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

HYDROPOWER ASSESSMENT REPORT

FINAL

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Author:	***JH Schroder, CR Fynn***
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CONSULTANTS: AECOM (BKS*) in association with AGES, MM&A and Urban-Econ.

Approved for ***Consultants****:*

DB Badenhorst	***HS Pieterse***
Task Leader	*Study Leader*

DEPARTMENT OF WATER AFFAIRS (DWA): Directorate: Options Analysis

Approved for DWA:

K Bester	***LS Mabuda***
Chief Engineer: Options Analysis (East)	*Chief Director: Integrated Water Resource Planning*

* *BKS (Pty) Ltd was acquired by AECOM Technology Corporation on 1 November 2012*

Prepared by:

AECOM

AECOM SA (Pty) Ltd
PO Box 3173
Pretoria
0001

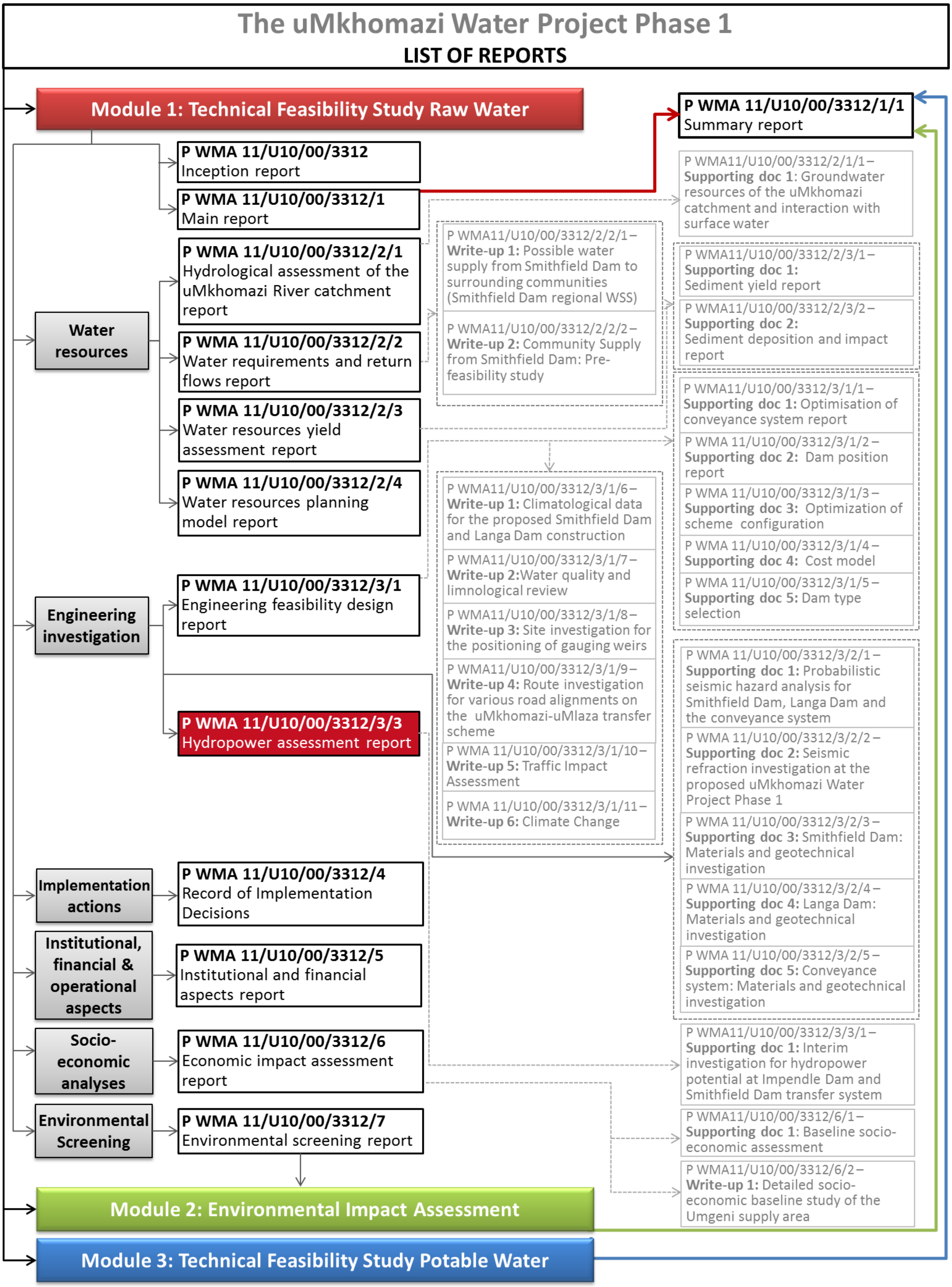
In association with:

Africa Geo-Environmental Services | **Mogoba Maphuthi and Associates** | **Urban-Econ**

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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Executive summary

This report provides a detailed description of the assessment undertaken to determine the feasibility of hydropower generation as a secondary benefit to the uMkhomazi Water Project (uMWP). It focuses on the hydropower potential of phase 1 of the uMWP (Smithfield Dam). The primary objectives of this assessment are to:

- *Determine the possible sites for hydropower generation, and the associated magnitude and reliability of such power at those sites (**Sections 2** and **3**);*
- *Perform a preliminary design of the hydro-mechanical, civil and transmission line components needed to accommodate the potential power generation (**Section 4**);*
- *Carry out a preliminary cost estimate of the above-mentioned hydropower scheme components (**Section 5**); and*
- *Ascertain the economic sustainability of such a scheme (**Section 6**).*

POSSIBLE SITES AND ENERGY YIELD

Two potential sites were identified; the first being at the Baynesfield water treatment works (WTW) as part of the conveyance structure from Smithfield Dam to the WTW, and the second just downstream of Smithfield Dam. At the first site, known as Baynesfield Hydropower Plant (HPP), power would be generated by water transfers through the conveyance structure. At the second site, known as Smithfield Dam Hydropower Plant, power would be generated by spills and releases from the dam.

The Water Resource Planning Model (WRPM) was used to accurately simulate the future dam levels and flow volumes for a number of stochastically generated sequences. Each variable was illustrated in the form of box plots indicating key probabilities, and this output was also arranged to produce probability distribution curves for each variable. Based on these plots, separate approaches were taken for determining the hydropower potential at each site.

BAYNESFIELD HPP

The box plots of Smithfield Dam's water levels showed the seasonal variation and annual trends, which is applicable to both sites. For Baynesfield HPP, the box plots of flows showed the increasing transfer volumes over the project period, as well as the seasonal variation, both driven by water requirements. Calculations were performed using the time series of data of these key probabilities of head and flow, which resulted *in a time series of power potential for key probabilities. These curves showed that there is a general increase in the hydropower potential over the project period, due to the increasing transfer volumes. The average potential increases from about 1.5 MW to 2.5 MW over the period, displayed in **Figure i**. For a 95% assurance of supply, a potential of approximately 1.0 MW is available at the beginning of the project period, which increases to approximately 1.8 MW by 2043.*

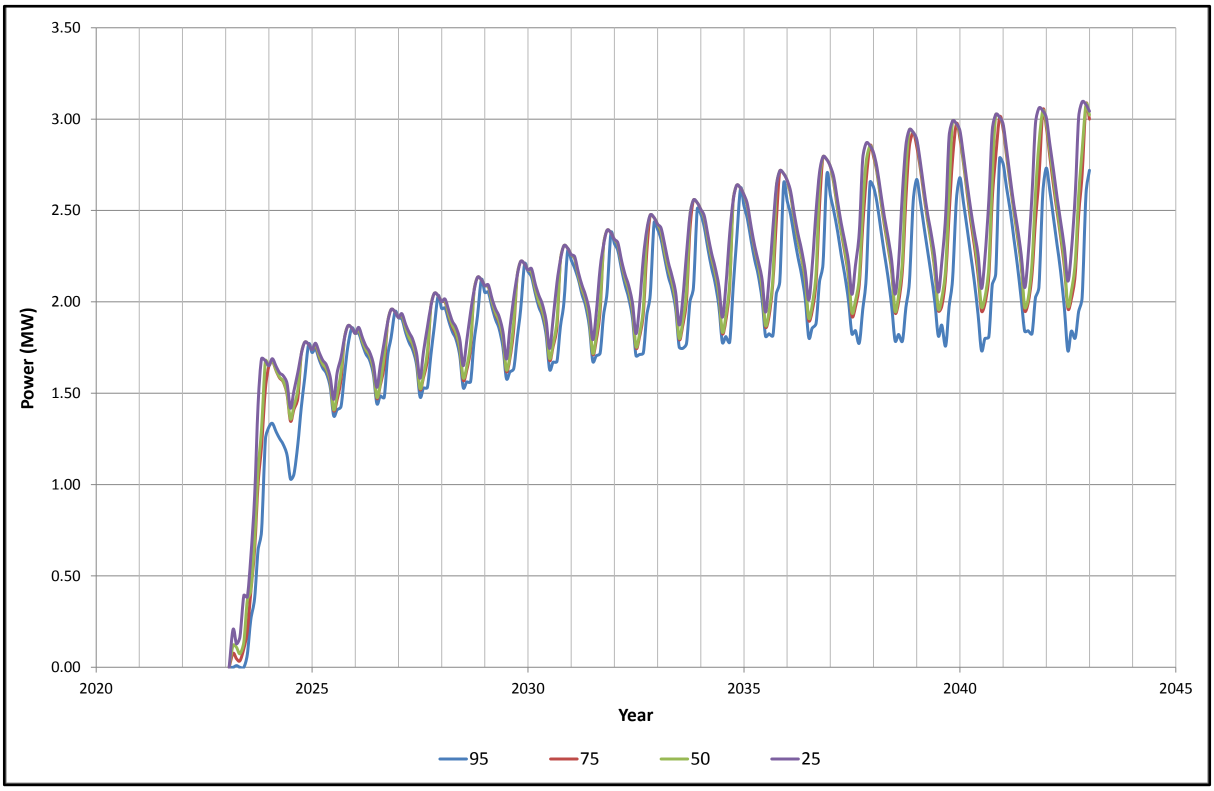

Figure i: ***Hydropower potential at the proposed hydropower plant at Baynesfield using the transferred flows***

SMITHFIELD DAM HPP

*For Smithfield Dam HPP, the box plots of flows (comprising spills and ecological water requirement releases) show an extremely large range of flow volumes. A clear seasonal trend can be seen, but there is no noticeable change over time. The time series of stochastic data was therefore not considered in this instance, as it is only used to monitor changes over time. Rather, a flow duration curve (or probability distribution curve) was developed based on the historic record. This curve plots a range of flows against the probability of their occurrence. Using the probability distribution curve for flows, a similar graph for hydropower potential was made, and is shown in **Figure ii**. It was found that an average power potential of approximately 2.0 MW could be produced throughout the project period, and that for a high assurance of 95% 0.5 MW could potentially be produced.*

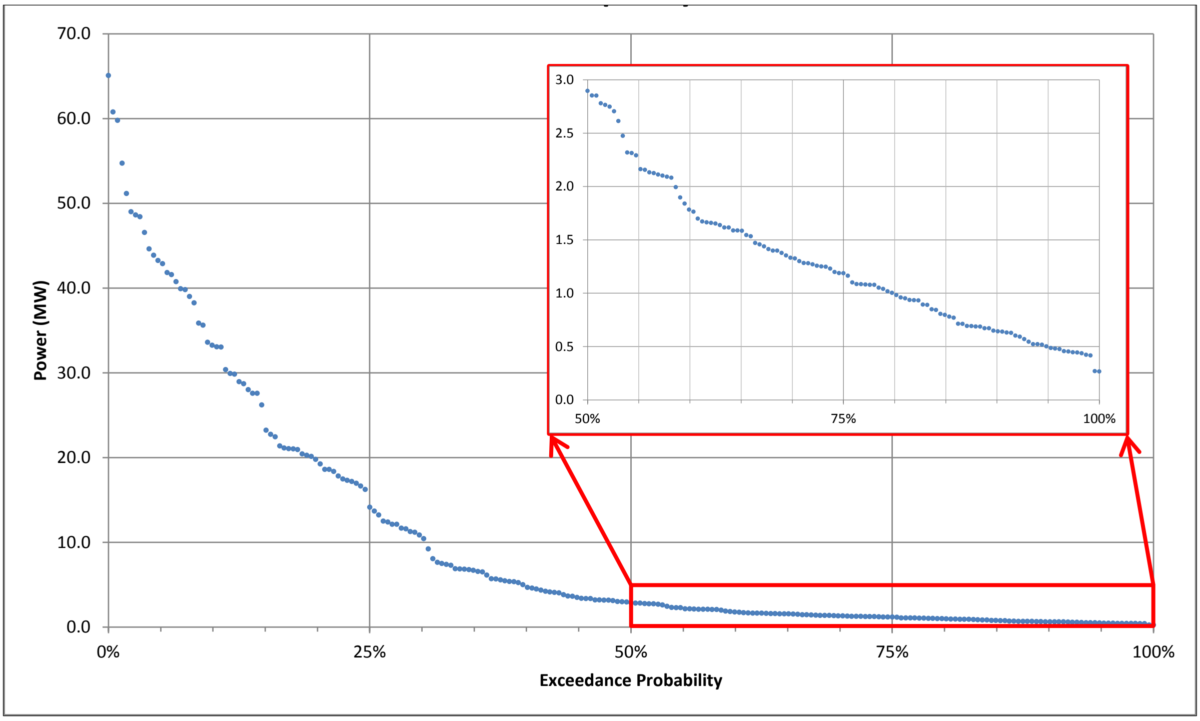

Figure ii: ***Probability distribution curve for power potential at Smithfield Dam HPP based on historic record***

CONCEPTUAL DESIGN OF HYDROPOWER PLANTS

Having calculated the hydropower potential at each of the sites, the conceptual design of the HPPs was done. This entailed the design of turbines, including design for water hammer effects; the layout of the HPPs and the design of the power transmission.

BAYNESFIELD HPP

At Baynesfield HPP, the rated point was calculated as 8.65 m³/s flow and 41.7 m net head, with 3 MW power potential. A Francis turbine was selected, being suitable to these operating conditions. The turbine configuration decided on was a single turbine capable of producing the full load of 3 MW, for the following reasons:

- *The maximum power is reached in a relatively short time period of 20 years from commencement*
- *A single turbine is more efficient than two for all flows, and installation is more cost-effective*

In order to accommodate the effects of water hammer, and because of the long penstock leading up to the turbine, a bypass to the turbine would be needed, in addition to a slow closure of the turbine. This will limit speed and pressure rise. In addition, a flywheel would also be needed to limit the increase of speed.

The design of power transmission infrastructure is dependent on the usage of the power. Due to the existence of infrastructure for providing power to the site for operation of Baynesfield WTW, as well as during its construction, the main additional requirement would be nominal infrastructure to "clean" the generated power for wheeling into the grid or for direct use by the WTW. In addition, short underground or overhead cables would be needed, for about 50 m.

The alternatives for the HPP at this site were as follows:

- *Baynesfield HPP alternative 1: Power wheeled into national grid for use at Baynesfield WTW*
- *Baynesfield HPP alternative 2: Power supplied directly into Baynesfield WTW with supply from the national grid as backup*

However, the infrastructure costs for these two options would effectively be the same, differing mainly in institutional arrangements.

SMITHFIELD DAM HPP

At Smithfield Dam HPP, two power generation alternatives were considered, with turbines rated 0.5 and 2.6 MW. For the latter alternative, this turbine size was used in order to capture the peak flows that will be experienced at this site. The rated point for 0.5 MW was calculated as 1.1 m^3/s flow and 55.5 m net head; and for 2.6 MW was 5.0 m^3/s flow and 64.0 m net head. A Francis turbine was also suitable for these operating conditions and was thus selected. Because the power generation potential will not change significantly over time, single turbines to meet the full loads were selected. Because of the short penstock length, no bypass pipe would be needed to limit water hammer, and the turbine could have a short closure time with acceptable pressure rise. A flywheel would be required to limit speed rise.

Additional variations will need to be made to the dam's outlet works in order to accommodate the potential powerhouse. This would include additional pipe work, as well as new and upgraded valves.

As with Baynesfield HPP, power transmission infrastructure will already be in place, and so limited additional infrastructure would be required. Approximately 500 m of overhead or underground cables would be needed for transmission of the power.

The alternatives for the HPP at this site were as follows:

- *Smithfield Dam HPP alternative 1: Power wheeled into national grid for operation and maintenance of Smithfield Dam (0.5 MW turbine)*
- *Smithfield Dam HPP alternative 2: Power wheeled into national grid for operation and maintenance of Smithfield Dam (2.6 MW turbine)*
- *Smithfield Dam HPP alternative 3: Power supplied directly to Smithfield Dam operation and maintenance facilities*

COST ESTIMATES

*The capital and O&M costs are summarised in **Table i** below. The capital costs are split between civil works, hydro-mechanical, and power transmission.*

Power transmission costs for Baynesfield HPP alternatives 1 and 2 have been assumed to be the same, since both options would require power to be "cleaned" before use. This means that the total costs for both options would be the same, differing only in institutional arrangements, and therefore only a single option is described further.

Costs for Smithfield Dam HPP alternative 3 are significantly lower than alternatives 1 and 2 due to its relatively small scale. Should this alternative be pursued further, detailed investigations into the exact infrastructure requirements and the costs thereof must be done.

Table i: Summary of capital and O&M costs

HPP alternative	Capital cost (R'000)				Annual O&M cost (R'000)
	Civil works	Hydro-mechanical	Transmission line	Total	
Baynesfield HPP alternative 1: Power wheeled into national grid for use at WTW	*3 748*	*36 968*	*2 075*	***42 791***	***1 571***
Smithfield Dam HPP alternative 1: Power wheeled into national grid for operation of dam (0.5 MW)	*2 542*	*12 647*	*2 750*	***17 939***	***622***
Smithfield Dam HPP alternative 2: Power wheeled into national grid for operation of dam (2.6 MW)	*3 748*	*30 082*	*2 750*	***36 580***	***1 323***

EVALUATION OF ECONOMIC SUSTAINABILITY

*The process whereby energy is injected into the national grid and sold to a third party is known as wheeling. Because this process does not reduce the required network capacity, charges are applicable for the delivery of the energy. However, a financial reconciliation is given for wheeled energy bought. An example of the potential revenue for wheeling power is given in **Table ii**. The revenue for only one energy value is given because available energy varies each year, but the comprehensive calculations showing revenue for each year are contained in **Appendix D**.*

Table ii: Revenue for wheeled energy

Item	*Value*
Hydropower potential (MW)	*0.50*
Maximum achievable annual wheeled savings (R'000)	*2 069*
Annual charges payable by generator (R'000)	*86*
Net annual revenue potential (R'000)	***1 983***
Average value per kWh generated (c/kWh)	*45.28*

*For direct supply of power to either Baynesfield HPP or the local dam operation facilities at Smithfield Dam HPP, a similar method of calculating the revenue would be used, with the exception that generator charges would not be applicable. An example of this potential revenue is shown in **Table iii**, for direct supply to Smithfield Dam's operation facilities.*

Table iii: Revenue for power generated for direct consumption

Item	*Value*
Hydropower potential (kW)	*30*
Net annual revenue potential (R'000)	***124***
Average value per kWh generated (c/kWh)	*47.24*

*Based on the costs and potential revenue associated with the HPP alternatives, net present values (NPVs) were determined for the life-cycle of the project, and are shown in **Table iv** below.*

Table iv: NPVs for HPP alternatives

HPP alternative	Net overall benefit at certain discount rate (R'000)		
	6%	8%	10%
Baynesfield HPP alternative 1: Power wheeled into national grid for use at WTW	*22 605*	*10 366*	*3 666*
Smithfield Dam HPP alternative 1: Power wheeled into national grid for operation of dam (0.5 MW)	*443*	*-1 213*	*-1 970*
Smithfield Dam HPP alternative 2: Power wheeled into national grid for operation of dam (2.6 MW)	*31 896*	*18 553*	*10 638*

The above table shows that wheeling into the grid is feasible at both sites; however, for Smithfield Dam HPP, it will only be feasible for higher hydropower generation. Two points should be noted:

- *HPPs can be implemented at both sites, as the water which generates the power is independent for each site.*
- *Two options require further investigation, which may also be feasible (direct supply of power into Baynesfield WTW or for operation and maintenance of Smithfield Dam).*

CONCLUSIONS AND RECOMMENDATIONS

Based on the assessment of the economic feasibility of the HPP alternatives, it was found that wheeling power into the grid is a feasible option for both Baynesfield HPP and Smithfield Dam HPP. For the latter HPP, the large turbine option will need to be used to ensure sustainability. These options should be discussed with Umgeni Water to determine whether they would be interested in such an arrangement, and should also be confirmed with Eskom.

Two options requiring further investigation into the infrastructure requirements and costs are: direct supply of power into Baynesfield WTW, and direct supply of power to the operation and maintenance of Smithfield Dam. If they are found to be feasible, they should also be discussed with the relevant institutions, including Umgeni Water, eThekwini Municipality and Eskom.

Further investigations should also be done to identify parties that would be interested in linking the scheme to a renewable energy program for small hydropower schemes. This arrangement should also be discussed with Eskom.

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LIST OF ABBREVIATIONS

BKS	BKS (Pty) Ltd
D:NWRP	Directorate: National Water Resource Planning
DM	district municipality
DWA	Department of Water Affairs
DWS	Department of Water and Sanitation
HPP	hydropower plant
KZN	KwaZulu-Natal
LM	local municipality
MAR	mean annual run-off
MMA	Mogoba Maphuthi and Associates
MMTS	Mooi Mgeni Transfer Scheme
MOL	minimum operating level
O&M	operation and maintenance
RSA	Republic of South Africa
uMWP	uMkhomazi Water Project
uMWP-1	uMkhomazi Water Project – Phase 1
uMWP-2	uMkhomazi Water Project – Phase 2
VAT	value added tax
WSS	water supply system
WTW	water treatment works

LIST OF UNITS

g	gravitational acceleration
H	head
h_f	friction loss
kℓ	kiloliter
ℓ/c/d	liter per capita per day
m^3	cubic meter
P	power
Q	flow
η	turbine efficiency
ρ	density

1 INTRODUCTION

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.

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

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

1.1 BACKGROUND TO THE PROJECT

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

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

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

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

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

The DWA aims to have this scheme implemented by 2023.

1.2 OBJECTIVE OF THE STUDY

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

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

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

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

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

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

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

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

1.3 STUDY AREA

The study focus and key objective is related to the feasibility investigation of the Smithfield Dam and related raw water conveyance infrastructure. However, this is a multi-disciplinary project with the study area defined as the uMkhomazi River catchment, stretching to the north to include the uMngeni River catchment, refer to **Figure 1.1**. The various tasks have specific focus area, defined as:

- Water Resources: uMkhomazi and Mgeni River catchments;
- Water requirements: water users in the Mgeni System and the uMkhomazi River catchment;
- Engineering Investigations: proposed dams at Impendle (only for costing purposes) and Smithfield, and the raw water conveyance infrastructure

corridor between Smithfield Dam and the Water Treatment Plant of Umgeni Water;

- Environmental screening as input for the Environmental Impact Assessment; and
- Socio-economic impact assessment: regional, provincial (KwaZulu-Natal (KZN)) and national.

1.4 SCOPE OF THIS REPORT

Although the proposed uMWP is planned for water supply, with government's focus on clean and renewable energy, there will be potential to generate hydropower while transferring or releasing water from the dams in the uMkhomazi. For the purposes of determining the hydropower potential of the uMWP, a hydropower assessment task was included in this Feasibility Study.

The purpose of this report is primarily to present the possible hydropower that can be generated as a secondary benefit to the uMWP (particularly that connected to phase 1 Smithfield Dam), and how economically feasible the addition of the hydropower infrastructure would be. However, the possibility of developing a part of the uMWP as a hydropower oriented scheme was briefly explored. The report also presents the approach, assumptions, and calculations used to determine this hydropower potential.

A detailed assessment of the hydropower potential of Impendle Dam (phase 2) has already been undertaken and is a supporting document to this report. For this reason, it is not discussed in detail in this report.

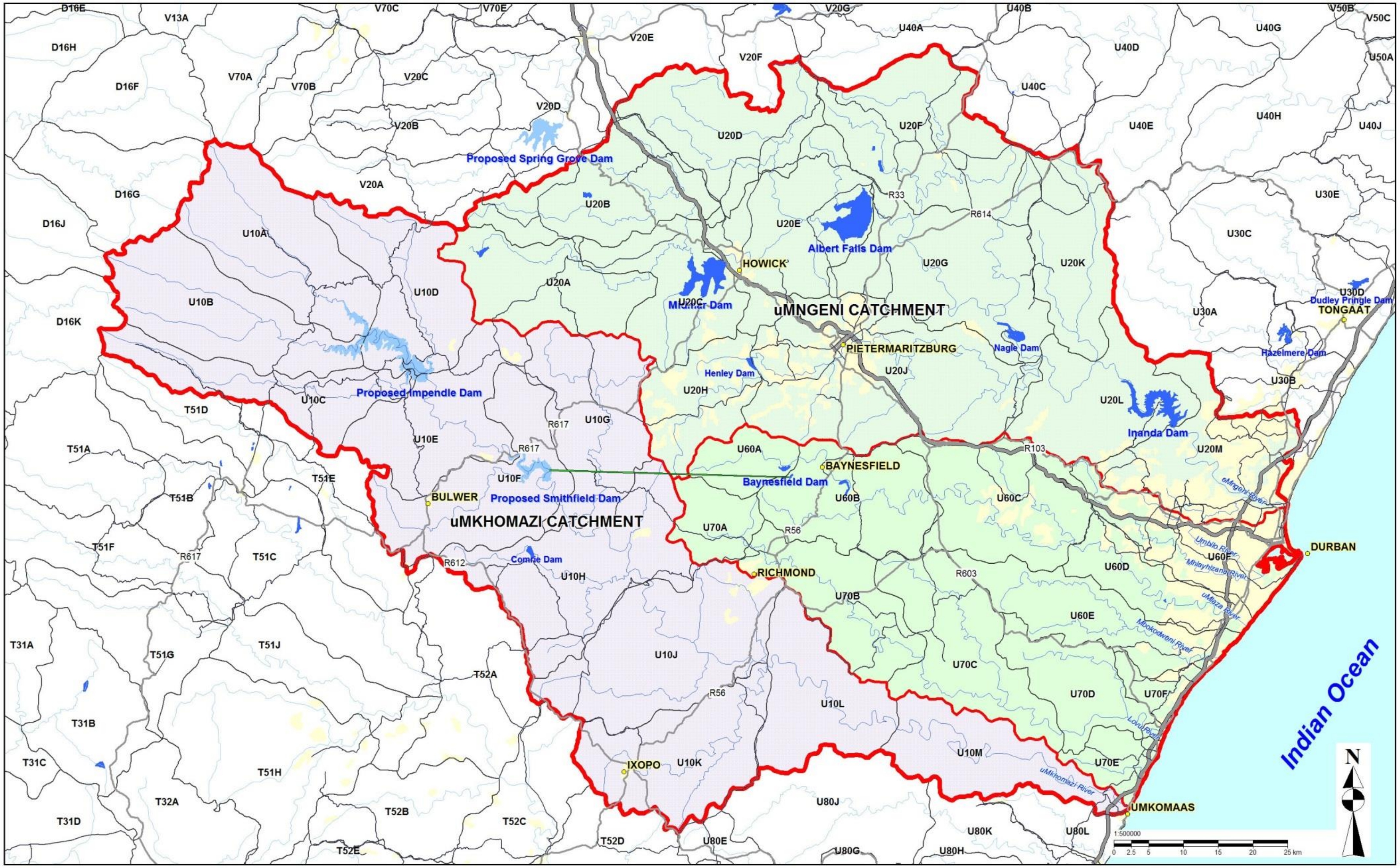

Figure 1.1: Locality map: study area of the uMWP

2 INTRODUCTION TO HYDROPOWER ASSESSMENT

2.1 GENERAL

Due to the large size of dams identified in the uMkhomazi to store water for transfer to the Mgeni Water Supply System (WSS), as well as the predicted volumes and reliability of flows of water both through the tunnel and below the dam wall, the potential exists for coupling hydropower to the uMWP. With the international push for green energy and the situation South Africa finds itself in with regards to energy generation capacity, the ability to couple hydropower to a water supply scheme is attractive.

Part of this hydropower task of the Feasibility Study was to identify and assess the possible locations for hydropower generation and then to explore the quantity and viability of hydropower generation. This report focusses on the hydropower generation at Baynesfield WTW and Smithfield Dam.

This report will discuss in detail the following components of the hydropower investigation:

- the energy yield;
- conceptual design; and
- cost estimates.

2.2 SELECTED SCHEME LAYOUT

Although the focus of the Feasibility Study was on the first phase of the uMWP, namely Smithfield Dam, the water resources and hydropower assessment required phase 2 (Impendle Dam) to also be included in the analyses, which was undertaken and is described in the *Interim Investigation for Hydropower Potential at Impendle Dam and Smithfield Dam Transfer System (Hydropower Assessment Report: Supporting Document 1 (P WMA 11/U10/00/3312/3/3/1))*. There are two potential hydropower generation locations linked to Smithfield Dam and the transfer of water, and one site linked to Impendle Dam. All potential hydropower plant (HPP) locations are shown schematically in **Figure 2.1**.

Apart from the potential sites for generating hydropower, the potential use for the power generated will also need to be explored. This is because the identified use for the power has a significant bearing on the income that can be received for the power, or on the savings in electricity costs, should the power be used directly to substitute an existing Eskom source. The potential uses for the power are discussed further in **Section 6**, once the amount of power and the sustainability thereof that can be generated is verified.

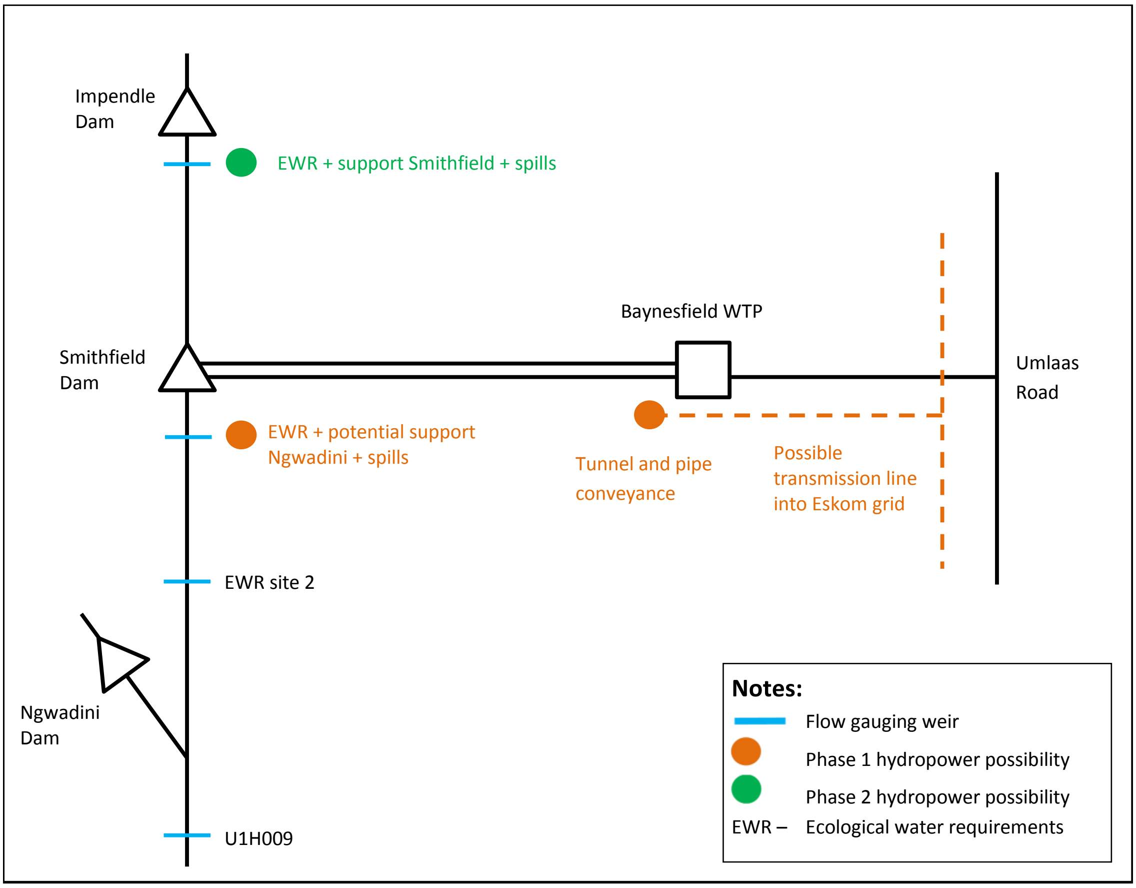

Figure 2.1: HPP layout schematic

2.3 uMWP-1 HYDROPOWER PLANTS

The first potential HPP location is on the conveyance structure (tunnel and pipeline) just upstream of the proposed Baynesfield water treatment works (WTW). This plant is called the Baynesfield Hydropower Plant. This hydropower could be generated when the dam level is above the minimum operating level (MOL) and there is excess head. The flow through this potential hydropower plant would be associated with the water transferred and would be regular and reliable.

The second location is just below the Smithfield Dam, where potential hydropower could be generated using the releases and spills of water. These flows/releases from Smithfield Dam include:

- Releases for the ecological reserve below the dam.
- Spills, where the volume is suitable for the chosen turbine flow capacity.
- Potential releases to augment the proposed Ngwadini Dam.

This plant is called the Smithfield Dam Hydropower Plant.

3 ENERGY YIELD

3.1 HYDROLOGY AND WATER TRANSFERS

The flows available for the generation of hydropower are one of the biggest limitations, particularly in sub-Saharan Africa where river flows are seasonal and variable. The hydrology of the uMkhomazi River has been updated as part of the Feasibility Report and is discussed in detail in the *Hydrological Assessment of the uMkhomazi River Catchment* (P WMA 11/U10/00/3312/2/1). In addition, the yield assessment of the dam is dealt with in the *Water Resources Yield Assessment Report* (P WMA 11/U10/00/3312/2/3).

In summary, the natural runoff at the phase 1 and 2 sites of the uMWP, as well as the yields at a 99% assurance of supply, are presented in **Table 3.1**. The figures given for phase 2 are based on the scenario of Impendle Dam being a 1 MAR capacity dam. The yield for phase 2 in 2020 was not included, as it is only likely to be developed in the long term for water supply (i.e. approximately 2050). The decrease in yield from 2020 to 2050 is due to upstream developments such as forestry and irrigation.

Table 3.1: Summary of hydrology for uMWP phases 1 and 2

Phase	Mean Annual Runoff (MAR) (million m^3/a)	Yield in 2020 (million m^3/a)	Yield in 2050 (million m^3/a)
Phase 1: Smithfield Dam	725.9	240	220
Phase 2 (Smithfield and Impendle Dams)	571.4 (Impendle) 154.5 (Smithfield)	-	347

The transfer volume from Smithfield Dam will be dictated by the augmentation requirements of the Mgeni WSS. A first order estimate of the projected growing transfer volume of water from the uMWP (phase 1) to the Mgeni is shown in **Figure 3.1**. The water requirements of the Mgeni WSS and associated transfer volumes needed for augmenting are discussed in further detail in the *Water requirements and return flows report* (P WMA 11/U10/00/3312/2/2).

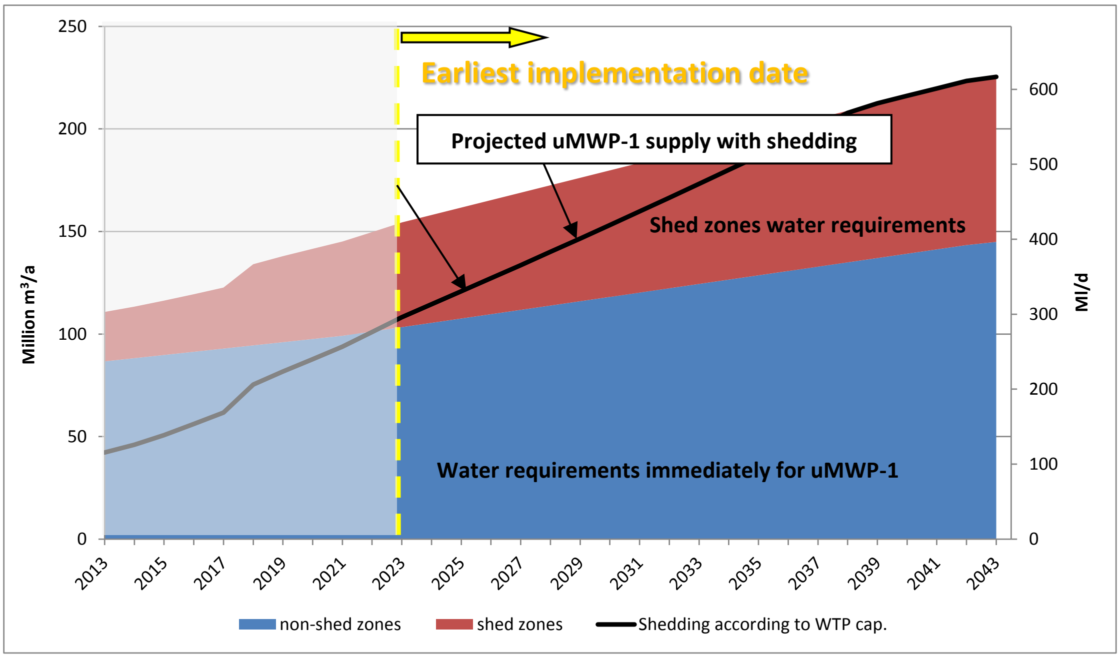

Figure 3.1: Water transfer requirements for uMWP-1

3.2 HYDROPOWER POTENTIAL

3.2.1 Required parameters

The equation to calculate the hydropower potential at any particular site is given below:

$$P = \rho \times g \times \eta \times Q \times H \qquad \text{Equation 3-1}$$

Where:

P = Power

ρ = Density of water

g = Gravitational acceleration

η = Turbine efficiency

Q = Flow rate

H = Head

Gravitational acceleration is dependent on the temperature at the site location, but for practical purposes was assumed to be 9.79 m/s^2. The turbine efficiency varies depending on the turbine and operating conditions, but an assumption of 85% was used for initial hydropower generation calculations. Flow rate and head are parameters that fluctuate over time, and were therefore modelled accordingly. This is discussed in detail in **Sections 3.2.2** and **3.2.3**.

3.2.2 Varying parameters

The variance of the flow rate and head are mainly governed by two factors, namely the seasonal weather variation and the changing water requirements.

Seasonal weather variation: South Africa's annual weather pattern consists of a wet season and a dry season, peaking in December/January and June/July respectively. During the wet season, the water level of Smithfield Dam will be higher, meaning a greater available head for hydropower. This increased water level also means that spills will occur more frequently in the wet season. The opposite will be true for the dry season.

Changing water requirements: The transfer requirements of the uMWP-1 will change over time as water requirements of the identified supply areas grow over time, and as additional areas are added to the uMWP-1. These increasing abstractions from Smithfield dam through the uMWP-1 conveyance system will cause the water level of the dam to trend lower, and this fluctuating water level will alter the available head for hydropower. This adds a further variable to the hydrological variability of the system.

In addition to the variance in all of the above-mentioned cases, whenever the flow rate changes, the friction losses in the conveyance system are also affected. These losses influence the available head for hydropower.

Due to these varying parameters, a dynamic scenario was needed to accurately determine the hydropower potential. The following section comprehensively explains the chosen methodology.

3.2.3 Methodology

To accurately capture the future scenario as best as possible, and with the current understanding of the proposed scheme and scheduled implementation thereof, the Water Resources Planning Model (WRPM) was used to simulate the future transfer requirements of the integrated uMkhomazi and Mgeni River systems. From this dynamic simulation, potential of hydropower that could be generated by Smithfield Dam and its conveyance structure (tunnel and steel pipe) was calculated. The chosen future scenario simulated with the WRPM model included the following key dates and information:

- Smithfield Dam with an FSL of 930 masl, to be implemented by 2023;
- Growing water requirements and associated transfer needs based on the Umgeni Water Sept 2011 scenario for the Mgeni WSS, updated with the preferred planning scenario for the uMWP supply area.
- Transfer volumes are based on the transfer of the outer West Supply area supplied by Midmar onto the uMWP, and shedding of the identified shed zones off Durban Heights WTW onto the uMWP, as the operational capacity of Durban Heights WTW is reached.
- Ecological water requirements (EWR) and associated releases are based on EWR site 1b.
- No releases to the possible Ngwadini off-channel storage Dam proposed on the lower uMkhomazi River. This will provide a conservative estimate of the potential power that can be generated below the dam wall.

The WRPM was used to simulate the projected future for a range of possible hydrological scenarios captured in 201 stochastically generated flow sequences, each 30 years long. These 201 stochastic flow sequences create a range of outputs such as dam levels, release and spill volumes and water available for transfer. These outputs, once ranked, create a probability distribution for each month for each output variable that varies over time. These probability distributions provide a risk based assessment of the elements that are an input into the hydropower estimates, and can be used to assist in choosing the most suitable flow and head ranges for the turbines at each site.

3.2.4 Calculations and results

The probabilistic distributions for each month in the 30 year simulated period are presented in the form of box and whisker plots. The box-and-whisker plots (or box plots) for Smithfield Dam storage volumes and the transfer volumes in the tunnel are shown in **Figure 3.2** and **Figure 3.3** respectively.

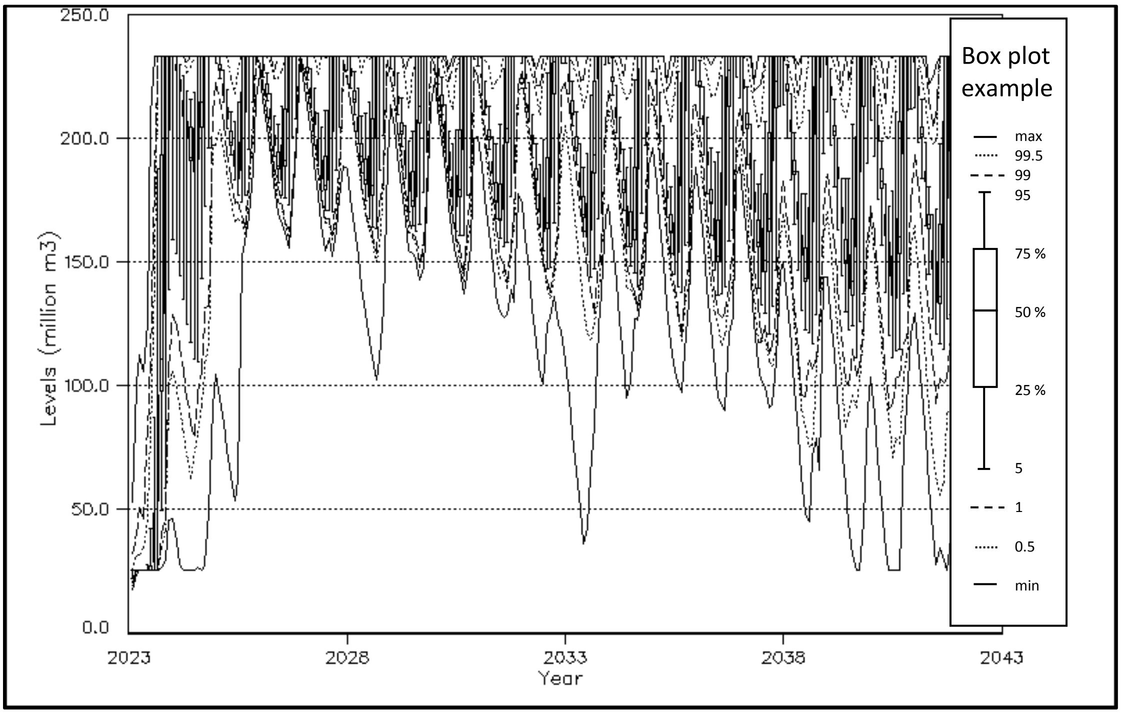

Figure 3.2: Box plots of projected storage volumes in Smithfield Dam

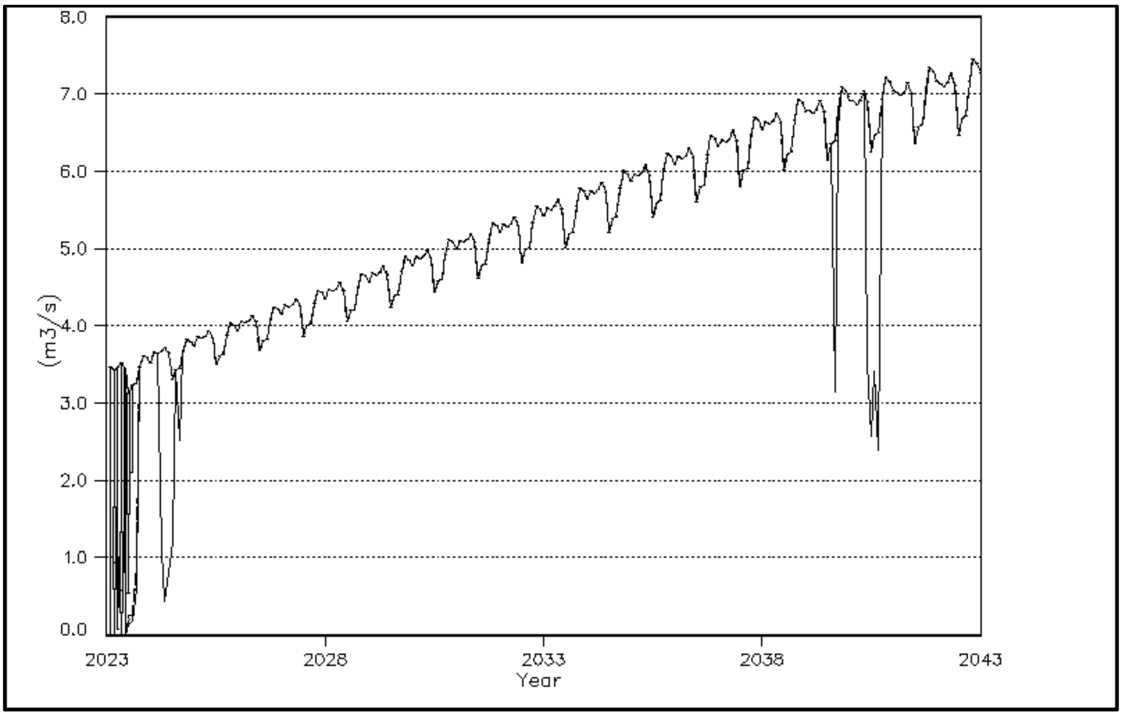

Figure 3.3: Box plots of transfer volumes from Smithfield Dam to the proposed Baynesfield WTW

To simplify the interpretation of the box plots, key probabilities were extracted for the dam storage, and these were converted into dam levels. The key probabilities used were 25, 50, 75 and 95%. This is plotted in **Figure 3.4**. The same key probabilities are plotted for the transfer volumes to the WTW. These are plotted in **Figure 3.5**.

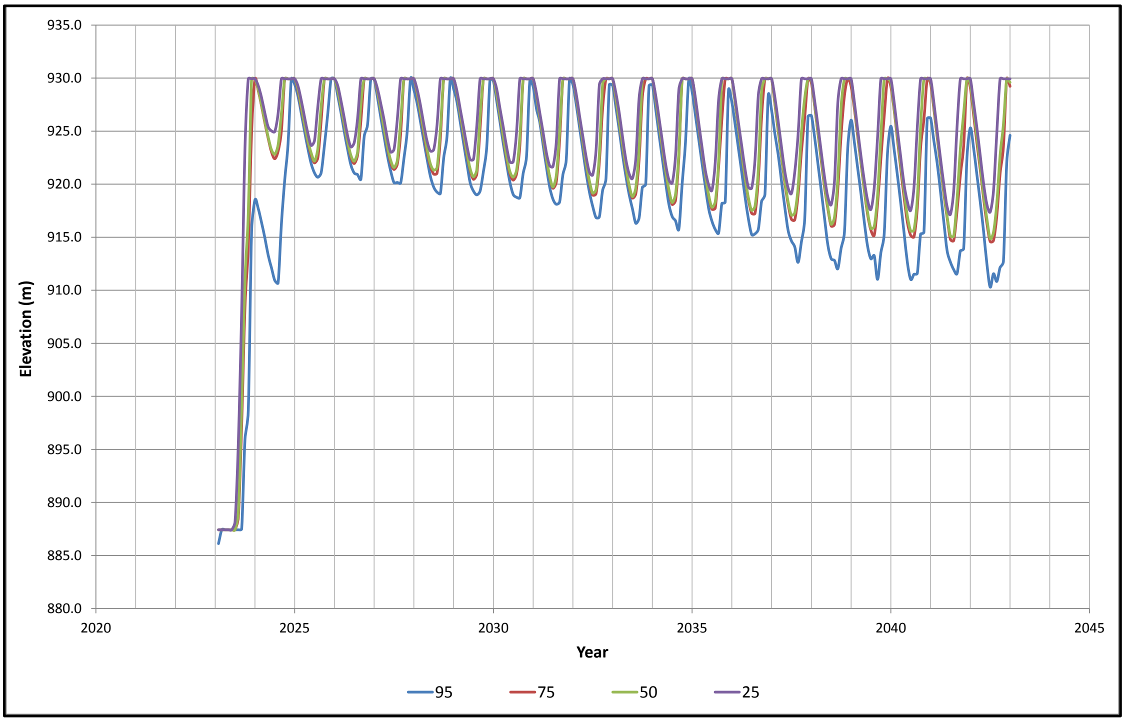

Figure 3.4: Smithfield Dam levels trajectories for selected probability levels

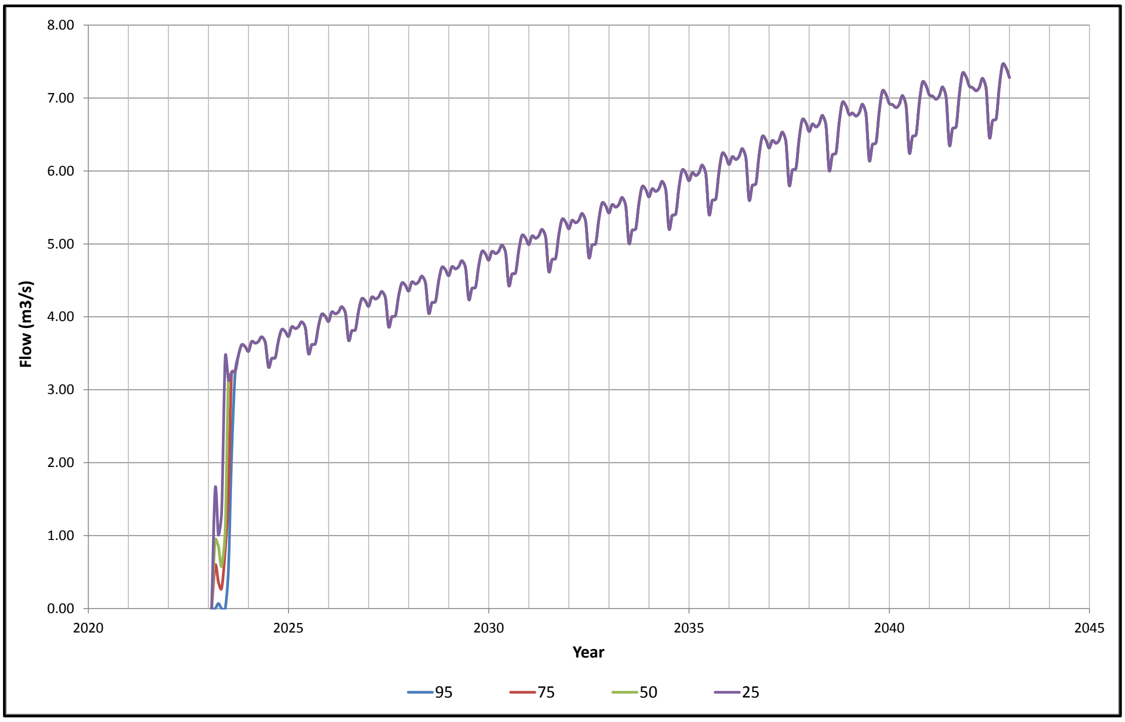

Figure 3.5: Transfer volumes projected from Smithfield Dam to Baynesfield WTW

From **Figure 3.4**, both the seasonal variation and annual trends can be seen. As the dam storage capacity is only about a 30% of the mean annual runoff, the dam has a high probability of spilling in the wet summer months. The probability of the dam being full and spilling each year does reduce as the projected utilization of the dam increases over time (see **Figure 3.3** for increasing abstraction volumes).

Focusing on the 25, 50 and 75 percentile dam level trajectories, which capture the most likely range, there appears to be a trend of decreasing levels over time (see **Figure 3.6**). This trend shows a fairly limited reduction in dam levels over the roughly 20 year period with an average level in the dam of approximately 924 masl.

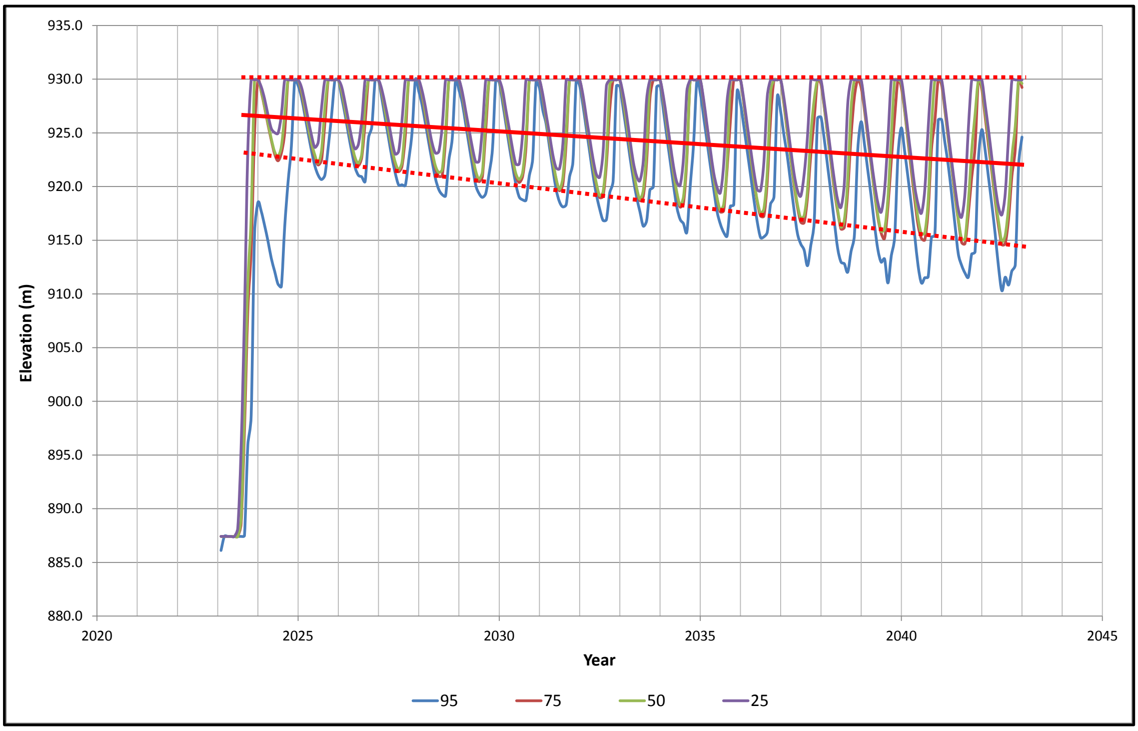

Figure 3.6: Trends in dam level trajectories for Smithfield Dam

3.2.5 Hydropower potential at specific sites

a) Hydropower potential at the Baynesfield HPP

To calculate the flow for the hydropower calculation at the Baynesfield HPP site, the transfer flow to the WTW was used. The time-series of flow values at certain probabilities is given in **Appendix A**.

The net head available for hydropower production was calculated by deducting friction losses through the conveyance structure (tunnel and pipe) from the difference in elevation between the dam level and the WTW. The elevation of the WTW is 872 masl. The friction loss was calculated using the Darcy-Weisbach equation (**Equation 3-2**), given below:

$$h_f = \frac{\lambda \times L \times V^2}{2 \times g \times D}$$ **Equation 3-2**

Where:

hf = Friction loss
λ = Friction factor
L = Length of conveyance structure
V = Velocity
g = Gravitational acceleration (9.79 m/s²)
D = Diameter of conveyance structure

The friction factor is dependent on flow and is calculated iteratively using the Colebrook-White equation (**Equation 3-3**), and because of the varying flows it would need to be calculated for each flow in the time-series, for both the tunnel and the steel pipe. For this reason, a sensitivity analysis was done to see the extent of the effect of the friction factors on the head loss in the range of flows expected in the conveyance structures. A conservative range of between 1 and 9 m^3/s was tested, with the flow being on average approximately 5 m^3/s. The difference in head loss between using the friction factors for 1 and 9 m^3/s was less than 0.6 m. This would have a negligible influence on hydropower. For this reason the friction factors for the average flow, 5 m^3/s, were calculated and used. They were 0.0166 and 0.0142 for the tunnel and the steel pipe, respectively.

$$\frac{1}{\sqrt{\lambda}} = -2 \times \log\left(\frac{k_s}{3.7 \times D} + \frac{2.51}{Re \times \sqrt{\lambda}}\right)$$ **Equation 3-3**

Where:

ks = hydraulic roughness
Re = Reynolds number

And where:

$$\mathrm{Re} = \frac{V \times D}{\nu}$$

v = kinematic viscosity (1.14 x 10-6 m²/s)

For the purpose of this study, minor losses were ignored as they had a negligible effect on the hydropower potential. The time-series of Smithfield Dam's levels, friction loss corresponding to flow, and net available head at certain probabilities are shown in **Appendix A**. The net head is plotted in **Figure 3.7**.

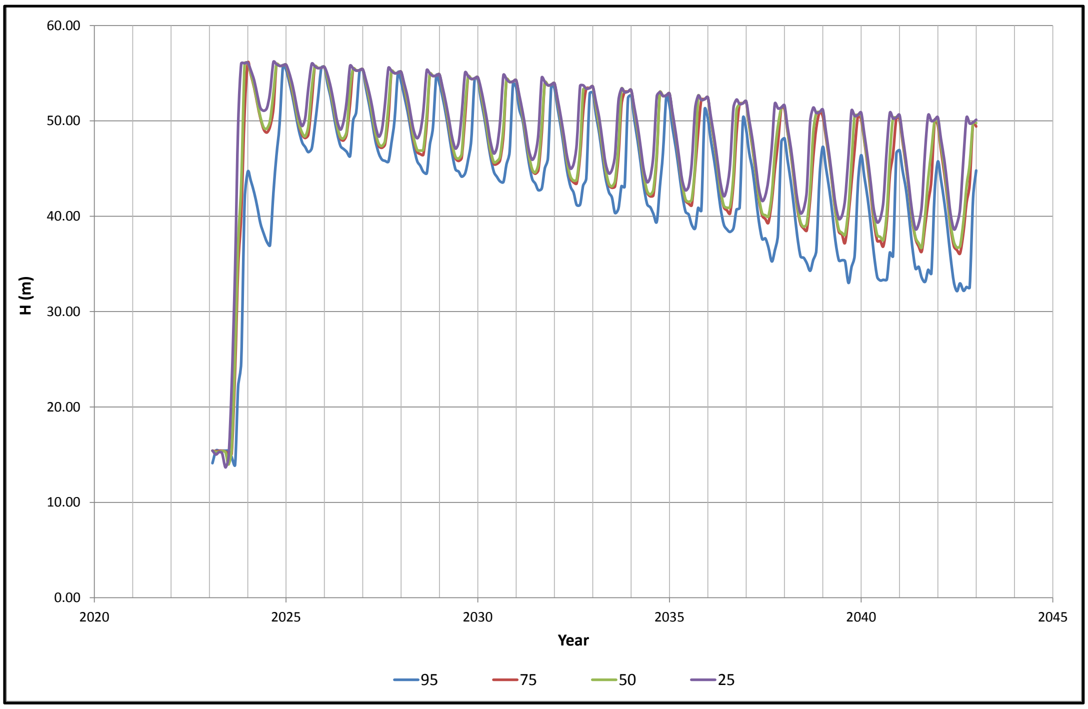

Figure 3.7: Net head available at proposed hydropower plant upstream of Baynesfield Water Treatment Plant

Based on this net head and the flow regime in **Figure 3.3**, an indication of hydropower potential is plotted in **Figure 3.8**, using an assumption of 85% efficiency for the turbine and generator as a starting point. As can be seen, although the projected flow is increasing over time, this is offset by generally decreasing net head. The result is a fairly small increase in average power potential increasing from about 0.5 MW to about 2.5 MW over the simulated record. At the beginning of the period, dam levels are unstable, resulting in unstable power potential; however, this stabilises within the first 2 years. For a higher assurance probability of 95%, the average power potential ranges from approximately 1.0 MW to 1.8 MW, after the levels stabilise.

The time-series of hydropower potential at certain probabilities is shown in **Appendix A**.

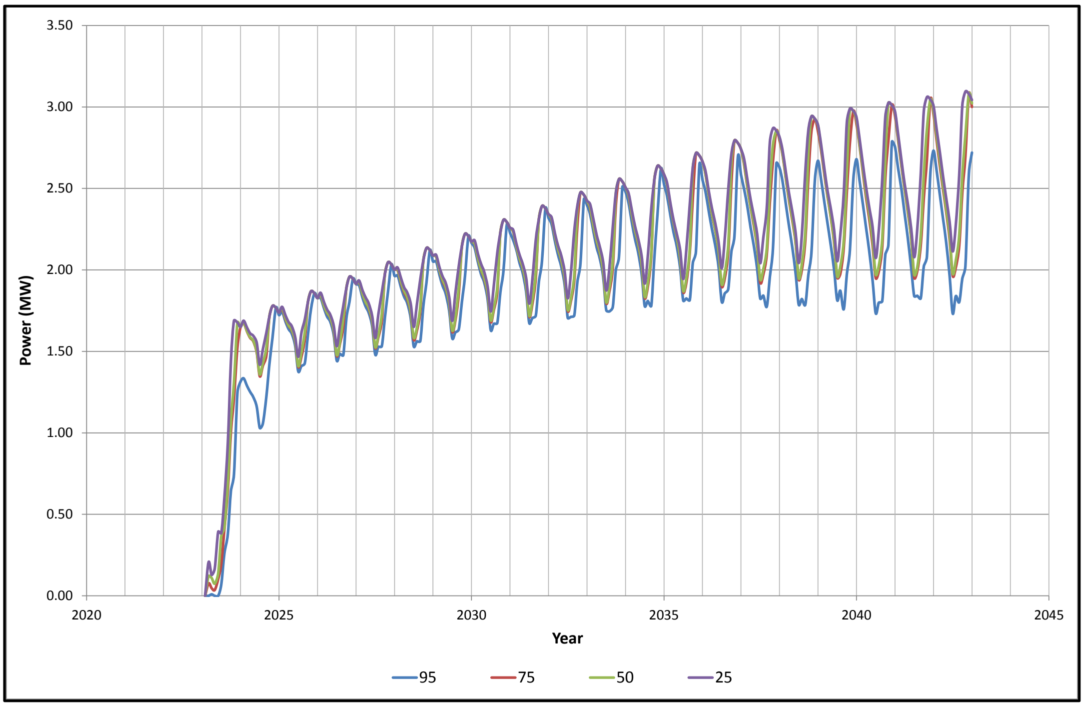

Figure 3.8: Hydropower potential at the proposed hydropower plant at Baynesfield using the transferred flows

Although the average hydropower potential does not increase significantly over the record period, there is the potential for meaningfully higher power generation during the summer months when the dam is more likely to be full. This is captured in the widening range of hydropower potential probability trajectories in the later part of the simulated period. When selecting a turbine, the following questions are raised:

- Can a single turbine accommodate the range of flows and heads indicated?
- Does a turbine need to be selected for the first part of the record, and then be replaced by a different turbine more appropriate for the flows and heads in the second part of the record?

It must be emphasized that while these trend lines show the average expected futures to the selected key probabilities, extreme events will most likely occur with occasional heads or flows differing to those plotted. These changes will however be known before the time as the dam level will be monitored during operation, and reduced transfer volumes due to the need for curtailments will be communicated with sufficient warning.

b) Hydropower potential below the Smithfield Dam

The water flows that can be used to generate power below the Smithfield Dam are due to releases of water (described in detail below) and spills. These are far more variable than the water transferred through the tunnel to Baynesfield. Although it will be dealt with in more detail in **Section 4.2.3**, it is important to mention the means by which the hydropower will be generated. This is because, typically, water that spills from a dam will do so over a spillway, and will therefore not be able to be used for hydropower generation. However, for the purpose of generating hydropower, spills will be controlled by monitoring the dam level, and releasing volumes of water through the hydropower turbine which will be suitable for the turbine capacity, as an equivalent to the water spilling over the dam. Any further volumes that would result in spilling will spill over the dam and will not be used to generate hydropower. This will require close monitoring and operation of the resource.

The head that can be used to generate power below the Smithfield Dam is also based on the surface elevations of water behind the dam. It is equal to the difference between the dam level and the water outlet level, less an assumed friction loss of 0.5 m from the dam to the HPP for the short penstock.

The following two scenarios have been considered and plotted:

- Releases for the Ecological Reserve and spills.
- Releases for the Ecological Reserve, releases to support Ngwadini off-channel dam (proposed on the lower uMkhomazi) and spills.

For a first order understanding of the range of flows, a single sequence based on the historic record was used to simulate scenario 1. The results of the simulation were then ranked and plotted as a flow duration curve, which depicts the frequency at which the combination of these flows below the dam can be expected. This curve is plotted in **Figure 3.9**. The time-series of data for the scenario based on the historic record is shown in **Appendix B.**

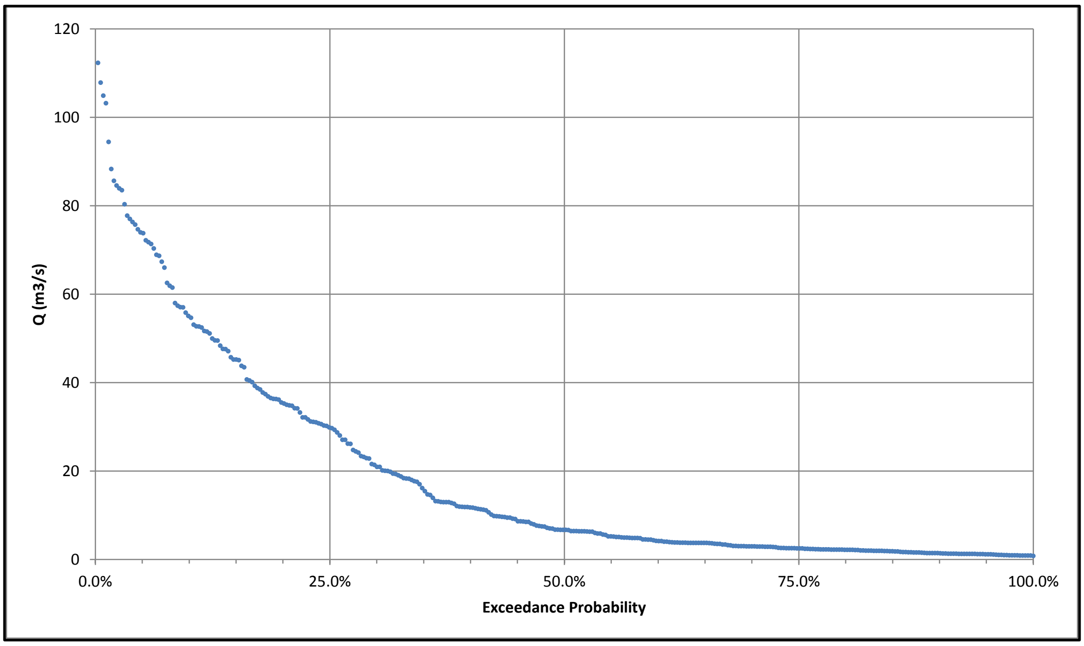

Figure 3.9: Flow duration curve for the total of releases and spills from Smithfield Dam based on historic record

From this figure, it can be seen that there is a very large variation in probable flows released and spilled from the dam. To check for seasonal trends and tendencies over time, box plots of releases and spills were created from the historic sequence and a further 200 stochastically generated scenarios. The box plot is presented in **Figure 3.10**.

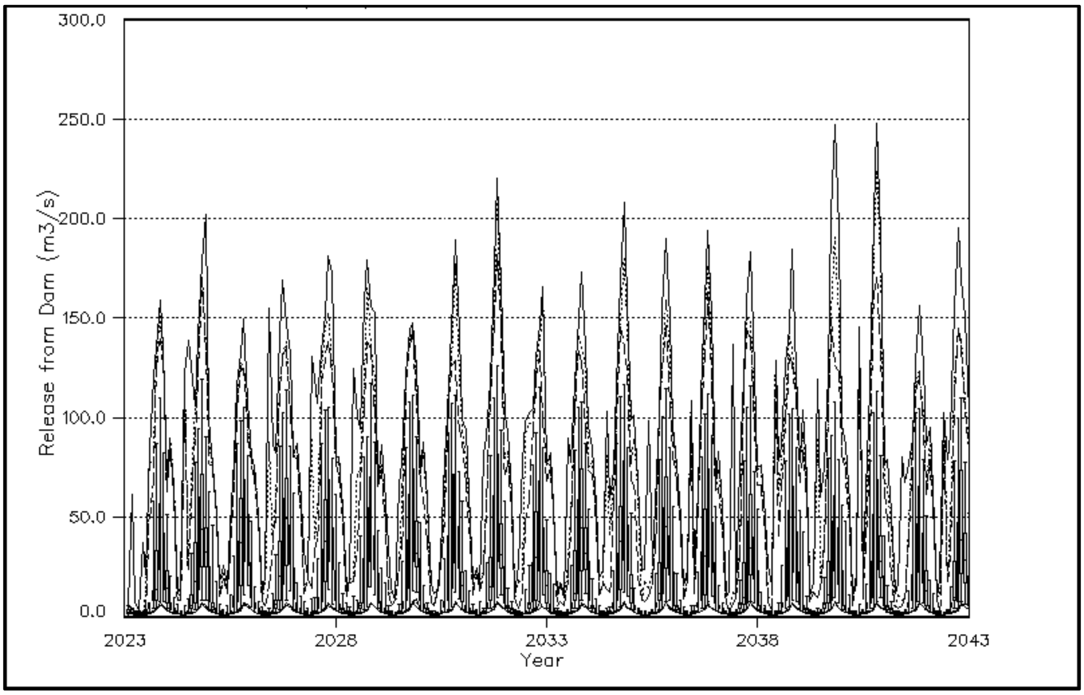

Figure 3.10: Box plot of combined releases and spills from Smithfield Dam

In this box plot it can be seen that there is a clear seasonal trend, but no significant change in flows over time. The high variability in flows presents some challenges in selecting the correct turbine size and design flow rate, in that a turbine is not able to operate efficiently over such a range.

Rather, the probability of certain flows occurring should be considered. For this reason, the flow duration curve based on the historic record was used to ascertain flows that could be delivered at certain significant assurances of supply. Only the historic record of the flow duration curves was considered, and not all of the stochastic sequences in the form of a box plot.

Similar probability distribution curves were produced for the net available head and the potential power, and are shown in **Figure 3.11** and **Figure 3.12**, respectively.

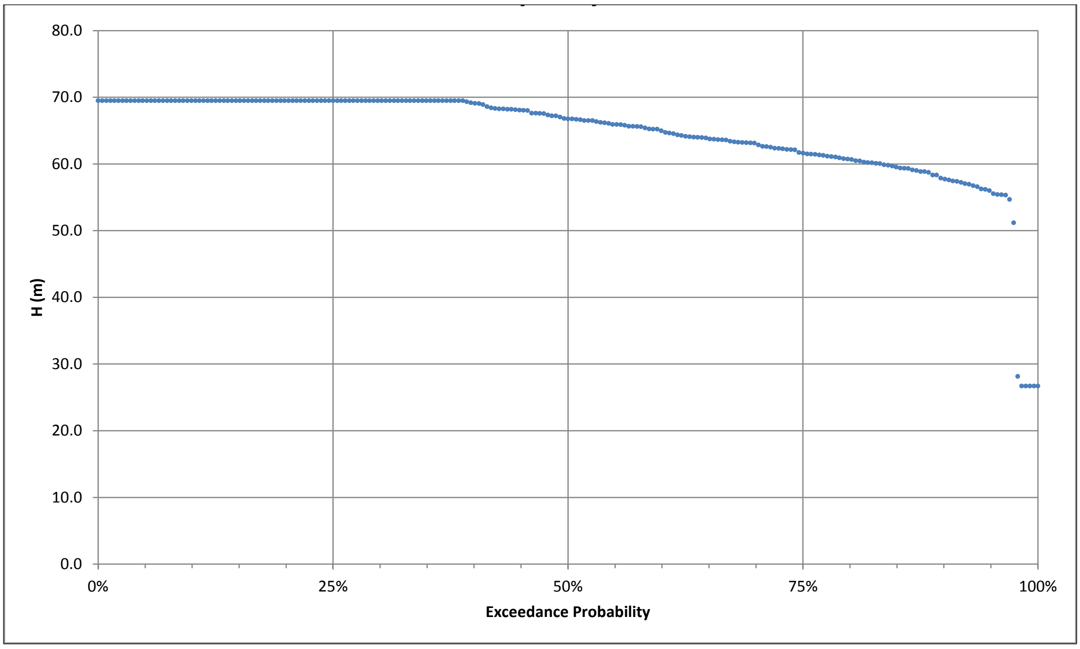

Figure 3.11: Probability distribution curve for available head at Smithfield Dam HPP based on historic record

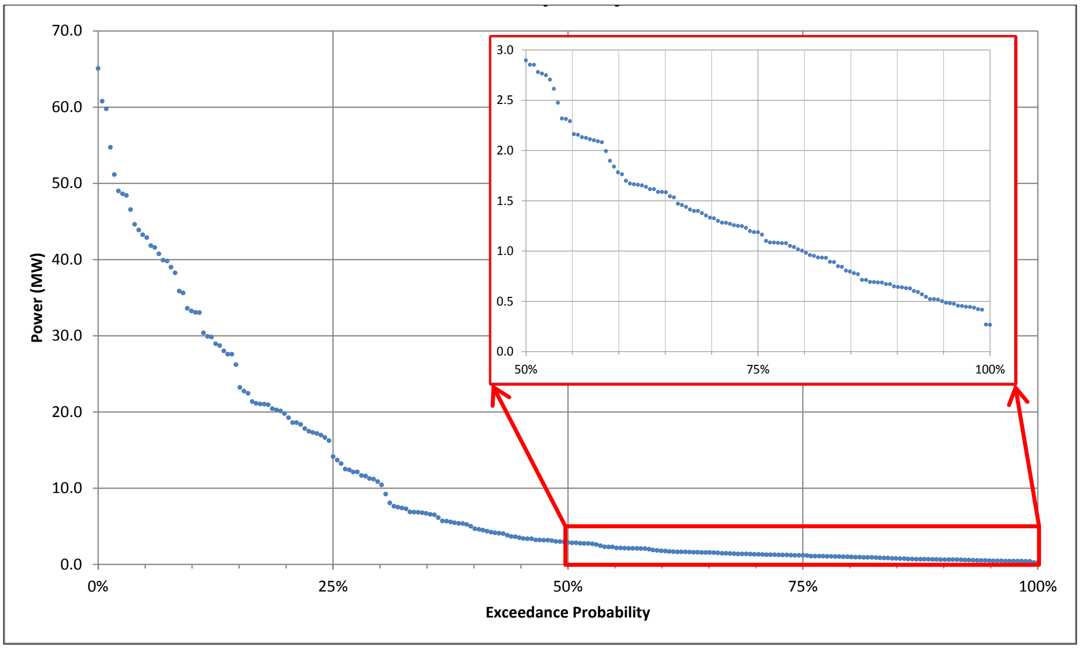

Figure 3.12: Probability distribution curve for power potential at Smithfield Dam HPP based on historic record

For a high assurance of supply of 95%, the flow, net head and power potential would be approximately 1.1 m³/s, 56.0 m and 0.5 MW respectively. For a lower assurance of supply (approximately 50%), which would allow for harnessing some of the peak flows, the average figures for the flow, net head and power potential would be roughly 5.0 m³/s, 64 m and 2.6 MW. The values used for turbine selection would depend on economic feasibility and other influential factors. These characteristics at specific assurances could be used for initial calculations, but further optimisation of the optimal design flow from an economic perspective would need to be done if this option turns out to be feasible.

4 CONCEPTUAL DESIGN OF HYDROPOWER PLANTS

Having determined the operational conditions and potential at the two HPP sites, the designs of the plants were carried out. This entailed the following for both sites:

- Selection and preliminary design of the turbines
- Design of the turbines to accommodate water hammer effects
- Layout of the HPPs
- Design of the power transmission line

4.1 BAYNESFIELD HYDROPOWER PLANT

4.1.1 Turbine design

a) Operating conditions

The flow and pressure conditions experienced at the Baynesfield HPP site have been discussed in detail previously in the report. The key operating conditions used for designing the turbine are given in **Table 4.1** below.

Table 4.1: Operating conditions for turbine design at Baynesfield HPP

Description	Gross head (m)	Net head (m)	Flow (m^3/s)
Rated point (max. flow)	52.0	41.7	8.65
Full supply level (max. head)	58.0	51.1	7.05
Minimum head	38.0	30.5	7.40

The waterway leading up to the HPP comprises a 32.5 km long concrete lined tunnel with a diameter of 3.5 m, followed by a 5.2 km steel pipe with a diameter of 2.6 m. An additional point to note is that the transfer volumes in the conveyance tunnel to the Baynesfield HPP begin with approximately 3.6 m^3/s in 2023 and peak at approximately 8.65 m^3/s in 2043 (see **Section 3.2.4** for detail).

b) Turbine type selection

The turbine types that were considered were Pelton, Turgo and Francis. The Pelton and Turgo type turbines have a favourable mechanism to shut off the water supply to limit the water hammer and the duration of excessive turbine acceleration. However, these turbine types are not suitable for the large flow and low head conditions of this site because of the resulting low rated speeds and large physical dimensions of the turbines. For this reason, the Francis type turbine was selected due to its suitability to the flow and head requirements, with a bypass pipe from the penstock to control water hammer (discussed in detail in **Section 4.1.2**). This selection corresponds to the design layout graph as by Mosonyi (1957). An equivalent chart by Gilbert Gilkes & Gordon Ltd (2014) is shown below in **Figure 4.1**.

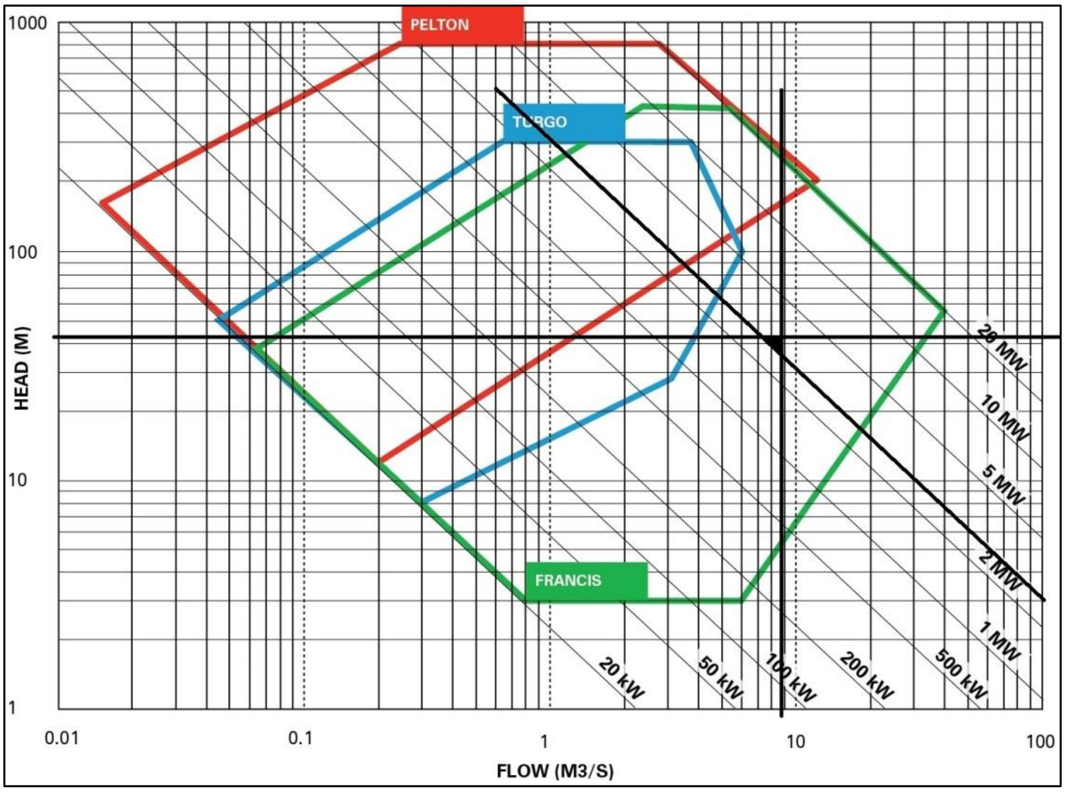

Figure 4.1: Turbine selection range chart for Baynesfield HPP

c) Turbine configuration

The possible turbine configurations that were investigated are as follows:

- One large set producing full load
- Two small sets producing full load
- One small set installed initially to meet initial load (two options)

The first option was to have one large turbine installed initially, which would be capable of producing the full load of 3 MW. This would perform at a rated point of 41.7 m head and 8.65 m^3/s flow when the maximum transfer volumes are reached.

The second option was to have two small turbines installed initially which would also be able to produce the full load. The rated point for each of the turbines would be 41.7 m head and 4.33 m^3/s flow, producing 1.5 MW of power each, also when the maximum transfer volumes are reached. Due to the fact that a single turbine is more efficient than two for all flows, this option is not the most appropriate.

The third option involved the installation of only one of these two small turbines initially because of the initially lower transfer volumes. The capacity of this turbine would be 1.5 MW as mentioned above. This would require an associated rated point with a head of 50.1 m and a flow of 3.6 m^3/s. The initial flow in the tunnel will be 3.6 m^3/s, meaning that the above-mentioned rated point would only just be satisfied by these flow conditions and would therefore not be suitable. In addition, the costs associated with installing turbines in phases are high, and therefore this option is unsuitable.

A fourth option was to initially install a turbine with a capacity larger than 1.5 MW to comfortably meet the initially lower transfer volumes, and then install a larger turbine when the transfer volumes require it. For the same reason mentioned above regarding cost, this option is also not suitable.

A single large Francis turbine was selected for implementation for the following reasons:

- The maximum flow, and therefore maximum power, is reached in 2043, which is 20 years from commencement. This timeline is relatively short.
- One turbine is more efficient than two for all flows.

The operating range of this machine is shown in **Figure 4.2** below, and its characteristics are as follows:

- Rated head: 41.7 m
- Rated flow: 8.65 m^3/s
- Approximate mass of turbine: 30 ton

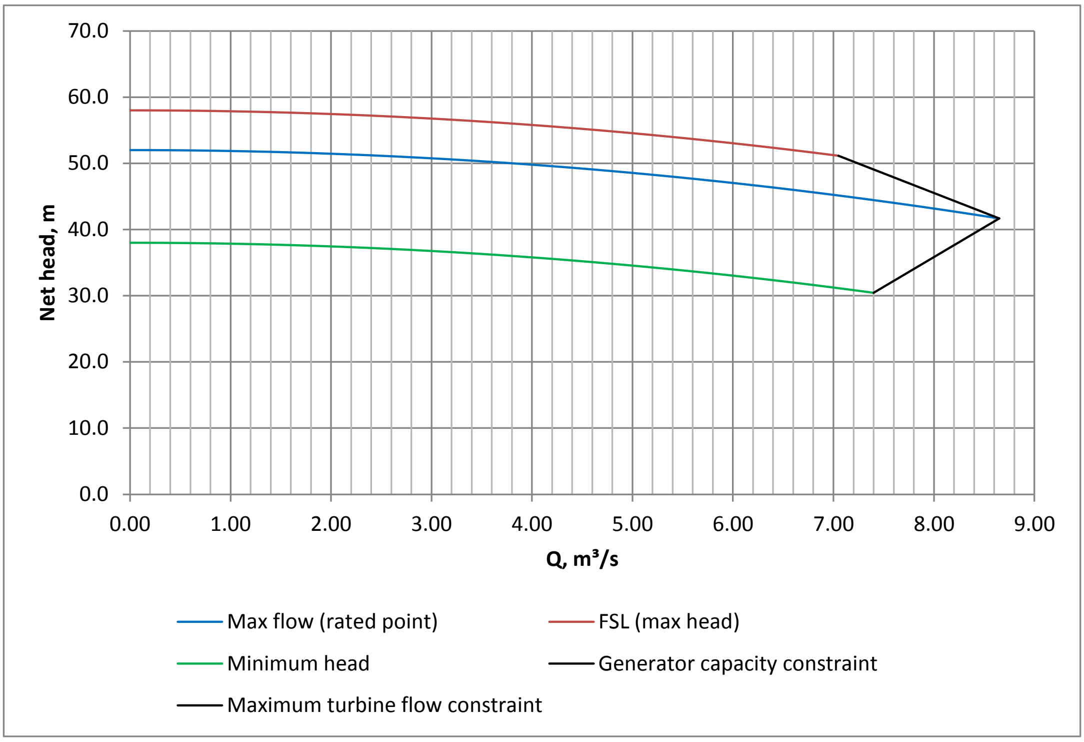

Figure 4.2: Operating range of single turbine at Baynesfield HPP

4.1.2 Turbine and tunnel design for water hammer

In order to design the turbine and tunnel for water hammer, the most adverse conditions of pressure rise and turbine speed rise had to be determined and limited to approximately 50%. This value of 50% speed rise is usually adopted as it results in a pressure rise of 50% or less; however, this would be economically optimised in the final detailed design.

Pressure rise is caused when moving water is brought to a stop, causing a pressure surge wave to propagate through the conduit. This pressure rise in the penstock could cause severe damage. The conveyance structure and powerhouse must be designed to withstand these pressure surges.

Turbine speed rise is caused when the load is suddenly removed from the turbine-generator unit (e.g. due to a fault on the transmission line), allowing the runner to rotate rapidly. This can cause great damage if the speed increase is too large or if it continues for too long. Speed rise is controlled by the mass moment of inertia of the rotating parts, which in this case would be the generator rotor and potentially a flywheel.

a) Normal operation

During normal operation, speed rise does not need to be considered because there will always be load on the turbine-generator unit. For this reason, the limiting criterion was to restrict the pressure rise to 50% during closure of the system. The full stroke operating time for closure of the guide apparatus was calculated to be in the order of 200 s to meet this criterion. This long duration is due to the long penstock leading up to the turbine.

b) Emergency shutdown

In the case of an emergency shutdown, the load on the turbine-generator would be rejected and therefore the turbine speed rise needed to be considered. The standard solution would be to have a 50% speed rise for a short duration, which would be achieved by a fast closure of the guide apparatus.

However, with the long closure time duration required for limiting pressure rise, the turbine would be subjected to speed rises for an unacceptably long duration. For this reason, a bypass will be needed in order to be able to close the guide vanes quickly, but still bring the flow of water to a complete stop over a long duration. Another reason for the adoption of the bypass is that the conventional solution of a surge tank will not be suitable for this long waterway, as it would have to be extremely high. The particulars of how the sleeve valve will operate are contained in the detailed conceptual design of the turbines in **Appendix C**.

A sleeve valve diameter resulting in the smallest pressure and speed rise for the operating range had to be iteratively calculated, due to transient pressure and head rises over the operating range. The sleeve valve diameter producing the lowest rises was 0.65 m. To limit speed rise, it was determined that a flywheel would be required, as the natural inertia of the generator is not sufficient to keep the speed increase below 50%. Because of the flywheel, the hydro-generating set has to be of the horizontal type.

4.1.3 Layouts

The initial layout of Baynesfield HPP powerhouse is shown in **Figure 4.3**.

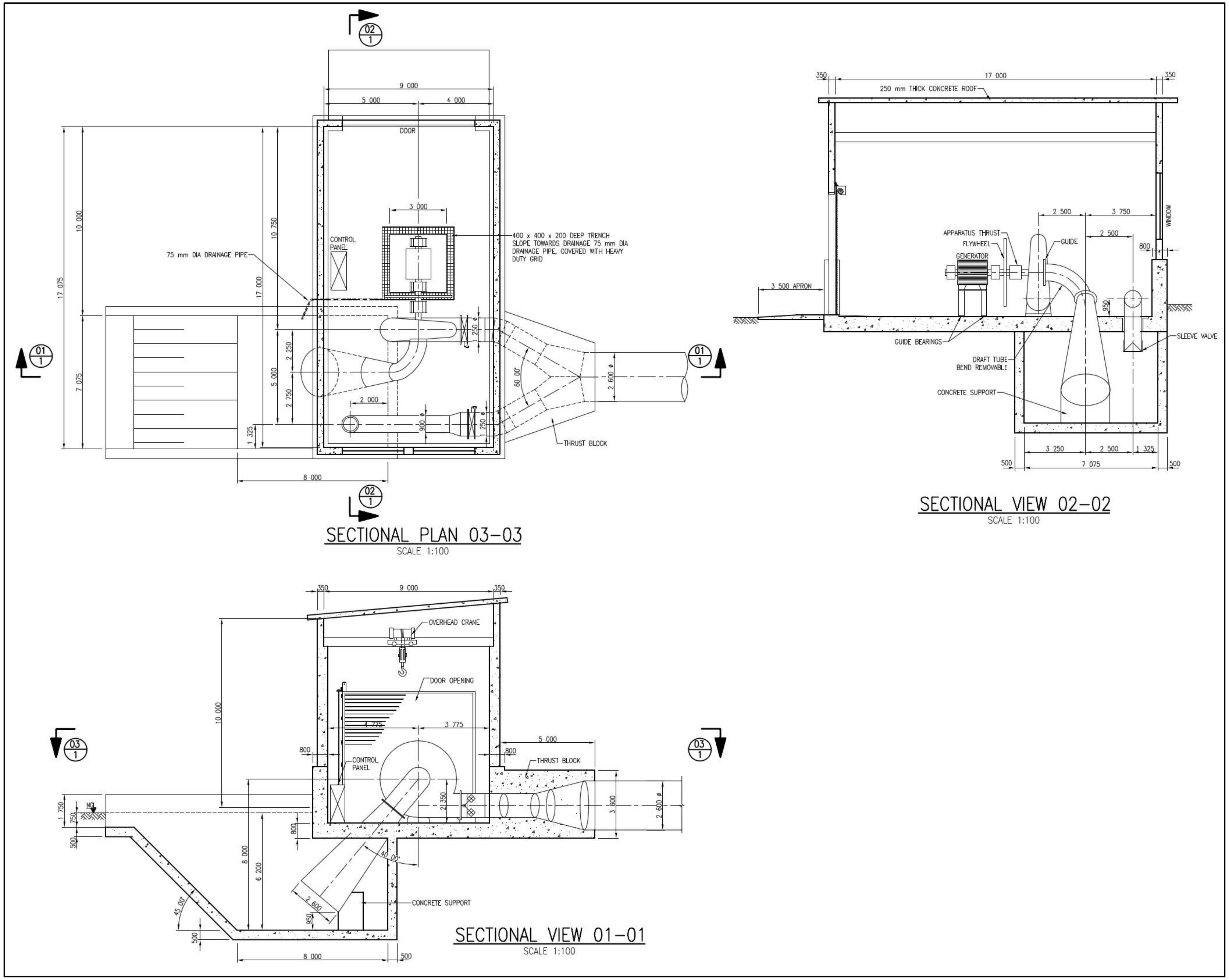

Figure 4.3: Baynesfield HPP layout

4.1.4 Power transmission

The precise power transmission infrastructure requirements are dependent on the use of the generated power. For Baynesfield HPP, the two possible uses would be wheeling the power into the grid for use by Baynesfield WTW (alternative 1), or providing the power directly to the WTW with an additional connection from the grid to make up for the shortfall in power (alternative 2). However, the main difference between these two options would be in the institutional arrangements, and the costs would be similar.

Due to the fact that Baynesfield WTW would require a power connection to it whether or not the HPP is constructed, power transmission infrastructure such as transmission lines and substations will already be in place. In addition, this infrastructure may already be in place for supplying power for construction of the WTW.

For these reasons and for the purposes of this investigation, the primary infrastructure that would be required for both power use scenarios would be nominal power transformation infrastructure. This infrastructure would serve to “clean” the generated power (with regards to frequency, voltage, etc.) for supply into the grid or for direct consumption. Subtle differences would exist between the exact infrastructure for the different power use scenarios, but are negligible for this investigation.

For both of these scenarios, approximately 50 m of overhead or underground cables would be required, because the power will not be transmitted over long distances. If this were the case, large overhead transmission lines would be required. The cost implications of these assumptions are discussed in **Section 5**.

4.2 SMITHFIELD DAM HYDROPOWER PLANT

4.2.1 Turbine design

a) Operating conditions

The flow and pressure conditions experienced at the Smithfield Dam HPP sites have been discussed in detail earlier in the report. A summary of the key operating conditions for designing the turbine are given in **Table 4.2** below. Both a 0.5 and a 2.6 MW turbine have been considered, which would be decided upon based on economic feasibility.

Table 4.2: Operating conditions for turbine design at Smithfield Dam HPP

Turbine size	Level	Gross head (m)	Net head (m)	Flow (m^3/s)
0.5 MW	Rated point (max. flow)	56.0	55.5	1.10
	Full supply level (max. head)	69.5	69.1	0.87
	Minimum head	26.7	26.3	0.95
2.6 MW	Rated point (max. flow)	65.0	64.0	5.00
	Full supply level (max. head)	71.0	70.2	4.56
	Minimum head	51.0	50.0	4.43

Water will be supplied to the HPP by the dam's outlet works, through a steel penstock approximately 100 m long pipe with a 2 m diameter.

b) *Turbine type selection*

For the same reasons as discussed for the Baynesfield HPP, the Francis type turbine should be selected. However, the turbine configuration at Smithfield Dam HPP does not require a bypass as is used at Baynesfield HPP, which is discussed in **Section 4.2.2**. The turbine selection criteria have also been shown on the chart in **Figure 4.4** below.

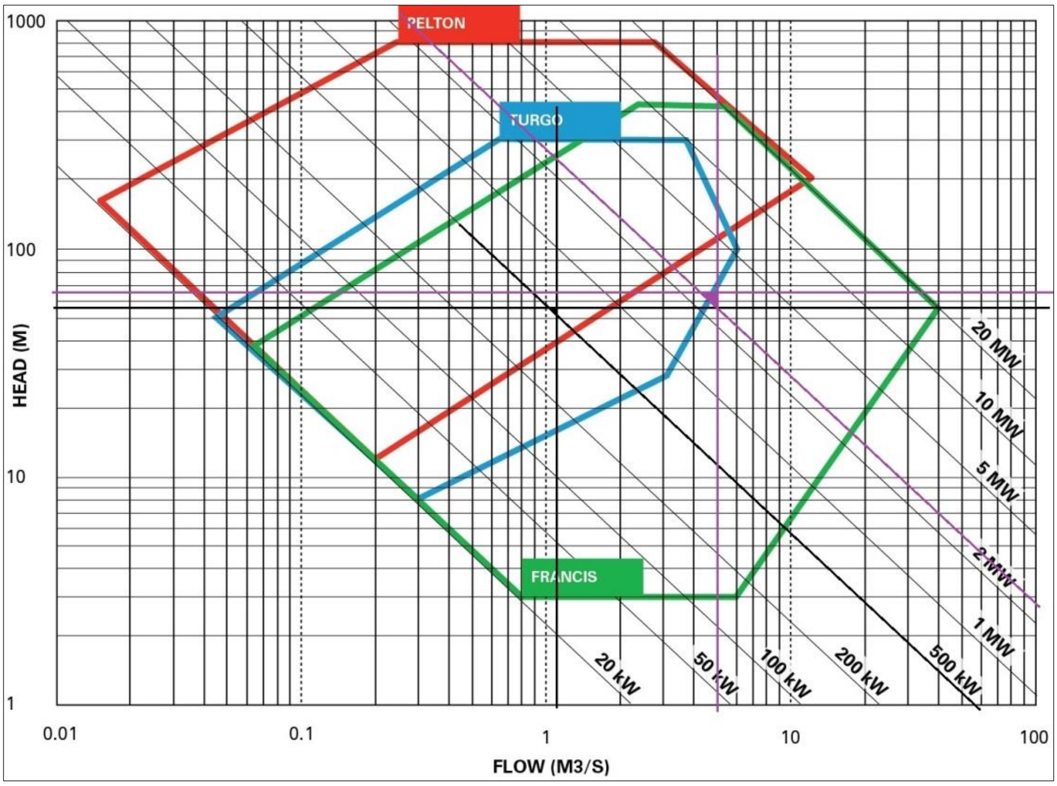

Figure 4.4: Turbine selection range chart for Smithfield Dam HPP

c) Turbine configuration

Because the Smithfield Dam HPP will be driven by spills and ecological releases from the dam, it will not experience low flows initially and gradually increasing flows as is the case with the Baynesfield HPP. For this reason, the turbine configuration will be a single turbine installed for the duration of the project. The operating ranges of the turbines are shown in **Figure 4.5** and **Figure 4.6**. The characteristics will be as follows operating at full load:

- 0.5 MW turbine:
  - Rated head: 55.5 m
  - Rated flow: 1.1 m^3/s
  - Approximate mass of turbine: 5 ton
- 2.6 MW turbine:
  - Rated head: 64.0 m
  - Rated flow: 5.0 m^3/s
  - Approximate mass of turbine: 20 ton

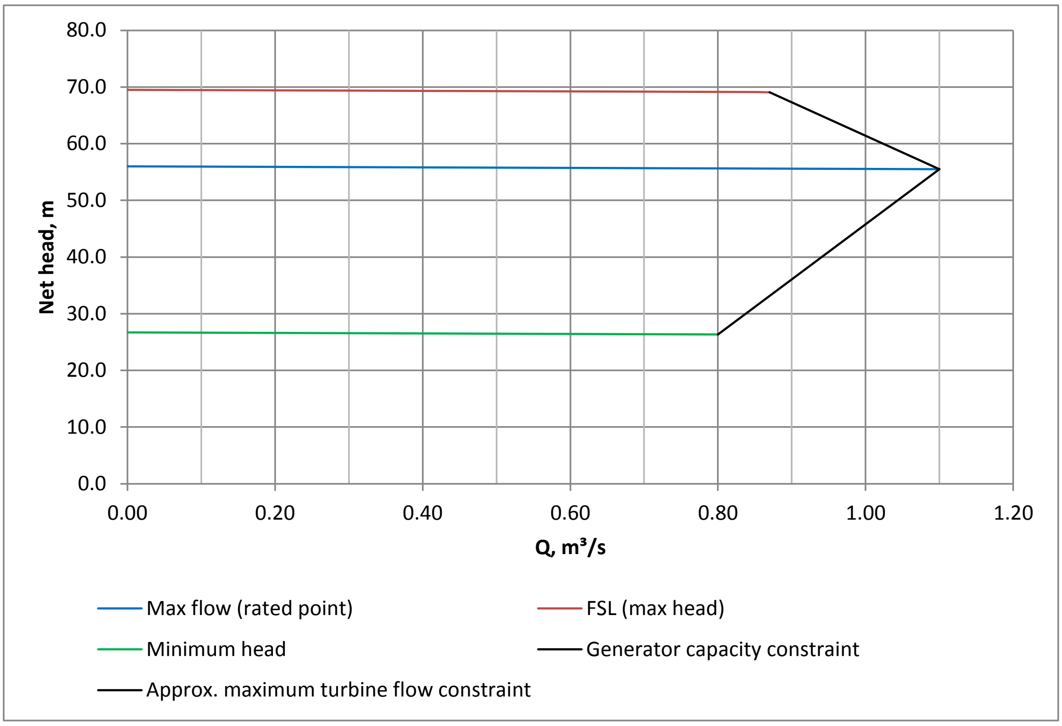

Figure 4.5: Operating range of 0.5 MW turbine at Smithfield Dam HPP

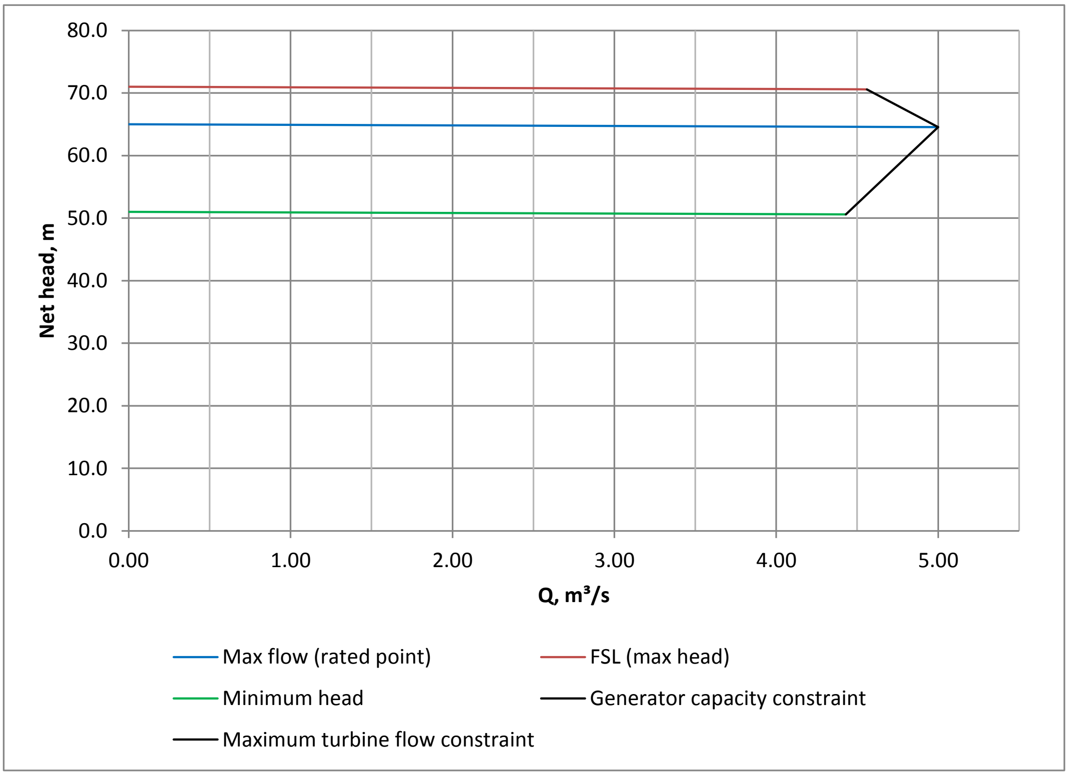

Figure 4.6: Operating range of 2.6 MW turbine at Smithfield Dam HPP

4.2.2 Turbine and tunnel design for water hammer

Because of the short penstock length, the standard solution for fast response frequency regulation can be adopted, i.e. regulation will be by means of the guide apparatus and no bypass is required (frequency regulation is explained in the detailed turbine design in **Appendix C**). For this reason, the design is simplified in that the closure of the system will operate in the same manner for normal operation as well as emergency shutdown.

For a reasonable guide vane closing time of 10s, the pressure rise is limited to 2.3%. This short time is an acceptable duration for speed rise, and confirms the statement above that fast response frequency regulation by the guide apparatus can be adopted.

In order to limit speed rise to 50%, a flywheel would be required. Due to the presence of a flywheel, the hydro-generating set will again have to be of the horizontal type.

4.2.3 Layouts

As was mentioned in **Section 3.2.5**, the spills and ecological releases are the flows that will be used to generated hydropower. The ecological releases will be made through the outlet works of the dam. In order to harness the hydropower potential of the spills, instead of allowing the dam to spill only over the spillway, the dam levels will be monitored and appropriate releases will be made through a turbine situated on the outlet works. This process is detailed in the section mentioned above.

The volumes of water that will be released through the outlet works for spills and releases has large variation, and are relatively high in comparison to the rated flow of the possible turbines for this site. Also, the flows to be released in emergency cases would far exceed the rating of the turbines. For this reason, adjustments would need to be made to the existing infrastructure to accommodate for hydropower generation. This would involve the following:

- A bypass pipe to accommodate the turbine, which will allow the turbine to not interfere with the operation of the outlet works during emergency releases.
- A connection between the two pipes, so that hydropower can be generated when maintenance is done on either of the pipes.
- Five additional butterfly valves, in order to control flow in the abovementioned connection and to the turbine.
- Larger diameter sleeve valves, due to lower head needing to be dissipated.

The details of these modifications would depend on the turbine configuration that is decided on, and should be confirmed during the detailed design of this hydropower plant, should this alternative turn out to be feasible. The superstructure of the powerhouse would be similar to that for Baynesfield HPP. Preliminary cost estimates have been made based on the abovementioned assumed modifications.

4.2.4 Power transmission

As was discussed in **Section 4.1.4**, the requirements of a transmission line are dependent on the usage of the power. For Smithfield Dam HPP, the investigated uses considered for the generated power were wheeling power into the national grid for supplying power for operation of the dam and other uses (alternative 1 and 2, depending on turbine selection), as well as directly supplying power for operation of the dam (alternative 3).

As with Baynesfield HPP, the power requirements during construction of Smithfield Dam are similar to the power generation capacity of Smithfield Dam HPP. The considerations taken into account were the same as those for Baynesfield HPP.

Due to the existence of power transmission infrastructure for construction, it was assumed that approximately 500 m of additional overhead or underground cables would be required. The cost implications of these assumptions are discussed in **Section 5**.

5 COST ESTIMATES

This section of the report details the cost estimate of the civil, hydro-mechanical and power transmission components of the hydropower scheme. All prices stated are exclusive of value added tax (VAT).

Table 5.1, **Table 5.2** and **Table 5.3** are bills of quantities (BOQ) which summarise the total quantities and costs of all work (civil, hydro-mechanical and power transmission) needed for Baynesfield and Smithfield Dam HPPs, respectively.

5.1 CIVIL WORKS

The civil works for the construction of the hydropower houses includes excavation, concrete and reinforcement. The unit costs of each of these items have been determined using the cost model, and are described in detail in the *Cost Model Report (P WMA 11/U10/00/3312/3/1/4)*. The following assumptions were made:

- the volume of reinforcement is 4% of the total concrete volume; and
- the unit weight for reinforcing steel is 7 800 kg/m³.

5.2 HYDRO-MECHANICAL

The costs of the hydro-generating sets are based on preliminary quotations made by *Gilbert Gilkes & Gordon Ltd*. The set that is quoted includes the Francis turbine, generator, inlet valve to the turbine, hydraulic control module, electrical package and operation and maintenance (O&M) manuals. The cost also includes installation and commissioning. In addition, a quote for shipping was given.

Where a quote for the hydro-generating set was not given (0.5 MW turbine at Smithfield Dam HPP), the cost was estimated based on quotes that were given. This cost was corroborated by a turbine cost evaluation tool developed by the *Lancaster University* (2008).

The costs of the valves used for the bypass at Baynesfield HPP are based on quotations from *Ithuba Valves and Industrial Supplies cc*, and are on an ex works basis, meaning that the cost of delivery from the factory to the site is not included.

The cost of the additions to the Smithfield Dam outlet works, as mentioned in **Section 4.2.3**, are also included in the BOQs. These costs are for additional pipe work and valves, and have been estimated based on the cost model and quotations from *Ithuba Valves and Industrial Supplies cc*.

5.3 POWER TRANSMISSION

The costs of the transmission of power include transmission lines, if applicable, and nominal power transformation infrastructure as discussed in **Sections 4.1.4** and **4.2.4**.

Although the power transmission infrastructure requirements of Baynesfield HPP alternatives 1 and 2 will differ slightly, the costs of both have been assumed to be the same because the main difference between them will be the institutional arrangements.

5.4 OVERALL (BILLS OF QUANTITIES)

Bills of quantities summarising all estimated costs for each alternative are shown in the table below.

Table 5.1: Bill of quantities for Baynesfield HPP alternative 1

HYDROPOWER PLANT - BILL OF QUANTITIES		OPTION 1: Baynesfield HPP (alternative 1)			
ITEM NO	**DESCRIPTION**	**UNIT**	**Quantity**	**Rate**	**AMOUNT (R)**
1	**Civil works**				
1.1	Excavation	m^3	600	R 150	R 90 000
1.2	Concrete (in structures)	m^3	600	R 1 980	R 1 188 000
1.3	Reinforcement	ton	190	R 13 000	R 2 470 000
	Sub-total: Civil works				**R 3 748 000**
2	**Hydro-mechanical**				
2.1	Hydro-generating set (quotation by Gilbert Gilkes & Gordon Ltd)	sum	1	R 35 696 000	R 35 696 000
2.2	Shipping of hydro-generating set (quotation by Gilbert Gilkes & Gordon Ltd)	sum	1	R 547 000	R 547 000
2.3	0.65 m diameter sleeve valve (quotation by Ithuba Valves and Industrial Supplies cc)	no	1	R 469 000	R 469 000
2.4	1.25 m diameter butterfly valve (quotation by Ithuba Valves and Industrial Supplies cc)	no	1	R 256 000	R 256 000
	Sub-total: Hydro-mechanical				**R 36 968 000**
3	**Power transmission**				
3.1	Power transformation infrastructure	sum	1	R 2 000 000	R 2 000 000
3.2	Transmission lines	m	50	R 1 500	R 75 000
	Sub-total: Power transmission				**R 2 075 000**
	Total: Baynesfield HPP (alternative 1)				**R 42 791 000**

Table 5.2: Bill of quantities for Smithfield Dam HPP alternative 1

HYDROPOWER PLANT - BILL OF QUANTITIES		OPTION 2: Smithfield Dam HPP			
ITEM NO	**DESCRIPTION**	**UNIT**	**Quantity**	**Rate**	**AMOUNT (R)**
1	**Civil works**				
1.1	Excavation	m^3	400	R 150	R 60 000
1.2	Concrete (in structures)	m^3	400	R 1 980	R 792 000
1.3	Reinforcement	ton	130	R 13 000	R 1 690 000
	Sub-total: Civil works				**R 2 542 000**
2	**Hydro-mechanical**				
2.1	Hydro-generating set (based on quotation by Gilbert Gilkes & Gordon Ltd)	sum	1	R 5 000 000	R 5 000 000
2.2	Shipping of hydro-generating set (based on quotation by Gilbert Gilkes & Gordon Ltd)	sum	1	R 547 000	R 547 000
2.3	Estimate of additional pipework and valves needed for Smithfield Dam outlet works	sum	1	R 7 100 000	R 7 100 000
	Sub-total: Hydro-mechanical				**R 12 647 000**
3	**Power transmission**				
3.1	Power transformation infrastructure	sum	1	R 2 000 000	R 2 000 000
3.2	Transmission lines	m	500	R 1 500	R 750 000
	Sub-total: Power transmission				**R 2 750 000**
	Total: Smithfield Dam HPP (alternative 1)				**R 17 939 000**

Table 5.3: Bill of quantities for Smithfield Dam HPP alternative 2

HYDROPOWER PLANT - BILL OF QUANTITIES		OPTION 2: Smithfield Dam HPP			
ITEM NO	**DESCRIPTION**	**UNIT**	**Quantity**	**Rate**	**AMOUNT (R)**
1	**Civil works**				
1.1	Excavation	m^3	600	R 150	R 90 000
1.2	Concrete (in structures)	m^3	600	R 1 980	R 1 188 000
1.3	Reinforcement	ton	190	R 13 000	R 2 470 000
	Sub-total: Civil works				**R 3 748 000**
2	**Hydro-mechanical**				
2.1	Hydro-generating set (based on quotation by Gilbert Gilkes & Gordon Ltd)	sum	1	R 22 435 000	R 22 435 000
2.2	Shipping of hydro-generating set (based on quotation by Gilbert Gilkes & Gordon Ltd)	sum	1	R 547 000	R 547 000
2.3	Estimate of additional pipework and valves needed for Smithfield Dam outlet works	sum	1	R 7 100 000	R 7 100 000
	Sub-total: Hydro-mechanical				**R 30 082 000**
3	**Power transmission**				
3.1	Power transformation infrastructure	sum	1	R 2 000 000	R 2 000 000
3.2	Transmission lines	km	500	R 1 500	R 750 000
	Sub-total: Power transmission				**R 2 750 000**
	Total: Smithfield Dam HPP (alternative 2)				**R 36 580 000**

6 EVALUATION OF SUSTAINABILITY

This section describes the investigation which was undertaken to determine the sustainability – economic and other – of the various HPP alternatives, which are summarised in **Table 6.1** below.

Table 6.1: HPP alternatives considered

Name	Use of power	Quantity of power
Baynesfield HPP alternative 1	Power wheeled into national grid for use at Baynesfield WTW	Varies from 0.5 to 2.5 MW
Baynesfield HPP alternative 2	Power supplied directly to Baynesfield WTW with national grid as backup	Varies from 0.5 to 2.5 MW
Smithfield Dam HPP alternative 1	Power wheeled into national grid for powering local dam operation facilities (0.5 MW)	0.5 MW
Smithfield Dam HPP alternative 2	Power wheeled into national grid for powering local dam operation facilities (2.6 MW)	2.6 MW
Smithfield Dam HPP alternative 3	Power supplied directly to local dam operation facilities	30 kW

As mentioned previously, the Baynesfield HPP alternatives are similar and alternative 1 will be indicative of the results of alternative 2. For this reason, only the sustainability of alternative 1 will be evaluated at this stage.

Regarding Smithfield Dam HPP alternative 3, further investigation would be required in order to determine the detailed capital cost of the civil, hydro-mechanical and power transmission components. For this reason, only the potential revenue is presently known, and so only this component will be discussed for this option.

6.1 METHODOLOGY

The methodology used to determine the economic sustainability of the HPP alternatives was to compare the net present value (NPV) net benefits of the various options (**Section 6.2**). The net benefit was determined by subtracting the NPV cost from the NPV potential revenue to be gained by power generation. Three discount rate percentages were used in the NPV calculation, namely 6, 8 and 10%. This comparison showed either a net economic benefit or deficit.

6.2 NET PRESENT VALUES

6.2.1 Assumptions

a) Hydropower potential

For the two Baynesfield HPP alternatives, the hydropower potential was used as determined in **Section 3.2.5** and shown in **Figure 3.8**, for an average annual supply. This was on approximately 0.5 MW at the start (2023) and 2.5 MW at the end (2043) of the water transfer period under consideration.

For Smithfield Dam HPP alternative 1, the hydropower potential for a 95% assurance of supply was used, as determined in **Section 3.2.5** and shown in **Figure 3.12**. This is equivalent to approximately 0.5 MW for the entire water transfer period. For alternative 2, an annual average of 2.0 MW was used. For alternative 3, the actual power requirement for operation and maintenance of the dam was used, being in the region of 30 kW.

b) Costs

The capital costs of the HPP alternatives were used as determined in **Section 5**. The total cost was implemented in the year 2022, being the year preceding the start of transfers. Hydropower generation and sale will only commence the year after this.

The operation and maintenance (O&M) costs were estimated as percentages of the capital costs per year, with the following percentages:

- Civil works: 0.25%
- Hydro-mechanical and transmission line: 4%

The capital and O&M costs are summarised in **Table 6.2** below.

Table 6.2: Summary of capital and O&M costs

HPP alternative	Capital cost (R'000)				Annual O&M cost (R'000)
	Civil works	Hydro-mechanical	Transmis sion line	Total	
Baynesfield HPP alternative 1: Power wheeled into national grid for use at WTW	3 748	36 968	2 075	**42 791**	**1 571**
Smithfield Dam HPP alternative 1: Power wheeled into national grid for operation of dam (0.5 MW)	2 542	12 647	2 750	**17 939**	**622**
Smithfield Dam HPP alternative 2: Power wheeled into national grid for operation of dam (2.6 MW)	3 748	30 082	2 750	**36 580**	**1 323**

c) *Revenue*

Supplying power into the national grid

Eskom has produced an information brochure on the process and pricing for third party transportation of energy, known as wheeling. According to the brochure, the wheeled power is injected into the network by the generator, and is extracted by the consumer at a point of delivery on the network *(Eskom, 2012)*. For this reason, wheeling does not reduce the required network capacity, and therefore charges are applicable for the delivery of this energy. However, a financial reconciliation is given for the wheeled energy bought, given at the Megaflex tariff.

Detailed calculations of the generator tariff charges, the maximum achievable wheeled savings, and the net revenue are contained in **Appendix D**. **Table 6.3** summarises the method of calculating this financial information. Due to the fact that for Baynesfield HPP different hydropower potentials were considered for each year, not all of the figures have been given in this table, but only a single instance to indicate the method followed. **Appendix D** shows the complete set of data.

The figures were calculated from the kWh/year generated, which was calculated by multiplying the hydropower potentials by the number of hours per year.

Table 6.3: Summary of financial calculations for wheeled energy

Item	Value
Hydropower potential (MW)	0.50
Power generated per year (kWh/year)	4 380 000
Maximum achievable annual wheeled savings (R'000)	2 069
Annual charges payable by generator (R'000)	86
Net annual revenue potential (R'000)	**1 983**
Average value per kWh generated (c/kWh)	45.28

For Baynesfield HPP, the annual net revenue applicable for 0.5 MW was applied in 2023, and that for 2.5 MW was applied in 2052. These were approximately R 2.0 m and R 10.2 m, respectively. For Smithfield Dam HPP, the annual net revenue figures related to the 0.5 MW and 2.0 MW hydropower potentials were approximately R 2.0 m and R 8.1 m, respectively.

Providing power directly to Baynesfield WTW

A similar method used to calculate revenue for wheeling was used to calculate the revenue for direct supply of power, with the exception that no charges payable by the generator would be applicable.

Providing power directly to local dam operation facilities

A similar method to that described above was used for the calculation of the net benefit of using generated power for local dam operation facilities. The revenue per year was determined by calculating the cost that would have been spent on purchasing electricity from the grid per year. Ruraflex tariffs were used to determine the cost of this power.

The economic feasibility of this option is dependent on the actual amount of power that would be needed for operation and maintenance of the dam. Initially, this was assumed to be a conservative amount of 0.4 MW, being below the assured power of 0.5 MW. However, upon further investigation, it was determined to be a fair amount below this assumption, in the range of 30 kW.

Due to this power being much smaller in magnitude than the initial assumption, further investigations would need to be undertaken to determine accurate cost estimates of the civil, hydro-mechanical and power transmission components. This alternative may be economically feasible, because operation of the dam would be completely independent of power from the grid, and costs would be highly reduced for this scale of power. However, it is recommended that further investigations are done to confirm this.

For illustration purposes, the financial calculations for the revenue of the potential option of 30 kW are given below in **Table 6.4**.

Table 6.4: Example of financial calculations for power generated for operation of Smithfield Dam

Item	Value
Hydropower potential (kW)	30
Power generated per year (kWh/year)	262 800
Net annual revenue potential (R'000)	**124**
Average value per kWh generated (c/kWh)	47.24

Linking scheme to the renewable energy program

Another option for the generation of revenue would be to link the scheme to the renewable energy program for small hydropower schemes. The benefit of this option would be that all power that is generated could be sold, meaning that power at a high assurance of supply would not be required but that extreme peaks could be exploited as well.

Further investigations would be required to determine parties interested in such an arrangement. Economic feasibility assessments would then need to be undertaken to determine the optimum turbine size for maximum net benefit between the potential cost and revenue.

6.2.2 Results

Appendix D contains the detailed calculations over the life-cycle of the HPPs to determine the NPVs for all four alternatives, and are summarised in **Table 6.5** below. Positive values indicate a net overall benefit, and negative values a deficit.

Table 6.5: NPVs for HPP alternatives

HPP alternative	Net overall benefit at certain discount rate (R'000)		
	6%	8%	10%
Baynesfield HPP alternative 1: Power wheeled into national grid for use at WTW	22 605	10 366	3 666
Smithfield Dam HPP alternative 1: Power wheeled into national grid for operation of dam (0.5 MW)	443	-1 213	-1 970
Smithfield Dam HPP alternative 2: Power wheeled into national grid for operation of dam (2.6 MW)	31 896	18 553	10 638

6.3 CONCLUSION

The figures in **Table 6.5** above show that the option of wheeling into the grid at Baynesfield HPP would be economically feasible. This option may also be feasible at Smithfield Dam HPP, depending on the amount of hydropower generated at this site. If the higher capacity of 2.0 MW is generated, the option is feasible; however, for smaller power generation such as 0.5 MW, the option would not be feasible.

It must be noted that HPPs can be implemented at both the Baynesfield and Smithfield sites, as the water which will generate the power is independent for each site.

It must also be mentioned that there are options requiring further investigation, which may also turn out to be feasible. Baynesfield HPP alternative 2, with direct supply of power to Baynesfield WTW, requires further investigation of the cost of power transmission infrastructure. Smithfield Dam HPP alternative 3, with direct supply of power for operation of the dam, requires further investigation of the cost of all infrastructure for this small-scale hydropower scheme.

Taking the above into consideration, the following points conclude the economic viability assessment:

- Wheeling power into the grid at Baynesfield HPP is feasible, but the costs of power transmission infrastructure for supplying power directly into Baynesfield WTW should be investigated further to decide which is the most feasible between the two.
- Wheeling power into the grid at Smithfield Dam HPP is feasible for higher hydropower generation only. The costs of all infrastructure for supplying power directly to the dam operation facilities should be investigated further.

7 CONCLUSIONS AND RECOMMENDATIONS

The purpose of this investigation was to identify and assess locations and the potential for generating hydropower on the uMWP water supply scheme. Sites were identified on the conveyance structure just upstream of the proposed Baynesfield WTW, and just below Smithfield Dam. Potential uses of the power generated at Baynesfield HPP investigated were wheeling of power into the national grid, and using the power for direct consumption by Baynesfield WTW. The investigated uses of power generated at Smithfield Dam was wheeling of power into the grid (for two turbine sizes), and directly powering local facilities needed for operation and maintenance of the dam.

Based on the assessment of the economic sustainability of these options, it was found that the wheeling of power into the grid is a feasible option for both Baynesfield HPP and Smithfield Dam HPP. For the latter, high hydropower generation is needed for economic feasibility. It is recommended that these possibilities be discussed with Umgeni Water or eThekwini Municipality, to determine whether they would be interested in such an arrangement, and also confirmed with Eskom.

An option which may show economic feasibility with further investigations is the use of power generated at Smithfield Dam HPP to directly supply local facilities needed to operate and maintain Smithfield Dam. It is recommended that a detailed cost assessment of the civil, hydro-mechanical and power transmission components be undertaken, to determine whether this small scale hydropower scheme would be feasible. This would allow for the dam to be operated independently of the grid. This arrangement would need to be discussed with the relevant institutions, including Umgeni Water, eThekwini Municipality and with Eskom.

Further investigations should also be done to determine parties that would be interested with linking the scheme to a renewable energy program for small hydropower schemes, to determine the potential cost benefits of this.

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Appendix A

Time series data used for calculations: Baynesfield HPP

Table A-1: Transfer flow from Smithfield Dam to Baynesfield WTW (m³/s)

	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
2013	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2014	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2015	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2016	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2017	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2018	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2019	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2020	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2021	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2022	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2023	0.00	3.44	2.40	0.35	0.72	1.97	3.24	3.26	3.47	3.62	3.59	3.53
2024	3.66	3.64	3.66	3.73	3.65	3.31	3.43	3.44	3.68	3.82	3.80	3.73
2025	3.86	3.84	3.87	3.93	3.85	3.49	3.62	3.63	3.88	4.04	4.01	3.94
2026	4.07	4.04	4.07	4.14	4.05	3.68	3.81	3.82	4.08	4.25	4.22	4.15
2027	4.27	4.25	4.27	4.35	4.26	3.86	4.00	4.02	4.29	4.46	4.43	4.35
2028	4.48	4.45	4.48	4.56	4.46	4.05	4.19	4.21	4.50	4.68	4.65	4.57
2029	4.69	4.66	4.69	4.77	4.67	4.24	4.39	4.41	4.70	4.90	4.86	4.78
2030	4.90	4.87	4.90	4.98	4.88	4.43	4.59	4.61	4.92	5.12	5.08	4.99
2031	5.11	5.08	5.11	5.20	5.09	4.62	4.79	4.80	5.13	5.34	5.30	5.21
2032	5.32	5.29	5.33	5.42	5.31	4.82	4.99	5.01	5.34	5.56	5.52	5.43
2033	5.54	5.50	5.54	5.64	5.52	5.01	5.19	5.21	5.56	5.79	5.74	5.65
2034	5.76	5.72	5.76	5.86	5.74	5.21	5.39	5.41	5.78	6.01	5.97	5.87
2035	5.97	5.94	5.98	6.08	5.96	5.41	5.60	5.62	6.00	6.24	6.20	6.09
2036	6.20	6.16	6.20	6.31	6.18	5.61	5.80	5.83	6.22	6.47	6.43	6.32
2037	6.42	6.38	6.42	6.53	6.40	5.81	6.01	6.04	6.44	6.71	6.66	6.54
2038	6.64	6.60	6.65	6.76	6.62	6.01	6.22	6.25	6.67	6.94	6.89	6.77
2039	6.79	6.75	6.80	6.92	6.77	6.15	6.36	6.39	6.82	7.10	7.05	6.93
2040	6.91	6.87	6.92	7.03	6.89	6.25	6.47	6.50	6.94	7.22	7.17	7.04
2041	7.03	6.98	7.03	7.15	7.01	6.36	6.58	6.61	7.05	7.34	7.29	7.16
2042	7.14	7.10	7.15	7.27	7.12	6.46	6.69	6.72	7.17	7.46	7.41	3.41

Table A-2: Smithfield Dam's levels (masl)

	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
2013	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0
2014	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0
2015	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0
2016	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0
2017	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0
2018	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0
2019	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0
2020	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0
2021	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0
2022	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0	856.0
2023	887.2	888.7	887.2	887.2	887.2	887.2	911.7	920.0	929.6	930.0	930.0	930.0
2024	928.6	926.7	924.8	923.4	922.0	921.0	921.4	923.2	930.0	930.0	930.0	930.0
2025	930.0	928.7	927.0	925.7	924.5	930.0	930.0	930.0	930.0	930.0	930.0	930.0
2026	929.1	927.3	925.2	923.7	923.6	925.1	930.0	930.0	930.0	930.0	930.0	930.0
2027	930.0	930.0	930.0	928.1	926.3	926.4	930.0	930.0	930.0	930.0	930.0	930.0
2028	928.8	926.6	924.5	922.8	921.2	920.2	919.8	920.8	930.0	930.0	930.0	930.0
2029	930.0	928.5	926.4	924.4	923.0	924.1	930.0	930.0	930.0	930.0	930.0	930.0
2030	930.0	930.0	930.0	930.0	930.0	930.0	930.0	930.0	930.0	930.0	930.0	930.0
2031	928.1	925.8	923.8	922.0	923.7	927.7	928.6	927.3	930.0	930.0	930.0	930.0
2032	929.7	927.3	924.7	922.7	920.7	918.8	916.8	915.2	917.5	920.7	926.9	930.0
2033	928.7	926.1	923.8	921.7	919.6	917.6	921.0	924.1	930.0	930.0	930.0	930.0
2034	928.6	928.1	927.0	924.5	922.6	921.3	926.1	930.0	930.0	930.0	930.0	930.0
2035	929.6	927.0	924.3	922.0	919.9	918.1	917.3	917.8	922.1	926.8	930.0	930.0
2036	928.1	925.2	922.9	920.6	918.4	916.5	916.0	921.9	926.2	930.0	930.0	930.0
2037	930.0	928.8	926.2	925.9	925.5	923.7	922.8	930.0	930.0	930.0	930.0	929.9
2038	927.2	924.2	921.8	919.9	918.9	919.4	918.3	921.6	930.0	930.0	930.0	930.0
2039	927.9	924.9	922.7	920.4	918.0	915.9	917.1	920.3	926.4	930.0	930.0	928.9
2040	925.7	923.1	920.6	917.9	915.9	915.9	919.3	927.7	930.0	930.0	930.0	930.0
2041	928.8	927.2	924.2	921.6	919.4	921.3	923.9	929.4	930.0	930.0	930.0	930.0
2042	927.5	924.6	922.2	919.5	916.7	913.8	910.7	907.0	902.6	897.7	890.7	887.2

Table A-3: Friction loss corresponding to transfer flows from Smithfield Dam to Baynesfield WTW (m)

	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
2013	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2014	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2015	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2016	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2017	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2018	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2019	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2020	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2021	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2022	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2023	0.00	1.74	0.85	0.02	0.08	0.57	1.55	1.56	1.78	1.92	1.90	1.83
2024	1.97	1.95	1.98	2.05	1.96	1.62	1.73	1.75	1.99	2.15	2.12	2.05
2025	2.20	2.17	2.20	2.28	2.18	1.80	1.93	1.94	2.21	2.40	2.36	2.28
2026	2.44	2.41	2.44	2.52	2.42	1.99	2.14	2.15	2.45	2.66	2.62	2.53
2027	2.69	2.66	2.69	2.78	2.67	2.20	2.36	2.38	2.71	2.93	2.89	2.79
2028	2.95	2.92	2.96	3.06	2.94	2.42	2.59	2.61	2.98	3.22	3.18	3.07
2029	3.23	3.20	3.24	3.35	3.22	2.65	2.84	2.86	3.26	3.53	3.48	3.36
2030	3.53	3.49	3.54	3.66	3.51	2.89	3.10	3.12	3.56	3.85	3.80	3.67
2031	3.84	3.80	3.85	3.98	3.82	3.15	3.37	3.40	3.87	4.19	4.13	3.99
2032	4.17	4.12	4.18	4.32	4.15	3.42	3.66	3.69	4.20	4.55	4.49	4.34
2033	4.52	4.46	4.52	4.68	4.49	3.70	3.96	4.00	4.55	4.93	4.86	4.69
2034	4.88	4.82	4.89	5.05	4.85	3.99	4.28	4.31	4.91	5.32	5.25	5.07
2035	5.26	5.19	5.27	5.45	5.23	4.30	4.61	4.65	5.30	5.74	5.66	5.46
2036	5.65	5.59	5.66	5.86	5.62	4.63	4.96	5.00	5.70	6.17	6.08	5.87
2037	6.07	6.00	6.08	6.29	6.03	4.97	5.32	5.37	6.11	6.62	6.53	6.30
2038	6.50	6.42	6.51	6.74	6.46	5.32	5.70	5.75	6.55	7.09	6.99	6.76
2039	6.80	6.72	6.81	7.04	6.76	5.56	5.97	6.01	6.85	7.42	7.31	7.06
2040	7.03	6.95	7.04	7.29	6.99	5.76	6.17	6.22	7.09	7.68	7.57	7.31
2041	7.27	7.18	7.28	7.53	7.23	5.95	6.38	6.43	7.33	7.94	7.82	7.56
2042	7.51	7.43	7.53	7.79	7.47	6.15	6.59	6.65	7.57	8.20	8.08	1.71

Table A-4: Net available head at Baynesfield HPP site (m)

	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
2013	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2014	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2015	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2016	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2017	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2018	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2019	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2020	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2021	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2022	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2023	15.20	14.91	14.35	15.18	15.12	14.63	38.13	46.48	55.78	56.08	56.10	56.17
2024	54.60	52.73	50.80	49.31	48.03	47.37	47.71	49.40	56.01	55.85	55.88	55.95
2025	55.80	54.53	52.81	51.45	50.35	56.20	56.07	56.06	55.79	55.60	55.64	55.72
2026	54.68	52.87	50.79	49.19	49.22	51.06	55.86	55.85	55.55	55.34	55.38	55.47
2027	55.31	55.34	55.31	53.34	51.63	52.20	55.64	55.62	55.29	55.07	55.11	55.21
2028	53.81	51.68	49.51	47.73	46.25	45.77	45.24	46.16	55.02	54.78	54.82	54.93
2029	54.77	53.34	51.20	49.05	47.80	49.44	55.16	55.14	54.74	54.47	54.52	54.64
2030	54.47	54.51	54.46	54.34	54.49	55.11	54.90	54.88	54.44	54.15	54.20	54.33
2031	52.28	49.97	47.98	45.97	47.91	52.57	53.23	51.93	54.13	53.81	53.87	54.01
2032	53.51	51.16	48.47	46.33	44.56	43.42	41.11	39.50	41.26	44.15	50.38	53.66
2033	52.19	49.68	47.25	45.00	43.14	41.85	45.01	48.14	53.45	53.07	53.14	53.31
2034	51.76	51.25	50.13	47.46	45.77	45.33	49.83	53.69	53.09	52.68	52.75	52.93
2035	52.33	49.84	46.99	44.57	42.63	41.80	40.64	41.10	44.84	49.01	52.34	52.54
2036	50.44	47.56	45.21	42.72	40.76	39.88	39.08	44.85	48.47	51.83	51.92	52.13
2037	51.93	50.84	48.08	47.62	47.46	46.70	45.51	52.63	51.89	51.38	51.47	51.56
2038	48.71	45.81	43.29	41.16	40.39	42.06	40.55	43.81	51.45	50.91	51.01	51.24
2039	49.05	46.16	43.89	41.36	39.21	38.35	39.14	42.30	47.58	50.58	50.69	49.85
2040	46.70	44.17	41.57	38.60	36.86	38.17	41.08	49.52	50.91	50.32	50.43	50.69
2041	49.51	47.97	44.88	42.08	40.14	43.31	45.55	50.98	50.67	50.06	50.18	50.44
2042	48.03	45.16	42.69	39.75	37.24	35.69	32.12	28.38	23.05	17.49	10.64	13.49

Table A-5: Hydropower potential at Baynesfield HPP site (MW)

	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
2013	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2014	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2015	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2017	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2018	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2019	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2020	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2021	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2022	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2023	0.0	0.4	0.3	0.0	0.1	0.2	1.0	1.3	1.6	1.7	1.7	1.7
2024	1.7	1.6	1.6	1.5	1.5	1.3	1.4	1.4	1.7	1.8	1.8	1.7
2025	1.8	1.7	1.7	1.7	1.6	1.6	1.7	1.7	1.8	1.9	1.9	1.8
2026	1.9	1.8	1.7	1.7	1.7	1.6	1.8	1.8	1.9	2.0	1.9	1.9
2027	2.0	2.0	2.0	1.9	1.8	1.7	1.9	1.9	2.0	2.0	2.0	2.0
2028	2.0	1.9	1.9	1.8	1.7	1.5	1.6	1.6	2.1	2.1	2.1	2.1
2029	2.1	2.1	2.0	2.0	1.9	1.7	2.0	2.0	2.1	2.2	2.2	2.2
2030	2.2	2.2	2.2	2.3	2.2	2.0	2.1	2.1	2.2	2.3	2.3	2.3
2031	2.2	2.1	2.0	2.0	2.0	2.0	2.1	2.1	2.3	2.4	2.4	2.3
2032	2.4	2.3	2.2	2.1	2.0	1.7	1.7	1.6	1.8	2.0	2.3	2.4
2033	2.4	2.3	2.2	2.1	2.0	1.7	1.9	2.1	2.5	2.6	2.5	2.5
2034	2.5	2.4	2.4	2.3	2.2	2.0	2.2	2.4	2.6	2.6	2.6	2.6
2035	2.6	2.5	2.3	2.3	2.1	1.9	1.9	1.9	2.2	2.6	2.7	2.7
2036	2.6	2.4	2.3	2.2	2.1	1.9	1.9	2.2	2.5	2.8	2.8	2.7
2037	2.8	2.7	2.6	2.6	2.5	2.3	2.3	2.6	2.8	2.9	2.9	2.8
2038	2.7	2.5	2.4	2.3	2.2	2.1	2.1	2.3	2.9	2.9	2.9	2.9
2039	2.8	2.6	2.5	2.4	2.2	2.0	2.1	2.3	2.7	3.0	3.0	2.9
2040	2.7	2.5	2.4	2.3	2.1	2.0	2.2	2.7	2.9	3.0	3.0	3.0
2041	2.9	2.8	2.6	2.5	2.3	2.3	2.5	2.8	3.0	3.1	3.0	3.0
2042	2.9	2.7	2.5	2.4	2.2	1.9	1.8	1.6	1.4	1.1	0.7	0.4

Appendix B

Time series data used for calculations: Smithfield Dam HPP

Table B-1: Net available head at Smithfield Dam HPP site (m)

	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
2013	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2014	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2015	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2016	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2017	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2018	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2019	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2020	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2021	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2022	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2023	26.70	28.15	26.70	26.70	26.70	26.70	51.18	59.54	69.06	69.50	69.50	69.50
2024	68.07	66.18	64.28	62.86	61.49	60.49	60.94	62.65	69.50	69.50	69.50	69.50
2025	69.50	68.20	66.51	65.23	64.03	69.50	69.50	69.50	69.50	69.50	69.50	69.50
2026	68.62	66.78	64.73	63.21	63.14	64.55	69.50	69.50	69.50	69.50	69.50	69.50
2027	69.50	69.50	69.50	67.62	65.80	65.90	69.50	69.50	69.50	69.50	69.50	69.50
2028	68.26	66.10	63.97	62.29	60.69	59.69	59.33	60.27	69.50	69.50	69.50	69.50
2029	69.50	68.04	65.94	63.90	62.52	63.59	69.50	69.50	69.50	69.50	69.50	69.50
2030	69.50	69.50	69.50	69.50	69.50	69.50	69.50	69.50	69.50	69.50	69.50	69.50
2031	67.62	65.27	63.33	61.45	63.23	67.22	68.10	66.83	69.50	69.50	69.50	69.50
2032	69.18	66.78	64.15	62.15	60.21	58.34	56.27	54.69	56.96	60.20	66.37	69.50
2033	68.21	65.64	63.27	61.18	59.13	57.05	60.47	63.64	69.50	69.50	69.50	69.50
2034	68.14	67.57	66.52	64.01	62.12	60.82	65.61	69.50	69.50	69.50	69.50	69.50
2035	69.09	66.53	63.76	61.52	59.36	57.60	56.75	57.25	61.64	66.25	69.50	69.50
2036	67.59	64.65	62.37	60.08	57.88	56.01	55.54	61.35	65.67	69.50	69.50	69.50
2037	69.50	68.34	65.66	65.41	64.99	63.17	62.33	69.50	69.50	69.50	69.50	69.36
2038	66.71	63.73	61.30	59.40	58.35	58.88	57.75	61.06	69.50	69.50	69.50	69.50
2039	67.35	64.38	62.20	59.90	57.47	55.41	56.61	59.81	65.93	69.50	69.50	68.41
2040	65.23	62.62	60.11	57.39	55.35	55.43	58.75	67.24	69.50	69.50	69.50	69.50
2041	68.28	66.65	63.66	61.11	58.87	60.76	63.43	68.91	69.50	69.50	69.50	69.50
2042	67.04	64.09	61.72	59.04	56.21	53.34	50.21	46.53	42.12	37.19	30.22	26.70

Table B-2: Flow from Smithfield Dam: EWR and spills (m^3/s)

	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
2013	5.0	4.5	3.3	1.5	13.0	18.3	17.0	43.8	49.5	40.7	52.7	31.1
2014	6.3	1.9	1.3	3.8	3.8	9.8	12.1	37.4	73.8	55.1	45.7	26.2
2015	6.3	2.9	1.4	1.9	2.2	6.7	8.7	31.0	52.7	35.5	34.9	24.2
2016	10.2	13.2	15.5	9.7	11.9	14.7	30.6	34.2	55.8	51.1	37.8	19.8
2017	4.9	2.3	1.6	2.4	2.8	4.0	7.7	38.5	54.7	45.2	30.3	18.3
2018	6.7	2.2	3.9	3.9	1.6	2.2	3.8	6.4	23.4	71.4	45.1	11.6
2019	4.2	3.9	2.6	1.3	2.4	5.9	19.1	27.1	16.2	17.7	20.1	13.0
2020	4.6	1.6	1.3	1.2	0.9	1.2	47.1	76.3	107.8	77.7	31.2	22.9
2021	6.7	9.2	5.1	4.4	4.0	7.6	62.5	85.6	43.5	27.1	23.2	14.6
2022	6.8	13.0	9.6	3.8	1.7	1.3	1.8	4.2	26.2	53.1	40.5	17.6
2023	1.9	3.8	2.9	1.2	1.2	2.6	6.4	11.5	10.7	52.4	29.9	8.7
2024	2.3	1.5	1.0	0.8	0.9	1.4	4.9	7.1	28.7	75.7	35.3	19.3
2025	9.3	3.7	2.6	2.6	2.2	6.3	22.8	57.0	47.6	104.9	70.3	18.0
2026	3.8	2.3	1.5	1.6	2.3	3.0	9.5	24.4	30.8	29.7	36.2	21.6
2027	12.8	20.2	5.9	2.6	2.0	2.9	11.9	80.3	74.0	66.0	38.8	13.9
2028	4.0	1.9	1.3	1.0	0.9	2.2	3.4	6.7	36.3	112.3	77.0	36.9
2029	11.3	3.7	2.0	2.4	2.1	3.0	29.3	88.3	94.4	71.8	36.3	83.5
2030	5.5	12.6	7.2	20.0	11.8	35.0	61.5	57.1	48.4	49.5	45.3	19.4
2031	2.8	2.0	1.6	1.3	2.3	3.0	5.6	4.2	11.7	34.2	67.3	40.1
2032	5.2	2.9	1.3	0.9	0.9	1.3	1.6	3.1	4.9	18.4	9.5	8.1
2033	5.1	2.4	1.2	0.9	0.9	1.3	6.4	8.5	11.3	68.9	58.0	21.0
2034	5.0	3.8	3.0	2.5	1.3	2.5	6.4	32.1	61.9	57.4	51.7	28.0
2035	5.2	3.6	1.5	0.9	0.9	1.9	3.5	6.7	7.4	24.8	32.1	18.8
2036	4.9	2.2	1.2	1.0	1.4	2.0	4.5	11.1	7.5	34.8	83.9	51.5
2037	11.9	3.8	3.0	2.6	2.3	2.4	3.4	20.9	74.7	50.0	13.2	4.5
2038	3.2	1.8	1.1	2.6	2.3	3.0	3.8	8.6	30.2	72.2	31.7	8.0
2039	5.0	3.1	2.0	2.5	2.0	2.2	6.0	8.5	9.8	39.3	21.4	3.7
2040	2.3	1.7	1.3	1.4	2.2	3.0	6.4	12.0	33.2	68.7	47.6	13.0
2041	5.2	3.8	2.9	1.4	2.0	3.0	6.4	9.7	84.6	103.2	36.5	7.0
2042	4.8	3.5	1.8	1.2	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table B-3: Hydropower potential at Smithfield Dam HPP site (MW)

	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
2013	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2014	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2015	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2017	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2018	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2019	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2020	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2021	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2022	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2023	0.4	0.9	0.6	0.3	0.3	0.6	2.7	5.7	6.2	30.4	17.3	5.0
2024	1.3	0.8	0.5	0.4	0.5	0.7	2.5	3.7	16.6	43.9	20.4	11.2
2025	5.4	2.1	1.5	1.4	1.2	3.7	13.2	33.1	27.6	60.8	40.7	10.4
2026	2.2	1.3	0.8	0.8	1.2	1.6	5.5	14.2	17.8	17.2	21.0	12.5
2027	7.4	11.7	3.4	1.4	1.1	1.6	6.9	46.6	42.9	38.3	22.5	8.1
2028	2.3	1.1	0.7	0.5	0.5	1.1	1.7	3.4	21.0	65.1	44.6	21.4
2029	6.5	2.1	1.1	1.3	1.1	1.6	17.0	51.2	54.7	41.6	21.1	48.4
2030	3.2	7.3	4.2	11.6	6.8	20.3	35.6	33.1	28.0	28.7	26.2	11.3
2031	1.6	1.1	0.8	0.7	1.2	1.7	3.2	2.3	6.8	19.8	39.0	23.2
2032	3.0	1.6	0.7	0.5	0.4	0.6	0.8	1.4	2.3	9.2	5.3	4.7
2033	2.9	1.3	0.6	0.5	0.4	0.6	3.2	4.5	6.6	39.9	33.6	12.1
2034	2.9	2.1	1.7	1.4	0.7	1.3	3.5	18.6	35.9	33.3	29.9	16.2
2035	3.0	2.0	0.8	0.5	0.4	0.9	1.7	3.2	3.8	13.7	18.6	10.9
2036	2.8	1.2	0.6	0.5	0.7	1.0	2.1	5.7	4.1	20.1	48.6	29.9
2037	6.9	2.2	1.6	1.4	1.2	1.3	1.8	12.1	43.3	29.0	7.6	2.6
2038	1.8	0.9	0.5	1.3	1.1	1.5	1.8	4.4	17.5	41.8	18.4	4.6
2039	2.8	1.7	1.0	1.2	1.0	1.0	2.9	4.2	5.4	22.8	12.4	2.1
2040	1.3	0.9	0.6	0.7	1.0	1.4	3.1	6.7	19.3	39.8	27.6	7.5
2041	3.0	2.1	1.5	0.7	1.0	1.5	3.4	5.6	49.0	59.8	21.2	4.1
2042	2.7	1.9	0.9	0.6	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Appendix C

Initial conceptual design of turbines for Hydropower Plants

1 BAYNESFIELD HYDRO POWER PLANT

1.1 TURBINE DESIGN

1.1.1 Operating conditions

The flow and pressure conditions experienced at the Baynesfield HPP site have been discussed in detail previously in the report. For ease of reference, a summary of these operating conditions for designing the turbine are given in **Table 1.1** below.

Table 1.1: Operating conditions for turbine design at Baynesfield HPP

Level	Gross head (m)	Net head (m)	Flow (m^3/s)
Minimum	38.0	30.5	7.40
Average (rated)	52.0	41.7	8.65
Maximum (FSL)	58.0	51.1	7.05

The waterway leading up to the HPP comprises a 32.5 km long concrete lined tunnel with a diameter of 3.5 m, followed by a 5 km steel pipe with a diameter of 2.6 m. An additional point to note is that the transfer volumes in the conveyance tunnel to the Baynesfield HPP begin with approximately 3.6 m^3/s in 2015 and peak at approximately 8.65 m^3/s in 2043.

1.1.2 Turbine type selection

The turbine types that were considered were Pelton, Turgo and Francis. The Pelton and Turgo type turbines have a favourable mechanism to shut off the water supply – they employ a slow moving needle to limit the water hammer, together with a fast moving jet deflector to limit the duration of excessive turbine acceleration. However, these turbine types are not suitable for the large flow and low head conditions of this site because of the resulting low rated speed and large physical dimensions of the turbines. For this reason, the Francis type turbine was selected due to its suitability to the flow and head requirements, with a bypass from the penstock to control water hammer (discussed in detail in **Section 1.2**). This selection corresponds to the design layout graph as by Mosonyi (1957).

1.1.3 Turbine configuration

The possible turbine configurations that were investigated are as follows:

- One large set producing full load
- Two small sets producing full load
- One small set installed initially to meet initial load (two options)

The first option was to have one large turbine installed initially, which would produce the full load of 3 MW. This would perform at a rated point of 41.7 m head and 8.65 m^3/s flow.

The second option was to have two small turbines installed initially which would also be able to produce the full load at the outset. The rated point for each of the turbines would be 41.7 m head and 4.33 m^3/s flow, producing 1.5 MW of power each. Due to the fact that one turbine is more efficient than two for all flows, this option is not the most appropriate.

The third option involved the installation of only one of these two small turbines initially because of the initially lower transfer volumes. The capacity of this turbine would be 1.5 MW as mentioned above. This would require an associated rated point with a head of 50.1 m and a flow of 3.6 m^3/s. The initial flow in the tunnel will be 3.6 m^3/s, meaning that the above-mentioned rated point would only just be satisfied by these flow conditions and would therefore not be suitable. In addition, the costs associated with installing turbines in phases are high, and therefore this option is unsuitable.

A fourth option was to initially install a turbine with a capacity larger than 1.5 MW to comfortably meet the initially lower transfer volumes, and then install a larger turbine when the transfer volumes require it. For the same reason mentioned above regarding cost, this option is also not suitable.

A single large Francis turbine was selected for implementation for the following reasons:

- The maximum flow is reached in 2040, which is 20 years from commencement. This timeline is relatively short.
- One turbine is more efficient than two for all flows.

The operating range of this machine is shown in **Figure 1.1** below, and its characteristics are as follows:

- Rated head: 41.7 m
- Rated flow: 8.65 m^3/s
- Rated speed: 428.6 RPM
- Runner outlet diameter: 1.1 m
- Spiral inlet diameter: 1.25 m
- Suction head: Positive 1.9 m
- Approximate mass of turbine: 30.0 ton

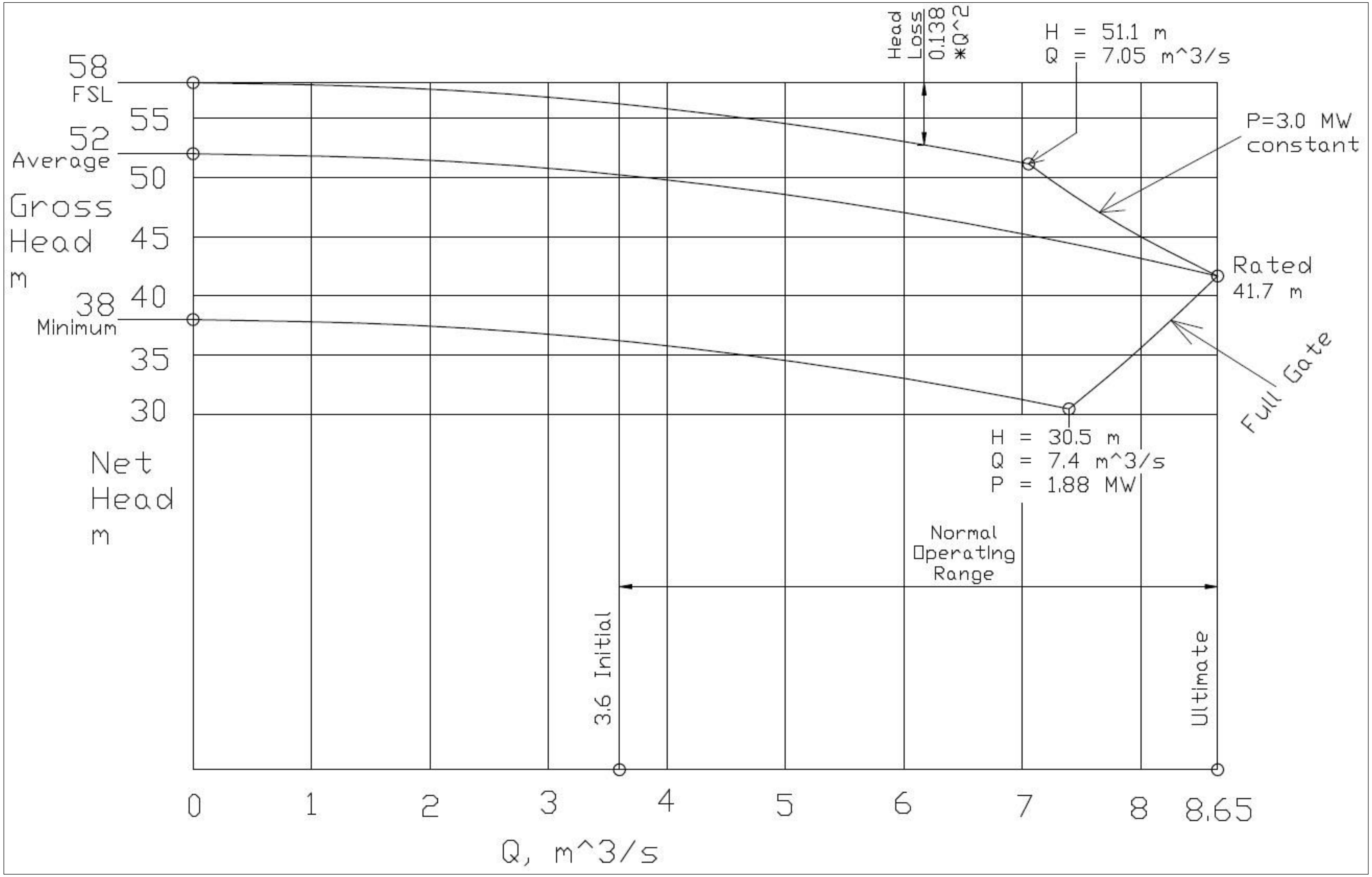

Figure 1.1: Operating range of single turbine at Baynesfield HPP

1.2 TURBINE AND TUNNEL DESIGN FOR WATER HAMMER

In order to design the turbine and tunnel for water hammer, the most adverse conditions of pressure rise and turbine speed rise had to be determined and limited to approximately 50%. This value of 50% speed rise is usually adopted as it results in a pressure rise of 50% or less; however, this would be economically optimised in the final design.

Pressure rise is caused when moving water is brought to a stop, causing a pressure surge wave to propagate through the conduit. This pressure rise in the penstock could cause severe damage. The conveyance structure and powerhouse must be designed to withstand these pressure surges.

Turbine speed rise is caused when the load is suddenly removed from the turbine-generator unit (e.g. due to a fault on the transmission line), allowing the runner to rotate rapidly. This can cause great damage if the speed increase is too large or if it continues for too long. Speed rise is controlled by the mass moment of inertia of the rotating parts, expressed as the flywheel effect, or GD^2, where:

- G represents the total mass of the rotating parts, which in this case is the generator rotor and the flywheel
- D represents the diameter of gyration of the rotating parts

Normally, the turbine-generator is the principal contributor and values for the minimum, average and maximum natural inertia are considered.

1.2.1 Normal operation

During normal operation, speed rise does not need to be considered because there will always be load on the turbine-generator unit. For this reason, the limiting criterion was to restrict the pressure rise to 50% during closure of the system. The full stroke operating time for closure of the guide apparatus was calculated to be in the order of 200 s to meet this criterion. This long duration is due to the long penstock leading up to the turbine.

In power systems, any discrepancy between power production and consumption causes a change in the frequency from the minimum (Peydayesh & Baldick, 2012). Because there are numerous instantaneous changes in power production and consumption, the frequency must be constantly monitored and regulated, and the regulation should be done with fast response. Due to the long full stroke operating time of the guide apparatus, the guide vanes are limited to opening and closing slowly. For this reason, the turbine is not suitable for fast response frequency regulation, and regulation of generated power must be done by means of the load limiter. The load limiter of the turbine-generator restricts its maximum allowable load.

1.2.2 Emergency shutdown

In the case of an emergency shutdown, the load on the turbine-generator would be rejected and therefore the turbine speed rise needed to be considered. The standard solution would be to have a 50% speed rise for a short duration, which would be achieved by a fast closure of the guide apparatus. However, with the long closure time duration required for limiting pressure rise, the turbine would be subjected to speed rises for an unacceptably long duration. For this reason, a bypass will be needed in order to be able to close the guide vanes quickly, but still bring the flow of water to a complete stop over a long duration. Another reason for the adoption of the bypass is that the conventional solution of a surge tank will not be suitable for this long waterway, as it would have to be extremely high.

The system will operate as follows: As the guide vanes start to close, the sleeve valve controlling flow through the bypass will start to open. This will be achieved by having the guide apparatus and the sleeve valve both controlled by servo-motors operated with oil pressure from the same source. From a fully open position, it will take the guide vanes 22 s to close fully, while the sleeve valve opens, to limit pressure rise to approximately 50%. For full load rejection (rejection of load while system is operating at the rated flow), the operating time of the sleeve valve will be equal to the operating time of the guide vanes. For part load rejection (rejection of load while system is operating at lower than the rated flow, meaning that the guide vanes are not fully open), the operating time of the sleeve valve will remain the same as for the full load rejection (i.e. 22 s). For example, if the turbine is operating at 80% load (meaning that the guide vanes are 80% open) when there is a shutdown, the sleeve valve will open to 80% while the guide vanes close, and then it will continue to open until fully open. This will simplify the control of operation to suit the full range of guide vane openings. Once the sleeve valve is fully open, it will then close fully over 200 s, as determined for normal operation to limit pressure rise.

The bypass will be via an alternative bifurcation from the penstock, as opposed to discharge via an opening in the spiral casing of the turbine. This is because of the disturbed flow conditions that would arise in the turbine, causing reduction in the turbine efficiency and possibly vibrations. The sleeve valve must not be opened during start-up, loading and normal operation of the hydropower plant, as this would cause unacceptable transient flow and head conditions.

The ideal for limiting water hammer would be to maintain a constant combined flow during the closing and opening of the guide vanes and sleeve apparatus respectively. This is however not possible due to the large variance in discharge factors for the sleeve valve over its range of opening sizes, leading to a variation of head and flow over the operating range. In turn, this causes transient pressure and head rises over the operating range. Consequently, a sleeve valve diameter resulting in the smallest pressure and speed rise for the operating range had to be iteratively calculated.

For this calculation, the pressure rise and speed rise were calculated for different combinations of sleeve valve diameters and load rejection percentages. The load rejection percentages that resulted in the maximum pressure rise and speed rise (independently) per sleeve valve diameter were considered as the most critical cases. These pressure and speed rises per sleeve valve diameter were then compared, and the diameter producing the lowest rises was selected.

For pressure rise, a full load closing time of 22 s was used. This time was previously calculated as an initial approximation to limit pressure rise to 50%. For speed rise, the minimum, average and maximum natural inertia of the turbine-generator was used to determine whether a flywheel would be required. It was found that the natural inertia is not sufficient to limit the speed rise to 50%, and a flywheel of 11.2 ton is required to provide a combined GD^2 of 114 ton.m^2 for the minimum GD^2 of the generator available. Because of the flywheel, the hydro-generating set has to be of the horizontal type. The sleeve valve diameter producing the lowest rises was 0.65 m, as shown in **Table 1.2.**

Table 1.2: Sleeve valve diameter selection criteria

Sleeve valve diameter (m)	0.6	0.65	0.7
Guide vane closing time (s)	26	**22**	38
Mass of flywheel (ton)	11.6	**11.2**	21.8
Speed rise (%)	47.7	**49.4**	48.7
Pressure rise (%)	-	**58.4**	-

Table 1.3 below shows the actual pressures and speeds resulting from the selected sleeve valve diameter of 0.65 m.

Table 1.3: Pressure and speed rise at Baynesfield HPP

Component	Rise (%)	Actual value of pressure or speed
Pressure	58.4	91.9 m
Speed	49.4	640 RPM

1.3 LAYOUTS

The initial layout of Baynesfield HPP powerhouse is shown in **Figure 1.2** below.

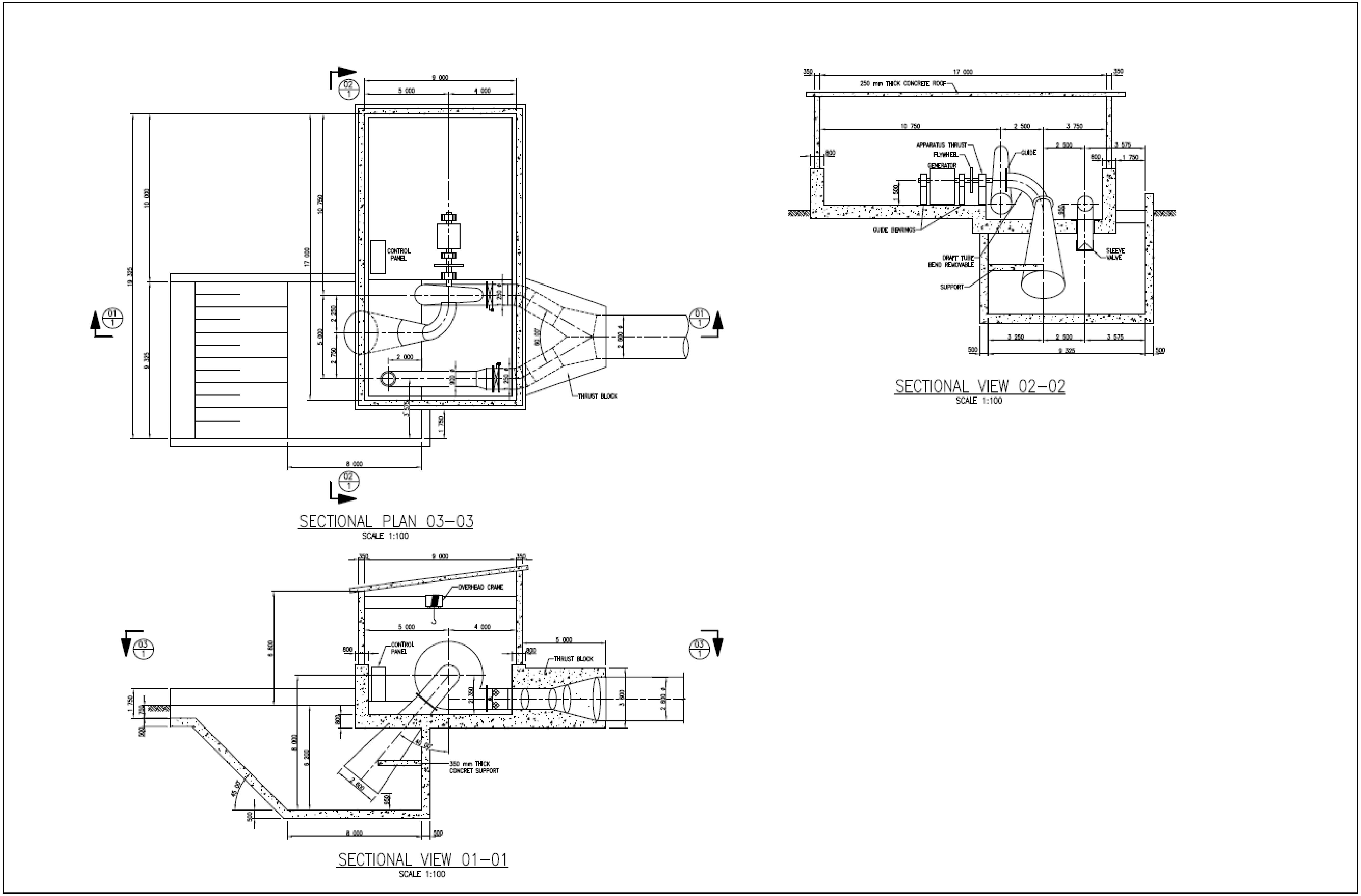

Figure 1.2: Baynesfield HPP layout

2 SMITHFIELD DAM HYDROPOWER PLANT

2.1 TURBINE DESIGN

2.1.1 Operating conditions

The flow and pressure conditions experienced at the Smithfield Dam HPP sites have been discussed in detail earlier in the report. For ease of reference, a summary of these operating conditions for designing the turbine are given in **Table 2.1** below.

Table 2.1: Operating conditions for turbine design at Smithfield Dam HPP

Level	Gross head (m)	Net head (m)	Flow (m^3/s)
Minimum	51.0	50.0	4.43
Average (rated)	65.0	64.0	5.00
Maximum (FSL)	71.0	70.2	4.56

Because this HPP is immediately below the dam, a short penstock of 25 m length and 1.5 m diameter has been assumed.

2.1.2 Turbine type selection

For the same reasons as discussed for the Baynesfield HPP, the Francis type turbine should be selected. However, the turbine configuration at Smithfield Dam HPP does not require a bypass as is used at Baynesfield HPP, which is discussed in **Section 2.2**.

2.1.3 Turbine configuration

Because the Smithfield Dam HPP will be driven by spills and ecological releases from the dam, it will not experience low flows initially and gradually increasing flows as is the case with the Baynesfield HPP. For this reason, the turbine configuration will be a single turbine installed for the duration of the project. The full load of this configuration would be 2.66 MW, operating at a rated point of 64 m head and 5 m^3/s flow. The operating range of the turbine is shown in **Figure** 2.1. The characteristics will be as follows:

- Rated head: 64.0 m
- Rated flow: 5.0 m^3/s
- Rated speed: 600 RPM
- Runner outlet diameter: 0.84 m
- Spiral inlet diameter: 0.92 m
- Suction head: Positive 1.60 m
- Approximate mass of turbine: 19.9 ton

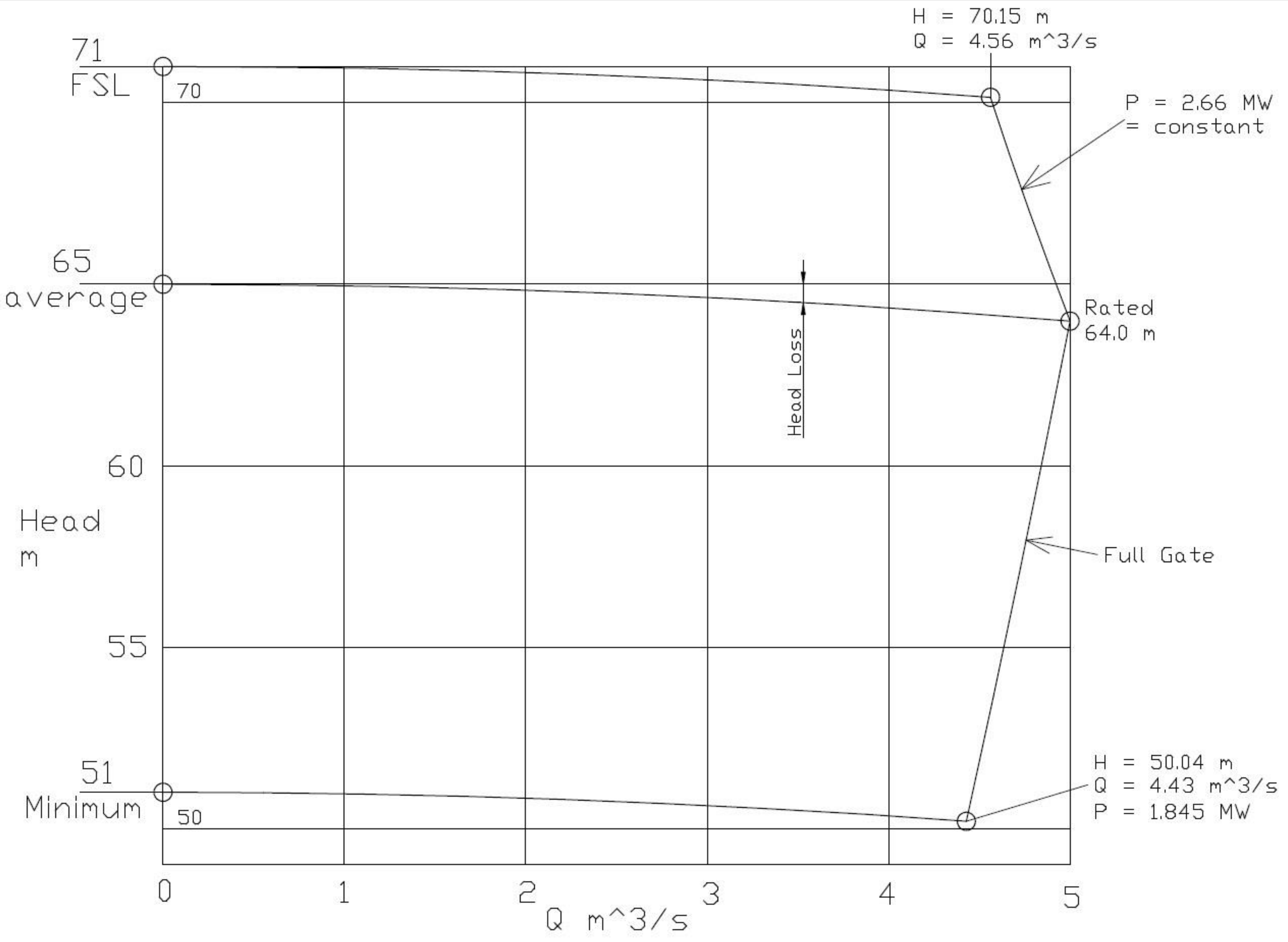

Figure 2.1: Operating range of single turbine at Smithfield Dam HPP

2.2 TURBINE AND TUNNEL DESIGN FOR WATER HAMMER

Because of the short penstock length, the standard solution for fast response frequency regulation can be adopted, i.e. regulation will be by means of the guide apparatus and no bypass is required. For this reason, the design is simplified in that the closure of the system will operate in the same manner for normal operation as well as emergency shutdown.

For a reasonable guide vane closing time of 10 s, the pressure rise is limited to 2.3%. This short time is an acceptable duration for speed rise, and confirms the statement above that fast response frequency regulation by the guide apparatus can be adopted.

As was done at the Baynesfield HPP site, the minimum, average and maximum natural GD^2 values of the turbine-generator were considered to determine the speed rise and whether a flywheel would be needed. In the case of the maximum GD^2, the turbine-generator will limit the speed rise to 50%. However, this case is unlikely, and the average or minimum GD^2 values show that a flywheel weighing 3.6 ton is needed to limit the speed rise to 50%. This results in a combined GD^2 of approximately 8.7 ton.m^2 for the generator and flywheel. Due to the presence of a flywheel, the hydro-generating set will again have to be of the horizontal type.

Table 2.2: Pressure and speed rise at Smithfield Dam HPP

Component	Rise (%)	Actual value of pressure or speed
Pressure	2.8	73 m
Speed	50	900 RPM

2.3 LAYOUTS

The initial layout of Baynesfield HPP powerhouse is shown in **Figure 2.2** below.

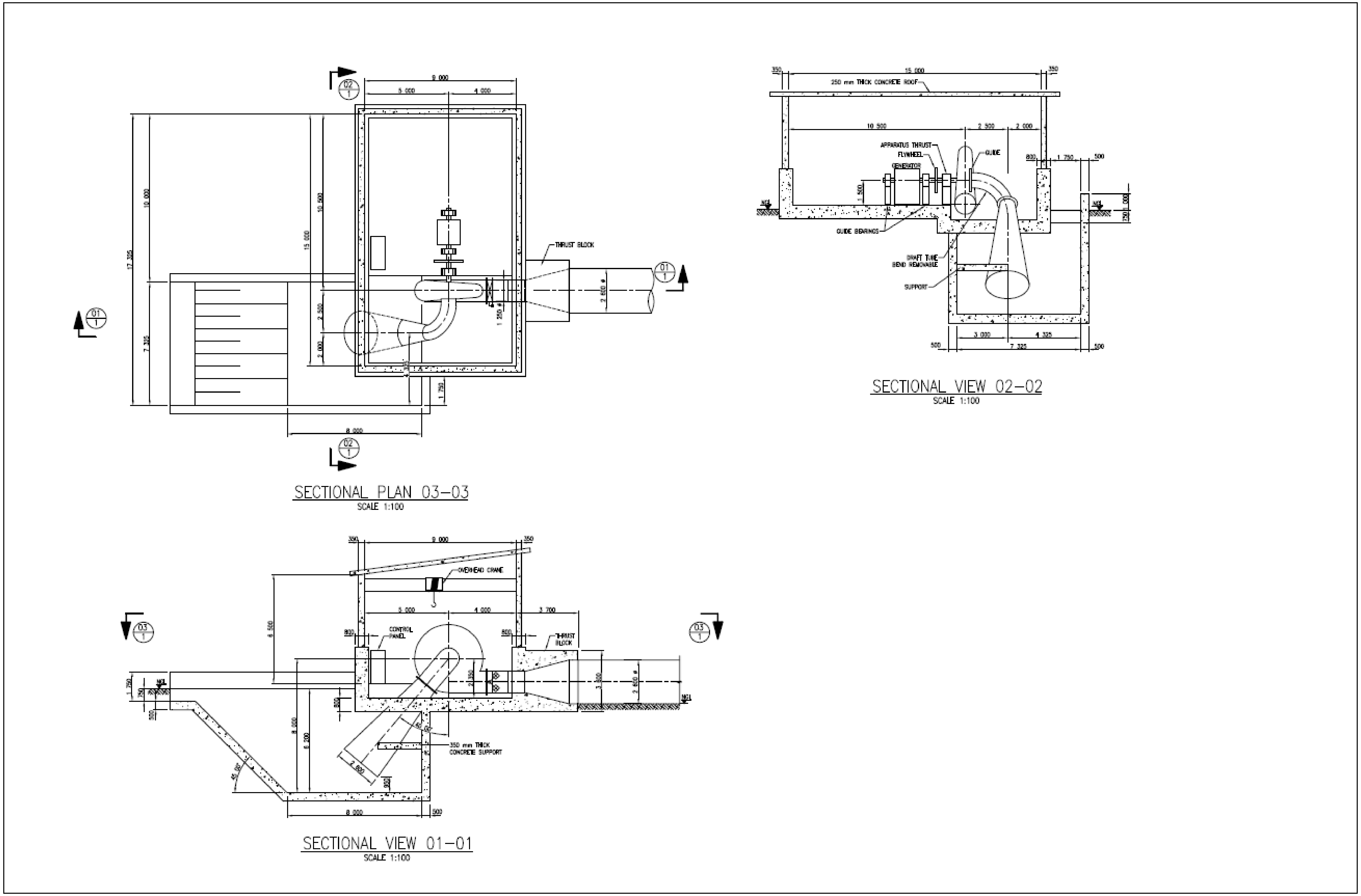

Figure 2.2: Smithfield Dam HPP

Appendix D

NPV calculations

Table D-1: Results

Item	Baynesfield HPP alternative 1: Power wheeled into national grid for use at WTW		Smithfield Dam HPP alternative 1: Power wheeled into national grid for operation of dam (0.5 MW)		Baynesfield HPP alternative 2: Power wheeled into national grid for operation of dam (2.6 MW)	
	Cost (R'000)	Revenue (R'000)	Cost (R'000)	Revenue (R'000)	Cost (R'000)	Revenue (R'000)
NPV 6%	35 970	58 575	14 800	15 243	30 592	62 489
NPV8%	28 013	38 379	11 554	10 341	23 841	42 394
NPV10%	22 208	25 874	9 178	7 208	18 910	29 548
Net benefit 6%	**22 605**		**443**		**31 896**	
Net benefit 8%	**10 366**		**-1 213**		**18 553**	
Net benefit 10%	**3 666**		**-1 970**		**10 638**	

Table D-2: NPVs

Item	Baynesfield HPP alternative 1: Power wheeled into national grid for use at WTW		Smithfield Dam HPP alternative 1: Power wheeled into national grid for operation of dam (0.5 MW)		Baynesfield HPP alternative 2: Power wheeled into national grid for operation of dam (2.6 MW)	
Civil works	3 748		2 542		3 748	
Hydro-mechanical	36 968		12 647		30 082	
Transmission line	2 075		2 750		2 750	
Total	**42 791**		**17 939**		**36 580**	
Hydropower potential (MW)	**0.5 – 2.5**		**0.5**		**2.6**	
Year	**Cost (R'000)**	**Revenue (R'000)**	**Cost (R'000)**	**Revenue (R'000)**	**Cost (R'000)**	**Revenue (R'000)**
2013	0	0	0	0	0	0
2014	0	0	0	0	0	0
2015	0	0	0	0	0	0
2016	0	0	0	0	0	0
2017	0	0	0	0	0	0
2018	0	0	0	0	0	0
2019	0	0	0	0	0	0
2020	0	0	0	0	0	0
2021	0	0	0	0	0	0
2022	42 791	0	17 939	0	36 580	0
2023	1 571	1 983	622	1 983	1 323	8 130
2024	1 571	6 081	622	1 983	1 323	8 130
2025	1 571	6 286	622	1 983	1 323	8 130
2026	1 571	6 491	622	1 983	1 323	8 130
2027	1 571	6 696	622	1 983	1 323	8 130
2028	1 571	6 901	622	1 983	1 323	8 130
2029	1 571	7 105	622	1 983	1 323	8 130
2030	1 571	7 310	622	1 983	1 323	8 130
2031	1 571	7 515	622	1 983	1 323	8 130
2032	1 571	7 720	622	1 983	1 323	8 130
2033	1 571	7 925	622	1 983	1 323	8 130
2034	1 571	8 130	622	1 983	1 323	8 130
2035	1 571	8 335	622	1 983	1 323	8 130
2036	1 571	8 540	622	1 983	1 323	8 130
2037	1 571	8 745	622	1 983	1 323	8 130
2038	1 571	8 950	622	1 983	1 323	8 130
2039	1 571	9 154	622	1 983	1 323	8 130
2040	1 571	9 359	622	1 983	1 323	8 130
2041	1 571	9 564	622	1 983	1 323	8 130
2042	1 571	9 769	622	1 983	1 323	8 130
2043	1 571	9 974	622	1 983	1 323	8 130

2044	1 571	10 179	622	1 983	1 323	8 130
2045	1 571	10 179	622	1 983	1 323	8 130
2046	1 571	10 179	622	1 983	1 323	8 130
2047	1 571	10 179	622	1 983	1 323	8 130
2048	1 571	10 179	622	1 983	1 323	8 130
2049	1 571	10 179	622	1 983	1 323	8 130
2050	1 571	10 179	622	1 983	1 323	8 130
2051	1 571	10 179	622	1 983	1 323	8 130
2052	1 571	10 179	622	1 983	1 323	8 130
NPV 6%	**35 970**	**58 575**	**14 800**	**15 243**	**30 592**	**62 489**
NPV 8%	**28 013**	**38 379**	**11 554**	**10 341**	**23 841**	**42 394**
NPV 10%	**22 208**	**25 874**	**9 178**	**7 208**	**18 910**	**29 548**

Table D-3: Baynesfield HPP alternative 1 – Revenue

Year			2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043 - 2052
Energy associated with wheeled energy (MW)			0.50	1.50	1.55	1.60	1.65	1.70	1.75	1.80	1.85	1.90	1.95	2.00	2.05	2.10	2.15	2.20	2.25	2.30	2.35	2.40	2.45
kWh/year (24 hour day)			4 380 000	13 140 000	13 578 000	14 016 000	14 454 000	14 892 000	15 330 000	15 768 000	16 206 000	16 644 000	17 082 000	17 520 000	17 958 000	18 396 000	18 834 000	19 272 000	19 710 000	20 148 000	20 586 000	21 024 000	21 462 000
Maximum achievable wheeled savings	**c/kWh**	**h/year**	**R'000/year**																				
High demand season (Jun - Aug):																							
Peak consumption	201.56	325	328	983	1 015	1 048	1 081	1 114	1 146	1 179	1 212	1 245	1 277	1 310	1 343	1 376	1 408	1 441	1 474	1 507	1 539	1 572	1 605
Standard consumption	61.06	806	246	738	763	787	812	837	861	886	910	935	960	984	1 009	1 034	1 058	1 083	1 107	1 132	1 157	1 181	1 206
Off-peak consumption	33.15	1 053	175	524	541	559	576	593	611	628	646	663	681	698	716	733	750	768	785	803	820	838	855
Low demand season (Sept - May):																							
Peak consumption	65.75	975	321	962	994	1 026	1 058	1 090	1 122	1 154	1 186	1 218	1 250	1 282	1 314	1 346	1 378	1 410	1 442	1 474	1 506	1 539	1 571
Standard consumption	45.25	2 418	547	1 641	1 696	1 751	1 805	1 860	1 915	1 969	2 024	2 079	2 134	2 188	2 243	2 298	2 352	2 407	2 462	2 517	2 571	2 626	2 681
Off-peak consumption	28.70	3 159	453	1 360	1 405	1 451	1 496	1 541	1 587	1 632	1 677	1 723	1 768	1 813	1 859	1 904	1 949	1 995	2 040	2 085	2 131	2 176	2 221
Total savings	**-**	**-**	**2 069**	**6 207**	**6 414**	**6 621**	**6 828**	**7 035**	**7 242**	**7 449**	**7 656**	**7 862**	**8 069**	**8 276**	**8 483**	**8 690**	**8 897**	**9 104**	**9 311**	**9 518**	**9 725**	**9 931**	**10 138**
Annual charges payable by generator	**Amount**	**Unit**	**R'000/year**																				
Network access charge	0	R/MW/month	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Reliability service charge	0.27	c/kWh	12	35	37	38	39	40	41	43	44	45	46	47	48	50	51	52	53	54	56	57	58
Service charge	126.23	R/day	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46
Administration charge	54.18	R/day	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Network charge	1.38	R/kW/month	8	25	26	26	27	28	29	30	31	31	32	33	34	35	36	36	37	38	39	40	41
Total charges	**-**	**-**	**86**	**126**	**128**	**130**	**132**	**134**	**136**	**138**	**140**	**142**	**144**	**146**	**148**	**150**	**152**	**154**	**156**	**158**	**160**	**162**	**164**
Net revenue (maximum savings less charges)			**R'000/year**																				
Total net revenue			**1 983**	**6 081**	**6 286**	**6 491**	**6 696**	**6 901**	**7 105**	**7 310**	**7 515**	**7 720**	**7 925**	**8 130**	**8 335**	**8 540**	**8 745**	**8 950**	**9 154**	**9 359**	**9 564**	**9 769**	**9 974**

Table D-4: Smithfield Dam HPP alternatives 1 and 2 – Revenue

		Year	All	All
Energy associated with wheeled energy (MW)			0.5	2.0
kWh/year (24 hour day)			4 380 000	17 520 000
Maximum achievable wheeled savings	**c/kWh**	**h/year**	**R'000/year**	
High demand season (Jun - Aug):				
Peak consumption	201.56	325	328	1 310
Standard consumption	61.06	806	246	984
Off-peak consumption	33.15	1 053	175	698
Low demand season (Sept - May):				
Peak consumption	65.75	975	321	1 282
Standard consumption	45.25	2 418	547	2 188
Off-peak consumption	28.70	3 159	453	1 813
Total savings	**-**	**-**	**2 069**	**8 276**
Annual charges payable by generator	**Amount**	**Unit**	**R'000/year**	
Network access charge	0	R/MW/month	0	0
Reliability service charge	0.27	c/kWh	12	47
Service charge	126.23	R/day	46	46
Administration charge	54.18	R/day	20	20
Network charge	1.38	R/kW/month	8	33
Total charges	**-**	**-**	**86**	**146**
Net revenue (maximum savings less charges)			**R'000/year**	
Total net revenue			**1 983**	**8 130**

Table D-5: Smithfield Dam HPP alternative 3 – Revenue

Maximum achievable wheeled savings	c/kWh	h/year	R'000/year
High demand season (Jun - Aug):			
Peak consumption	201.56	325	20
Standard consumption	61.06	806	15
Off-peak consumption	33.15	1 053	10
Low demand season (Sept - May):			
Peak consumption	65.75	975	19
Standard consumption	45.25	2 418	33
Off-peak consumption	28.70	3 159	27
Total net revenue	**-**	**-**	**124**

Table D-6: Megaflex tariffs used

Megaflex tariff

Local authority

Transmission zone	Voltage	Active energy charge [c/kWh] – High demand season [Jun - Aug] Peak	VAT incl	Standard	VAT incl	Off Peak	VAT incl	Low demand season [Sep - May] Peak	VAT incl	Standard	VAT incl	Off Peak	VAT incl	Transmission network	VAT incl
≤ 300km	< 500V	**209.42**	*238.74*	**63.72**	*72.64*	**34.78**	*39.65*	**68.57**	*78.17*	**47.32**	*53.94*	**30.16**	*34.38*	**R 5.83**	*R 6.65*
	≥ 500V & < 66kV	**206.12**	*234.98*	**62.45**	*71.19*	**33.91**	*38.66*	**67.24**	*76.65*	**46.28**	*52.76*	**29.36**	*33.47*	**R 5.32**	*R 6.06*
	≥ 66kV & ≤ 132kV	**199.61**	*227.56*	**60.47**	*68.94*	**32.83**	*37.43*	**65.11**	*74.23*	**44.82**	*51.09*	**28.43**	*32.41*	**R 5.18**	*R 5.91*
	> 132kV	**188.13**	*214.47*	**56.99**	*64.97*	**30.95**	*35.28*	**61.37**	*69.96*	**42.24**	*48.15*	**26.80**	*30.55*	**R 6.55**	*R 7.47*
> 300km and ≤ 600km	< 500V	**211.12**	*240.68*	**63.96**	*72.91*	**34.73**	*39.59*	**68.88**	*78.52*	**47.41**	*54.05*	**30.08**	*34.29*	**R 5.87**	*R 6.69*
	≥ 500V & < 66kV	**208.18**	*237.33*	**63.07**	*71.90*	**34.25**	*39.05*	**67.92**	*77.43*	**46.74**	*53.28*	**29.65**	*33.80*	**R 5.38**	*R 6.13*
	≥ 66kV & ≤ 132kV	**201.56**	*229.78*	**61.06**	*69.61*	**33.15**	*37.79*	**65.75**	*74.96*	**45.25**	*51.59*	**28.70**	*32.72*	**R 5.22**	*R 5.95*
	> 132kV	**190.00**	*216.60*	**57.56**	*65.62*	**31.25**	*35.63*	**61.97**	*70.65*	**42.66**	*48.63*	**27.06**	*30.85*	**R 6.62**	*R 7.55*
> 600km and ≤ 900km	< 500V	**213.23**	*243.08*	**64.59**	*73.63*	**35.07**	*39.98*	**69.55**	*79.29*	**47.87**	*54.57*	**30.37**	*34.62*	**R 5.94**	*R 6.77*
	≥ 500V & < 66kV	**210.27**	*239.71*	**63.70**	*72.62*	**34.59**	*39.43*	**68.60**	*78.20*	**47.20**	*53.81*	**29.95**	*34.14*	**R 5.42**	*R 6.18*
	≥ 66kV & ≤ 132kV	**203.62**	*232.13*	**61.68**	*70.32*	**33.49**	*38.18*	**66.41**	*75.71*	**45.71**	*52.11*	**28.99**	*33.05*	**R 5.27**	*R 6.01*
	> 132kV	**191.91**	*218.78*	**58.14**	*66.28*	**31.57**	*35.99*	**62.61**	*71.38*	**43.09**	*49.12*	**27.34**	*31.17*	**R 6.71**	*R 7.65*
> 900km	< 500V	**215.37**	*245.52*	**65.25**	*74.39*	**35.43**	*40.39*	**70.26**	*80.10*	**48.35**	*55.12*	**30.68**	*34.98*	**R 5.97**	*R 6.81*
	≥ 500V & < 66kV	**212.37**	*242.10*	**64.33**	*73.34*	**34.93**	*39.82*	**69.27**	*78.97*	**47.67**	*54.34*	**30.24**	*34.47*	**R 5.48**	*R 6.25*
	≥ 66kV & ≤ 132kV	**205.66**	*234.45*	**62.30**	*71.02*	**33.83**	*38.57*	**67.08**	*76.47*	**46.17**	*52.63*	**29.29**	*33.39*	**R 5.30**	*R 6.04*
	> 132kV	**193.80**	*220.93*	**58.74**	*66.96*	**31.92**	*36.39*	**63.25**	*72.11*	**43.54**	*49.64*	**27.64**	*31.51*	**R 6.76**	*R 7.71*

Voltage	Distribution network charges – Network access charge [R/kVA/m]	VAT incl	Network demand charge [R/kVA/m]	VAT incl	Urban low voltage subsidy charge [R/kVA/m]	VAT incl
< 500V	**R 11.63**	*R 13.26*	**R 22.05**	*R 25.14*	**R 0.00**	*R 0.00*
≥ 500V & < 66kV	**R 10.67**	*R 12.16*	**R 20.23**	*R 23.06*	**R 0.00**	*R 0.00*
≥ 66kV & ≤ 132kV	**R 3.81**	*R 4.34*	**R 7.05**	*R 8.04*	**R 9.39**	*R 10.70*
> 132kV	**R 0.00**	*R 0.00*	**R 0.00**	*R 0.00*	**R 9.39**	*R 10.70*

Voltage	Reliability service charge	VAT incl
< 500V	**0.27**	*0.31*
≥ 500V & < 66kV	**0.26**	*0.30*
≥ 66kV & ≤ 132kV	**0.25**	*0.29*
> 132kV	**0.23**	*0.26*

Customer categories	Service charge [R/account/day]	VAT incl	Administration charge [R/POD/day]	VAT incl
>1 MVA	**R 132.88**	*R 151.48*	**R 59.89**	*R 68.27*
Key customers	**R 2 603.95**	*R 2 968.50*	**R 83.16**	*R 94.80*

Reactive energy charge [c/kVArh] High season	VAT incl	Low season	VAT incl
9.35	*10.66*	**0.00**	*0.00*

Electrification and rural network subsidy charge [c/kWh] All seasons	VAT incl
5.17	*5.89*