield Dam (19% MAR)	177 million m³/a = 485 Mℓ/d = 5,61 m³/s	147 million m³/a = 402 Mℓ/d = 4,66 m³/s
2 Smithfield Dam (19% MAR) plus Impendle Dam (150% MAR)	409 million m³/a = 1 120 Mℓ/d = 12,96 m³/s	376 million m³/a = 1 029 Mℓ/d = 11,91 m³/s

The above yields are still subject to verification and confirmation from *Task 4* under this feasibility study.

2.2 PROJECTED WATER DEMANDS

It is envisaged that the present water supply from the Upper Mgeni System to the eThekwini Municipality will be replaced with water supply from the Smithfield Dam. The present supply from the upper Mgeni System will be disconnected downstream of the Umlaas Road reservoir.

The projected water demand downstream of Umlaas Road by 2023, will reach 125,16 million m³/a (4,0 m³/s) the year when the supply from Smithfield Dam is expected to be in operation. The annual growth in water demands beyond 2023 is estimated to be 1,3% per annum.

Based on the firm yield of 147 million m³/a (4,66 m³/s) for Phase 1 under the future development scenario (2040) given in **Table 2.1**, the Smithfield Dam should be able to meet the future water demands until about 2035, only 12 years after implementation of Phase 1 as shown in **Figure 2.1**. Phase 2 (Impendle Dam) should thus be in operation by this time. This issue must be further investigated during the assessment options (see also **Section 10.2**).

2.3 DESIGN TRANSFER CAPACITIES

The design transfer capacities are dependent on the peak factor applied to the yields given in **Table 2.2**. The highest peak factor recorded is 1,26 with a duration of approximately one month. However, the eThekwini Municipality requested that the design transfer capacities be based on a SDD peak factor of 1,5. The pre-feasibility study assumed a peak factor of 1,25.

The design transfer capacities for the different peak factors are shown in **Table 2.2**.

Table 2.2: Design Transfer Capacities

Phase	1 Smithfield Dam 19% MAR	2 Smithfield Dam 19% MAR plus Impendle Dam 150% MAR
Yields (m³/s) (From Table 1)	4,66	11,91
Design Transfer Capacity (m³/s)		
• 1,25 Peak Factor	5,83	14,89
• 1,50 Peak Factor	6,99	17,87

The sizing of the conveyance system is very much dependent on the peak factor applied to the available yield. Balancing storage is required at the Baynesfield Dam for inspection and maintenance purposes of the tunnel (see Section 4.2). This balancing storage can also be used to balance the difference in volumes of water transferred with different peak factors. For instance, accepting a 30 days duration for the peak demands, a storage of 7,72 million m^3 will be required to balance the difference in volumes of water transferred with peak factors of 1,25 and 1,5.

The lower design transfer capacity with a peak factor of 1,25 will definitely result in cost benefits. This peak factor should be optimised further for the final selected transfer option.

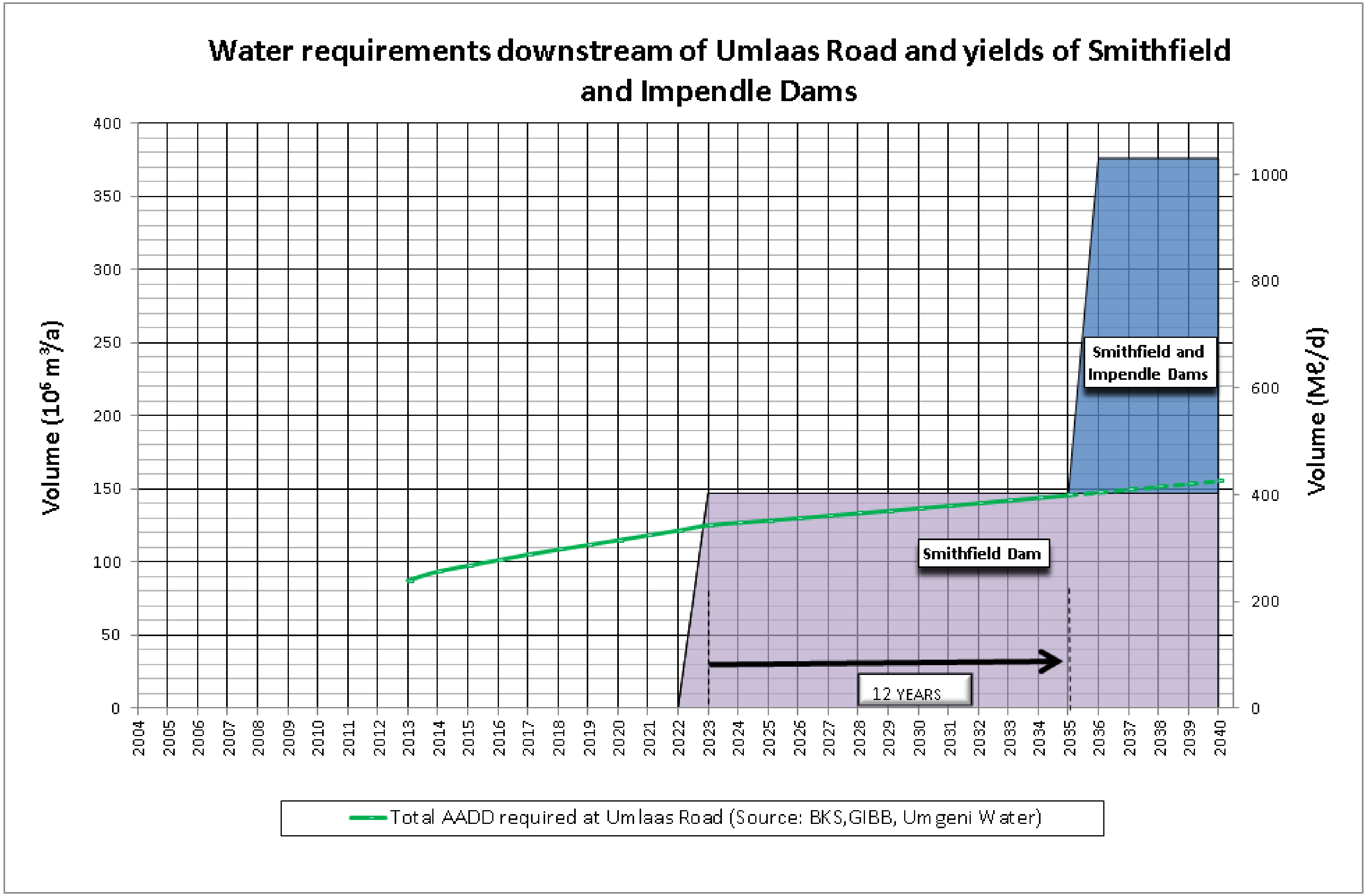


Figure 2.1: Requirements and yields

3 CONDITIONS AND LIMITATIONS AT THE TUNNEL INTAKE

3.1 STORAGE DETAILS

The gross storage volume of the Smithfield Dam is 137 million m³ (19% MAR or 84% of the incremental MAR) in accordance with the pre-feasibility study. The FSL at Site B is given as 915 masl with a net storage volume of 129 million m³ (17,6% MAR or 79% of the incremental MAR). This storage volume provides the yields listed in **Table 2.1** in accordance with the pre-feasibility study.

The re-assessed stage-storage characteristics for the two dam sites shown in are listed in **Table 3.1** (determined from the available contour maps and described in the *Dam Position Report*). The pre-feasibility FSL at 915 masl for Site B has been accepted resulting in a MOL at 875,9 masl (7,18 million m³ dead storage), ensuring a live storage of 129 million m³ as considered in the pre-feasibility study. Adopting the same dead storage for Site A, resulted in a MOL at 880,7 masl and FSL at 921,5 masl as shown in **Table 3.1**.

Table 3.1: Smithfield Dam - Stage Storage Characteristics

Site A		Site B	
Stage (masl)	Storage (million m³)	Stage (masl)	Storage (million m³)
864	0	856	0
880,7 (MOL)	7,18	875,9 (MOL)	7,18
890	31,38	880	12,02
900	46,21	890	31,38
910	78,12	900	62,39
920	126,98	910	107,51
921,5 (FSL)	136,18	915 (FSL)	136,18

3.2 PUMPING HEADS

In the case of pumping from the Smithfield Dam (Option 1), the maximum pumping head is measured from the MOL and the minimum head from the FSL. The average (or median) water level in the dam, as required for determination of energy cost, can only be determined from a stage exceedance relationship. This information will follow from *Task 4* under this feasibility study. For the purpose of this report, the available storage-stage exceedance relationship for the Gongo Dam (30% MAR) on the Mzimvubu River, which shows that the water level would be about 3 m below FSL for 50% of the time, could provide an indication of the average water level in the Smithfield Dam.

The abovementioned average water level will be affected when the Impendle Dam (Phase 2) comes into operation. It is expected that future operation of the scheme will endeavour to maintain a high level of storage in Impendle Dam and to accommodate variations in storage in the Smithfield Dam with consequent larger variations of the water level.

Based on the above and due to actual data not yet available for the Smithfield Dam, the pumping heads for energy calculations have been based on a more conservative average water level of 10 m below the FSL's at the two dam sites.

3.3 INTAKE STRUCTURE

With reference to **Figure 1.1** the Site A dam wall is located upstream of the tunnel intake with water supplied through the outlet works of the dam. The Site B dam wall is located some 1,5 km downstream of Site A (similar to the pre-feasibility dam site).

As already mentioned, the cost of the tunnel dominates the net present value analyses. The shortest tunnel route, as shown in **Figure 1.1**, was thus selected for both dam sites. An intake tower is thus required for the Site B dam, about 1,5 km upstream of the dam wall.

Releases to meet the IFR can be accommodated through an intake tower and outlet works for the Site A dam, but an additional intake tower and outlet works for releases to meet the EWR will be required for the Site B dam.

4 CONDITIONS AND LIMITATIONS AT THE TUNNEL OUTLET

4.1 REQUIRED WORKS

Water needs to be conveyed from the tunnel outlet to Umlaas Road connecting into the downstream supply pipeline. The works between the tunnel outlet and connection at Umlaas Road comprise a balancing dam, waterworks, clear water reservoir and pipelines over a distance of about 21 km.

For the purpose of this report, it has been assumed that the above works will be implemented in phases, as described hereinafter.

4.2 BALANCING STORAGE

The tunnel discharges into the Baynesfield dam as shown in **Figure 1.1**. Balancing of the transfer supply and peak demands can be created by enlarging the Baynesfield Dam.

As described in **Section 2.3** a balancing storage of 7,72 million m³ is required to balance a transfer capacity associated with a peak factor of 1,25 and the ultimate demand capacity associated with a peak factor of 1,5.

However, storage is also required to ensure an uninterrupted water supply during inspections and maintenance of the tunnel. The DWA indicated that the storage should be based on the average demand over a period of 3 weeks (21 days). The ultimate average demand is based on the total yield of the scheme (11,91 m³/s as per **Table 2.1**), resulting in a required storage of 21,61 million m³. This storage was further addressed and optimised in *Task 5.14* of this feasibility study, where the average demand over longer periods was considered.

Accepting that inspections and maintenance will be arranged for the winter months when the demand drops to below the average demand, the storage of 7,72 million m³ to balance the transfers and peak demands can form part of the storage required for maintenance.

The storage in the balancing dam needs to be kept at 7,72 million m³ during the summer months and increased to 21,61 million m³ before inspecting the tunnel, which is expected to take place during the winter months. Therefore, no provision for evaporation and other losses need to be made.

The storage of 21,61 million m³ is based on the ultimate yield of the scheme, which will be reached by about 2108. It will thus be beneficial to provide the balancing storage in two phases. With reference to **Section 4.3**, the outlet of the balancing dam for supply to the water treatment works is positioned at 872 masl, (the present FSL of the existing Baynesfield Dam). Balancing storage must thus be provided above this level of 872 masl. It is also important to keep the FSL of the balancing storage as low as possible to ensure that sufficient head is available from the Smithfield Dam for water transfers, particularly for the pressure tunnel option. A number of balancing dam options was considered. A larger Baynesfield Dam, as shown in **Figure 4.1**, was investigated in more detail. Balancing dam options (the layout and the cost) are described under *Task 5.2: Dam Position Report*.

The cost of the balancing dam/s is not included in the comparison analysis as they are considered as common cost options.

4.3 OTHER WORKS

The other works, i.e. the waterworks, clear water reservoir and pipelines to Umlaas Road are not included in the scope of works for the uMWP. It is, however, necessary to estimate the head loss through the water treatment works to determine whether the supply to Umlaas Road can be affected under gravity.

The outlet from the Baynesfield Dam to the waterworks is positioned at the FSL of the existing dam (872 masl), such that the present usage of the dam with a lower outlet for irrigation is not affected. The head loss from the balancing dam to Umlaas Road is also dependent on the extent of the area available for the waterworks. Assuming that this will not be a limitation and based on other similar works, the head loss through the water treatment works and clear water reservoir is estimated at 10 m.

Water will be supplied through pipelines (in phases) from the clear water reservoir to Umlaas Road. The existing supply, from the Upper Mgeni System to the eThekwini Municipality will be disconnected downstream of the Umlaas Road reservoir and replaced by the supply from the Smithfield Dam. The FSL of the Umlaas Road reservoir is at 844 masl. Assuming a head loss of 2 m from the Umlaas Road reservoir to the downstream connection point, water should be supplied at the connection point at a head coinciding with 842 masl. The total available head from the Baynesfield Dam outlet to Umlaas Road is thus 30 m.

Allowing for the 10 m head loss through the waterworks and the clear water reservoir, a head of 20 m is available to convey the water from the clear water reservoir to Umlaas Road. The discharge is based on a 1,5 peak factor, resulting in an ultimate capacity of 17,87 m^3/s (see **Table 2.2**). Provisionally it is assumed that the conveyance will comprise three pipelines in phases, each with a capacity of about 6 m^3/s. Using the Darcy-Weisbach flow formula with a Colebrook-White friction factor of 0,01 and a 6 m^3/s discharge, a 2,0 m pipeline will be required for each of the three phases.

The waterworks and clear water reservoir and pipelines to Umlaas Road are similar for both options and the cost thereof will thus not affect the economic analyses and comparison of the transfer options.

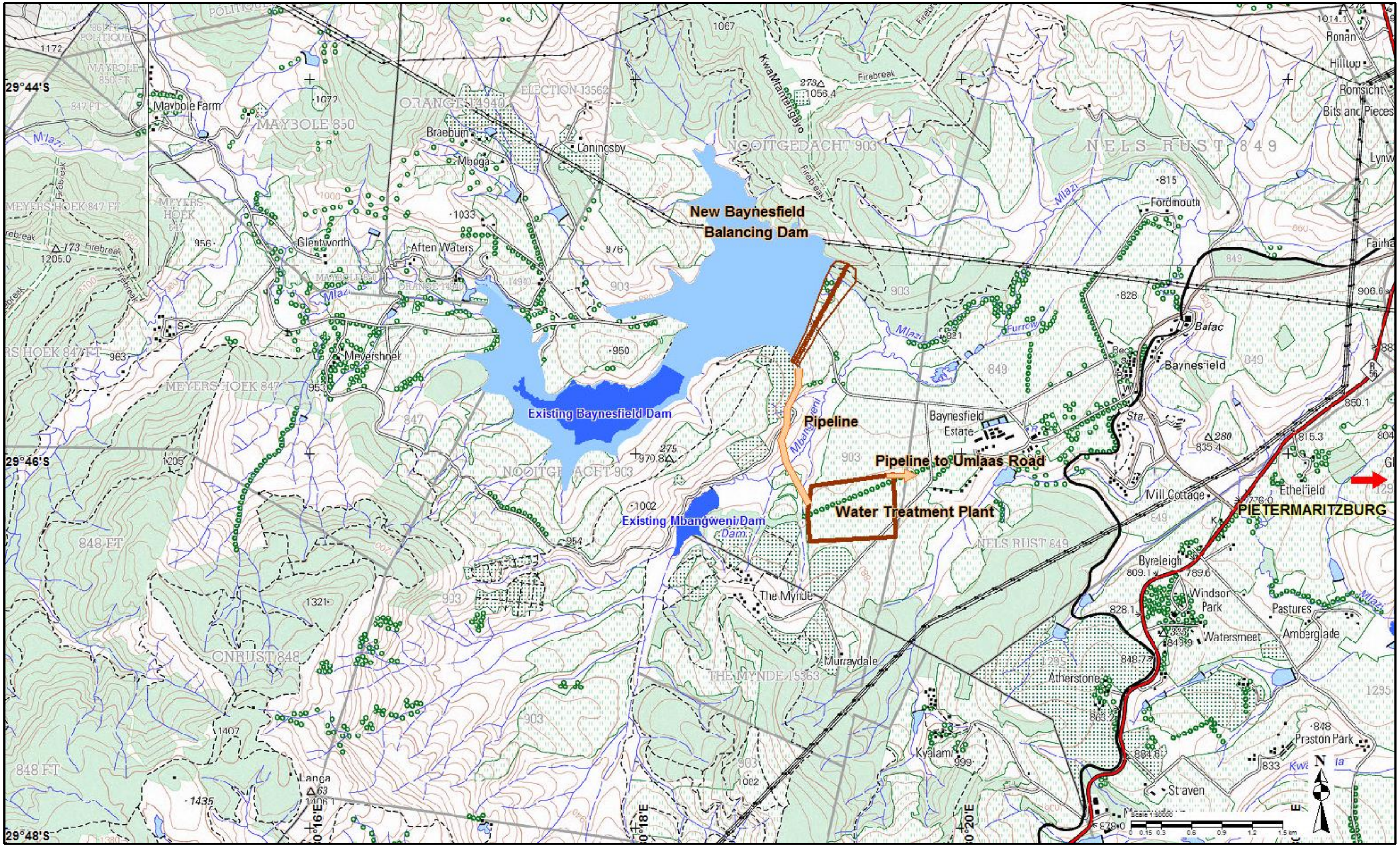


Figure 4.1: Balancing dam

5 TRANSFER OPTIONS

5.1 OPTIONS CONSIDERED

The tunnel options considered from Smithfield Dam cover pumping into a free flow tunnel and a pressure tunnel. Originally, it was envisaged that a single tunnel for each option be provided, capable of transferring the total yield associated with Phase 2 when the Impendle Dam comes on line. The transfer capacity will vary from 5,0m³/s (1,25 x 4,0m³/s) in 2023 to 14,89 m³/s (1,25 x 11,91 m³/s) by 2108, when the tunnel will be fully utilized. Therefore, it may be beneficial to provide twin tunnels each sized for half of the ultimate transfer capacity, namely 7,45 m³/s. The second tunnel will then be required by 2054. This is particularly applicable to the pressure tunnel option requiring a large size tunnel to transfer the total yield of both the Smithfield and the Impendle Dams.

Due to the high tunnel cost, pumping via a shorter tunnel with longer pipelines becomes a possibility. This will reduce the construction cost of the tunnel, but with higher energy costs. The following options have thus been evaluated for each dam site shown in **Figure 1.1**:

- Option 1: Pumping via a free flow tunnel
  - 1A: Single tunnel (with a capacity of 14,89 m³/s)
  - 1B: Twin tunnels (with capacities of 7,45 m³/s each)
- Option 2: Pressure tunnel
  - 2A: Single tunnel (with a capacity of 14,89 m³/s)
  - 2B: Twin tunnels (with capacities of 7,45 m³/s each)
- Option 3: Pumping via pipelines and a free flow single tunnel.

Figure 5.1 shows schematic presentations of the options, which are described in more detail in the following sections.

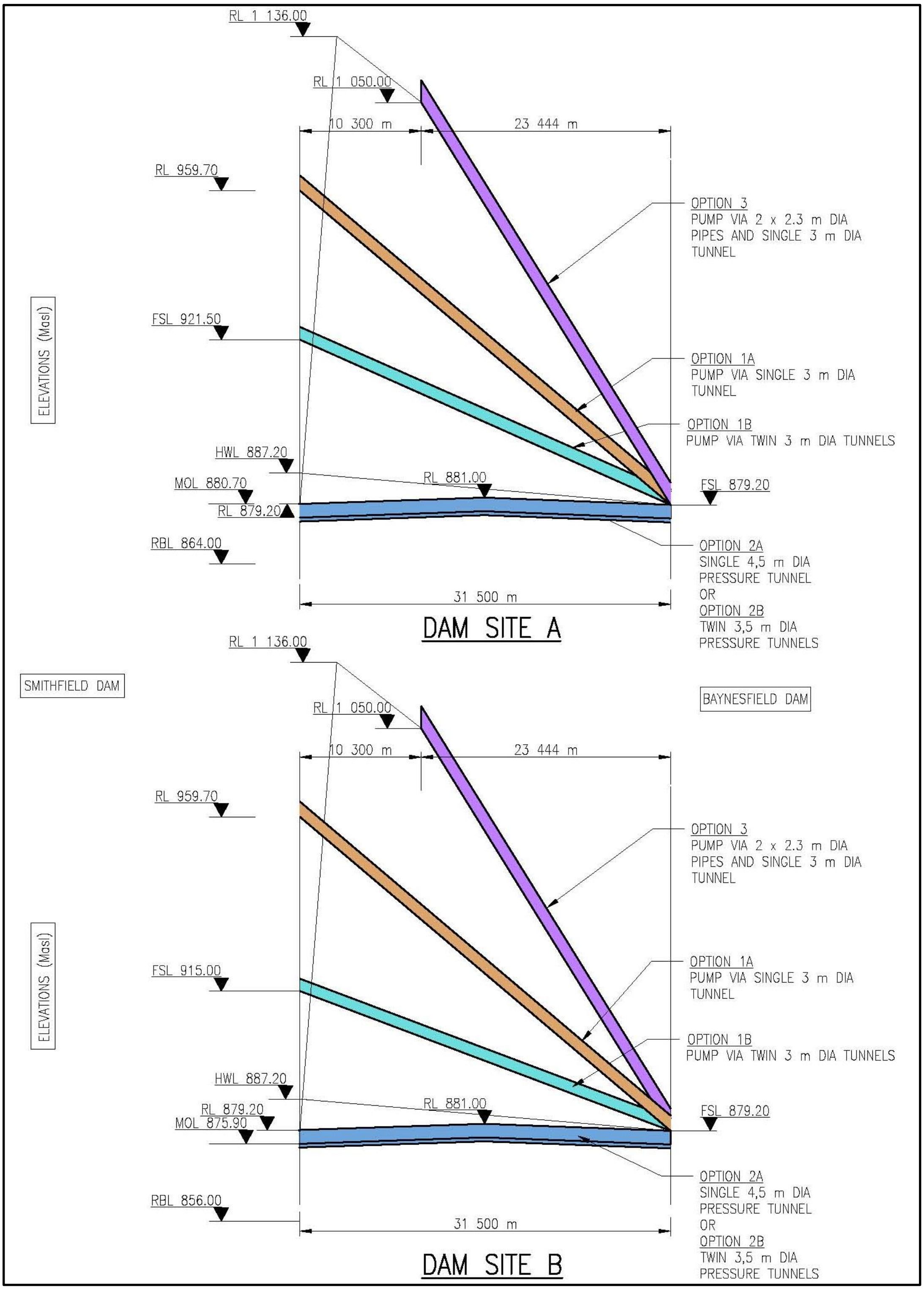


Figure 5.1: Conveyance system: Schematic presentation of tunnel options

5.1.1 Option 1: Pumping via a free flow tunnel

a) Dam Site A

For Dam Site A the pump station is located downstream of the dam wall and will transfer water from a connection to the outlet works of the dam to the tunnel intake situated higher up along the left bank. A longitudinal section showing the tunnels for Option 1 appears in **Figure 5.2**.

The tunnel design details for this dam Site A and for both options 1A (single tunnel) and 1B (twin tunnels) are shown in **Table 5.1**. The discharges or head losses through the tunnels have been based on Manning's flow formula with a discharge coefficient of 0,016. The cross-sectioned flow area has been taken equal to 80% of the total tunnel area in line with the recommendation in VAPS.

The total pumping head for Option 1A (single tunnel) varies from 43,2 m with the Site A dam at FSL (921,5masl) to 84,0 m with the water level at the MOL (880,7masl). With reference to **Section 3.2**, the average pumping head for energy calculation is 53,2 m. For Option 1B (twin tunnels) the pumping head varies from 5 m at FSL to 45,8 m with the water at the MOL with an average head of 15,0m. These pumping heads include 2 m head loss through the outlet works and pipes to the tunnel intake. The water is pumped at a peak factor of 1,25 meaning that the pumps will be operated for 80% of the time in the long term.

In the case of Option 1B (twin tunnels) the invert of the tunnel intake is set at the FSL to avoid the pumps being operated intermittently. This is higher than required, meaning that the first tunnel will accommodate a higher flow of 10,79 m^3/s requiring the second tunnel only by 2082.

b) Dam Site B

Option 1A (single tunnel) for this dam site represents the transfer option considered in the pre-feasibility study. A tower housing the pumps is located about 1,5km upstream of the dam wall, feeding through 2 x 1800 mm pipelines over a length of 300 m to the tunnel intake. Conceptual details of the intake tower are shown in **Figure 5.2**.

The tunnel design details for this dam Site B and for both Options 1A (single tunnel) and 1B (twin tunnels) are also shown in **Table 5.1**.

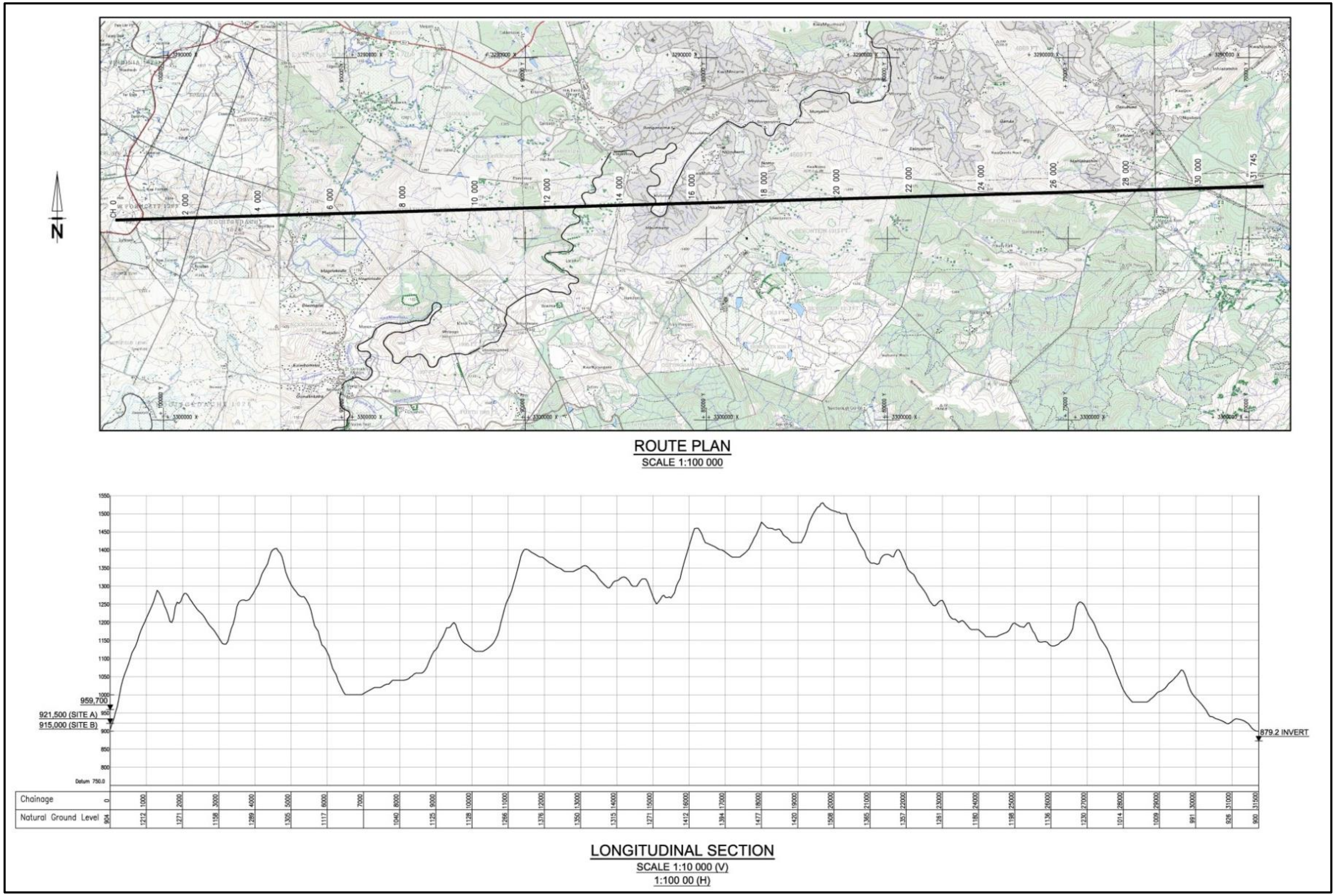
The total pumping head for Option 1A (single tunnel) varies from 49,7 m with Site B dam at FSL (915,0 masl) to 88,8 m with the water level at the MOL (875,9 masl).

The average head for pumping is 59,7 m. For Option 1B (twin tunnels) the pumping head varies from 5 m at FSL to 44,1 m with the water level at the MOL, with an average head of 15,0 m. For Option 1B (twin tunnels) the invert of the tunnel intake is also set at the FSL to avoid the pumps being operated intermittently. A flow of 9,93 m³/s can be accommodated with this steeper tunnel, meaning that the second tunnel will only be required towards the year 2075.

The longitudinal sections of the tunnels for dam Site B (Option 1) are similar to those shown in **Figure 5.2** for dam Site A.

Table 5.1: Design Details: Option 1 - Pumping via a Free Flow Tunnel

Smithfield Dam	Site A		Site B	
Option	**1A Single Tunnel**	**1B Twin Tunnels**	**1A Single Tunnel**	**1B Twin Tunnels**
Design capacity (m³/s)	14,89	7,45	14,89	7,45
Tunnel diameters (m) (Minimum size)	3,0	3,0	3,0	3,0
Design flow velocity (m/s)	2,10	1,05	2,10	1,05
Tunnel lengths (km)	31,5	31,5	31,5	31,5
Tunnel head loss (m)	80,5	20,2	80,5	20,2
Tunnel outlet invert (masl)	879,2	879,2	879,2	879,2
Tunnel intake invert (masl)	959,7	899,4	959,7	899,4
FSL limitation (masl)	-	921,5	-	915,0
Maximum discharge (m³/s)	14,89	10,69	14,89	9,84
Average pumping head (m)	53,2	15,0	59,7	15,0
Pipelines to Tunnel intake				
• Diameter (sum)	2 x 1800	2 x 1800	2 x 1800	2 x 800
• Length (m)	300	300	300	300
• Head loss (m)	2	2	2	2



Chainage	Natural Ground Level
0	904
1000	1212
2000	1271
3000	1158
4000	1289
5000	1305
6000	1117
7000	
8000	1040
9000	1125
10000	1128
11000	1266
12000	1376
13000	1350
14000	1315
15000	1271
16000	1412
17000	1394
18000	1477
19000	1420
20000	1508
21000	1365
22000	1357
23000	1261
24000	1180
25000	1198
26000	1136
27000	1230
28000	1014
29000	1009
30000	991
31000	926
31500	900

Figure 5.2: Option 1 - Pumping via free flow tunnel

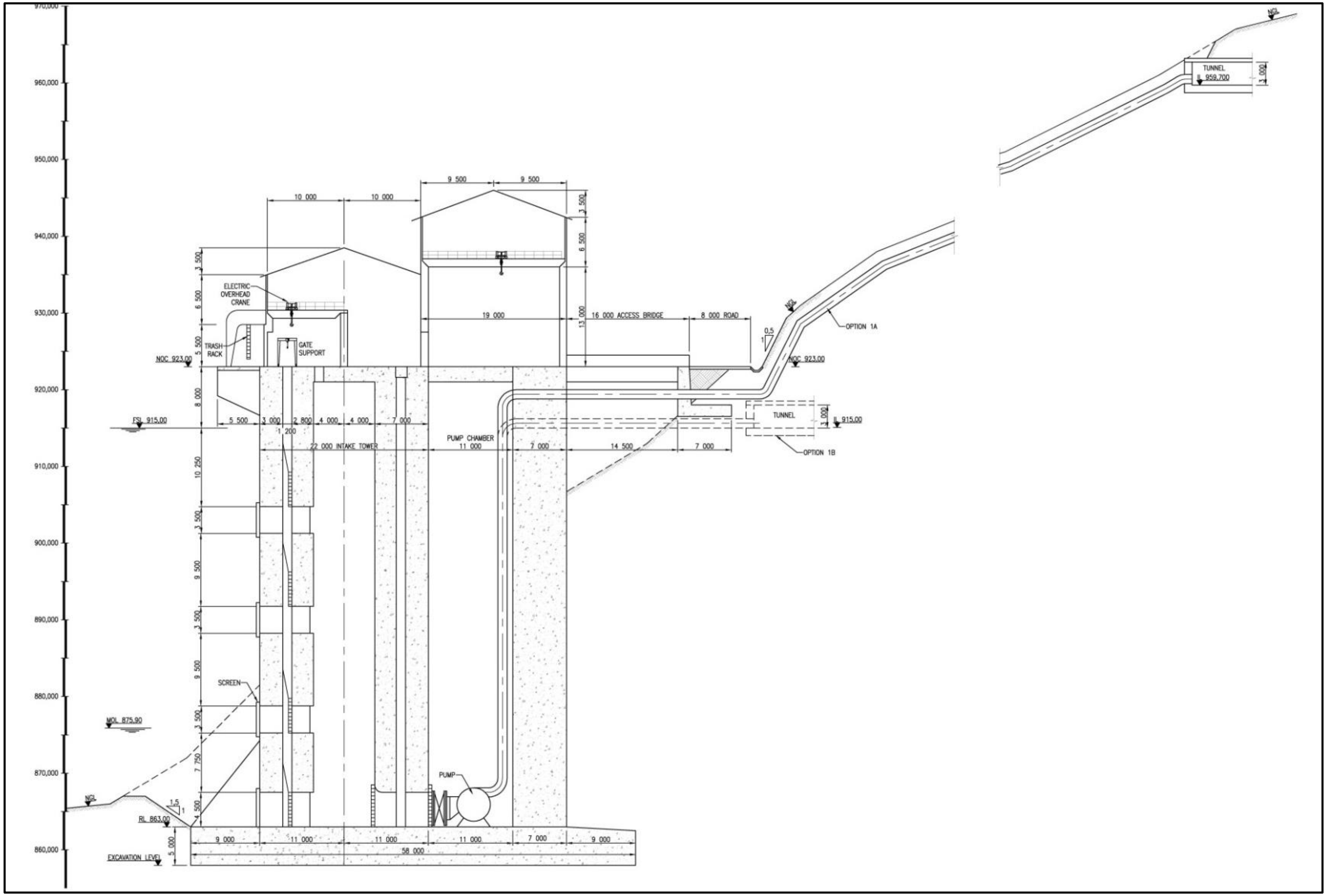


Figure 5.3: Dam site B - Intake tower (Pumping)

5.1.2 Option 2: Pressure tunnel

a) Dam Site A

For Dam Site A the tunnel intake is located downstream of the dam wall and fed from the outlet works of the dam under gravity.

The tunnel design details for this dam Site A and for both Options 2A (single tunnel) and 2B (twin tunnels) are shown in **Table 5.2**.

The tunnel will be flowing full under pressure and the soffit of the outlet is positioned on the FSL of the balancing storage in the Baynesfield Dam. The minimum water levels in the Smithfield Dam to discharge the required design capacities have been determined using Manning's flow formula for the tunnel with a discharge coefficient of 0,016. The tunnel head losses have been kept as low as practically possible to achieve minimum water levels in the dam close to the MOL, resulting in a tunnel diameter of 4,5m for a single tunnel (Option 2A) and 2 x 3,5 m for the twin tunnels (Option 2B).

As shown in **Table 5.2** the minimum required water levels in the dam are higher than the MOL's with storage losses of 9,73 million m³ and 9,21 million m³ for Option 2A and Option 2B respectively. This loss in storage is only about 1% of the total storage of the Smithfield and Impendle Dams (947 million m³ according to the pre-feasibility study). The reduction in yield will thus be very small, but this aspect needs to be verified and confirmed by the yield analyses to be carried out as part of this feasibility study (*Task 4.5*). As shown in the pressure tunnels are sloped towards the intake and the outlet to minimize cost (see **Appendix A**).

Longitudinal sections of the pressure tunnels are shown in **Figure 5.4**.

b) Dam Site B

For Dam Site B the tunnel intake is located 1,5 km upstream of the dam wall, requiring an intake tower, with conceptual details shown in **Figure 5.5**. The tunnel design details are shown in Table 5.2 for both Options 2A (single tunnel) and 2B (twin tunnels). The design details are similar to that described in **Section 5.1.2** for Dam Site A, except that the dead storage increases to 13,94 million m³ and 13,55 million m³ with the live storage decreasing by 6,76 million m² and 6,37 million m³ for a single and twin tunnels respectively.

Longitudinal sections of the tunnels from dam Site B are shown in **Figure 5.4**.

Table 5.2: Design Details: Option 2 - Pressure tunnel

Smithfield Dam	Site A		Site B	
Option	2A Single Tunnel	2B Twin Tunnels	2A Single Tunnel	2B Twin Tunnels
Design capacity (m^3/s)	14,89	7,45	14,89	7,45
Tunnel diameter (m)	4,5	3,5	4,5	3,5
Design flow velocity (m/s)	0,94	0,77	0,94	0,77
Tunnel lengths (km)	31,5	31,5	31,5	31,5
Tunnel head loss (m)	6,0	5,8	6,0	5,8
Tunnel outlet invert (masl)	874,7	875,7	874,7	875,7
Required headwater level in Smithfield Dam (masl)	885,2	885,0	885,2	885,0
Minimum water level in dam to discharge the design capacity (masl)	887,2	887,0	887,2	887,0
Dam MOL (masl)	880,7	880,7	875,9	875,9
Loss of dam storage (Mm^3)	9,73	9,21	13,94	13,55

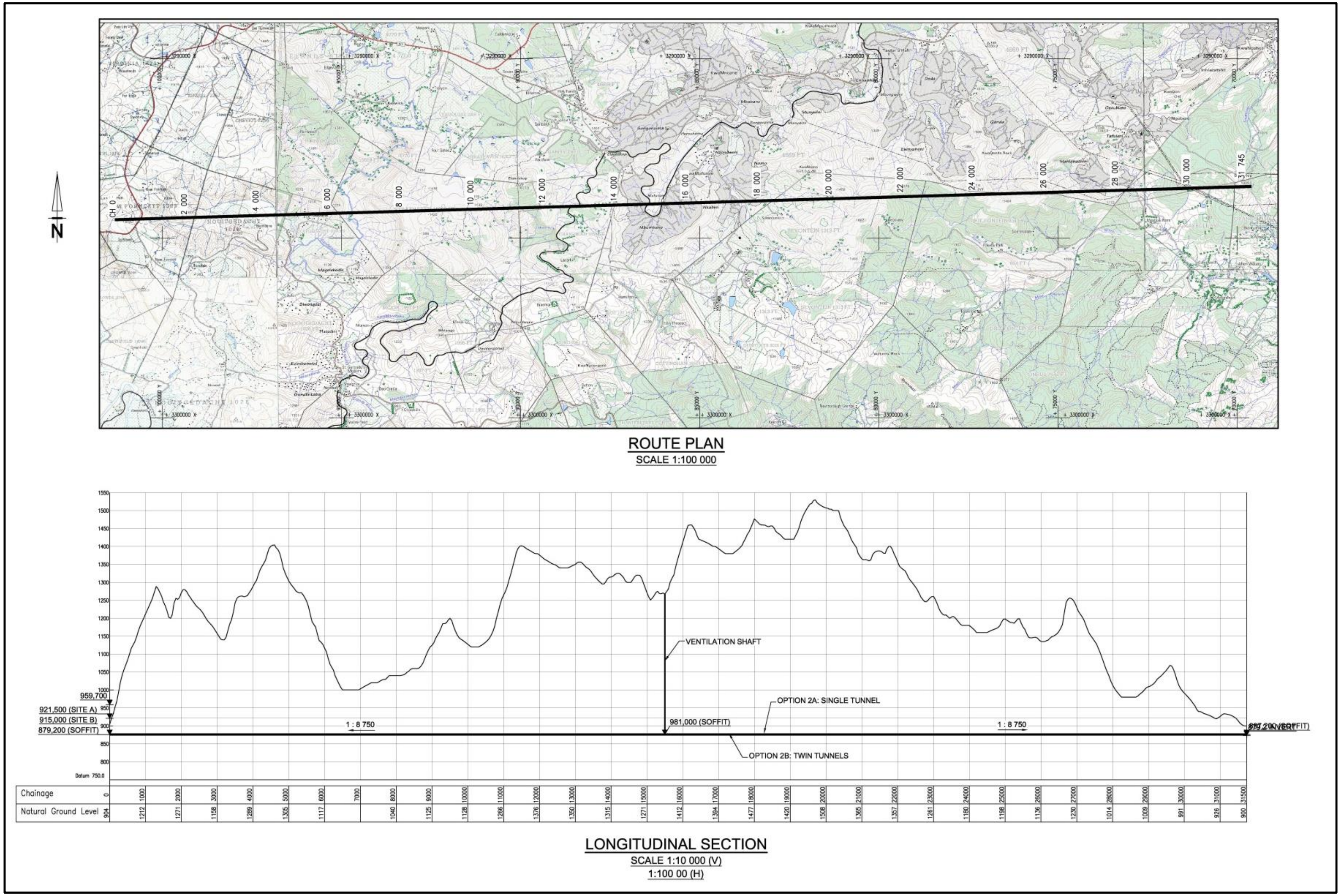


Figure 5.4: Option 2 – Pressure tunnels

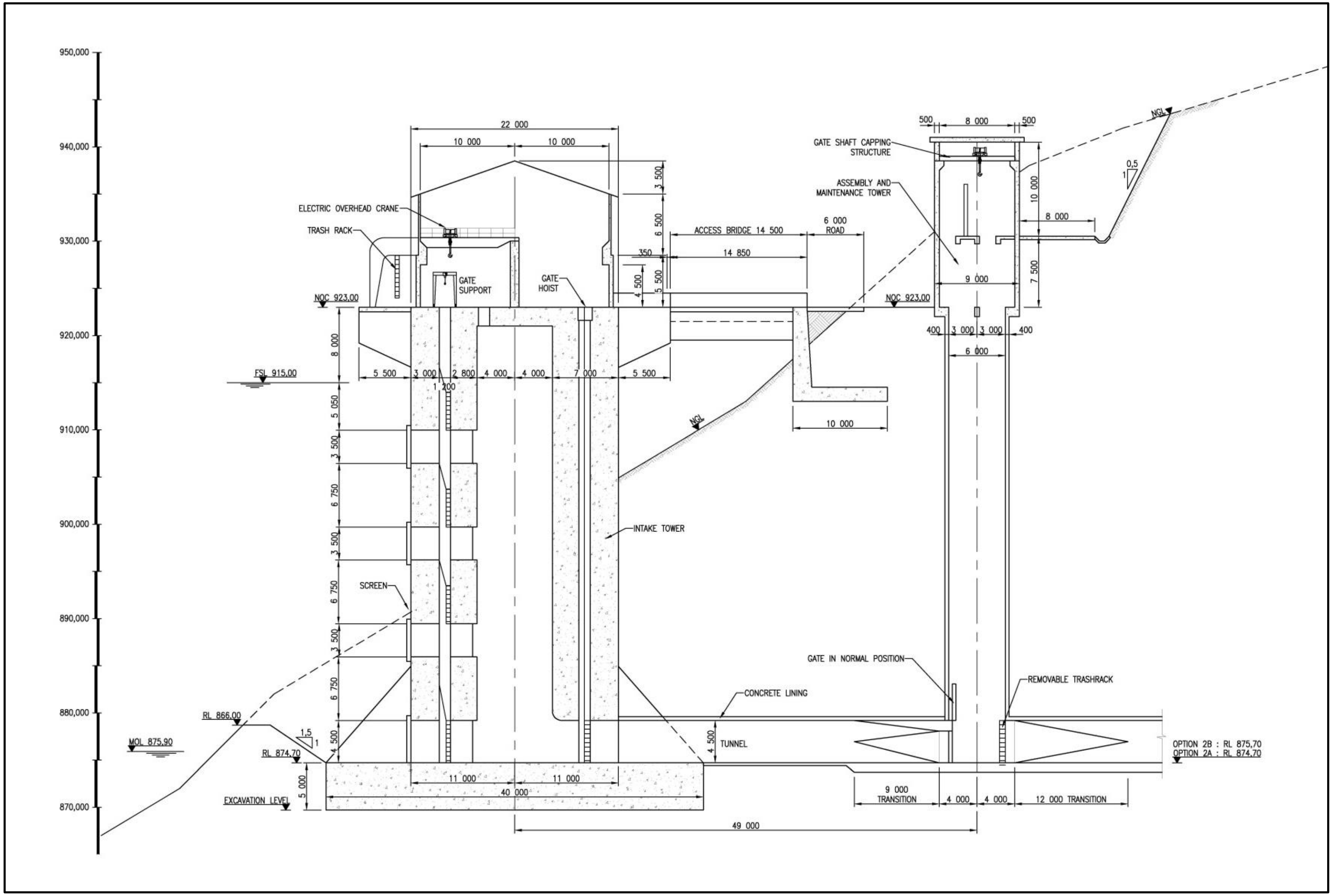


Figure 5.5: Intake tower gravity, conceptual details

5.1.3 Option 3: Pumping via combination of pipelines and tunnel

Due to the high tunnel cost, this option endeavours to shorten the tunnel length by increasing the length of pipelines from the abstraction point in the Smithfield Dam. Initially the tunnel was omitted completely with transfers conveyed by means of pipelines. Apart from the pump station at the Smithfield Dam, a further four booster pump stations would be required to pump the water to the highest point along the longitudinal section. Such an option was thus discarded due to practical and operational considerations.

A combination of pipelines and a free flow tunnel was thus selected as shown in **Figure 5.6**. The route of the pipelines deviates around a “koppie” from the tunnel route near the Smithfield Dam as shown in **Figure 1.1**. This was necessary to minimise the pumping head. The pipelines will be implemented in two stages, each capable of conveying a flow of 7,42 m^3/s with the second stage to follow in 2054. Each pipeline will comprise a 2 300mm diameter rising main over a distance of 4,2 km to a break pressure tank at level 1 136 masl and a gravity main of 1 300mm diameter over a distance of 6,1 km to the tunnel intake with its invert at 1 050 masl as shown in **Figure 5.6**.

The tunnel outlet invert is at the FSL of the Bayensfield Balancing Dam at 879,2 masl. The minimum tunnel size of 3,0 m diameter can handle the ultimate total flow of 14,89 m^3/s under free flow conditions due to its steeper grade. Therefore, twin tunnels need not to be considered.

The two different dam sites (Site A and B) affect only the pumping head, which will be about 6,5 m more for Site B (i.e. the difference in FSL’s). The intake tower shown in **Figure 5.3** will be applicable to dam Site B.

The design details for this option are shown in **Table 5.3**.

Table 5.3: Design Details: Option 3 - Pumping via a combination of pipelines and free flow tunnel

Smithfield Dam	Site A	Site B
Option	**3 Single Tunnel**	**3 Single Tunnel**
Tunnel		
• Diameter (m)	3,0	3,0
• Length (km)	23,44	23,44
• Design flow velocity (m/s)	2,10	2,10
• Outlet invert (masl)	879,2	879,2
• Intake invert (masl)	1050,0	1050,0
Pipelines		
• Diameter		
• Rising main (mm)	2 x 2300	2 x 2300
• Gravity line (mm)	2 x 1300	2 x 1300
• Design flow velocity		
• Rising main (m/s)	1,80	1,80
• Gravity line (m/s)	5,61	5,61
• Length		
• Rising main (km)	4,2	4,2
• Gravity line (km)	6,1	6,1
• Head loss		
• Rising main (m)	3,0	3,0
• Gravity line (m)	45,0	45,0
• Break pressure tank (m^3)	2 x 1000	2 x 1000
Average pumping head (m)	233	240

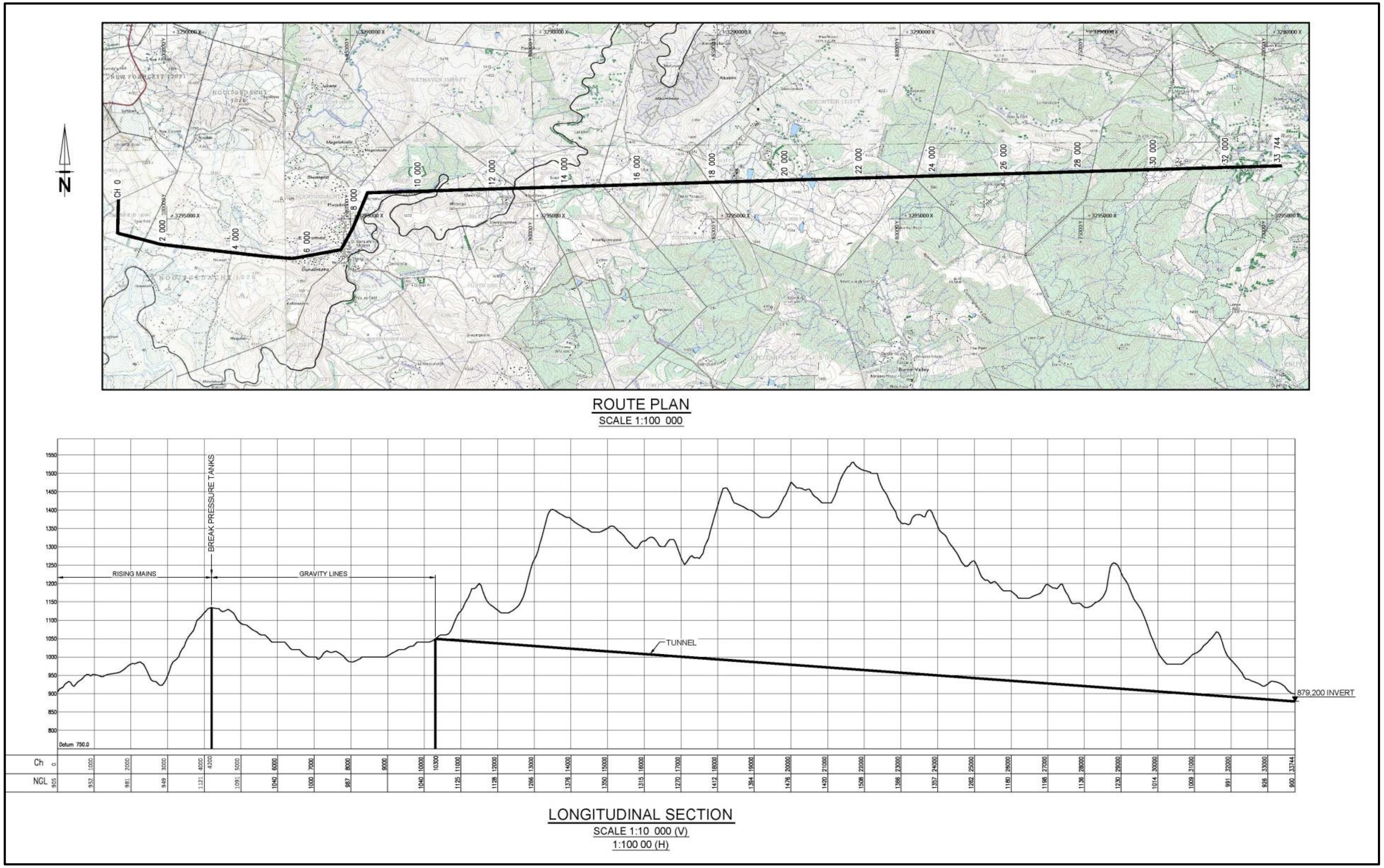


Figure 5.6: Option 3 - Combination of pipe lines and free flow tunnel

6 COSTS AND PHASING

6.1 PHASING

The years and the capital costs in which the different components should be operational are shown in **Table 6.1**, **Table 6.2** and **Table 6.3** for the three options. This is based on the following assumptions:

- The projected water demand will reach 125,16 million m³/a (4,0 m³/s downstream of Umlaas Road by 2023).
- The annual growth in water demand beyond 2023 will remain at 1,3 % pa.
- The total average yields are as follows:
  - Phase 1 (Smithfield Dam): 147 million m³/a (4,66 m³/s);
  - Phase 2 (+ Impendle Dam): 376 million m³/a (11,91 m³/s);

6.2 CAPITAL COSTS

The capital cost estimates are described in **Appendix A** and **Appendix B.** The cost estimates of the Smithfield Dam (Sites A and B) are taken from the Dam Position Report.

6.3 ENGINEERING, OPERATING AND MAINTENANCE COSTS

Engineering, operations and maintenance costs were assumed as a percentage of the capital costs as shown in **Table 6.4**.

Table 6.1: Option 1 - Pumping via Free Flow Tunnels - Phasing and Capital Cost

COMPONENT	Smithfield Dam Site A				Smithfield Dam Site B			
	OPTION 1A (Single		OPTION 1B (Twin tunnels)		OPTION 1A (Single tunnel)		OPTION 1B (Twin tunnels)	
	Year	Cost (R mill)	Year	Cost (R mill)	Year	Cost (R mill)	Year	Cost (R mill)
Smithfield Dam	2023	1334	2023	1334	2023	999	2023	999
Transfer Tunnel								
Stage 1	2 023	2 150,0	2 023	2 150,0	2 023	2 150,0	2 023	2 150,0
Stage 2	-	-	2 082	2 150,0	-	-	2 075	2 150,0
Tunnel Intake								
Stage 1								
Intake Tower	-	-	-	-	2 023	Note 1*	2023	Note 1*
Pipeline	2 023	Note 1*	2 023	Note 1*	2 023	Note 1*	2 023	Note 1*
M & E	2 023	90,0	2 023	72,0	2 023	95,0	2 023	72,0
Pump station (Civil)	2 023	Note 1*	2 023	Note 1*	-	-	-	-
Stage 2								
Pipeline	2 054	Note 1*	2 054	Note 1*	2 054	Note 1*	2 054	Note 1*
M & E	2 054	90,0	2 054	72,0	2 054	95,0	2 054	-72,0

*Note 1: Cost of intake tower, civil component of the pump station and the pipes to the tunnel inlet, included in Dam Costs

Table 6.2: Option 2 - Pressure Tunnels - Phasing and Capital Cost

COMPONENT	Smithfield Dam Site A				Smithfield Dam Site B			
	OPTION 2A (Single tunnel)		OPTION 2B (Twin tunnels)		OPTION 2A (Single tunnel)		OPTION 2B (Twin tunnels)	
	Year	Cost (R mill)	Year	Cost (R mill)	Year	Cost (R mill)	Year	Cost (R mill)
Smithfield Dam	2023	1 328	2023	1 328	2023	817	2023	817
Transfer Tunnel								
Stage 1	2 023	2 724,0	2 023	2 236,0	2 023	2 724,0	2 023	2 236,0
Stage 2	-	-	2 054	2 236,0	-	-	2 054	2 236,0
Tunnel Intake								
Stage 1	-	-	-	-	-	-	-	-
Intake Tower		-	-	-	2 023	Note 1*	2023	Note 1*
Pipeline to Intake portal	2 023	5,4	2 023	5,4	-	-	-	-
Tunnel connection	-	-	-	-	2 023	13,0	2 023	13,0
Stage 2								-
Pipeline to intake portal	2 054	5,4	2 054	5,4	2054	13,0	2054	13,0

*Note 1: Cost of intake tower and civil component of the pump station included in the dam costs

Table 6.3: Option 3 - Pipelines and Tunnel - Phasing and Capital Costs

COMPONENT	Smithfield Dam Site A Option 3 (Single Tunnel)		Smithfield Dam Site B Option 3 (Single Tunnel)	
	Year	Cost (R mill)	Year	Cost (R mill)
Smithfield Dam	2023	1 334,0	2023	999,0
Transfer Tunnel	2023	1 600,0	2023	1 600,0
Pipelines				
Stage 1	2023	175,9	2023	175,9
Stage 2	2054	175,9	2054	175,9
Intake				
Stage 1				
Intake Tower	-	-	2023	Note 1*
M & E	2023	182,0	2023	182,0
Stage 2				
M & E	2054	182,0	2054	182,0
Break pressure tank				
Stage 1	2023	3,0	2023	3,0
Stage 2	2054	3,0	2054	3,0

**Note 1: Cost of intake tower and civil component of pump station included in the dam costs*

Table 6.4: Engineering, Operating and Maintenance Costs

Element	Engineering		Operational and Maintenance		Useful life (years)	
	Pre engineering	Supervision	Civil	M&E	Civil	M&E
Dams	5.00%	10%	0.25%	1%	50	30
Pump station and pipes	5.00%	10%	0.5%	4%	50	30
Tunnels	5.00%	10%	0.25%	1%	50	30

7 ENERGY REQUIREMENTS

The energy requirements for pumping were calculated on the basis of the following:

- The flow in 2023 of 1,25 x 4 m³/s = 5 m³/s increasing gradually by 1,3% pa.
- Pumps will be operated for 80% of the time.
- Pumping efficiency of 80%.
- Motor efficiency of 95%.
- Energy cost based on Eskom Megaflex tariff structure for 2011/2012.
- Two pumping stages with each stage delivering a maximum of 7,45 m³/s. The second stage required in 2054.
- The energy requirements in 2023 for the different options are shown in **Table 7.1**. The energy requirements will increase gradually by 1,3% pa, similar to the predicted growth in water demand.

Table 7.1: Energy Requirements in 2023

Smithfield Dam	Site A			Site B		
Option	1A Single Tunnel	1B Twin Tunnels	3 Single Tunnel	1A Single Tunnel	1B Twin Tunnel	3 Single Tunnel
Flow (1,25 x 4m³/s)	5,0	5,0	5,0	5,0	5,0	5,0
Average head (m)	53,2	15,0	233,0	59,7	15,0	240,0
Motor input power (kw)	3 434	968	15 038	3 853	968	15 490
Active energy (MWh/a)	24 082	6 789	105 458	27 020	6 788	108 628

**Note: 1.These energy requirements will increase by 1,3 % pa.*
2. Based on pumping for 80 % of the time

8 PRELIMINARY IMPLEMENTATION PROGRAMME

The preliminary implementation programme for the uMkhomazi Water Project Phase 1 including the waterworks, as well as the supply pipelines to Umlaas Road is shown in **Figure 8.1**.

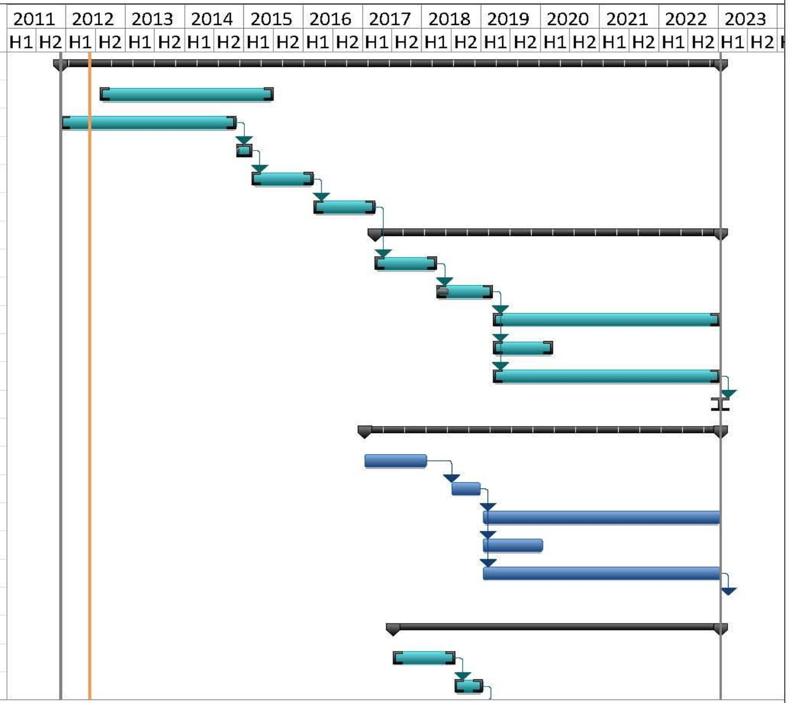
This preliminary implementation programme has been compiled at the request of the DWA, to merely show that the construction of the various components of Phase 1 of the uMWP can be achieved by 2023, the year when the supply from the Smithfield Dam is expected to be in operation.

Finalisation of the programme will be affected by the securance of finance, institutional arrangements, environmental and social baseline studies, etc.

eMKHOMAZI TECHNICAL FEASIBILITY STUDY

Optimisation of conveyance system

ID	Task Name	Duration	Start	Finish
1	**eMkhomazi project**	**2903 days**	**Thu 11/12/01**	**Mon 23/01/16**
2	Environmental impact Assessment	761 days	Wed 12/08/01	Wed 15/07/01
3	Feasibility study	772 days	Thu 11/12/01	Fri 14/11/14
4	Feasibility review	69 days	Mon 14/11/17	Thu 15/02/19
5	Securing financing	271 days	Fri 15/02/20	Fri 16/03/04
6	Procurement for all tender designs	271 days	Mon 16/03/07	Mon 17/03/20
7	**Smithfield Dam**	**1520 days**	**Tue 17/03/21**	**Mon 23/01/16**
8	Tender design	271 days	Tue 17/03/21	Tue 18/04/03
9	Procurement	245 days	Wed 18/04/04	Tue 19/03/12
10	Construction	1000 days	Mon 19/03/18	Fri 23/01/13
11	Detail design	262 days	Mon 19/03/18	Tue 20/03/17
12	Construction monitoring	1000 days	Mon 19/03/18	Fri 23/01/13
13	Water supply	1 day	Mon 23/01/16	Mon 23/01/16
14	**Transfer structure/s**	**1566 days**	**Mon 17/01/16**	**Mon 23/01/16**
15	Tender design	271 days	Mon 17/01/16	Mon 18/01/29
16	Procurement	124 days	Thu 18/07/05	Tue 18/12/25
17	Construction	1045 days	Mon 19/01/14	Fri 23/01/13
18	Detail design	262 days	Mon 19/01/14	Tue 20/01/14
19	Construction monitoring	1045 days	Mon 19/01/14	Fri 23/01/13
20	Conveying	1 day	Mon 23/01/16	Mon 23/01/16
21	**Balancing Dam/s**	**1441 days**	**Mon 17/07/10**	**Mon 23/01/16**
22	Tender design	271 days	Mon 17/07/10	Mon 18/07/23
23	Procurement	124 days	Tue 18/07/24	Fri 19/01/11



Project implementation programme

Task	External Milestone	Manual Summary Rollup	
Split	Inactive Task	Manual Summary	
Milestone	Inactive Milestone	Start-only	
Summary	Inactive Summary	Finish-only	
Project Summary	Manual Task	Deadline	
External Tasks	Duration-only	Progress	

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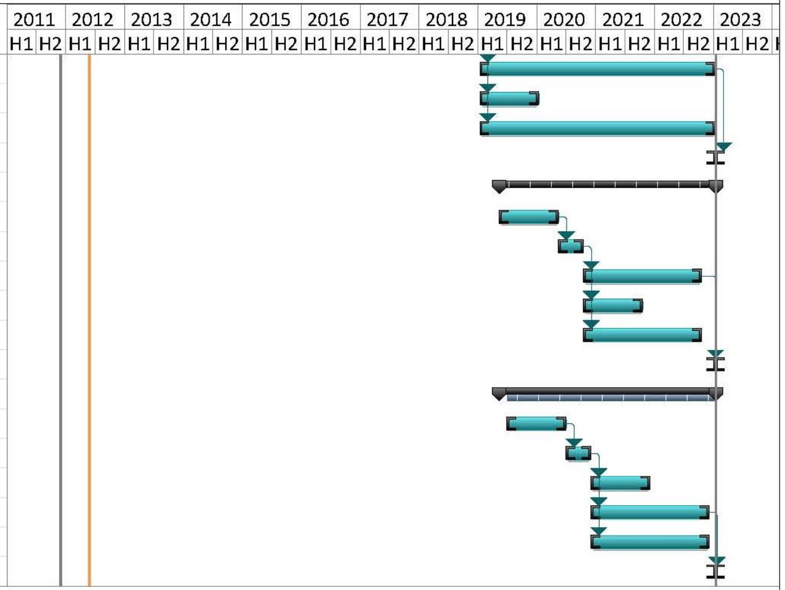
Figure 8.1: Project implementation

eMKHOMAZI TECHNICAL FEASIBILITY STUDY

Optimisation of conveyance system

ID	Task Name	Duration	Start	Finish
24	Construction	1045 days	Mon 19/01/14	Fri 23/01/13
25	Detail design	262 days	Mon 19/01/14	Tue 20/01/14
26	Construction monitoring	1045 days	Mon 19/01/14	Fri 23/01/13
27	Water supply	1 day	Mon 23/01/16	Mon 23/01/16
28	**Water treatment works**	**959 days**	**Wed 19/05/15**	**Mon 23/01/16**
29	Tender design	262 days	Wed 19/05/15	Thu 20/05/14
30	Procurement	110 days	Fri 20/05/15	Thu 20/10/15
31	Construction	524 days	Fri 20/10/16	Wed 22/10/19
32	Detail design	262 days	Fri 20/10/16	Mon 21/10/18
33	Construction monitoring	524 days	Fri 20/10/16	Wed 22/10/19
34	Water supply	1 day	Mon 23/01/16	Mon 23/01/16
35	**Pipeline to Umlaas**	**959 days**	**Wed 19/05/15**	**Mon 23/01/16**
36	Tender design	262 days	Mon 19/07/01	Tue 20/06/30
37	Procurement	110 days	Wed 20/07/01	Tue 20/12/01
38	Detail design	262 days	Wed 20/12/02	Thu 21/12/02
39	Construction	524 days	Wed 20/12/02	Mon 22/12/05
40	Construction monitoring	524 days	Wed 20/12/02	Mon 22/12/05
41	Conveying	1 day	Mon 23/01/16	Mon 23/01/16



Project implementation programme

Task	External Milestone	Manual Summary Rollup	
Split	Inactive Task	Manual Summary	
Milestone	Inactive Milestone	Start-only	
Summary	Inactive Summary	Finish-only	
Project Summary	Manual Task	Deadline	
External Tasks	Duration-only	Progress	

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Figure 8.2: Project implementation (Continued)

9 ECONOMIC ANALYSES

The details and capital costs and phasing of stages are shown in **Table 6.1**, **Table 6.2** and **Table 6.3** for the different options analysed and compared. The following options are compared for both sites A and B of the Smithfield Dam:

- Option 1A: Pumping via a 3 m diameter single tunnel
- Option 1B: Pumping via twin 3 m diameter tunnels
- Option 2A: Single 4,5 m diameter pressure tunnel
- Option 2B: Twin 3,5 m diameter pressure tunnels
- Option 3: Twin 2,3 m diameter pipelines and 3m diameter single tunnel

The details of the economic comparison are described in **Appendix C** and are summarised in the tables below.

Table 9.1: Net Present Value (NPV) Costs (R million) of Conveyance Options

Option	Smithfield Dam Site A			Smithfield Dam Site B		
	Discount rate			Discount rate		
	6%	8%	10%	6%	8%	10%
1A	2 838	2 365	1 997	2 632	2 188	1 846
1B	2 723	2 291	1 946	2 494	2 100	1 786
2A	3 015	2 559	2 187	2 647	2 246	1 919
2B	2 881	2 369	1 985	2 514	2 057	1 717
3	3 132	2 490	2 037	2 905	2 293	1 866

Table 9.2: Net Present Value (NPV) of Energy Cost (R Million)

Option	Smithfield Dam Site A			Smithfield Dam Site B		
	Discount rate			Discount rate		
	6%	8%	10%	6%	8%	10%
1A	129,6	80,6	53,0	145,4	90,4	59,4
1B	36,9	22,9	15,1	36,9	23,0	15,1
2A	-	-	-	-	-	-
2B	-	-	-	-	-	-
3	565,8	352,0	231,3	582,9	362,6	238,3

10 CONCLUSIONS AND RECOMMENDATION

10.1 COST COMPARISON

The following conclusions can be drawn from the considerations and NPV analyses described in this report:

- The Smithfield Dam must be located at Site B. **Table 9.1** shows that the NPV's are lower for all options with the Smithfield Dam at Site B.
- Option 2B (i.e. twin 3,5 m diameter pressure tunnels) at Site B provides the lowest NPV at higher discount rates of 8 % and 10 %. Option 1B (i.e. pumping via twin 3 m diameter tunnels) at Site B provides a slightly lower NPV than Option 2B (0,8% lower).
- Option 2B (i.e. twin 3,5 m diameter pressure tunnels) becomes the preferred option on the basis of the following consideration:
    - Minimal O & M requirements with no pump station;
    - Generation of hydropower at the tunnel outlet
    - Residual head advantages for gravity supply pipelines to Umlaas Road;

Taking all the above into account it is recommended that the Smithfield Dam at Site B, as well a pressure tunnel to the upper reaches of the Baynesfield Dam be selected for further optimisation. In order to optimise the recommendations the investigations as described below will be required.

10.2 FIRM YIELDS AND STORAGE PROVIDED

The design capacities of the transfer tunnel are based on the long-term stochastic yield analyses for a recurrence interval of 100 years, as carried out in the pre-feasibility study. These analyses need to be verified and confirmed, and specific attention should be given to the following:

- The effect of the environmental water requirements (EWR) on the yield of the Smithfield Dam.
- The effect of a raised MOL on the yield of the Smithfield Dam, as a higher MOL will result in smaller sized pressure tunnel(s). For instance, raising the MOL by 10m to 885 masl will require a higher FSL at approximately 918 masl.

- The effect of different storage volumes on the yield at the Smithfield Dam. Based on the information in this report, Impendle Dam (Phase 2) will be required by 2035 (see **Figure 2.1**). Phase 2 can be implemented later than 2035, if the storage volume and yield at the Smithfield Dam is increased or the supply downstream of Umlaas Road supplemented from the Upper Mgeni system.

10.3 TRANSFER CAPACITY PEAK FACTOR

Umgeni Water requires a supply capacity of 1.5 times the average demand. The analyses in this report are based on a transfer capacity of 1.25 times the average demand with the difference being provided by balancing storage at the tunnel outlet. If water is transferred at a capacity equal to the average demand and the difference made up by larger balancing storage, a smaller tunnel size may become a possibility for the pressure tunnel option.

10.4 ASPECTS AT THE TUNNEL INTAKE

The average residual head at the outlet are dependent on the stage-exceedance relationship (see **Section 3.2**). Analyses are required to establish an accurate relationship for the Smithfield Dam and how it will be affected when Impendle Dam is constructed.

10.5 ASPECTS AT THE TUNNEL OUTLET

The benefit of incorporating power generation at the tunnel outlet needs to be investigated (*Task 5.15*).

To fully utilise the residual head at the tunnel outlet, an investigation into whether the waterworks can be moved to within the vicinity of Umlaas Road should be done. The pipelines from the tunnel outlet to Umlaas Road can be decreased in size for this scenario.

10.6 TUNNEL DESIGN

The costs of the tunnel(s) dominate the net present value analyses. It is thus essential to establish whether the tunnels should be concrete lined over their full length. This will only be possible upon completion of the geological and geotechnical investigations.

10.7 FOUNDATION AND CONSTRUCTION MATERIALS INVESTIGATIONS

These investigations are to be focused on the following:

- Smithfield Dam site B Option 3 (ECRD with side channel spillway in neck adjacent to saddle dam, and with ECRD saddle dam as described in the *Dam Position Report*);
- The pressure tunnel as indicated in this report;
- The new Baynesfield balancing dam, also described in the *Dam Position Report*. The capacity of these dams should, however, be confirmed by Umgeni Water when the conveyance system from Baynesfield to Umlaas Road is evaluated.

11 REFERENCES

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APPENDIX A

TUNNEL COSTS

1 TUNNEL CONSTRUCTION AND ANTICIPATED COSTS

1.1 ENGINEERING GEOLOGY

The Smithfield – Baynesfield transfer tunnel is expected to be approximately 32 km long. The proposed tunnel is expected to be mainly driven within rocks of the Volksrust Formation (70%), which almost exclusively comprises mudrocks (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 interbedded 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.

1.2 EXPECTED TUNNELLING CONDITIONS

With the exception of the areas close to the portals, the tunnel is expected to be excavated within an unweathered rock mass. Siltstone, 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 the installation of 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 dolerite contact zones.

1.3 TUNNEL CONSTRUCTION METHODS

Little information is currently available on the rock to be excavated along the tunnel route. However sufficient information is available to suggest that the tunnel will be suitable for excavation by hard rock tunnel boring machines. Due to the length of the transfer tunnel, the use of TBM's will be far more economical than conventional tunnelling methods.

Various options have been considered, as follows:

- 3,5m diameter machines excavating on two headings with a lined diameter of 3,0m.
- 3,5m diameter machines excavating on three headings with a lined diameter of 3,0m.
- 4,0m diameter machines excavating on two headings with a lined diameter of 3,5m, or
- 4,6m diameter machines excavation on two headings with a lined diameter of 4,0m.

Special precautions will have to be taken for machines operating on downgrade drives.

The tunnel has been assumed to be fully concrete lined along their entire length. Waterproof membrane and steel liners have not been considered at this stage. These assumptions should be refined at tender stage once more data is available.

Hydraulically a smaller diameter tunnel such as the 3,0m 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 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 Tunnel Boring Machine (TBM). Aspects such as access and ventilation can become problematic with longer drives.

The possibility also exists that, during the tender stage, the Contractor could propose an alternative diameter based on machine availability at that stage.

Construction of the transfer tunnels will commence with the portal developments and adit excavations. These activities can be completed, for the most part, during the lead in period before the TBM's are assembled on site. This lead in period comprises the procurement, transport and assembly of the TBM which generally takes approximately one year.

Advance rates of TBM excavation and concrete lining have been assumed to be an average of 130 m per week, per heading for TBM excavation.

1.4 Anticipated Tunnel Costs

As discussed under Section 3 above, four options were investigated taking into account various tunnel diameters and number of tunnel drives. These may be summarised as follows:

- 3,0m diameter lined tunnel – two headings
- 3,0m diameter lined tunnel – three headings
- 3,5m diameter lined tunnel – two headings
- 4,0m diameter lined tunnel – two headings

The anticipated costs for a 33 km length of tunnel for these various options are summarised in **Table 1** below.

As can be inferred from **Table 1**:

- The cost of excavating three (3) 3,0m diameter lined tunnels simultaneously is marginally cheaper than driving two (2) 3,0m diameter tunnels. This would be as a result of the faster production rate of three drives as opposed to two drives.
- The total cost for excavation and lining of the tunnels increases with final lined tunnel diameter.

Table 1: Tunnel costs

	3,0m internal diameter 2 Drives	3,0m internal diameter 3 Drives	3,5m internal diameter 2 Drives	4,0m internal diameter 2 Drives
Excavation Cost / m	R 41 000	R 40 000	R 44 000	R 47 000
Lining Cost / m	R 24 000	R 24 000	R 27 000	R 30 000
Total Cost / m	R 65 000	R 64 000	R 71 000	R 77 000
Total Cost for 33 km	R 2 145 000 000	R 2 112 000 000	R 2 343 000 000	R 2 541 000 000

(The above costs relate to upgrade drives. These rates may be increased by 10% for down-grade drives due to increased pumping costs for ground-water).

APPENDIX B

INTAKE AND PUMP STATIONS - CAPITAL COSTS AND ENERGY REQUIREMENTS

1 CAPITAL COSTS FOR PUMPING SCHEMES

Capital costs for mechanical and electrical equipment were estimated as follows:

The cost for pumps and motors were based on budget cost information that was obtained from a pump supplier for horizontal split casing pumps and water cooled 6.6 kV electric motors. This compared favourably on a R/kW basis with the actual cost (escalated) for a large pump station that was awarded in 2010 and which is currently under construction. The costs for valves, pipework, electrical (assuming variable speed drives will be used) and appurtenant equipment (overhead crane, ventilation, drainage, emergency generator etc.) were estimated as a percentage of the pump and motor costs based on the ratios between the various costs of a recent large pump station contract.

Pipeline costs were based on a cost of R18 000 per meter which is a good estimate when compared with the actual cost of a recent pipeline project of similar diameter. This includes manufacture, corrosion protection, transport, trenching, laying and cathodic protection.

The capital cost for the civil structure for the pump station at Site A, was estimated from an existing pump station dimensions that deliver approximately the same flow and the same discharge height. For the Site B pump station, the conceptual layout drawing as depicted in **Figure 5.3** was utilised to estimate the cost.

1.1 ESTABLISHING ENERGY REQUIREMENTS AND ENERGY COSTS

The following assumptions were made when calculating the pump electrical energy requirements and energy costs:

- 1.8 m diameter 300 m long epoxy lined welded steel pipeline
- Pumping efficiency = 80 %
- Motor efficiency = 95 %
- Power factor = 0.95
- Average pump hours per day = 19.2 (80% of 24 hours – long term average for 1,25 peak transfers).
- The Eskom tariff used is Megaflex (for non-local authority users) at a voltage of 6.6 kV and distance of >300 km but <600 km from Johannesburg

- No effort was made to utilise the Eskom Time of Use tariff structure

1.2 MAINTENANCE COSTS

The yearly cost of maintenance was based on the following:

Table 1: Yearly Maintenance Cost as percentage of Capital Cost

Component	Civil - cost per year (percentage of capital cost)	Mechanical and Electrical - cost per year (percentage of capital cost)
Dams	0.25%	1%
Pump station and pipelines	0.25%	4%
Tunnels	0.25%	1%

APPENDIX C

NET PRESENT VALUE ANALYSES

OPTION 1A

Mkomazi Water Project
Dam Site A, Option 1A: Pump and Free Flow through single 3.0 m dia tunnel

		Civil	M&E	Engineering		Maintenance		Useful life	
Element		**R'000**	**R'000**	**Pre engineer**	**Supervision**	**Civil**	**M&E**	**Civil**	**M&E**
Smithfield Dam		1 334 000	0	5.00%	10%	0.25%	1%	50	30
Impendle Dam		0	0	5.00%	10%	0.25%	1%	50	30
Smithfield Pump station and pipes and electricity supply (Stage 1)	7,45 m^3/s	0	90 000	5.00%	10%	0.50%	4%	50	30
Smithfield pipes (Stage 2)	7,45 m^3/s	0	90 000	5.00%	10%	0.50%	4%	50	30
Tunnel - Stage 1		2 150 000		5.00%	10%	0.25%	1%	50	30
Tunnel - Stage 2		0	0	5.00%	10%	0.25%	1%	50	30
Baynesfield Dam Enlargement		0		5.00%	10%	0.25%	1%	50	30
Total	3 664 000	3 484 000	180 000						

Element		**Capital**	**Annual**
		R'000	**R'000**
Admin cost		20 000	1 000
Environmental cost		7 000	1 000
Social cost		7 000	1 000
Electricity variable Stage 1 - max	5117	KW	15 588
Electricity Fixed Stage 1 - max	5117	KW	1 952
Electricity variable Stage 2 - max	5117	KW	15 588
Electricity Fixed Stage 2 - max	5117	KW	1 952

Results	**Total**	**6%**	**8%**	**10%**
	R'000	**R/m^3**	**R/m^3**	**R/m^3**
PV Costs	5 970 316	2 838 498	2 364 651	1 996 505
PV Electricity (Included in costs above	858 816	129 652	80 654	53 010
PV Water	8 737 457	1 333 005	830 082	545 638
URV	0.68	2.13	2.85	3.66

Mkomazi Water Project
Dam Site B, Option 1A: Pump and Free Flow through single 3.0 m dia tunnel

		Civil	M&E	Engineering		Maintenance		Useful life	
Element		**R'000**	**R'000**	**Pre engineer**	**Supervision**	**Civil**	**M&E**	**Civil**	**M&E**
Smithfield Dam		999 000	0	5.00%	10%	0.25%	1%	50	30
Impendle Dam		0	0	5.00%	10%	0.25%	1%	50	30
Smithfield Pump station and pipes and electricity supply (Stage 1)	7,45 m^3/s	0	95 000	5.00%	10%	0.50%	4%	50	30
Smithfield pipes (Stage 2)	7,45 m^3/s	0	95 000	5.00%	10%	0.50%	4%	50	30
Tunnel - Stage 1		2 150 000		5.00%	10%	0.25%	1%	50	30
Tunnel - Stage 2		0	0	5.00%	10%	0.25%	1%	50	30
Baynesfield Dam Enlargement		0		5.00%	10%	0.25%	1%	50	30
Total	3 339 000	3 149 000	190 000						

Element		**Capital**	**Annual**
		R'000	**R'000**
Admin cost		20 000	1 000
Environmental cost		7 000	1 000
Social cost		7 000	1 000
Electricity variable Stage 1 - max	5741	KW	17 490
Electricity Fixed Stage 1 - max	5741	KW	2 183
Electricity variable Stage 2 - max	5741	KW	17 490
Electricity Fixed Stage 2 - max	5741	KW	2 183

Results	**Total**	**6%**	**8%**	**10%**
	R'000	**R/m^3**	**R/m^3**	**R/m^3**
PV Costs	5 679 509	2 631 622	2 188 092	1 846 393
PV Electricity (Included in costs above	963 125	145 404	90 453	59 450
PV Water	8 737 457	1 333 005	830 082	545 638
URV	0.65	1.97	2.64	3.38

OPTION 1B

Mkomazi Water Project
Dam Site A, Option 1B: Pump and Free Flow through twin 3.0 m dia tunnels

		Civil	M&E	Engineering		Maintenance		Useful life	
Element		**R'000**	**R'000**	**Pre engineer**	**Supervision**	**Civil**	**M&E**	**Civil**	**M&E**
Smithfield Dam		1 334 000	0	5.00%	10%	0.25%	1%	50	30
Impendle Dam		0	0	5.00%	10%	0.25%	1%	50	30
Smithfield Pump station and pipes and electricity supply (Stage 1)	7,45 m^3/s	0	72 000	5.00%	10%	0.50%	4%	50	30
Smithfield pipes (Stage 2)	7,45 m^3/s	0	72 000	5.00%	10%	0.50%	4%	50	30
Tunnel - Stage 1		2 150 000		5.00%	10%	0.25%	1%	50	30
Tunnel - Stage 2		2 150 000	0	5.00%	10%	0.25%	1%	50	30
Baynesfield Dam Enlargement		0		5.00%	10%	0.25%	1%	50	30
Total	5 778 000	5 634 000	144 000						

Element		**Capital**	**Annual**
		R'000	**R'000**
Admin cost		20 000	1 000
Environmental cost		7 000	1 000
Social cost		7 000	1 000
Electricity variable Stage 1 - max	1442	KW	4 394
Electricity Fixed Stage 1 - max	1442	KW	591
Electricity variable Stage 2 - max	1442	KW	4 394
Electricity Fixed Stage 2 - max	1442	KW	591

Results	**Total**	**6%**	**8%**	**10%**
	R'000	**R/m³**	**R/m³**	**R/m³**
PV Costs	5 260 527	2 723 274	2 290 838	1 946 415
PV Electricity (Included in costs above	244 907	36 949	22 983	15 106
PV Water	8 737 457	1 333 005	830 082	545 638
URV	0.60	2.04	2.76	3.57

Mkomazi Water Project
Dam Site B, Option 1B: Pump and Free Flow through twin 3.0 m dia tunnels

		Civil	M&E	Engineering		Maintenance		Useful life	
Element		**R'000**	**R'000**	**Pre engineer**	**Supervision**	**Civil**	**M&E**	**Civil**	**M&E**
Smithfield Dam		999 000	0	5.00%	10%	0.25%	1%	50	30
Impendle Dam		0	0	5.00%	10%	0.25%	1%	50	30
Smithfield Pump station and pipes and electricity supply (Stage 1)	7,45 m^3/s	0	72 000	5.00%	10%	0.50%	4%	50	30
Smithfield pipes (Stage 2)	7,45 m^3/s	0	72 000	5.00%	10%	0.50%	4%	50	30
Tunnel - Stage 1		2 150 000		5.00%	10%	0.25%	1%	50	30
Tunnel - Stage 2		2 150 000	0	5.00%	10%	0.25%	1%	50	30
Baynesfield Dam Enlargement		0		5.00%	10%	0.25%	1%	50	30
Total	5 443 000	5 299 000	144 000						

Element		**Capital**	**Annual**
		R'000	**R'000**
Admin cost		20 000	1 000
Environmental cost		7 000	1 000
Social cost		7 000	1 000
Electricity variable Stage 1 - max	1442	KW	4 394
Electricity Fixed Stage 1 - max	1442	KW	591
Electricity variable Stage 2 - max	1442	KW	4 394
Electricity Fixed Stage 2 - max	1442	KW	591

Results	**Total**	**6%**	**8%**	**10%**
	R'000	**R/m³**	**R/m³**	**R/m³**
PV Costs	4 838 777	2 494 391	2 099 996	1 786 477
PV Electricity (Included in costs above	244 907	36 949	22 983	15 106
PV Water	8 737 457	1 333 005	830 082	545 638
URV	0.55	1.87	2.53	3.27

OPTION 2A

Mkomazi Water Project
Dam Site A, Option 2A: Pressure Flow through single 4.5 m dia tunnel

		Civil	M&E	Engineering		Maintenance		Useful life	
Element		**R'000**	**R'000**	**Pre engineer**	**Supervision**	**Civil**	**M&E**	**Civil**	**M&E**
Smithfield Dam		1 328 000	0	5.00%	10%	0.25%	1%	50	30
Impendle Dam		0	0	5.00%	10%	0.25%	1%	50	30
Smithfield Pipes (Stage 1)	7,45 m^3/s	5 400	0	5.00%	10%	0.50%	4%	50	30
Smithfield pipes (Stage 2)	7,45 m^3/s	5 400	0	5.00%	10%	0.50%	4%	50	30
Tunnel - Stage 1		2 724 000		5.00%	10%	0.25%	1%	50	30
Tunnel - Stage 2		0		5.00%	10%	0.25%	1%	50	30
Baynesfield Dam Enlargement		0		5.00%	10%	0.25%	1%	50	30
Total	4 062 800	4 062 800	0						

Element		**Capital**	**Annual**
		R'000	**R'000**
Admin cost		20 000	1 000
Environmental cost		7 000	1 000
Social cost		7 000	1 000
Electricity variable Stage 1 - max			
Electricity Fixed Stage 1 - max			
Electricity variable Stage 2 - max			
Electricity Fixed Stage 2 - max			

Results	**Total**	**6%**	**8%**	**10%**
	R'000	**R/m^3**	**R/m^3**	**R/m^3**
PV Costs	5 367 127	3 015 266	2 559 384	2 187 080
PV Electricity (Included in costs above)				
PV Water	8 737 457	1 333 005	830 082	545 638
URV	0.61	2.26	3.08	4.01

Mkomazi Water Project
Dam Site B, Option 2A: Pressure Flow through single 4.5 m dia tunnel

		Civil	M&E	Engineering		Maintenance		Useful life	
Element		**R'000**	**R'000**	**Pre engineer**	**Supervision**	**Civil**	**M&E**	**Civil**	**M&E**
Smithfield Dam		817 000	0	5.00%	10%	0.25%	1%	50	30
Impendle Dam		0	0	5.00%	10%	0.25%	1%	50	30
Tunnel connection (Stage 1)		13 000	0	5.00%	10%	0.50%	4%	50	30
Tunnel connection (Stage 2)		0	0	5.00%	10%	0.50%	4%	50	30
Tunnel - Stage 1		2 724 000		5.00%	10%	0.25%	1%	50	30
Tunnel - Stage 2		0		5.00%	10%	0.25%	1%	50	30
Baynesfield Dam Enlargement		0		5.00%	10%	0.25%	1%	50	30
Total	3 554 000	3 554 000	0						

Element		**Capital**	**Annual**
		R'000	**R'000**
Admin cost		20 000	1 000
Environmental cost		7 000	1 000
Social cost		7 000	1 000
Electricity variable Stage 1 - max			
Electricity Fixed Stage 1 - max			
Electricity variable Stage 2 - max			
Electricity Fixed Stage 2 - max			

Results	**Total**	**6%**	**8%**	**10%**
	R'000	**R/m^3**	**R/m^3**	**R/m^3**
PV Costs	4 722 975	2 647 077	2 246 298	1 919 201
PV Electricity (Included in costs above)				
PV Water	8 737 457	1 333 005	830 082	545 638
URV	0.54	1.99	2.71	3.52

OPTION 2B

Mkomazi Water Project
Dam Site A, Option 2B: Pressure Flow through twin 3.5 m dia tunnels

		Civil	M&E	Engineering		Maintenance		Useful life	
Element		**R'000**	**R'000**	**Pre engineer**	**Supervision**	**Civil**	**M&E**	**Civil**	**M&E**
Smithfield Dam		1 328 000	0	5.00%	10%	0.25%	1%	50	30
Impendle Dam		0	0	5.00%	10%	0.25%	1%	50	30
Smithfield Pipes (Stage 1)	7,45 m^3/s	5 400	0	5.00%	10%	0.50%	4%	50	30
Smithfield pipes (Stage 2)	7,45 m^3/s	5 400	0	5.00%	10%	0.50%	4%	50	30
Tunnel - Stage 1		2 236 000		5.00%	10%	0.25%	1%	50	30
Tunnel - Stage 2		2 236 000		5.00%	10%	0.25%	1%	50	30
Baynesfield Dam Enlargement		0		5.00%	10%	0.25%	1%	50	30
Total	5 810 800	5 810 800	0						

Element		**Capital**	**Annual**
		R'000	**R'000**
Admin cost		20 000	1 000
Environmental cost		7 000	1 000
Social cost		7 000	1 000
Electricity variable Stage 1 - max			
Electricity Fixed Stage 1 - max			
Electricity variable Stage 2 - max			
Electricity Fixed Stage 2 - max			

Results	**Total**	**6%**	**8%**	**10%**
	R'000	**R/m³**	**R/m³**	**R/m³**
PV Costs	5 991 497	2 881 387	2 369 370	1 984 843
PV Electricity (Included in costs above)				
PV Water	8 737 457	1 333 005	830 082	545 638
URV	0.69	2.16	2.85	3.64

Mkomazi Water Project
Dam Site B, Option 2B: Pressure Flow through twin 3.5 m dia tunnels

		Civil	M&E	Engineering		Maintenance		Useful life	
Element		**R'000**	**R'000**	**Pre engineer**	**Supervision**	**Civil**	**M&E**	**Civil**	**M&E**
Smithfield Dam		817 000	0	5.00%	10%	0.25%	1%	50	30
Impendle Dam		0	0	5.00%	10%	0.25%	1%	50	30
Tunnel connection (Stage 1)		13 000	0	5.00%	10%	0.50%	4%	50	30
Tunnel connection (Stage 2)		13 000	0	5.00%	10%	0.50%	4%	50	30
Tunnel - Stage 1		2 236 000		5.00%	10%	0.25%	1%	50	30
Tunnel - Stage 2		2 236 000		5.00%	10%	0.25%	1%	50	30
Baynesfield Dam Enlargement		0		5.00%	10%	0.25%	1%	50	30
Total	5 315 000	5 315 000	0						

Element		**Capital**	**Annual**
		R'000	**R'000**
Admin cost		20 000	1 000
Environmental cost		7 000	1 000
Social cost		7 000	1 000
Electricity variable Stage 1 - max			
Electricity Fixed Stage 1 - max			
Electricity variable Stage 2 - max			
Electricity Fixed Stage 2 - max			

Results	**Total**	**6%**	**8%**	**10%**
	R'000	**R/m³**	**R/m³**	**R/m³**
PV Costs	5 355 210	2 514 431	2 056 896	1 717 266
PV Electricity (Included in costs above)				
PV Water	8 737 457	1 333 005	830 082	545 638
URV	0.61	1.89	2.48	3.15

OPTION 3

Mkomazi Water Project
Dam Site A, Option 3: Pump to hill and Free Flow through single 3.0 m dia tunnel

		Civil	M&E	Engineering		Maintenance		Useful life	
Element		**R'000**	**R'000**	**Pre engineer**	**Supervision**	**Civil**	**M&E**	**Civil**	**M&E**
Smithfield Dam		1 334 000	0	5.00%	10%	0.25%	1%	50	30
Impendle Dam		0	0	5.00%	10%	0.25%	1%	50	30
Smithfield Pump station and pipes and electricity supply (Stage 1)	7,45 m^3/s	178 900	182 000	5.00%	10%	0.50%	4%	50	30
Smithfield pipes (Stage 2)	7,45 m^3/s	178 900	182 000	5.00%	10%	0.50%	4%	50	30
Tunnel - Stage 1		1 600 000		5.00%	10%	0.25%	1%	50	30
Tunnel - Stage 2		0	0	5.00%	10%	0.25%	1%	50	30
Baynesfield Dam Enlargement		0		5.00%	10%	0.25%	1%	50	30
Total	3 655 800	3 291 800	364 000						

Element		**Capital**	**Annual**
		R'000	**R'000**
Admin cost		20 000	1 000
Environmental cost		7 000	1 000
Social cost		7 000	1 000
Electricity variable Stage 1 - max	22407	KW	68 261
Electricity Fixed Stage 1 - max	22407	KW	8 355
Electricity variable Stage 2 - max	22407	KW	68 261
Electricity Fixed Stage 2 - max	22407	KW	8 355

Results	**Total**	**6%**	**8%**	**10%**
	R'000	**R/m^3**	**R/m^3**	**R/m^3**
PV Costs	9 006 620	3 132 110	2 490 343	2 036 582
PV Electricity (Included in costs above	3 747 622	565 879	352 028	231 372
PV Water	8 737 457	1 333 005	830 082	545 638
URV	1.03	2.35	3.00	3.73

Mkomazi Water Project
Dam Site B, Option 3: Pump to hill and Free Flow through single 3.0 m dia tunnel

		Civil	M&E	Engineering		Maintenance		Useful life	
Element		**R'000**	**R'000**	**Pre engineer**	**Supervision**	**Civil**	**M&E**	**Civil**	**M&E**
Smithfield Dam		999 000	0	5.00%	10%	0.25%	1%	50	30
Impendle Dam		0	0	5.00%	10%	0.25%	1%	50	30
Smithfield Pump station and pipes and electricity supply (Stage 1)	7,45 m^3/s	178 900	182 000	5.00%	10%	0.50%	4%	50	30
Smithfield pipes (Stage 2)	7,45 m^3/s	178 900	182 000	5.00%	10%	0.50%	4%	50	30
Tunnel - Stage 1		1 600 000		5.00%	10%	0.25%	1%	50	30
Tunnel - Stage 2		0	0	5.00%	10%	0.25%	1%	50	30
Baynesfield Dam Enlargement		0		5.00%	10%	0.25%	1%	50	30
Total	3 320 800	2 956 800	364 000						

Element		**Capital**	**Annual**
		R'000	**R'000**
Admin cost		20 000	1 000
Environmental cost		7 000	1 000
Social cost		7 000	1 000
Electricity variable Stage 1 - max	23080	KW	70 313
Electricity Fixed Stage 1 - max	23080	KW	8 605
Electricity variable Stage 2 - max	23080	KW	70 313
Electricity Fixed Stage 2 - max	23080	KW	8 605

Results	**Total**	**6%**	**8%**	**10%**
	R'000	**R/m^3**	**R/m^3**	**R/m^3**
PV Costs	8 692 020	2 904 529	2 292 907	1 865 561
PV Electricity (Included in costs above)	3 860 147	582 871	362 599	238 320
PV Water	8 737 457	1 333 005	830 082	545 638
URV	0.99	2.18	2.76	3.42