The Orange-Senqu River Commission (ORASECOM)

Sharing the Water Resources of the Orange-Senqu River Basin

Botswana | Lesotho | Namibia | South Africa

Contract No.: P-Z1-EAZ-048/CS/01

Preparation of Climate Resilient Water Resources Investment Strategy & Plan and Lesotho-Botswana Water Transfer Multipurpose Transboundary Project

PRE-FEASBILITY REPORT PHASE 1

Component III

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FINAL REPORT
Revision 6

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Prepared by

PREPARATION OF CLIMATE RESILIENT WATER RESOURCES INVESTMENT STRATEGY & PLAN AND LESOTHO-BOTSWANA WATER TRANSFER MULTIPURPOSE TRANSBOUNDARY PROJECT

COMPONENT III

PRE-FEASIBILITY REPORT PHASE 1

Validation of Water Requirements and Identification of Options

Prepared for

Orange-Senqu River Commission (ORASECOM)

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PREPARATION OF CLIMATE RESILIENT WATER RESOURCES INVESTMENT STRATEGY & PLAN AND LESOTHO-BOTSWANA WATER TRANSFER MULTIPURPOSE TRANSBOUNDARY PROJECT

COMPONENT III

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TABLE OF REPORTS

Reports submitted	ORASECOM Selected Numbering
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Core Scenario Update Report Component I	ORASECOM 003/2019
Core Scenario Supporting Report: Water Requirements and Return flows Component I	ORASECOM 004/2019
Core Scenario Supporting Report: Water Conservation, Water Demand management and Re-use Report Component I	ORASECOM 005/2019
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Pre-feasibility report Phase 2 Report Component III (Technical Pre-Feasibility of the Dam and Conveyance System)	ORASECOM 015/2019
Lesotho-Botswana water transfer multipurpose transboundary project Component IV - Feasibility Phase	
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EXECUTIVE SUMMARY

The Southern African Development Community (SADC) has adopted the principle of basin–wide management of the water resources for sustainable and integrated water resources development, guided by a basin level Integrated Water Resources Management (IWRM).

To enhance the objectives of integrated water resources development and management in the region, the Orange–Senqu River Basin Commission (ORASECOM) was established by the Governments of the four States for managing the transboundary water resources of the Orange-Senqu River basin and promoting its beneficial development for socio-economic wellbeing and safeguarding of the basin environment. The Lesotho-Botswana Water Transfer Scheme was envisaged to be able to contribute to the Botswana water requirements up to 2050, with additional supply to various users in Lesotho and South Africa along the conveyance.

The objective of this study as stated in the Terms of Reference is the selection of two dam sites, on the Makhaleng river, and two conveyance routes to transfer water to Lobatse or Gaborone, in Botswana, to be investigated in more detail during the second phase of the pre-feasibility study.

Net Water Requirements (2050)

The projected net water requirements for Botswana in 2050 range from approximately 59 million m^3/a to 136 million m^3/a for the low scenario and high scenario respectively. These demand estimates exclude any water treatment or conveyance losses which may or may not have to be taken into account depending upon the type of conveyance (full pipeline or mixed pipeline and canal) to be selected during Phase 2 of the study.

The estimated allocation to South Africa from the pipeline as originally proposed was approximately 18 million m^3/a which will cover various small demand centres up to the year 2050. An additional option of supplying water to Bloemfontein from the pipeline was also raised in discussions although this has not been agreed to or confirmed. Should the Bloemfontein demand be included, it would add an additional 43 million m^3/a at 2030 development levels. It should be noted that the Bloemfontein allocation is already included as part of the demand being supported from the Orange River Project although the transfer infrastructure from Gariep Dam to Bloemfontein has yet to be developed. For the full pipeline option, the following scenarios and related gross demands were considered:

- **High Scenario.** The total gross urban, mining, and industrial water requirement, including losses, is **199 million m^3/a** of which approximately 80% of the water requirement is for Botswana with approximately 10% each for South Africa and

Lesotho. These demands were taken from the Reconnaissance Phase report undertaken for Lesotho/Botswana by BIGEN and updated.

- **Low Scenario.** The total gross urban, mining, and industrial water requirement, including losses, is **111 million m³/a** of which approximately 60% of the water requirement is for Botswana with about 20% each for South Africa and Lesotho. Subsequent discussions between the basin states have indicated that the Low Demand Scenario will not be taken forward to Phase 2 of the Pre-feasibility Study.

The total potential irrigable land below Makhaleng Dam at site S2 is 9 500 hectares, which equates to a water requirement of approximately **84 million m³/a**. The estimated net water requirement to be supplied to Lesotho from the pipeline is estimated to be 19 million m³/a at 2050 development levels.

Water Resources

The water resource assessment took into consideration a number of key issues which have a significant impact on the yield and potential viability of any new development.

Historical Firm Yield and Stochastic Yields. The analyses results presented in this report are all based on the historical flow sequences derived from previous hydrological assessments. The resulting yield estimates are therefore considered to be the Historical Firm Yields which are typically based on streamflow records of between 70 and 100 years in length. Due to the long droughts experienced in Southern Africa, it is normal practice to undertake further analyses which are based on multiple stochastic streamflow sequences which are synthetic flow sequences that have similar statistical properties to the historical streamflow sequence at each node in the system. These stochastic sequences are then analysed in exactly the same manner as the historical sequence in order to derive a more accurate estimate of the yield which is tied to a specific level of assurance of supply. In this way, the yield and reliability characteristics for any specific development option can be calculated. The stochastic analyses are very time-consuming due to the large number of streamflow sequences that are analysed to calculate the yield for a specific dam development option. For this reason, the initial dam selection process is based on the historical sequences and the resulting “Historical Firm Yield" is used to select the one or two most promising options which will then be analysed in more detail using stochastic sequences. The yield figures provided in this report may therefore change slightly in future in accordance with the results from the subsequent stochastic analyses to be undertaken in the next phase of the project.

Impact on downstream users. One of the most important issues, concerns the impact of any new upstream development on the downstream users. In a river basin system that has abundant water resources, a new dam development may not cause any noticeable impact on the downstream users and in such cases, there may be no need to investigate additional reconciliation strategies to support the downstream users since they have not experienced any reduction in their supply. This was the situation with the first phase of the Lesotho Highlands Water Project which was planned back in the 1970's and developed in the 1980's. At this time, there was still water available for new developments. Over the past 30 years, however, the situation has changed and water in the Orange/Senqu basin is over utilised and has become a scarce resource. It is therefore important to evaluate the impact of any new dam development options on the downstream users and if possible, to quantify any reduction in water availability that will be experienced by them. It should be noted that if it is considered necessary to mitigate the reduction in water availability to the downstream users, then a separate study will be required that evaluates viable and cost-effective reconciliation strategies that address the basin-wide shortfalls. In the case of a new dam anywhere in the Orange/Senqu river basin, the initial yield assessment will determine the possible maximum yield that can be abstracted from the new dam at the location of the dam, referred to as the local yield. A second basin-wide assessment will then be undertaken to assess the net or incremental yield from the Orange/Senqu river basin as a whole which will still be a positive yield but is likely to be lower than the local maximum yield available at the dam site. It is therefore important to present both the maximum local yield as well as the net additional basin yield also referred to as the incremental yield, for any proposed new development.

Compensation Releases. Another important issue concerns the required releases from any proposed new development. The term "compensation releases" is often used to cover the required water to be released from a proposed new dam primarily for environmental purposes. In certain scenarios, an additional volume of water is included to restore the overall balance so that there is no noticeable impact to the downstream users from the proposed development. If both the environmental requirements (usually very small) and the additional mitigation flows (often very large) are combined and shown as "compensation releases" it can create both confusion and some concern as it may appear that much of the benefit of the proposed new dam is being released for no apparent reason. In such cases, the incremental yield from the proposed new dam may be half of the gross maximum local yield which may, in turn, make a potentially viable project appear to be unviable.

Local Yield and Net System Yield. Having highlighted the key issues of the maximum local yield as well as the possible incremental yield of a potential new dam development, it is also important to mention one more very significant consideration when assessing any new dam development. The maximum local yield given in the report for each possible new development is the actual yield that can be abstracted at the proposed dam site. This water is available high up in the catchment and as such may have significant additional value due to the fact that it can be used to supply specific areas or consumers which cannot be supplied from a development lower down in the system. Even in cases where the incremental yield may be half of the local maximum yield, the full local maximum yield can still be used or diverted to external users. In such a case, it may be necessary to investigate some further reconciliation strategies to provide additional yield somewhere in the river basin to restore the status quo to the existing downstream users. Releasing water from the new Makhaleng Dam high up in the catchment for this purpose is possible but would not always be an attractive strategy due to the fact that water higher up in a catchment has greater value and usually experiences low evaporation making it an ideal location to store water.

The various local yields and incremental system yields provided in the remainder of this section are presented in a manner in which any flow required by the downstream users is shown as a separate item and is not included in the "compensation flows" which relate specifically to the Environmental Flow Requirements.

The water resources yield analyses were carried out in support of the Dam Engineers to provide yields at various dam sites and for a wide range of dam sizes. The gross yield of a large dam (approx. 3 times Mean Annual Runoff, i.e. 3 MAR) in the Makhaleng River is dependent on the location and size of the dam. At the upstream sites, N1a and N1, the **gross yield** is estimated to be a maximum of 335 million m^3/a. At the downstream sites, S1 and S2, the maximum gross local yield is estimated to be approximately **390 million m^3/a**. The recommended and preferred dam site will be selected not only on the yield but will include various other technical and environmental considerations

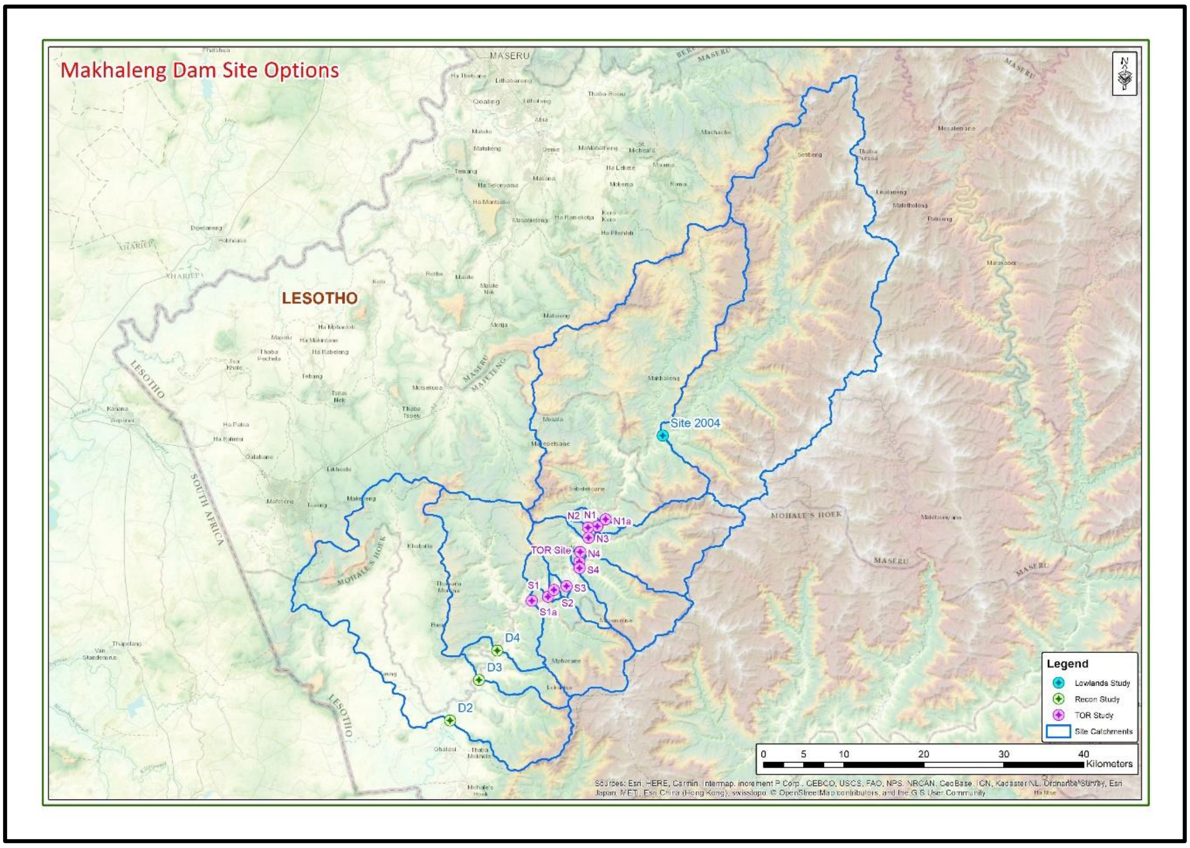
Key Yield Results

There is more than sufficient local yield (390 mil m^3/a) at Makhaleng Dam to support the **high demand scenario (approx. 200 mil m^3/a).** It will, however, result in some decrease in water availability to the downstream users in the Orange-Senqu system. It should be noted that there are a number of possible options to offset the reduction in downstream yield that must still be investigated in detail as part of a separate study.

Makhaleng Dam Sites

Fifteen sites were identified in the Makaleng River. The sites were divided into three groups;

- Lowlands – 2004 study (Northern) site = Lowlands 2004.
- TOR group of sites (Central) = S1a, S1, S2, S3, S4, TOR, N1a, N1, N2, N3, and N4.
- Reconnaissance (Southern) group of sites = D2, D3, and D4.



Makhaleng River, Potential Dam Sites and their Catchments

For each dam site, a complete set of technical data was compiled to compare the sites for selecting two sites for more detailed investigation in Phase 2 of the Pre-Feasibility study. The sites in the upper catchment had the advantage of lower social impact, better geological conditions, closer proximity to construction materials, lower sedimentation risks, lower conveyance costs, smaller design floods, and less evaporation. The sites in the lower catchment had the advantage of lower environmental impact, greater run off at the site and therefore higher yields. The sites with the narrower valleys had a lower unit cost per available yield. Site S2 had the advantage of a natural side channel spillway if the dam is built to a large capacity to reach the elevation of the saddle.

Dam site selection using multi criteria analysis

A multi-criteria analysis approach was used to rate the suitability of each dam site, with the unit reference value (URV) being used to estimate the cost of the dam per unit of water transferred.

The URVs for the dam sized to its maximum capacity are R 0.90 /m^3 for S2, R 1.21 /m^3 for N1a, R 1.26 /m^3 for S1, and R 2.12 /m^3 for N1.

Each site was scored according to the URV, Yield, Founding Conditions, Proximity to Construction Materials, Sedimentation Risks, Ecological Impacts, Socio-economic impacts, Strategic, Incremental impact on URV for conveyance route. Based on the weighting structure given to each of the criteria during a Joint Study Management Committee (JSMC) workshop, an overall rating was determined for each site. For the dams sized for the maximum possible yield at each site, site S2 and N1a are the most favourable, with S1 and N1 the third and fourth most favourable sites. All dam sites are costed on Roller Compacted Concrete (RCC) gravity dams except for site S2 which is costed on a Concrete Faced Rockfill Dam (CFRD).

The table below provides the results of the multicriteria analyses for the larger dam sizes for all the sites near the TOR site.

DAM SITE	SELECTION CRITERIA (Max Dam capacity)									
	1. URV	2. Yield	3. Founding conditions	4. Construction Materials	5. Sedimentation Risks	6. Ecological Impacts	7. Socio-economic impacts	8. Strategic	9. conveyance route URV	10. Final Score
Weighting (%)	15	10	10	10	10	10	10	10	15	-
N1a	3.0	2.2	3	3	2	1	3	2	2.41	60.9
N1	1.7	2.3	3	3	2	1	3	2	2.41	56.1
N2	1.4	2.3	2	3	2	1	3	2	2.41	52.8
N3	1.6	2.3	2	3	2	1	3	2	2.41	53.2
N4	1.5	2.6	2	3	2	1	2	2	2.41	51.1
TOR	1.8	2.6	2	2	2	2	2	2	2.41	52.1
S4	2.6	2.6	2	2	2	2	2	2	2.41	55.5
S3	1.3	2.7	1	2	2	2	2	2	2.81	49.8
S2	4.0	2.6	2	2	2	2	2	2	2.89	62.4
S1	2.9	2.7	2	2	2	2	2	2	2.96	58.6
S1a	1.9	2.6	2	2	2	2	2	2	2.41	52.9

Conveyance Selection

Five conveyance routes were investigated, namely one Central route and four Western River Conveyance routes with piped sections. Each route was assessed to determine its directness between source and destination. Sections of pipeline were rerouted to ensure accuracy of location alongside roads and to avoid infrastructure.

A hydraulic model was developed for each route and the conveyance infrastructure required for each option was determined, which included weirs, abstraction works, pump stations, and pipelines. Capital and energy costs were determined and the NPVs and URVs were calculated.

The fully piped central conveyance route is the most direct between Lesotho and Botswana and was calculated to have a URV of R 25.47 /m^3 for the high demand scenario and R 33.17 /m^3 for the low demand scenario suggesting that the high demand scenario is the most viable option.

The western routes each had variations in terms of location, length of pipe, length of river conveyance sections, and energy requirements. In addition, losses due to evaporation from the river conveyance sections had to be allowed for in the capital and operational costs of the western routes. It is estimated that between 8 and 10 million m^3/a of water will be lost to evaporation depending on the route and the water volume transferred. Route ACF was found to be the most favourable of the Western routes with a URV of R 19.19 /m^3 for the high growth scenario and R 24.08 /m^3 for the low growth scenario.

However, the JSMC concluded that a river conveyance was not acceptable, and another option must be investigated. Therefore, options for the Western Routes ACE and ACF were investigated using a canal instead of the Groot Vet, Sand and Vaal Rivers as river conveyances. If the river conveyance section is replaced with a canal of 226km running parallel to the rivers then for the Western Route ACF, the URV will increase to R 23.05 /m^3 for the high growth scenario and R 27.78 /m^3 for the low growth scenario.

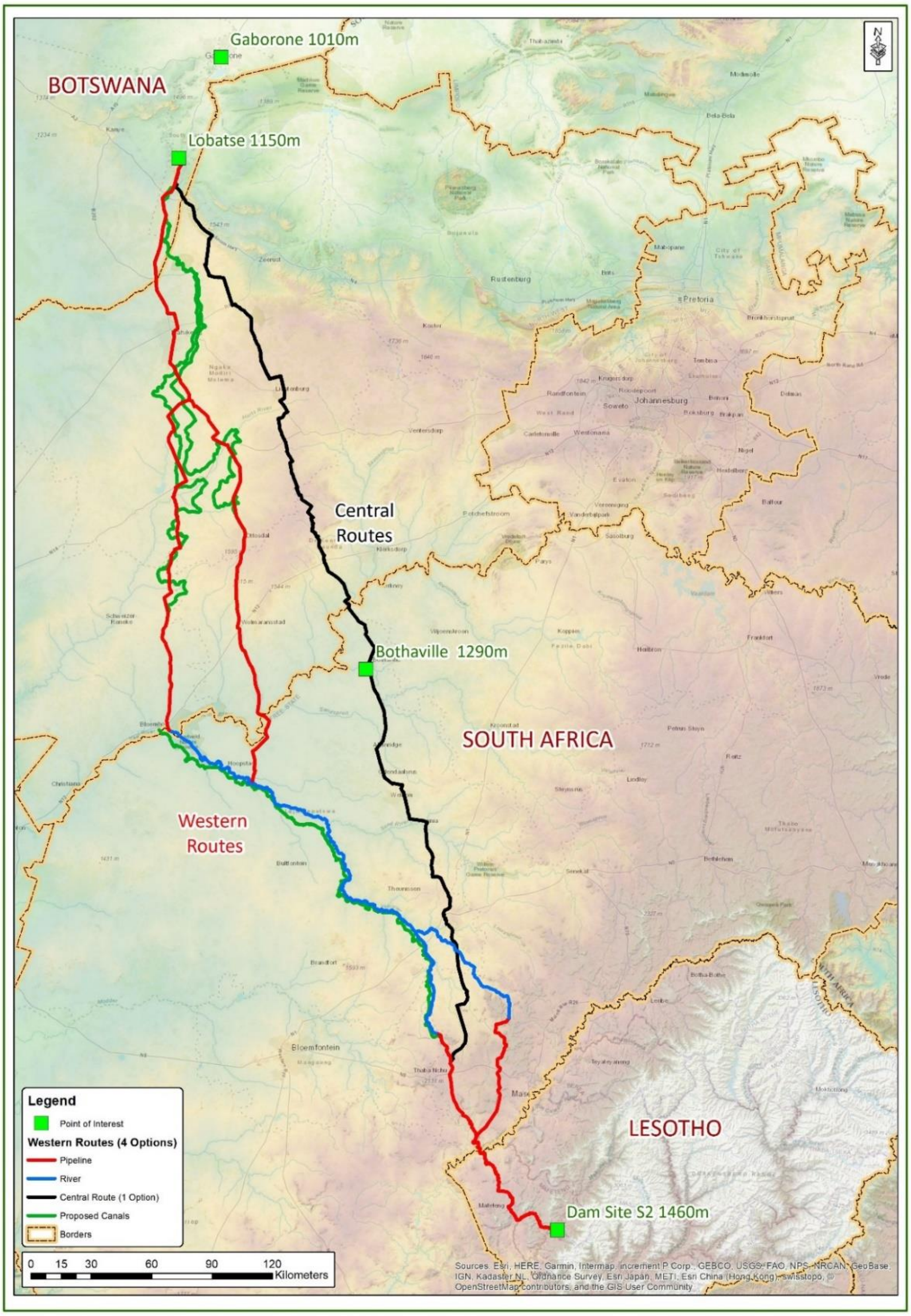
If Bloemfontein is added to the low growth scenario there will be an approximate incremental decrease in the URV of R 3.46 /m^3.

Conveyance route selection using multi criteria analysis.

A multi-criteria analysis (MCA) was used to rate the suitability of each conveyance route. Each route was scored on URV, Demand-distribution factor, Susceptible to unauthorised draw-off, Water Quality, River evaporation Losses, Energy Efficiency, Ecological Impacts and Socio-economic impacts.

High Demand Scenario											
Conveyance	River	URV:	Demand-dist. factor:	Susceptible to unauthorised drawoff	Water Quality	River/canal losses	Energy efficiency:	Social impact:	Ecological impact:	Overall rating:	
		20%	*10%*	*20%*	*15%*	*5%*	*10%*	*10%*	*10%*	*100%*	
Central route		2.8	2.0	4.0	4.0	4.0	4.0	1.0	3.5	80.4	*1*
Western ACE	Groot Vet/Sand/Vaal	4.0	4.0	1.1	1.1	1.1	3.6	3.0	1.5	61.3	*8*
Western ACF	Groot Vet/Sand	3.8	3.0	2.2	2.2	2.2	3.8	2.0	1.5	66.6	*6*
Western BDE	Klein Vet/Sand/Vaal	3.8	4.0	1.0	1.0	1.0	2.9	3.0	2.0	58.6	*9*
Western BDF	Klein Vet/Sand	3.6	3.0	2.0	2.0	2.0	3.1	2.0	2.0	63.5	*7*
New options using canals as conveyances for River Section plus additional canal sections											
Western ACE	Canal instead of River Section	3.1	4.0	3.0	3.0	3.0	3.6	2.5	2.5	76.9	*3*
Western ACF	Canal instead of River Section	3.1	3.0	3.2	3.2	3.4	3.8	3.0	3.0	79.9	*2*
Western ACE	Extra canal to replace pipeline	3.6	4.0	2.6	2.6	2.2	3.6	1.5	1.5	69.8	*5*
Western ACF	Extra canal to replace pipeline	3.3	3.0	2.8	2.8	2.6	3.8	2.0	2.0	71.3	*4*

The table on the previous page provides the results of the multicriteria analyses for the high demand scenario for the water conveyances.



Potential Conveyance Routes

For the high scenario for the options including the canal options, the most favourable route was the Central Piped Route and the second ranked route was the ACF with a canal replacing the river conveyance.

Recommendations

It is recommended that the high-water requirement scenario be used in the Phase 2 of the Pre-Feasibility Study. The decision on whether or not to include Bloemfontein as a demand centre to be supplied from the pipeline must be decided by the four countries. It is, however, recommended that the Bloemfontein demand be further investigated in Phase 2 of the study for economic, technical and sustainability reasons and also bolster advancement of a basin-wide reconciliation strategy.

It is recommended that a detailed geohydrological and water balance study per mine site be considered in the Feasibility Phase to determine the sustainable groundwater exploitation potential, to derive a water balance, and determine the augmentation requirements.

It is recommended that the large Makhaleng Dam should be built to provide more flexibility in the system as well as to support additional irrigation in Lesotho. Water stored high up in the catchment will generally have significant additional value due to the fact that it can be used to supply or support more areas at lower pumping costs. Mitigation releases may be required to restore the overall balance so that there is no noticeable impact to the downstream users from the proposed development. Such releases can be supplied from Makhaleng Dam or from another development in the Orange Senqu system which would be preferable. The cost of the proposed Makhaleng Dam is an order of magnitude lower than the cost of the conveyance infrastructure and it is therefore sensible to develop the largest dam possible on the selected site.

Several promising options have been identified that can be used to provide some or all of the required mitigation flows to restore the water yield to the downstream users. Such options should be analysed in more detail during a separate and independent study.

Sites N1a/N1 and S1/S2 are the best upstream and downstream options for both the 200 million m^3/a yield and the maximum yield options. It is recommended that these two sites be investigated further in Phase 2 of Pre-feasibility study.

For the conveyance, it is recommended that the Central Conveyance Route(fully piped) and the Western Conveyance Route ACF with a canal section be investigated in the Phase 2 Pre-Feasibility Study.

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ABBREVIATIONS AND ACRONYMS

ACC	Australian Community Climate and Earth System Simulator (ACCESS1-0)
BDWS	Botswana Department of Water and Sanitation
BNWMPR	Botswana National Water Master Plan Review
BNWMPU	Botswana National Water Master Plan Update
BPT	Break Pressure Tank
CCS	Community Climate System Model (CCSM4)
CFRD	Concrete Faced Rockfill Dam
CMP	Common Point
CNR	National Centre for Meteorological Research Coupled Global Climate Model version 5 (CNRM-CM5)
DWS	Department Water and Sanitation
EC	Ecological Category
ENSO	El-Nino-Southern Oscillation
EWR	Environmental Water Requirement
FRAI	Fish Response Assessment Index
GFD	Geophysical Fluid Dynamics Laboratory Coupled Model (GFDL-CM3)
ha	Hectare
HFY	Historic Firm Yield
hrs	Hours
H-W	Hazen-Williams
ICOLD	International Commission on Large Dams
IPCC	International Panel for Climate Change
IPPF	Infrastructure Project Preparation Facility
IVRS	Integrated Vaal River System
IWRM	Integrated Water Resources Management
JSMC	Joint Study Management Committee
km^2	Square Kilometers

kW	Kilowatt
kWhr	Kilowatt hour
l/s	Litre per second
L-BWT	Lesotho Botswana Water Transfer
LHDA	Lesotho Highlands Development Authority
LHWP	Lesotho Highlands Water Project
LWC	Lesotho Water Sector
m^3/a	Cubic Meters per annum
m^3/s	Cubic Meters per second
m/s	Meters per second
MAFS	Ministry of Agriculture and Food Security (Lesotho)
mamsl	Meters Above Mean Sea Level
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
MAWF	Ministry of Agriculture, Water and Forestry (Namibia)
MCA	Multi Criteria Analysis
MCM	Million Cubic Meter
MIV	Main inlet valve
ML	Megalitres
mm/a	Millimetres per annum
MMEWR	Ministry of Minerals, Energy and Water Resources (Botswana)
MPI	Max Planck Institute Coupled Earth System Model (MPI-ESM-LR)
MW	Megawatts
NGO	Non-governmental organization
NOR	Norwegian Earth System Model (NorESM1-M)
NPV	Net Present Value
NVD	Noordoewer/Vioolsdrift Dam
NWA	National Water Act (South Africa)
ORASECOM	Orange Senqu River Commission
ORP	Orange River Project (Gariep and Vanderkloof dams and supply area)
PD	Present Day
PES	Present Ecological State
PFS	Pre-Feasibility Study
PS	Pump Station

PV	Present Value
PWC	Permanent Water Commission
RC	River Conveyance
RCC	Roller Compacted Concrete
REC	Recommended Ecological Category
RDRM	Revised Desktop Reserve Model
RMF	Regional Maximum Flood
RSA	Republic of South Africa
SADC	Southern African Development Community
SANCOLD	South African National Committee on Large Dams
SIWI	Stockholm Infrastructure Water Institute
SRTM	Shuttle Radar Topography Mission
TDS	Total dissolved solids
TOR	Terms of Reference
TTT	Technical Task Team
URV	Unit Reference Value
VEGRAI	Vegetation Response Assessment Index
VRS	Vaal River System
WARMS	Water Authorization and Registration Management System
WASCO	Water and Sanitation Company (Lesotho)
WC	Water Conservation
WCWDM	Water Conservation and Water Demand Management
WDM	Water Demand Management
WMA	Water Management Area
WRPM	Water Resources Planning Model
WRYM	Water Resources Yield Model
WTW	Water Treatment Works
WUC	Water Utilities Corporation (Botswana)
WWTW	Wastewater Treatment Works

1 INTRODUCTION

1.1 BACKGROUND TO THE STUDY AREA

The Orange-Senqu River basin is one of the largest river basins south of the Zambezi River with a catchment area of approximately one million km^2. It encompasses all of Lesotho, a significant portion of South Africa, Botswana and Namibia. The Orange-Senqu River originates in the Lesotho Highlands and flows in a westerly direction for approximately 2 200 km to the west coast of South Africa and Namibia, where the river discharges into the Atlantic Ocean. See **Figure 1-1**.

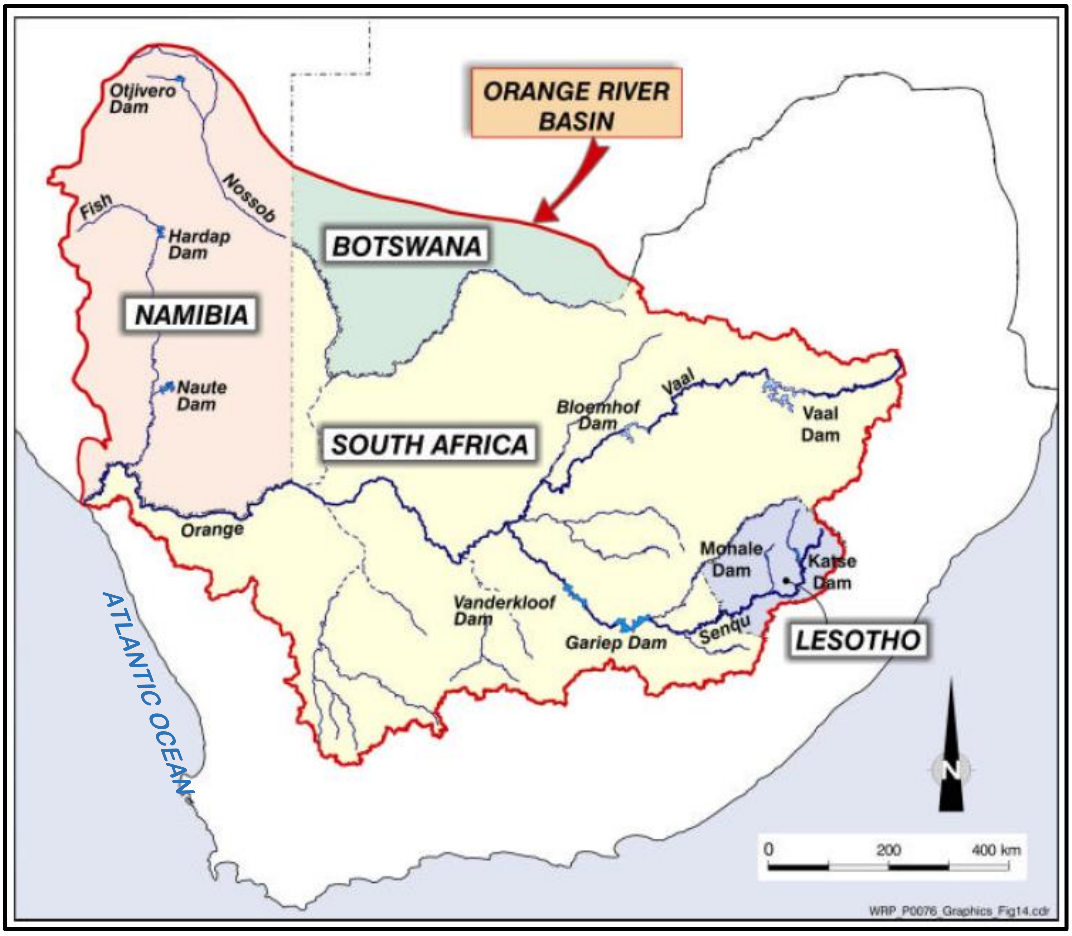


Figure 1-1: Orange-Senqu River Basin

On the part of Lesotho, there are three distinct hydrologically homogenous river basins, where each river basin has its clear source where it originates. These river basins, namely: Senqu, Mohokare and Makhaleng River Basins all flow in the westerly direction and join together outside the border of Lesotho with the Orange River to form one large basin known as the Orange-Senqu River Basin.

It has been estimated that the natural runoff of the Orange-Senqu River Basin is in the order of 11 300 million m^3/a (See **Figure 1-2**), of which approximately 4 000 million m^3/a originate in the Senqu basin in the Lesotho Highlands, 6 500 million m^3/a from the Vaal and Upper Orange, with approximately 800 million m^3/a from the Lower Orange and Fish River (Namibia). The basin also includes a portion in Botswana and Namibia (north of Fish River) feeding the Nossob and Molopo rivers.

Southern Africa has fifteen (15) transboundary watercourse systems of which thirteen (13) exclusively stretch over the Southern African Development Community (SADC) Member States. The Orange–Senqu is one of these thirteen (13) transboundary water course systems. SADC member states embrace the ideals of utilizing the water resources of these transboundary watercourses for the regional economic integration and for the mutual benefit of the riparian states. The region has demonstrated a great deal of goodwill and commitment towards collaboration on water issues. Thus, SADC has adopted the principle of basin–wide management of the water resources for sustainable and integrated water resources development.

To enhance the objectives of integrated water resources development and management in the region, the Orange–Senqu River Basin Commission (ORASECOM) was established in November 2000.

ORASECOM was established by the Governments of four States, namely, South Africa, Lesotho, Botswana and Namibia, for managing the transboundary water resources of the Orange-Senqu River Basin and promoting its beneficial development for the socio-economic wellbeing and safeguarding the basin environment. This led to the development of a basin level Integrated Water Resources Management (IWRM) Plan adopted in February 2015 by the ORASECOM Member States. The IWRM Plan provides a strategic transboundary water resources management framework and action areas and serves as a guiding and planning tool for achieving the long-term development goals in the basin. A key aspect of the transformative approach for strengthening cooperation has been identified as the need for joint project implementation that provides a mutually inclusive transboundary benefit.

The IWRM Plan recommends strategies and measures for promoting sustainable management of the water resources of the basin and defines strategic actions that will ensure and enhance water security, considering the long term socio-economic and environmental demands on the water resources of the basin. The Lesotho to Botswana Water Transfer Scheme, a major component under this study, was not included in the 2015 IWRM Plan as one of the strategic actions but has lately been identified as a priority project.

The Orange-Senqu River basin is a highly complex and integrated water resource system, characterized by a high degree of regulation and major inter-basin transfers to manage the resource availability between the location of relatively abundant precipitation and the location of greatest water requirements. The infrastructure involves water storage and distribution infrastructure, transferring water to demand centres that are in some cases located outside of the basin through intra and inter basin transfers. Most of the existing infrastructure are those under the Lesotho Highlands Water Project (LHWP) which transfers water to South Africa and also those for inter basin transfer to the Vaal Basin.

Figure1-2 provides approximate values of the natural run-off in the Orange-Senqu River basin. These figures highlight the variable and uneven distribution of runoff from east to west in the basin. The figures refer to the natural runoff which would have occurred had there been no developments or impoundments in the catchment. The actual runoff reaching the river mouth is considerably less than the natural values and are estimated to be in the order of half the natural values.

The difference is due mainly to the extensive water utilisation in the Vaal River Basin, most of which is for domestic and industrial purposes. Several major transfer systems are used to bring water into the Upper Vaal River catchment to support the high-water requirements, in particular those within the Gauteng area as well as for several Power Stations.

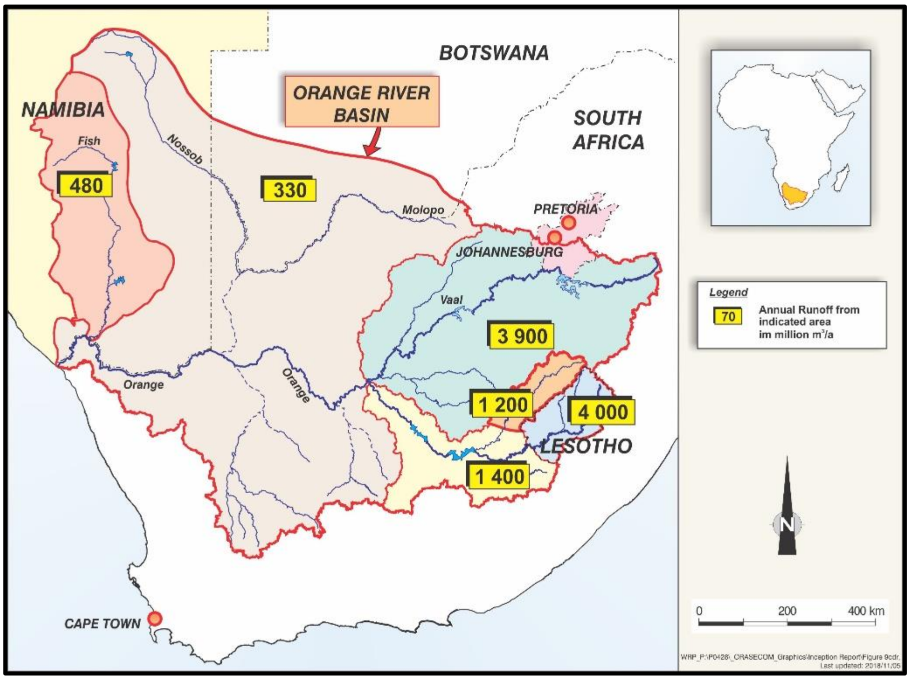


Figure 1-2: Approximate Natural Run-off in the Basin

Large volumes of water are also used to support extensive irrigation and some mining demands along the Orange River downstream of the Orange-Vaal confluence, as well as significant irrigation developments in the Eastern Cape in South Africa, supplied through the Orange-Fish Tunnel. In addition to the water demands, evaporation losses from the Orange

River and the associated riparian vegetation that depend on the river account for 500 to 1 000 million m^3/a.

As already indicated, there are locations of relatively abundant precipitation and water availability and the locations of greatest water requirements. Water scarcity in locations of greatest need is the main challenge in the basin, and this requires a coordinated joint development, management and conservation of the water resources system. The climate in the basin varies from relatively temperate in the eastern source areas, to hyper-arid in the western areas. As shown in **Figure 1.3**, average annual precipitation decreases from more than 1 000 mm/a in the source areas of the basin to less than 50 mm/a at the river mouth. This varies considerably from year to year. Much of the rainfall occurs as intense storms, which can be highly localised. The temporal and spatial distribution of precipitation within any particular year can be considerable.

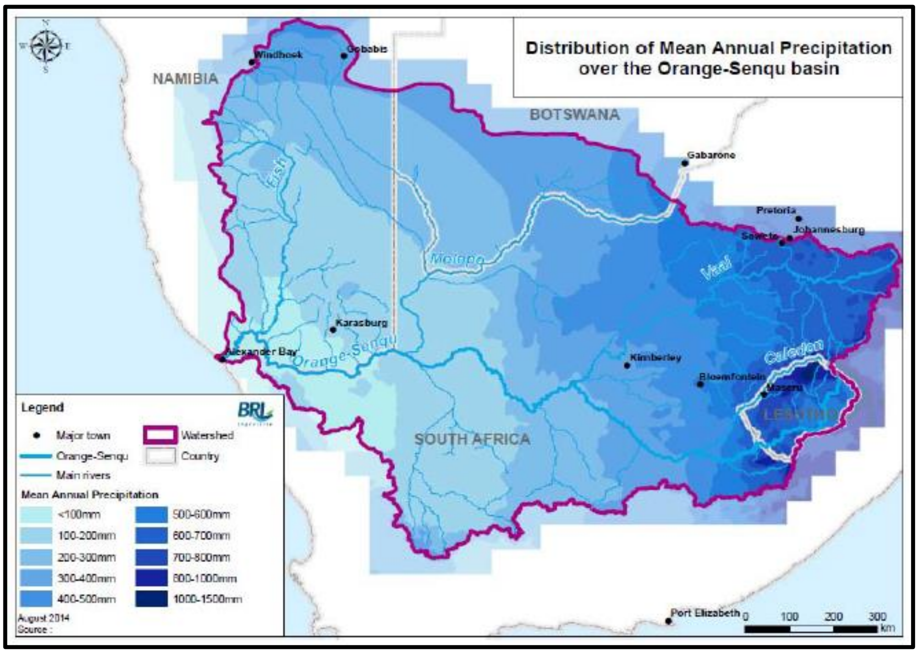


Figure 1-3: Distribution of Mean Annual Precipitation

In **Figure 1.4** it is evident that evaporation increases from south-east to north-west reaching a maximum of more than 1 650 mm/a in the west. Even in the cooler and wetter parts of the basin, evaporation in most cases exceeds precipitation. Temperature and evaporation follow a similar distribution with the coolest temperatures in the Lesotho Highlands and the hottest in the western Kalahari.

It is generally accepted that Southern Africa will be highly impacted by climate change. Consequently, there are concerns around the changes in precipitation and temperature due to climate variability and climate change. This study therefore aims to enhance investment in transboundary water security and to build resilience to climate change into the implementation of the strategic projects and actions described in the IWRM Plan.

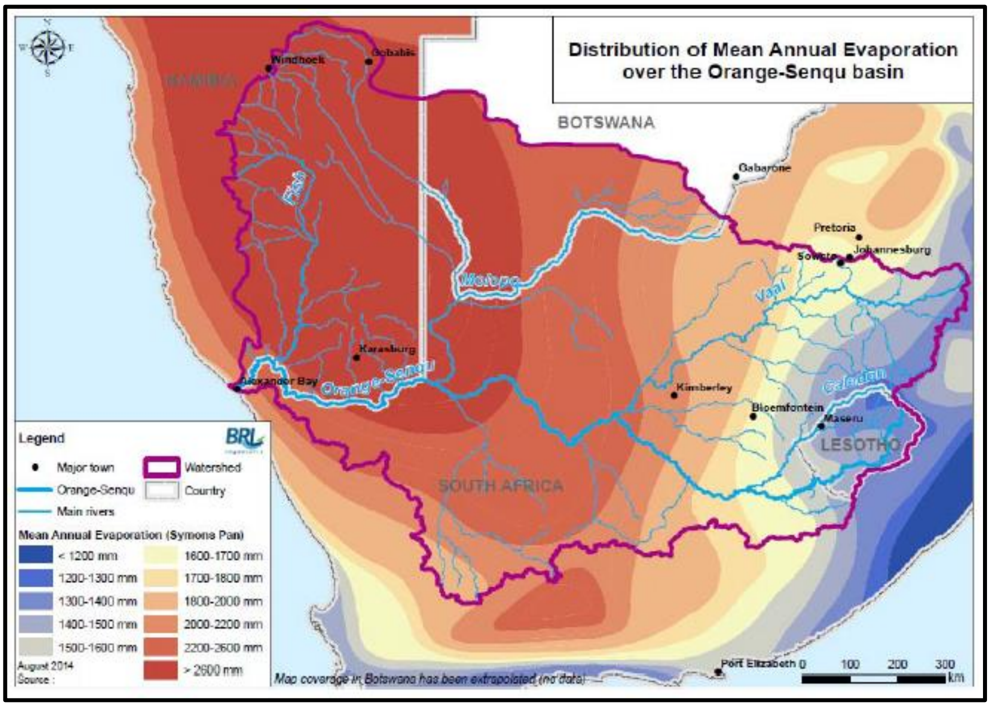


Figure 1-4: Distribution of mean annual evaporation over the Orange-Senqu basin

The Republic of Botswana is an arid country faced with serious water constraints which will worsen with the expected effects of climate change. Botswana will experience chronic water shortages by about 2025, unless major new water sources are developed. Already Gaborone was critically hit by the 2015-2016 drought.

As a consequence, the Governments of Botswana, Lesotho and South Africa, signed a Memorandum of Understanding to undertake a reconnaissance study on the Lesotho to Botswana Water Transfer scheme (L-BWT), which aimed at developing water infrastructure in Lesotho and through South Africa, to convey water to Botswana, at the same time supplying various users in Lesotho and South Africa. This reconnaissance study led to the selection of a technical option which included a new dam on the Makhaleng River in Lesotho and a water conveyance (pipeline) system to Botswana. It was envisaged that eventually 150 million m^3/a will be pumped to Botswana with additional supplies for consumers along the route in Lesotho and South Africa.

1.2 OBJECTIVE OF THE ASSIGNMENT

The objective of the study is to update the IWRM Plan endorsed in 2015 and propose an updated Core Scenario which should include the L-BWT Project, studying at pre-feasibility level the L-BWT Project including the feasibility of the dam, and to assist ORASECOM and the riparian countries in operationalizing the updated IWRM Plan. The objective will therefore be met through three outputs:

- A Climate Resilient Investment Plan for the Orange-Senqu River Basin based on the updated Core Scenario;
- Operationalization Plan for ten (10) priority actions selected from the updated IWRM Plan; and
- Pre-feasibility level report for the L-BWT Project, and the feasibility level report for a new dam, on Makhaleng River in Lesotho.

The study is divided into two distinct parts:

1) Preparation of a Climate Resilient Investment Plan, based on the updated Water Resources Yield and Planning Model and the updated Core Scenario defined in the IWRM Plan of 2015, as Components I & II of the study; and
2) The pre-feasibility study of Lesotho-Botswana Water Transfer Project, including the feasibility study of a new dam on Makhaleng River in Lesotho as Components III & IV of the study.

The four components of the study referred to above are:

- Component I: Climate Resilient Water Resources Investment Plan;
- Component II: Operationalisation of the Integrated Water Resources Management Plan;
- Component III: Pre-feasibility study of the Lesotho to Botswana Water Transfer Project;
- Component IV: Feasibility Study of the Dam on Makhaleng River in Lesotho.

1.2.1 Climate Resilient Investment Plan (Components I and II)

The high level of variability in precipitation due to climate variability and change, defines the need to optimize and implement efficient water resources development and management in the basin. The development of new infrastructure to meet increasing water demands, even if technically and environmentally feasible, is both expensive and complex. Economic considerations of water use have been identified as a key part in the planning and optimum use of what will become an increasingly scarce and expensive resource. Projections of future water demand and associated infrastructure development must be based on balanced considerations of economic, social, and environmental factors. The integration of water resources yield analysis, water resources development planning and economic optimization will ensure the development of short, medium- and long-term solutions to address basin water resources needs and development challenges.

The study includes water resource studies in Botswana, Lesotho, Namibian and South Africa. This will include updating of inputs from the Reconciliation Strategy Studies, updating of inputs with more recent results from the Reconciliation Strategy Maintenance Studies as well as other recent water resource related studies conducted in the basin countries. The study will establish comprehensive basin wide analyses which will be integrated with economic analyses to determine the optimized and most efficient development options, as part of setting the long-term development investment strategy and plan for the basin.

Components I & II will thus address the water resources investment plan and the operationalization of the updated IWRM Plan with the following outputs:

- Updated Core Scenario of the IWRM Plan, which would include the Lesotho-Botswana Water Transfer Scheme and any other new projects identified;
- Estimate of the Climate Change Effects on the updated Core Scenario;
- Optimised IWRM Plan Core Scenario through an economic approach;
- Financial Strategy for the Core Scenario;
- Updated Basin Wide Investment Plan approved by ORASECOM, which would include new projects that takes into consideration climate change effects;
- A comprehensive assessment of existing policies, legal and institutional arrangements and structures;
- Selected ten (10) strategic actions, Terms of Reference and cost estimates for each strategic action; and
- A road map for operationalization of the ten (10) strategic actions contained in the updated Integrated Water Resource Management Plan.

1.2.2 Lesotho-Botswana Water Transfer (L-BWT) Project (Components III and IV)

The south eastern urban complex of Botswana centred around the capital city, Gaborone, has experienced rapidly increasing growth over the last few decades, and is expected to continue doing so. Its water demands have long outstripped local bulk water resources, which are already supplemented by sources in the north-east of the country. The country has experienced several severe drought spells that have, in the recent past, led to water restrictions. Despite several concerted efforts to alleviate the water shortage challenges, indications are that the water sources will not be adequate to meet the growing demand as early as 2025.

The solution for addressing the water security challenges lies in the need for increasing the efficient use of existing water resources, developing additional water resources and improving the management systems based on availability and usage.

A Reconnaissance Study to identify possible water resources was completed in October 2015, which outlined various options of water sources and conveyance routes to supply water from Lesotho to Botswana. The various sources covered by the study include the Lesotho Highlands Water Project, the Makhaleng River and the Orange-Senqu in the south of Lesotho. The preferred supply scheme recommended in the Reconnaissance Study was a dam on the Makhaleng River, and a conveyance system to bring the water from Lesotho, across South Africa to Botswana.

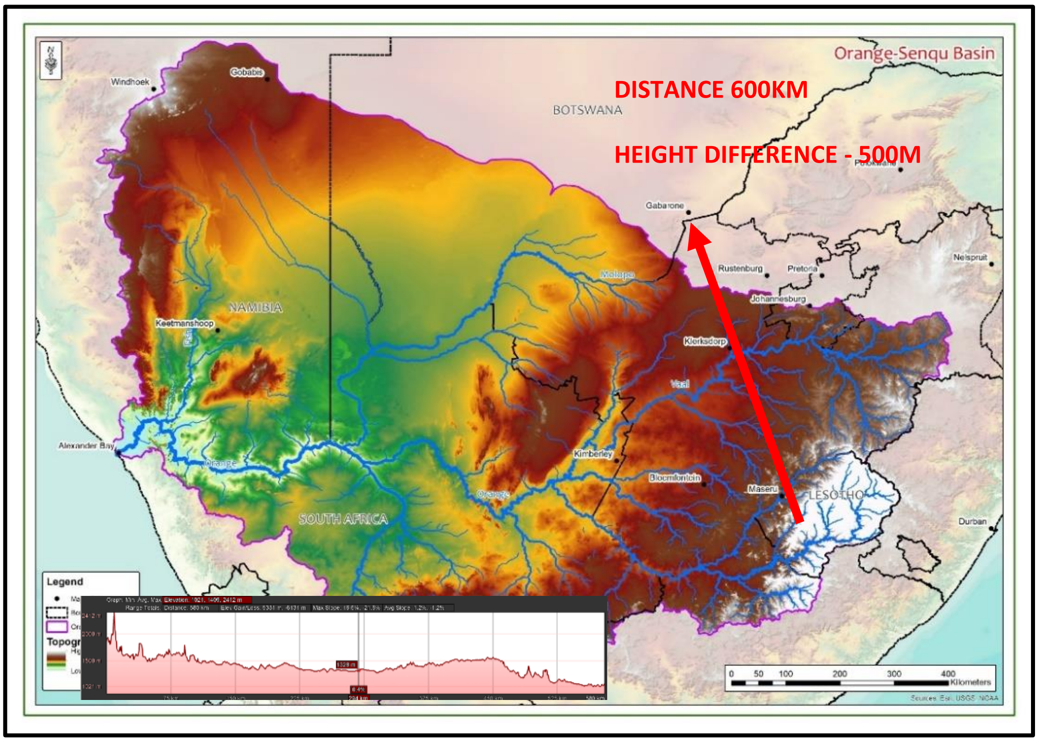


Figure 1-5: Orange Senqu basin topographical map showing the possible Lesotho Botswana Water Transfer Project

A Pre-feasibility Study is required to validate the water demands up to 2050 for specified areas in Botswana, Lesotho and South Africa from available relevant information in all countries. , This study will also further investigate suitable dam site(s) by analyzing the Makhaleng catchment hydrology and determining dam sizes on the basis of topography, geology, yield, sedimentation, hydropower generation etc. For the conveyance system, the study is only required to investigate pipeline options along the shortest route, to either Gaborone or Lobatse in Botswana, preferably along existing road servitudes.

Depending on the results and recommendations from the Pre-feasibility Study, a Feasibility Study for a new dam on the Makhaleng River will follow, but this depends on a final decision by the State Parties to the project. **Figure 1.5**, is the topographic map of the catchment, showing the Lesotho to Botswana water transfer project stretch and the major topographic features of the two end points of the water transfer scheme.

Components III & IV of the study focus on the Lesotho-Botswana Water Transfer Multipurpose Trans-boundary (L-BWT) Project and address:

Component III - Phase 1 (Validation of water requirements and identification of options)

Validation of water requirements and identification of options for dam site and water conveyance route. This Phase shall involve, the update of the water requirements & the identification and selection of two dam sites and definitions of two options for the conveyance route.

- Validation of the water requirements for irrigation in Lesotho, the water demand in South Africa along the pipeline route, and the water demand in Botswana;
- Assessment of the water resource, in the Makhaleng River catchment;
- Dam site selection; and
- Conveyance route selection.

Component III - Phase 2 (technical pre-feasibility of the dam and conveyance system)

Technical pre-feasibility of the dam and water conveyance system with due consideration of the environmental and economic issues, including preliminary costing of each option to enable comparison. This Phase shall constitute the pre-feasibility of the dam and the conveyance system. Two options in terms of dam sites and conveyance systems will be comprehensively compared. The Consultant shall undertake limited topographical and geotechnical investigations, which will be carried out with the objective of providing enough data for a sound comparison of the options. Required preliminary studies shall include technical, economic and environmental themes as developed below, including an optimization of the dam volume.

- Pre-feasibility study of a dam on the Makhaleng River;
- Prefeasibility study of the water conveyance pipeline from Makhaleng to Gaborone/Lobatse;
- Assessment of environmental and social impacts;
- Economic assessment of the dam and the Lesotho-Botswana water conveyance pipeline; and
- Multi-Criteria Analysis (MCA) of the options.

Component IV - Feasibility of the Makhaleng Dam (Depending on the outcomes from the Pre-Feasibility Study):

- Hydrological analysis, including climate change effects;
- Feasibility Study of the Makhaleng Dam:
- Economic, Social and Financial analysis update; and
- *Preparation of project implementation plan.*

1.3 PURPOSE AND STRUCTURE OF THIS REPORT

This Pre-feasibility Phase 1 Report will address component III - phase 1 of the study which comprises the selection of two dam sites on the Makhaleng River and two conveyance routes from Makhaleng Dam to Lobatse or Gaborone in Botswana.

The Pre-feasibility Phase 1 Report includes;

- The review and update of the projected additional water requirements in Botswana and along the route in both South Africa and Lesotho to potentially be serviced from the project to 2050. The water requirements included a desktop review of the environmental water requirements. The Water Requirements were used to determine the sizing of the infrastructure.
- The selection of potential dam sites on the Makhaleng River based on the topography, geology and catchment size.
- A site visit to the selected dam sites.
- Compilation of the technical data for each of the dam sites including high-level cost estimates and URVs.
- The selection of the two dam sites using weighted MCA for more detailed investigation at prefeasibility level of detail.
- The review of the Makhaleng River hydrology including an assessment of the most recent streamflow data.
- Catchment water resources modelling.
- Estimate design floods & Safety evaluation flood (SEF) for spillway design
- An estimate of the historic firm yields available from the dam sites selected.
- An estimation of the impact of the EWR on the yield of Makhaleng Dam.
- An estimate of the impact of the scheme on the downstream system yield and related incremental yields.
- A technical review of the conveyance routes from the Makhaleng River to Botswana.
- The selection of the two conveyance routes using weighted MCA for more detailed investigation at prefeasibility level of detail.

2 VALIDATION OF WATER REQUIREMENTS

The net water requirements of the countries partaking in the Lesotho Highlands Botswana Water Transfer (L-BWT) project (Lesotho, South Africa and Botswana) were investigated in detail as part of the Lesotho Highlands Botswana Water Transfer Desktop Study (MMEWR, 2015). For the Pre-feasibility study the objective of this task (Validation of Water Requirements) was to validate the information used in the desktop study and update the water requirements where additional or newer information has become available subsequent to the previous study for a planning horizon of up to 2050.

The latest available studies and relevant information for the specific areas was sourced from the relevant authorities and updated where applicable. The assessment approach for the different countries and sectors are presented in the subsequent sections.

Over the time period working on Phase 1 of the prefeasibility study, new information became available, which was not available at the start of this phase. This resulted in some changes in the approach followed to validate the information used in the desktop study and to update water requirements where applicable. As the Countries for some scenarios also want to utilize results from the validation process produced during the initial period of this task, it was decided to document the results obtained from all the different approaches followed during Phase 1 of the prefeasibility study.

A map which illustrates the L-BWT pipeline routes as well as the selected Lesotho, Botswana and South Africa supply areas is presented in **Figure A-1** in **Appendix A**.

2.1 LESOTHO WATER REQUIREMENTS – INITIAL APPROACH

2.1.1 Urban and Industrial Sector

Subsequent to the L-BWT Project Desktop Study (MMEWR, 2015), the Lesotho Water Sector Improvement Project Phase II: Consulting Services for the Update Detail Designs, and Construction Supervision of the Lesotho Lowlands Water Supply Scheme (LWC, 2017a) investigated the water requirements of the Lesotho Lowlands Water Supply zones illustrated in **Figure 2-1**. This was confirmed as the latest information available by the Lesotho Water and Sewerage Company (WASCO) as well as the Lesotho Ministry of Water. The zones identified by the L-BWT Project Desktop Study (MMEWR, 2015) to be supported by the L-BWT project are zones 3 to 6. (see **Figure 2-1**) In the January 2019 meeting, Lesotho indicated that Lesotho Lowlands Water Supply Zones as used in the reconnaissance phase study (zones 3 to 6) was incorrect. Only Zones 5 to 7 should receive water from the proposed Makhaleng Scheme. The correct zones are addressed in **Section 2.4.1.** For comparison purposes with the reconnaissance phase results, the initial set of zones and related results were still included in this report:

- Zone 3 (Peka/ Mapoteng/ Tayeteyaneng)
- Zone 4 (Maseru/ Mazenod/ Roma)
- Zone 5 (Morija/ Matsieng)
- Zone 6 (Mafeteng)

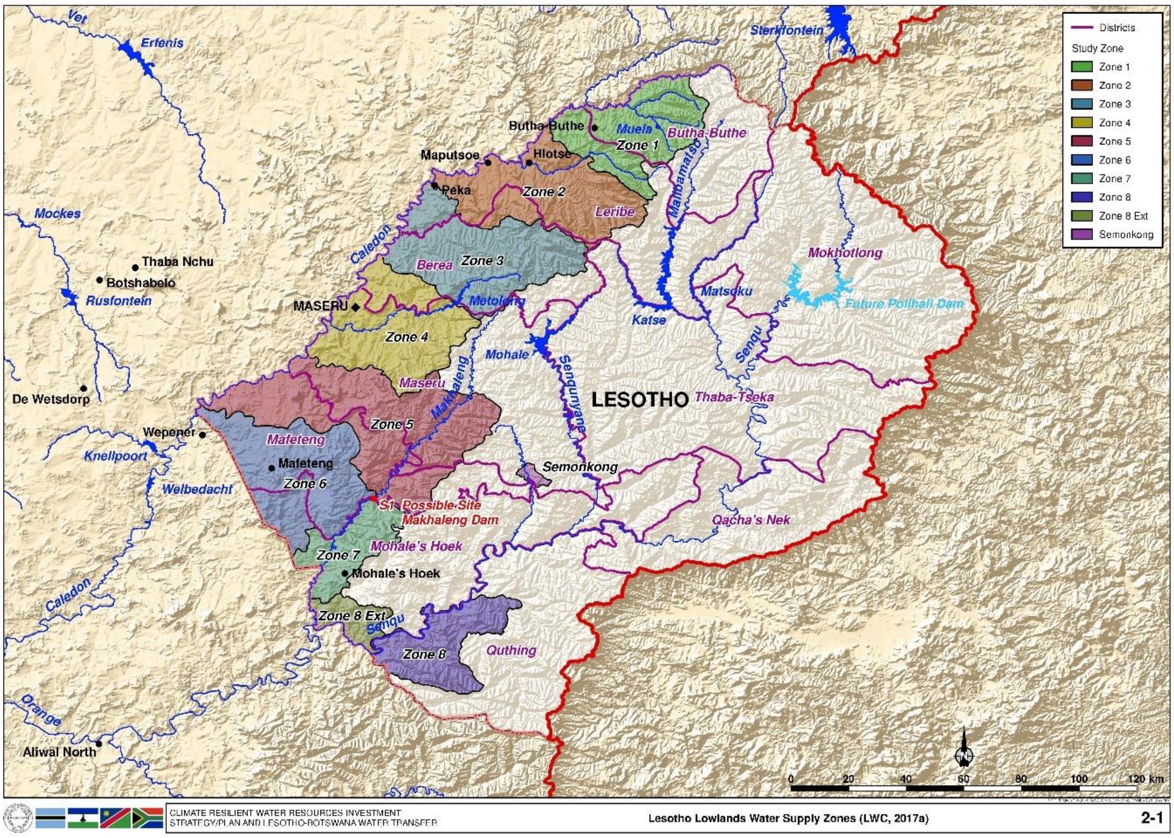


Figure 2-1: Lesotho Lowlands Water Supply Zones (LWC, 2017a)

A comparison of the previous L-BWT study (MMEWR, 2015) and updated information (LWC, 2017a) Lesotho Lowlands total net water requirements (Zone 3 –6) excluding irrigation, is presented in **Figure 2-2**. The net water requirements refer to the water requirements that excludes the losses in the Lesotho-Botswana transfer pipeline and related water treatment work losses. The reticulation losses within the towns/cities are however included. From the figure it can be seen that the latest projection starts off lower than the previous projection, but then increases to be slightly higher than the previous projection by 2045 as a result of an accelerated growth, predominantly in Zone 4, from approximately 2030 onwards.

The projected growth rates for water requirements of the four zones were compared against the Lesotho 2016 Census growth rates (2001-2016) of the districts in the associated zones.

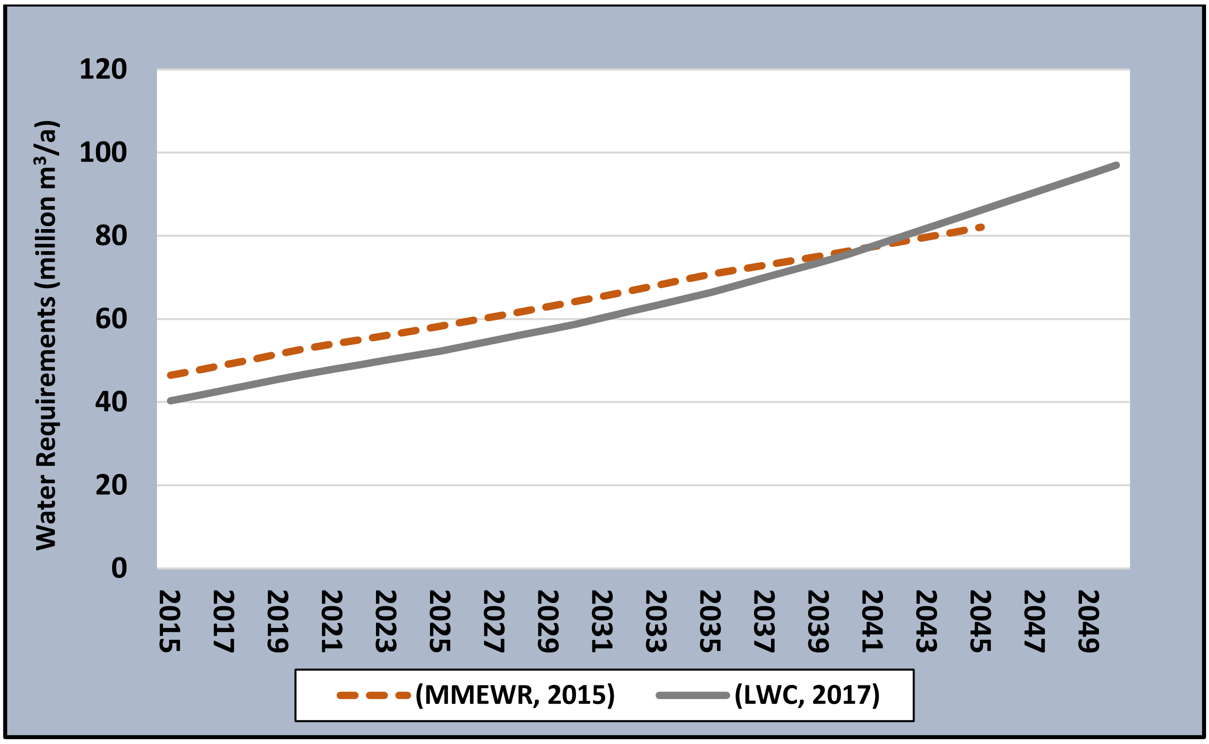


Figure 2-2: Comparison Lesotho Lowlands net water requirements (Zones 3 – 6)

The growth rates compared relatively well, except for the Zone 4 water requirements, which is the reason for the accelerated growth as shown in **Figure 2-3** (average annual compounded growth rates (%) are shown next to each Zone's projection).

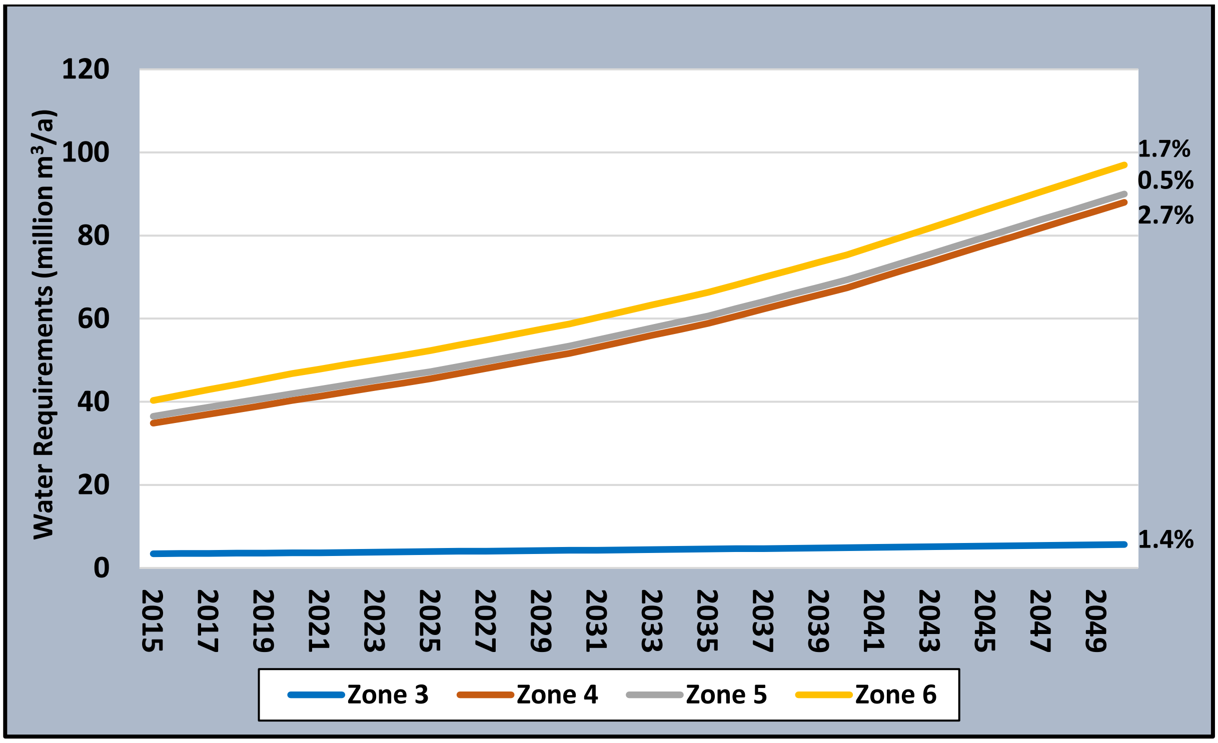


Figure 2-3: Lesotho Lowlands projected net water requirements (Zones 3 – 6) (LWC, 2017a) (NB- These are stacked lines thus Zone 6 means Zone 3 + 4 + 5 + 6 etc

2.1.2 Irrigation Sector

The purpose of this task was to assess the potential irrigation and associated water requirements that could be supplied from the L-BWT project. The Lesotho Water Sector Improvement Project II - Consulting Services for the Update Detail Designs, and Construction Supervision of the Lesotho Lowlands Water Supply Scheme: Final Water Resources Assessment Report (LWC, 2017b), assessed the potential irrigable lands as well as the associated irrigation water requirements for the Hololo, Hlotse, and Makhaleng catchments. The net irrigation water requirements (rainfall accounted for) were assessed based on long-term average climatic data using CROPWAT 8.0, where the crop properties and soil properties are included as default.

The total potential irrigable lands for the Makhaleng catchment were reported as 17 076 ha (151.5 million m^3/a) and reduced to 12 076 ha (107.1 million m^3/a) when buffer distance from the river is considered with maximum slopes not exceeding 10%. The upper and lower portion of the Makhaleng catchment represent different agro-climatic conditions and hence the study assessed the irrigation water requirements separately for these two catchments. Typical crops currently grown in the two catchments were reported as:

- **Upper Makhaleng:** Peas, wheat, sesame, onion, garlic, cabbage, spinach, pumpkin
- **Lower Makhaleng:** Peas and leafy vegetables, wheat, peas, mustard, beans, and sorghum

Table 2-1 presents the net irrigation water requirements that were estimated for the different crops for the upper and lower catchments.

Table 2-1: Makhaleng Irrigation Water Requirements (LWC, 2017b)

Crops	Planting Date	Irrigation Requirement, (m^3/ha)	
		Makhaleng Lower Catchment	Makhaleng Upper Catchment
Summer Crops			
Cabbage	1-Nov	4 230	3 766
Potato	15-Oct	3 208	5 306
Carrot	1-Nov	3 258	2 910
Green Peas	1-Nov	3 258	2 910
Sweet Pepper	15-Oct	5 990	5 306
Green Beans	1-Nov	3258	2 910
Tomato	15-Oct	5 108	4 602

Crops	Planting Date	Irrigation Requirement, (m³/ha)	
		Makhaleng Lower Catchment	Makhaleng Upper Catchment
Green Maize	15-Oct	5 108	4 602
Pumpkin	15-Oct	5 990	5 306
Onion	15-Oct	4 930	4 424
Lettuce	15-Oct	5 990	5 306
Maize	1-Nov	4 230	3 766
Winter Crops			
Cabbage	15-Feb	2 380	1 668
Green Peas	1-Mar	1 890	1 396
Carrot	1-Mar	1 890	1 396
Onion	15-Feb	3 208	2 602
Garlic	15-Feb	2 874	2 294
Green beans	15-Feb	1 868	1 352
Lettuce	15-Feb	2 380	1 668
Wheat	15-Apr	2 466	2 584
Orchards			
Pears	15 612	15 874	14 220
Apples	15 612	15 874	14 220
Peaches		15 142	13 548

The financial viability for the irrigation sector is very sensitive to the cost of the water. The cost of the water will increase further if the water is pumped and supplied along the pipeline route and the most feasible irrigation development would thus likely be downstream of the proposed Makhaleng Dam. From a satellite imagery assessment, it is evident that crop farming is practiced downstream of the proposed Makhaleng Dam. The Lesotho Ministry of Agriculture and Food Security (MAFS) has however confirmed that the identified areas are dryland crop production and that no irrigation is currently being practiced. The intention is however to shift from rain fed agriculture to irrigated agriculture.

The study team engaged with the MAFS to establish the irrigation development areas currently prioritized by the ministry, in an attempt to identify whether any of the prioritized developments could potentially be irrigated by the L-BWT. The MAFS advised that they are in the process of commissioning the Irrigation Master Plan and Investment Framework, which will identify and prioritise irrigation scheme developments in Lesotho and that the ministry would only be able to confirm these areas once the study has been completed.

Maps from the Final Water Demand Assessment Report (LWC, 2017a), provided indication of the location of the possible future irrigation of 12 076 ha in the Makhaleng River catchment. The original files for this map could not be obtained and some approximations had to be made to determine the irrigation downstream of the proposed Makhaleng Dam. This indicated that about 10 000 ha is located downstream of the N1 dam site and 9 500 ha downstream of the S1 possible Makhaleng Dam site. These irrigation areas represent irrigation requirements of approximately 88.7 and 84.3 million m^3/a respectively (See **Figure 2-4**).

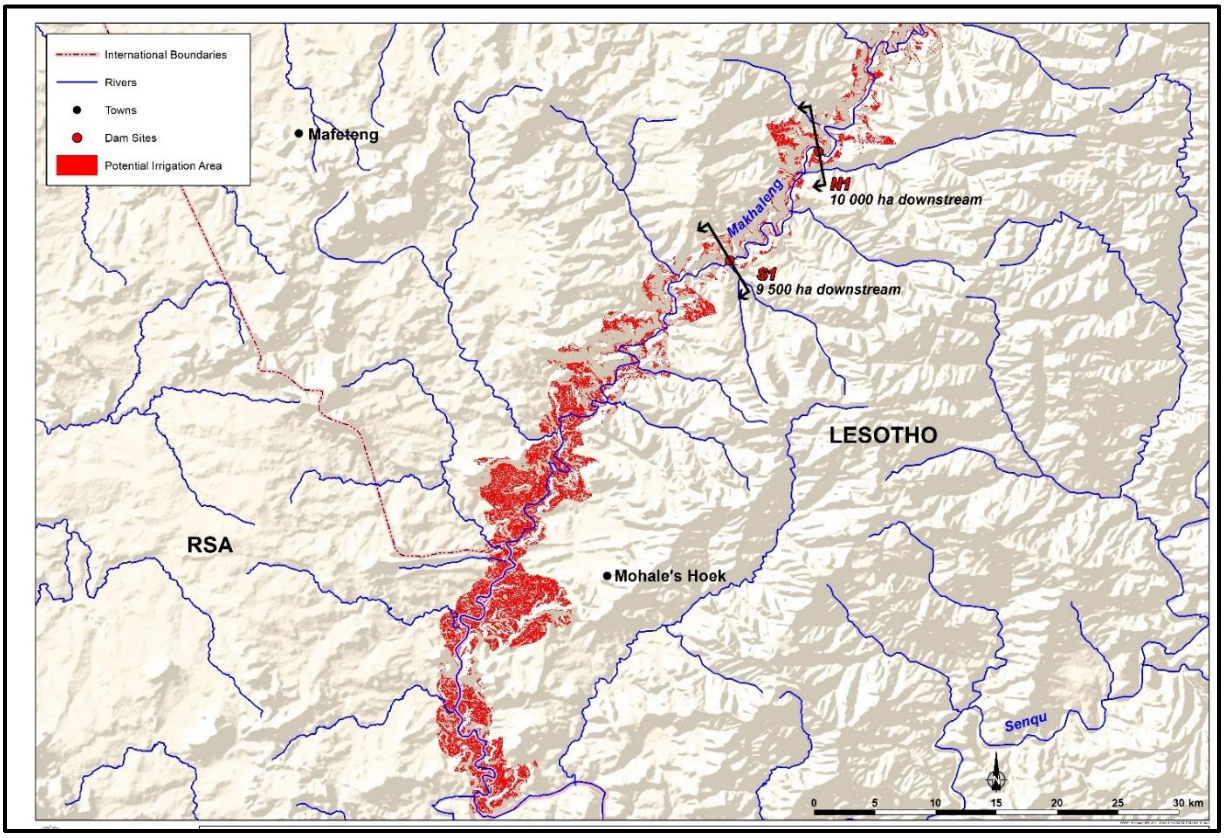


Figure 2-4: Location of possible irrigation in the Makhaleng catchment

It is important to note that the development of irrigation currently has a high priority in Lesotho.

It is recommended that these total irrigation requirements be used as the maximum irrigation requirements for the purpose of the Phase 1 Pre-feasibility Report. It is further recommended that the current phase of the study commence with the remaining urban/domestic, industrial and mining requirements for the different countries, as well as the ecological water requirements as first priority users. These requirements will then first be supplied and any remaining yield from Makhaleng Dam be allocated to irrigation to the maximums as given above, unless Lesotho indicate that a higher amount of irrigation need to be considered. Provision for any irrigation could then be revisited and refined once information becomes available from the MAFS in the current phase or at the Feasibility Phase.

2.2 SOUTH AFRICA URBAN AND INDUSTRIAL WATER REQUIREMENTS -INITIAL APPROACH

The urban, industrial and mine water requirements that could potentially be supplied by the L-BWT were assessed by superimposing the L-BWT pipeline route options on satellite imagery to confirm the various demands centers that are within close proximity for possible augmentation. The study made use of the DWS Directorate: National Water Resource Planning latest planning information as discussed below. The following stepped approach was followed to identify the potential users as well as the augmentation requirements:

- **Step 1:** Identify all potential users within a reasonable range of the different L-BWT pipeline routes. The reasonable range from the pipeline will differ from town to town and is based on the assessment carried out as part of steps 2 and 3.
- **Step 2:** Undertake a water balance assessment (comparison of projected water requirements against the available yield of the local surface and/or groundwater resources) to identify towns in need of augmentation. The assessment was based on the DWS Deployment of a Reconciliation Strategy for All Towns in the Central and Northern Regions (DWS, 2016a and DWS, 2016b).
- **Step 3:** Evaluate towns where a local augmentation scheme was recommended by the DWS All Towns Study (DWS, 2016a and DWS, 2016b) and eliminate the town when the local resource is the more beneficial resource to develop or where it has either been implemented or in advanced phase of implementation.
- **Step 4:** Findings from Step 1-3 were presented at a workshop (1 November 2018) attended by DWS National Water Resource Planning, Options Analysis and the Free State and North West Regional Offices. The Free State Regional Office did not attend but inputs were discussed and received telephonically and electronically.
- **Step 5:** Refine the short list of identified users based on comments received from the DWS workshop.

The net South Africa L-BWT augmentation requirements were calculated for the towns/villages identified for three scenarios as defined in **Table 2-2**.

The towns/villages identified for each of the scenarios are presented in **Figure A-1** in **Appendix A**.

Figure 2-5 presents a comparison of the net South Africa L-BWT augmentation requirements for the three scenarios against the previous study results. The 2050 net augmentation volumes for the Low, Realistic and High Scenario are 12.33 million m^3/a, 17.80 million m^3/a and 28.74 million m^3/a respectively (previous study **(MMEWR, 2015)** 2045 volume: 24.549 million m^3/a).

Table 2-2: South Africa L-BWT net water requirements scenarios

Scenario	Definition
Low	• Towns within reasonable range of proposed pipeline routes that are currently in deficit where no "local" intervention/augmentation option has been identified • Lichtenburg and Ramotshere Moiloa LM Clusters were added (DWS Workshop, 1 November 2018) • L-BWT net requirement calculated using the water requirement projection: High (incl. Water Conservation and Water Demand Management potential savings)
Realistic	• Low scenario towns with towns/villages added where groundwater augmentation was recommended • L-BWT net requirement calculated using the water requirement projection: High
High	• Realistic scenario with Kroonstad added

The augmentation projections for the three scenarios are presented in **Tables A3, A4, and A5** in **Appendix A.**

It is unlikely that the High Scenario (includes Kroonstad) will feature, due to both the location of Kroonstad relative to the pipeline routes and the fact that it was already recommended that a feasibility study be undertaken, to augment Kroonstad from the Vaal River System. This recommendation was from the "Continuation of the Central Planning Region All Towns Reconciliation Strategies: Reconciliation Strategy for Kroonstad Town Area consisting of Kroonstad and Maokeng settlements a well as the Kroonstad Rural settlements in Moqhaka Local Municipality in the Upper Orange Water Management Area, September 2015" study by DWS RSA.

It is important to note that the selection of some of the identified towns are dependent on the final selected route and it is thus expected that some of the towns will likely no longer feature, and the water requirements may thus reduce once the final optimized pipeline route has been confirmed.

During the initial discussions with DWS RSA it was requested to exclude the Greater Bloemfontein system from the RSA water requirements to be imposed on the L-BWT augmentation scheme, as a pipeline from Gariep to Bloemfontein is currently planned to augment the Greater Bloemfontein System. At the 27-28 May 2019 ORASECOM meeting in Gaborone, RSA however requested to also test the possibility of the Greater Bloemfontein augmentation requirement to be supplied via the L-BWT scheme pipeline, instead of using the Gariep Bloemfontein pipeline option.

Table 2-3: Net South Africa L-BWT water requirements scenarios

Province	District Municipality	Local Municipality	Identified Towns/Villages		
			Low	Realistic	High
Free State	Fezile Dabi	Moqhaka	-	-	Kroonstad
	Lejweleputswa	Masilonyana	-	Verkeerdevlei	Verkeerdevlei
North West	Dr Ruth Segomotsi Mompati	Mamusa	-	Glaudina	Glaudina
				Migdol	Migdol
	Ngaka Modiri Molema	Ditsobotla	Lichtenburg	Lichtenburg	Lichtenburg
		Mahikeng	Mahikeng	Mahikeng	Mahikeng
			Driehoek South Cluster	Driehoek South Cluster	Driehoek South Cluster
			-	Miga North Cluster	Miga North Cluster
		Ramotshere Moiloa	Motswedi Gopane	Motswedi Gopane	Motswedi Gopane
			Khunotswane	Khunotswane	Khunotswane
			Dinokona	Dinokona	Dinokona
			Zeerust	Zeerust	Zeerust
		Ratlou	-	Maaipeng / Mareetsane	Maaipeng / Mareetsane
				Delareyville	Delareyville
				Atemelang	Atemelang
				Motsitlane	Motsitlane
				Setlagole	Setlagole

The augmentation requirement for Bloemfontein from Gariep was determined as 43 million m^3/a. This means that the RSA augmentation requirement from the L-BWT scheme pipeline will then have to increase by another 43 million m^3/a by 2050.

It is recommended that the realistic demand projection be used for planning purposes. The High and low projections should be used to carry out sensitivity analyses where appropriate.

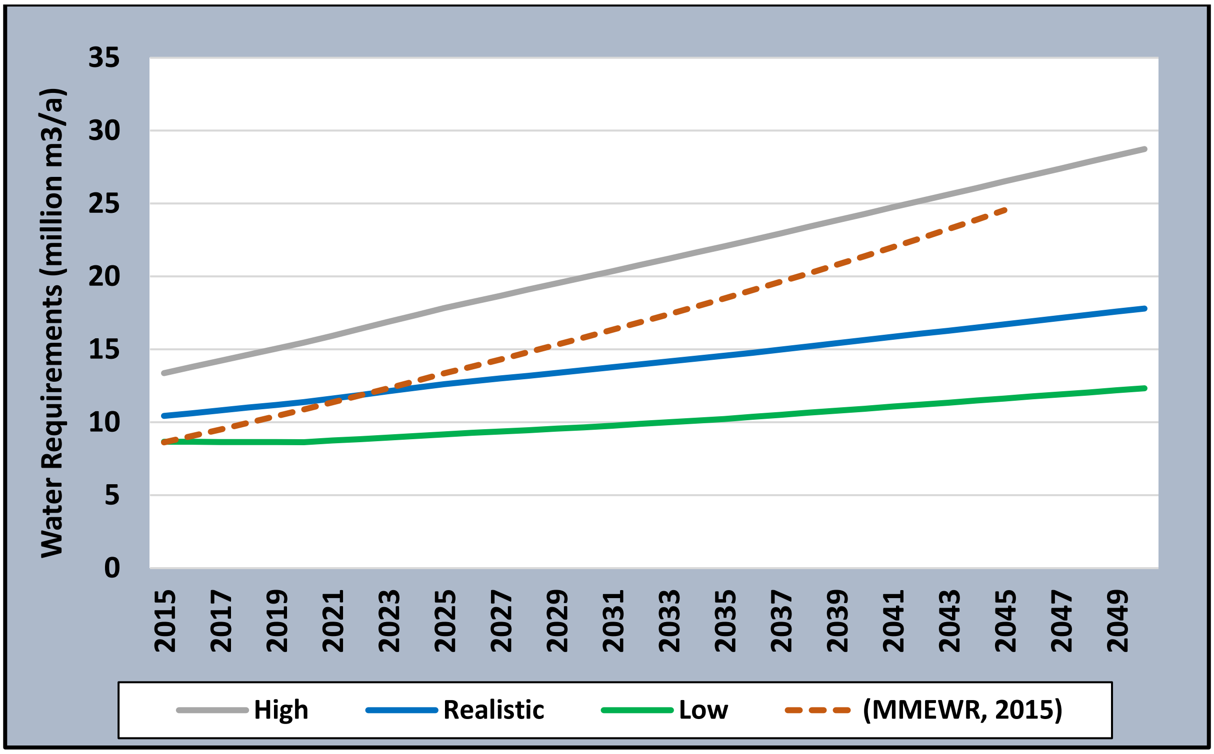


Figure 2-5: Net South Africa L-BWT water requirements projections

2.3 BOTSWANA – INITIAL APPROACH

2.3.1 Urban and Industrial Sector

The water requirements for urban/domestic water use in Botswana were well qualified in the L-BWT Project Desktop Study (MMEWR, 2015). The Desktop study adopted the water requirements from the studies undertaken for the conceptual design of the North-South Carrier Phase 2 as a base scenario for the settlements included in that study. These were largely based on the Botswana National Water Master Plan Review (BNWMPR) of 2010. The BNWMPR includes the current and projected water requirement for every settlement in Botswana up to 2035. It was reported that the Water Utilities Corporation (WUC) experienced higher growths in water requirements than the BNWMPR, and additional requirements relating to mining were added. For settlements not included in the North-South Carrier Phase 2 investigations, and where no other updated studies were available, the water requirements from the BNWMPR were used. The water requirements were extended from 2035 to 2045.

The urban/domestic water requirements from the L-BWT Project Desktop Study (MMEWR, 2015) were presented for the individual settlements categorized into the following nodes:

- Letsibogo Node
- Palapye Node
- Mahalapye Node

- Mmamashia/Gaborone Node
- Lobatse Node

The water requirement projection growth rates of the individual settlements were reviewed and assessed against the historic population growth rates (2000-2011) as well as Botswana Population Projections 2011-2026 (StatsBot, 2015) growth rates (low and high scenario) of the related districts. The water requirement projection growth rates were all more or less in line, except for the Lestibogo Node, that has an accelerated growth from 2035 onwards, which is questionable. The geographic location of the identified towns/villages relative to the existing (North-South Carrier Phase 1 and 2) and planned L-BWT infrastructure were determined and it was established that some settlements were located large distances away from the infrastructure.

The combined urban, industrial and mining sector water requirements projections are presented in **Section 2.3.3**.

2.3.2 Mining Sector

L-BWT Project Desktop Study (MMEWR, 2015) also assessed the mine water requirements by utilizing information from the Chobe-Zambezi Water Transfer Scheme, which assessed the existing and future mine water requirements. Discussions were held with the Botswana Ministry of Minerals, Energy and Water Resources as well as the Chamber of Mines. It was confirmed that the information used in the desktop is the latest information available that is currently used for planning purposes. The team tried to contact the relevant individual mines to confirm whether any updated information could be made available. Despite various follow ups, feedback was only received from one group (Jindal Mmamabula Energy Project).

The total existing and future mine water requirements were sourced from the Chobe-Zambezi Water Transfer Scheme by the L-BWT Project Desktop Study (MMEWR, 2015). The total water requirements are high and are currently predominantly supported by groundwater resources. The previous study thus applied a degree of probability (+-35%) to make a reasonable provision for the mines.

The geographic location of the existing mines and future mines relative to the existing (North-South Carrier Phase 1 and 2) and planned L-BWT infrastructure were identified. The mines in close proximity or more or less in range of the bulk infrastructure were identified and summarized in **Table 2-4** below. From the results it can be seen that:

- **Existing mines:**
  - Three of the mines (BCL Limited, Tati Nickel and Mopani Mine) are supported by Shashe Dam

  - Three mines (Debswana Mining Company (Jwaneng Mines), Mantle Mines-Lerala Mine and Morupule Colliery) are supported by groundwater (supply to Morupule Colliery is also augmented by the North-South Carrier Phase 1).
  - From the long-term planning perspective of BCL Limited and Mantle Mines- Lerala Mine are expected to close in 2027 and 2022 respectively.
- **Future mines:**
  - The listed mine groupings are to be supported from groundwater

The combined long-term (2052) water requirement projections of the existing and future mines were summarized, and the combined long-term projected water requirements are 115.7 million m^3/a. The total long-term water requirements for the future "Possible Coal mines" are 100 million m^3/a alone.

Table 2-4: Existing mines within range of the existing and planned bulk water infrastructure

Existing Mines	Mine Closure	Current Source of Water
Debswana Mining Company (Jwaneng Mines)	>2029	Groundwater about Magagarape Wellfield
BCL Limited	2027	Shashe Dam
Tati Nickel	2037	Shashe Dam
Mantle Mines- Lerala Mine	2022	Groundwater
Morupule Colliery	>2065	Groundwater and NSC 1
Mopani Mine	2037	Shashe Dam
Future Mines	**Mine Start**	**Identified Water Source**
A-CAP Resource	2012	Groundwater
African Energy- Sese Mine	2012	Groundwater
Possible Coal Mines including: CIC energy, Mmamantswe, impact Resource, Daheng Group	2022	Groundwater

It is clear that groundwater is the main water resource currently and also expected to be utilized in future by the mining sector. In order to accurately determine the augmentation requirements of the mining sector, a detailed geohydrological and water balance study per mine site is required to determine the sustainable groundwater exploitation potential and derive a water balance. The mining houses prefer to continue to maximize the utilization of groundwater for economic reasons.

The L-BWT Project Desktop Study (MMEWR, 2015) applied a degree of probability to the total mine requirement identified to make a reasonable provision for the mines, which equated to a long-term requirement of approximately 45 million m^3/a. If the same probability is applied to the identified existing and future mines described above, the long-term requirements equate to approximately 40 million m^3/a.

The combined urban, industrial and mining sector water requirements projections are presented in **Section 2.3.3**.

2.3.3 Combined Water Requirement Projections

Based on the findings presented in the previous sections, three net water requirement projection scenarios were derived as presented in **Table 2-5**. The water requirement projections were based on the L-BWT Project Desktop Study (MMEWR, 2015) with presented adjustments applied for each of the scenarios based on the discussed findings.

Table 2-5: Net Botswana L-BWT water requirements scenarios

Scenario	Description (adjustments applied to L-BWT Project Desktop Study (MMEWR, 2015) projection)
High	• L-BWT Project Desktop Study (MMEWR, 2015) projection
Realistic	• Towns/villages within reasonable proximity from existing and future bulk water infrastructure included • Letsibogo Node excessive/exponential growth reduced by almost 55% from 81.9 to 37.1 million m^3/a by 2050 • Total mining demand 40 million m^3/a • Jwaneng Mine demand for 2025-2027 (11 million m^3/a) reduced to long term requirement (8 million m^3/a)
Low	• Towns/villages within close proximity from existing and future bulk water infrastructure included • Letsibogo Node excessive/exponential growth reduced by almost 55% from 81.9 to 37.1 million m^3/a by 2050 • Total mining demand 40 million m^3/a • Jwaneng Mine demand for 2025-2027 (11 million m^3/a) reduced to long term requirement (8 million m^3/a)

The water requirement projections for the High, Realistic and Low scenarios are presented in **Figure 2-6**, **Figure 2-7** and **Figure 2-8**. The 2050 net augmentation volumes for the High, Realistic and Low scenarios are 186.34 million m^3/a, 136.48 million m^3/a and 106.36 million m^3/a respectively as given in **Figure 2-9** (previous study 2045 volume: 147.072 million m^3/a). The details of the net augmentation projections are presented in **Table A-6**,

Table A-7 and **Table A-8** in **Appendix A** for the Low, Realistic, and High Scenarios respectively.

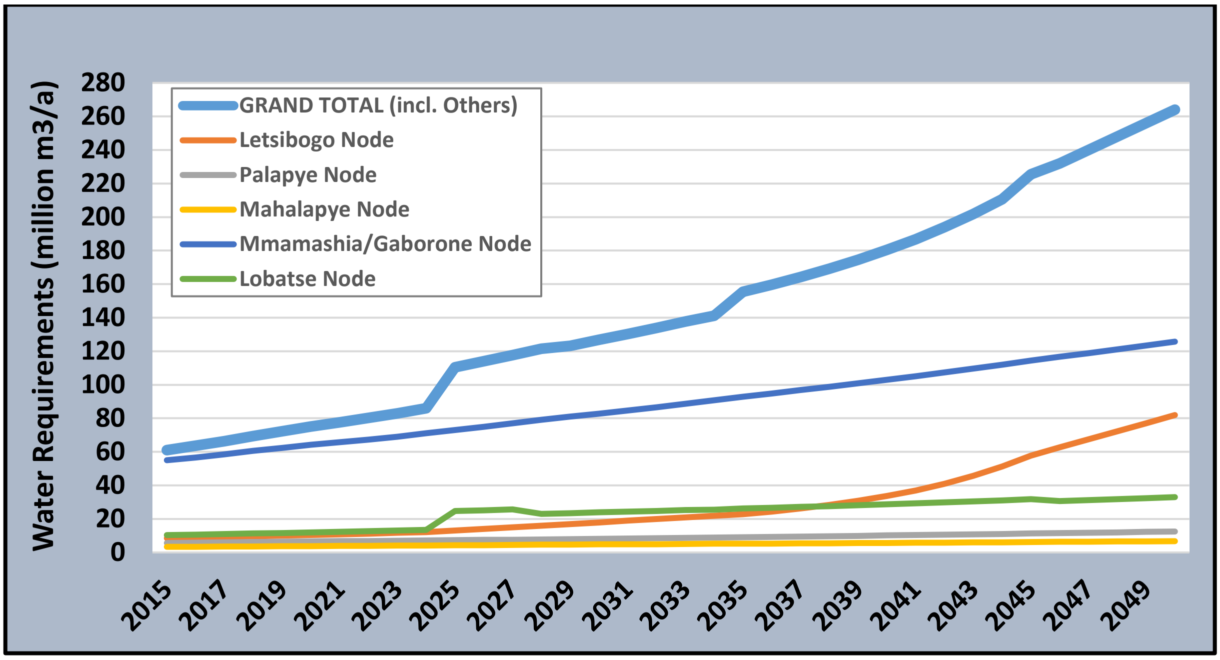


Figure 2-6: Botswana net L-BWT Requirements: High Scenario

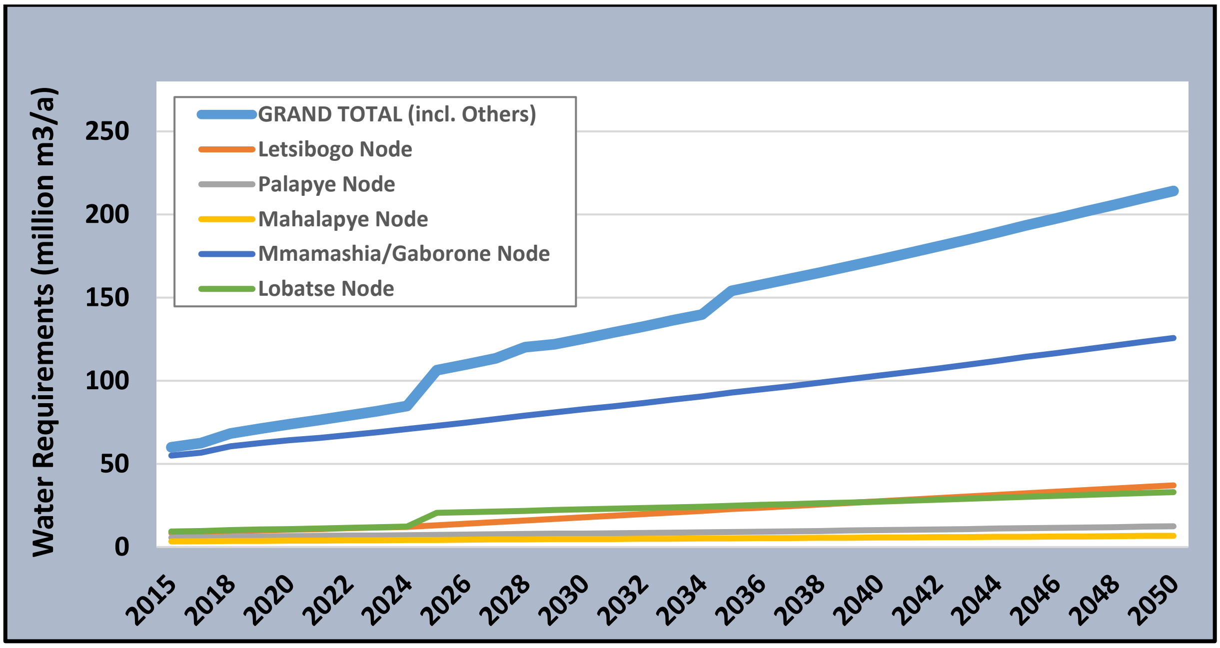


Figure 2-7: Botswana net L-BWT Requirements: Realistic Scenario

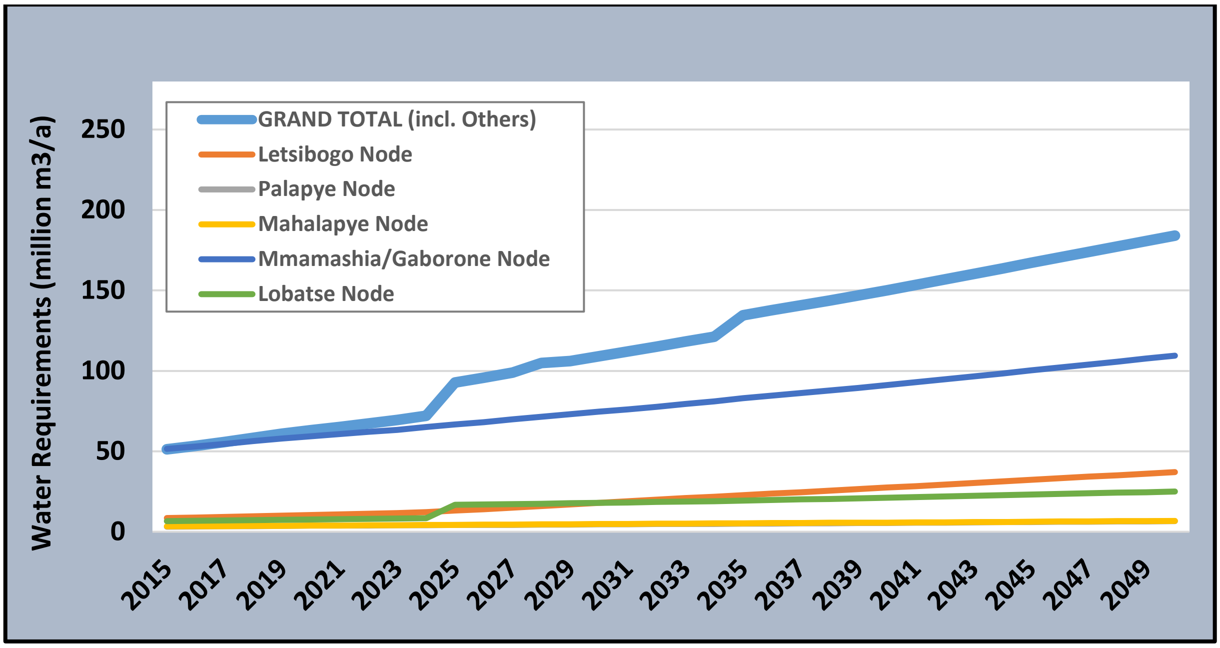


Figure 2-8: Botswana net L-BWT Requirements: Low Scenario

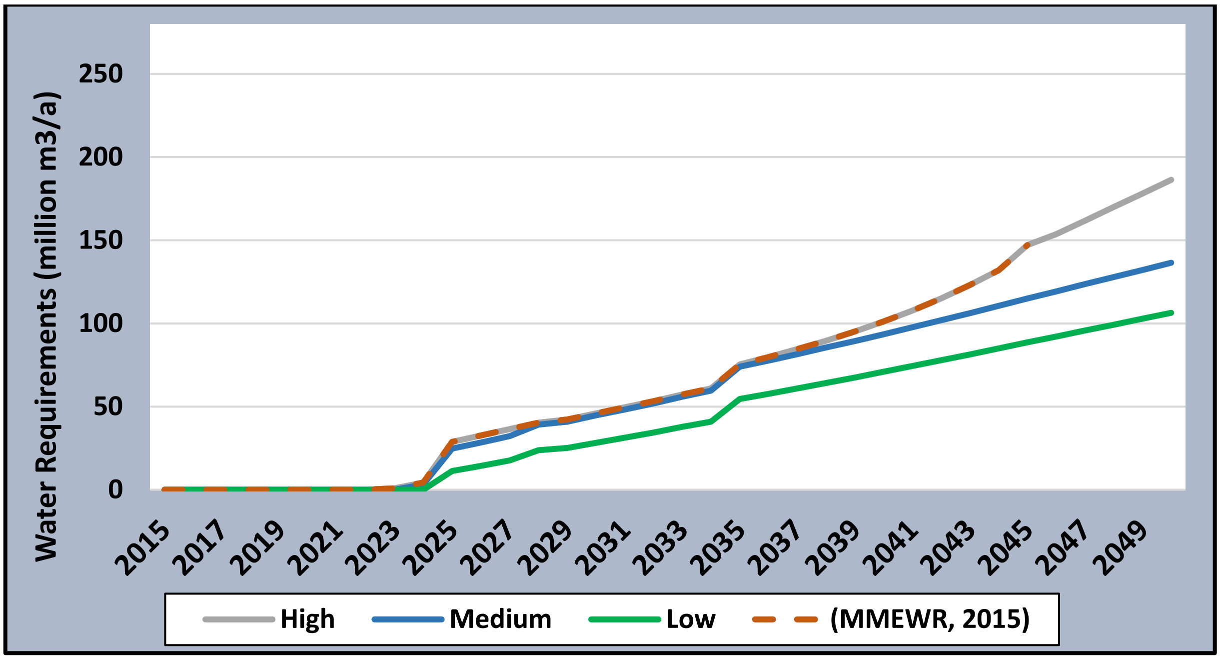


Figure 2-9: Botswana net L-BWT Augmentation Requirements

The projections as given in **Section 2.3.3** were presented to ORASECOM and the related countries in January 2019 in Maseru at the JSMC and TTT meetings. Based on the feedback received at the meeting these demand projections were adjusted as described in **Section 2.4.**

2.4 SECOND VALIDATION OF WATER REQUIREMENTS APPROACH

The second approach or round of the validation of water requirements started after the January 2019 meeting in Lesotho as result of the following.

- In the January 2019 meeting Lesotho indicated that Lesotho Lowlands Water Supply Zones as used in the recognisance phase study (zones 3 to 6) was incorrect. Only Zones 5 to 7 should receive water from the proposed Makhaleng Scheme.
- The Botswana National Water Master Plan Update (BNWMPU) Based on Smart Water Management (BDWS, 2018) became available. This is the most recent available data from Botswana and thus needed to be compared to the work already carried out as presented at the January 2019 meeting.
- The first indication of the incremental yield available from Makhaleng Dam became available from the Water Resource Analysis task undertaken as part of this study (Phase 1). These results showed that with proper mitigation of the downstream impacts, large transfer volumes from the Makhaleng Dam are possible including the future Bloemfontein allocation.

2.4.1 Adjustments to the Lesotho water requirements

Based on the feedback received from Lesotho at the ORASECOM and Partners meeting (29 January to 1 February 2019, Maseru, Lesotho) and a follow up meeting with the Lesotho Officials (26 April 2019, Maseru, Lesotho) it was confirmed that Lesotho's current planning for Metolong Dam is to fully augment Zone 3 and Zone 4 and that the following zones are to be augmented from the L-BWT project:

- Zone 5 (Morija/ Matsieng)
- Zone 6 (Mafeteng)
- Zone 7 (Mohale's Hoek)

According to the desktop analysis undertaken by this study, additional augmentation to Zone 4 (Maseru/ Mazenod/ Roma), over and above the support from Metolong Dam, will be required in the distant future (+-2041 onwards). It is important that the total water requirements are continuously monitored and tracked against the water requirement projections in order to confirm whether additional augmentation is required in the distant future.

A comparison of the total water requirements of Zones 3-6 (MMEWR, 2015 and LWC, 2017) against the revised zones based on Lesotho's most recent planning (LWC, 2017) are presented in **Figure 2-10**. It is clearly evident that the total revised water requirement projections for Zones 5–7 are noticeably lower than the projections for Zones 3-6. The water requirements for the individual zones and the associated compounded growth rates are presented in **Figure 2-11**. The highest growth in water requirements is projected for Zone 6.

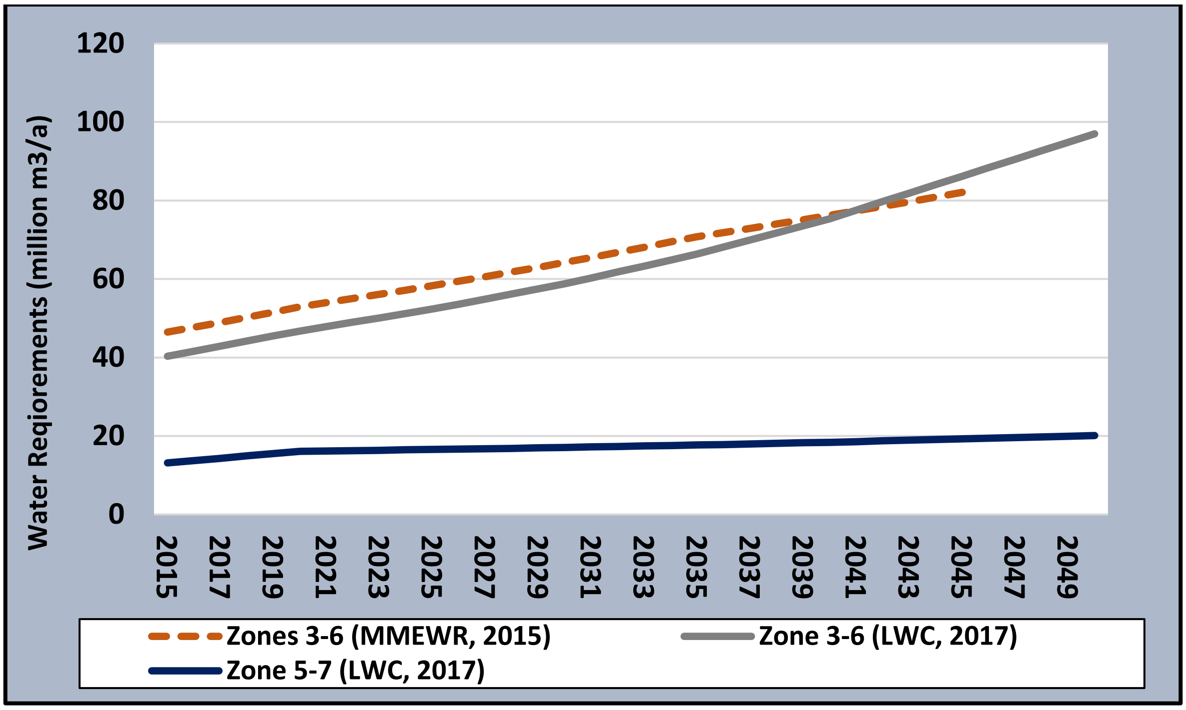


Figure 2-10: Comparison Lesotho Lowlands total net water requirements (Zones 3 – 6 and Zones 5-7)

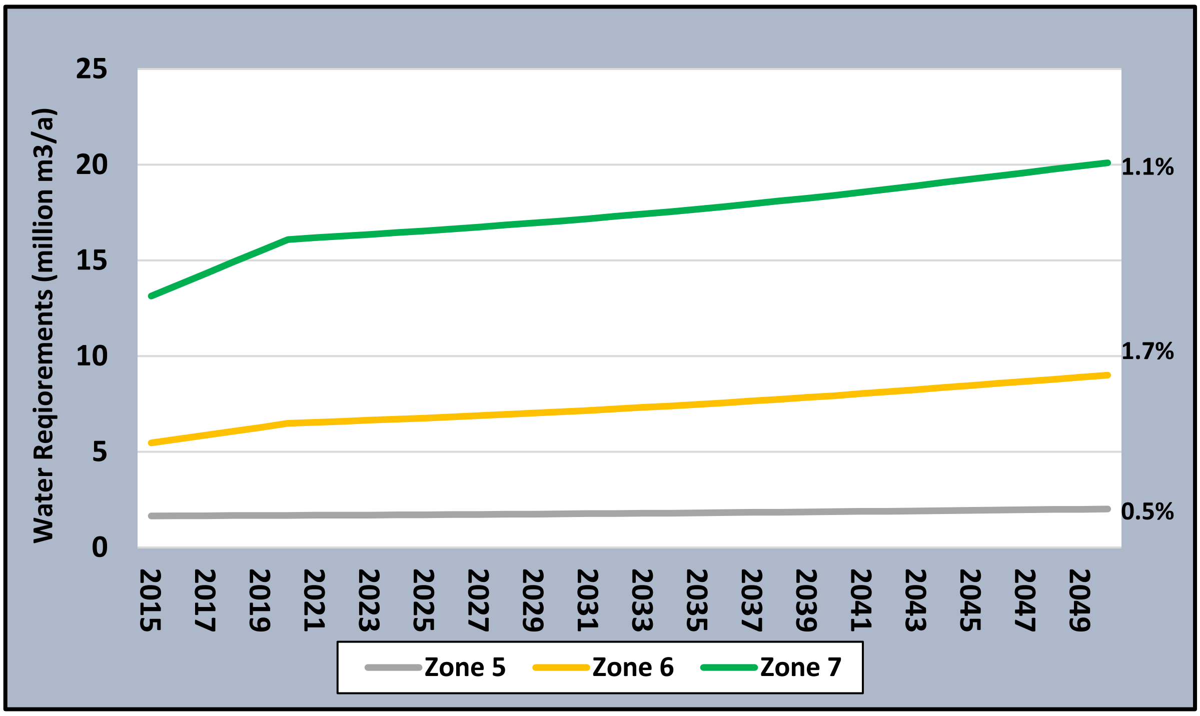


Figure 2-11: Lesotho Lowlands projected net water requirements (Zones 5 – 7) (LWC, 2017a)

The existing local water resources currently utilized in each of the supply zones include water treatment works abstracting water from surface water resources, boreholes, springs and well points as presented in **Table 2-6** (MNR, 2012). The Metolong Dam scheme is presented as an augmentation scheme. The downstream conveyance system consists of pipelines to distribute water to Teyateyaneng (Zone 3) and Maseru, Roma and Mazenod (Zone 4). The total existing local water resources available to support the water requirements of these supply zones, including the newly constructed Metolong Dam, equate to 63.10 million m^3/a.

Table 2-6: Existing water resources (MNR, 2012)

Supply Area	Local Water Resources (million m^3/a)				Augmentation Scheme (million m^3/a
	WTW Capacity	Total Boreholes/ Spring Yield	Total Well Points Yield	Total	Metolong Dam 1:100 Yield
Zone 3 (Peka/ Mapoteng/ TY)	0.44	1.04	0.09	**1.57**	**35.00**
Zone 4 (Maseru/ Mazenod/ Roma)	23.90	0.16	0.91	**24.98**	
Zone 5 (Morija/ Matsieng)	0.04	0.08	-	**0.12**	
Zone 6 (Mafeteng)	0.95	0.07	-	**1.02**	-
Zone 7 (Mohale's Hoek)	0.29	0.12	-	**0.41**	
TOTAL	**25.62**	**1.48**	**1.00**	**28.10**	

Figure 2-12 presents a comparison of the augmentation requirements for Zones 3-6 (MMEWR, 2015 and LWC, 2017) against the revised Zones 5-7, based on Lesotho's most recent planning (LWC, 2017). Zone 7 is currently in deficit and augmentation is thus required from the start of the projection period. The total augmentation required for the Zone 5-7 supply area by 2050 is 18.55 million m^3/a.

The location of the Zones 5-7 relative to the proposed Makhaleng Dam and L-BWT infrastructure is presented in **Figure 2-13**. Based on the preferred dam site position that is being taken forward to the Pre-Feasibility Study, support to Zone 5 and 6 will be provided through the proposed L-BWT transfer link, while Zone 7 will require a separate support linkage due to its location. A comparison of the total Zone 5-7 augmentation requirements compared to the augmentation requirements supported through the L-BWT transfer infrastructure (Zone 5 and 6) is illustrated in **Figure 2-13**. The 2050 augmentation for Zone 7 is 10.68 million m^3/a.

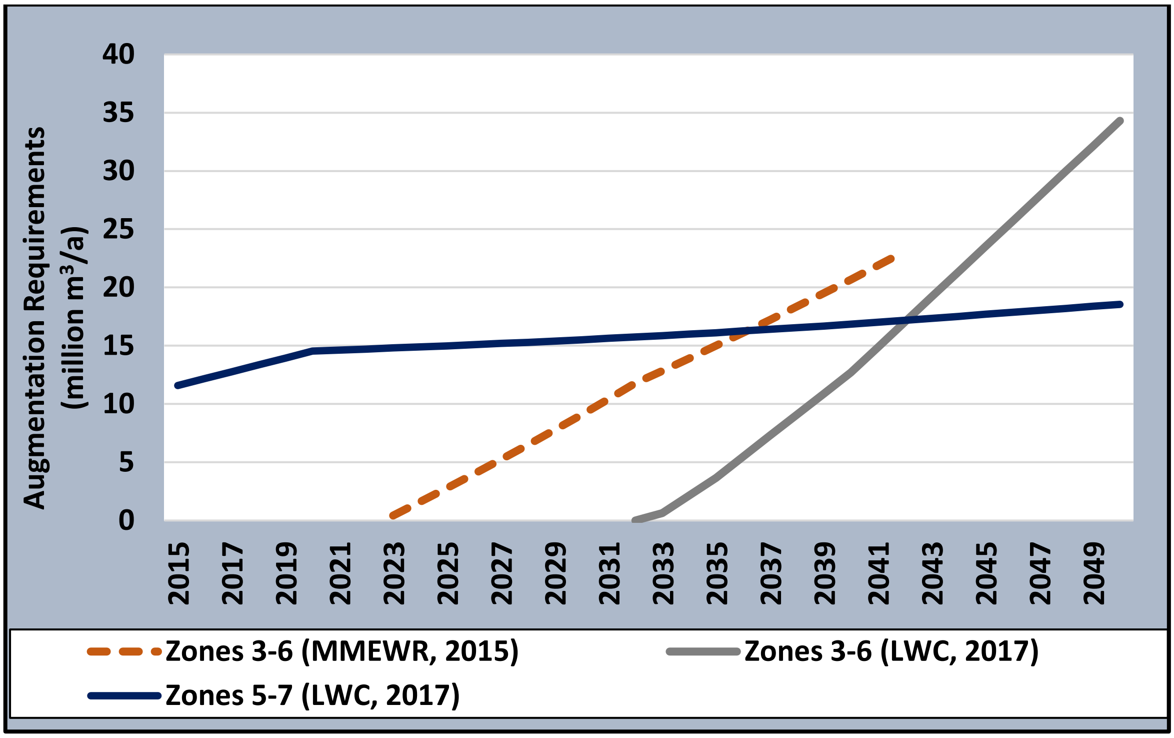


Figure 2-12: Net Lesotho L-BWT water requirements

The water balance tables (water requirements and local water resource) used to derive the presented net augmentation requirements are presented in **Table A-1** and **Table A-2** in **Appendix A** for the Realistic and High Scenarios respectively.

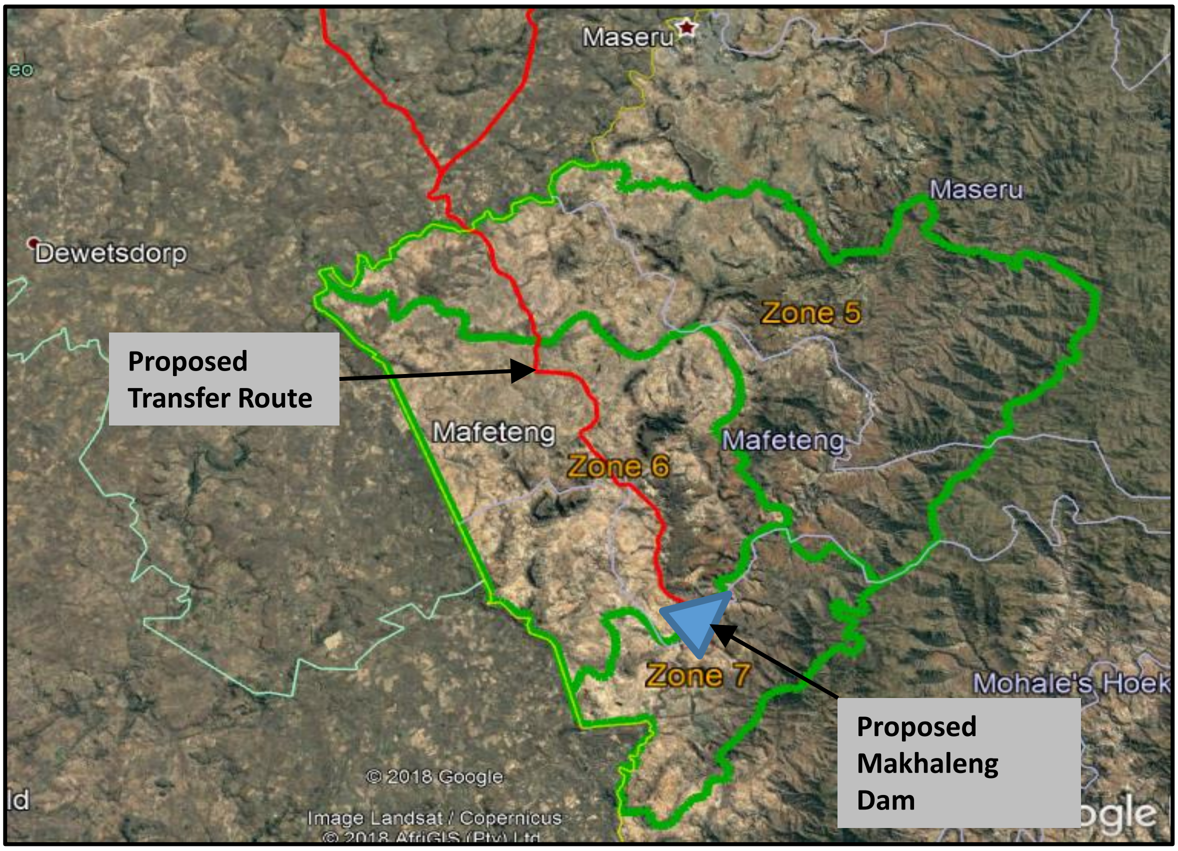


Figure 2-13: Location of Zones 5-7 relative to the proposed L-BWT infrastructure

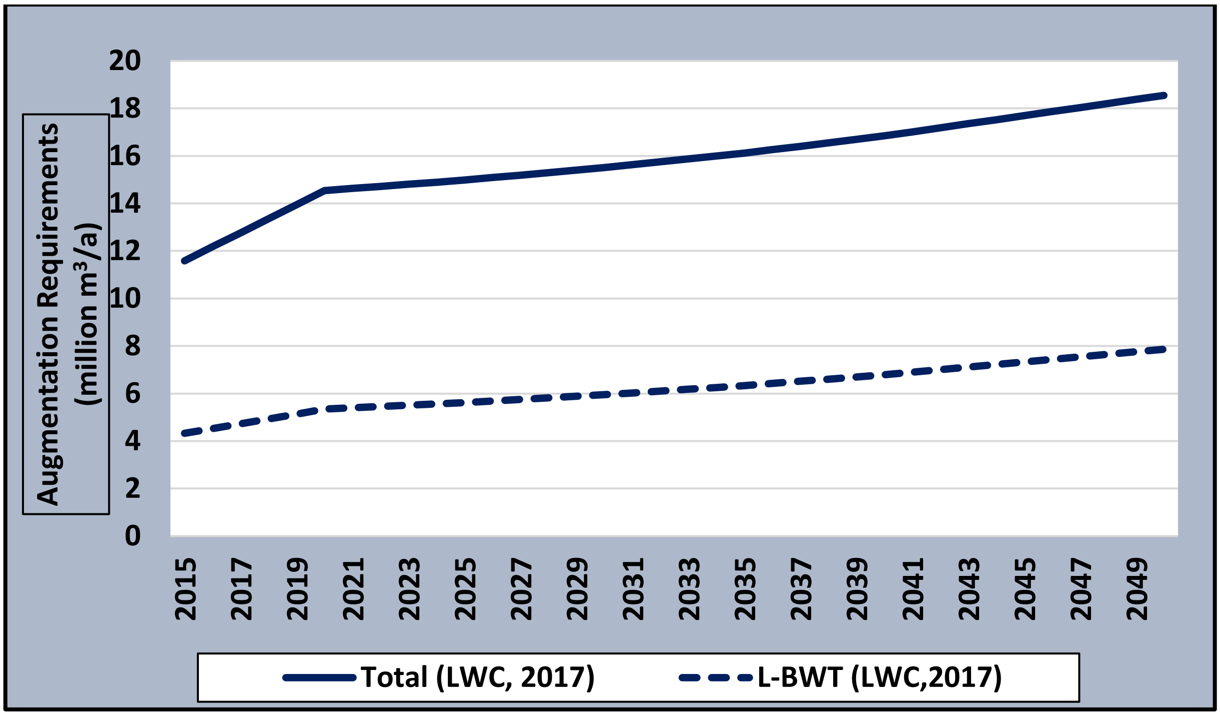


Figure 2-14: Total Zone 5-7 net augmentation requirements

The irrigation requirements remain the same as determined in the initial approach.

2.4.2 Botswana demand adjustments based on National Water Master Plan Update

The Botswana National Water Master Plan Update (BNWMPU) based on Smart Water Management (BDWS, 2018) was provided as the latest information currently utilized for planning by the Botswana Department of Water and Sanitation (BDWS). This information became available after the January 2019 meeting in Maseru and improved demand and augmentation projection were thus prepared as described in **Section 2.4.2**.

The BNWMPU undertook a water balance analysis (comparison of projected water requirements against available resources) for the entire Botswana. As part of the water balance analysis water requirement forecasts for all water use sectors (domestic, industrial and commercial and agricultural sectors) as well as a review of the groundwater and surface water availability was undertaken. The results of individual demand centers were summarized into 16 management centers (MC) (see **Figure 2-15**). A water balance analysis was undertaken for each of the MC's in order to determine the projected augmentation requirements.

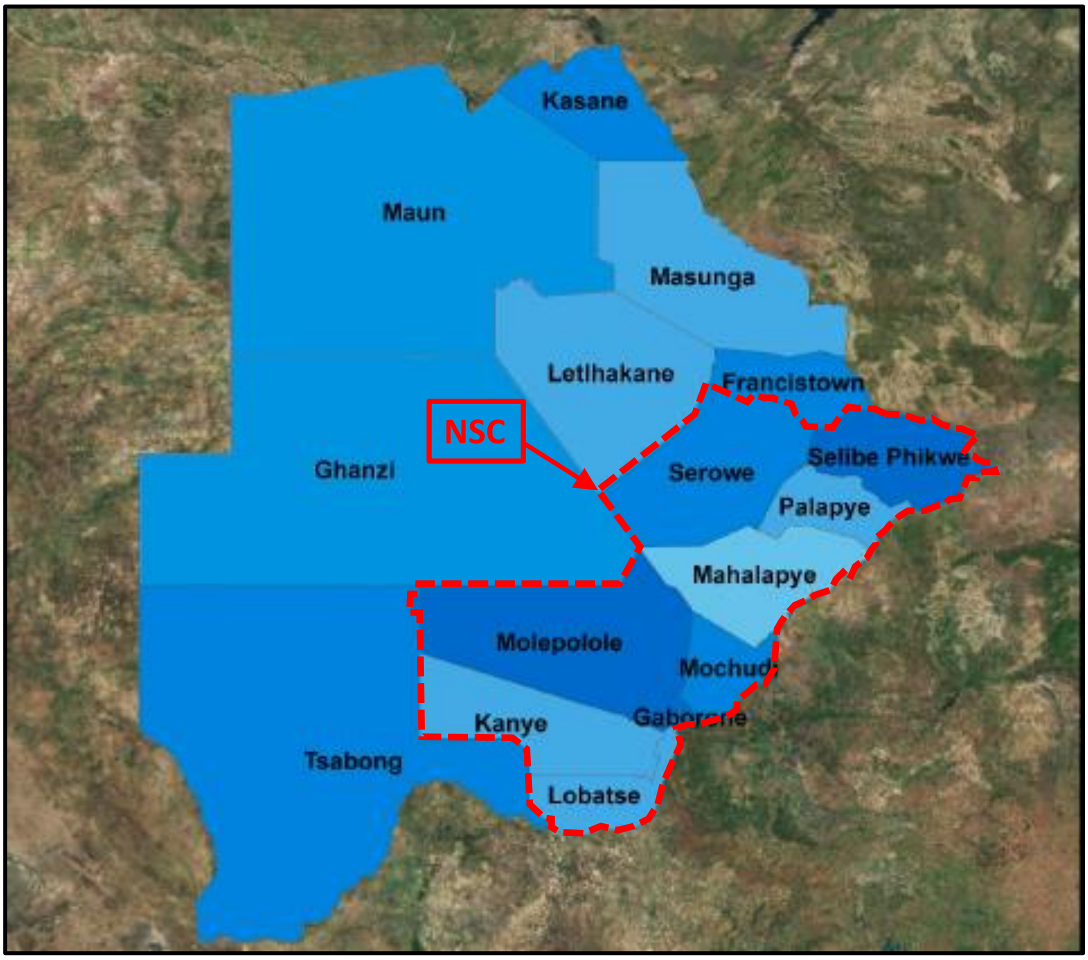


Figure 2-15: Botswana management centers (BDWS, 2018)

The Gaborone/Lobatse Node and North-South Carrier Supply Area water requirements were considered for the water requirement and augmentation requirements as described in **Section 2.3.3.** and indicated by the red dashed line in **Figure 2-15**. The North South Carrier should be able to sort out the water supply to most of the northern management centers. Deficits are mainly expected within the Gaborone Lobatse node. A second option was thus considered where only the Gaborone Lobatse node was supported with transfers via the Lesotho Botswana Transfer Scheme. Initial yield analysis also indicated that with the available incremental yield from the proposed Makhaleng Dam it will be difficult to supply water to the entire Gaborone/Lobatse Node and North-South Carrier Supply Area. The location of the Gaborone Lobatse node is shown in **Figure 2-16**. It should be noted that the reduction in the Botswana augmentation requirements is only one of the options to address the problem concerning insufficient incremental yield from Makhaleng Dam.

By utilizing the local yield from Makhaleng Dam it will be possible to supply the total envisaged water requirements to be imposed on the dam. In that case it will be important to add another development in the system to supply the mitigation releases on behalf of Makhaleng Dam in order to restore the downstream water balance due to the impact of Makhaleng Dam. Detail of these options are given in **Section 4.2** of this report.

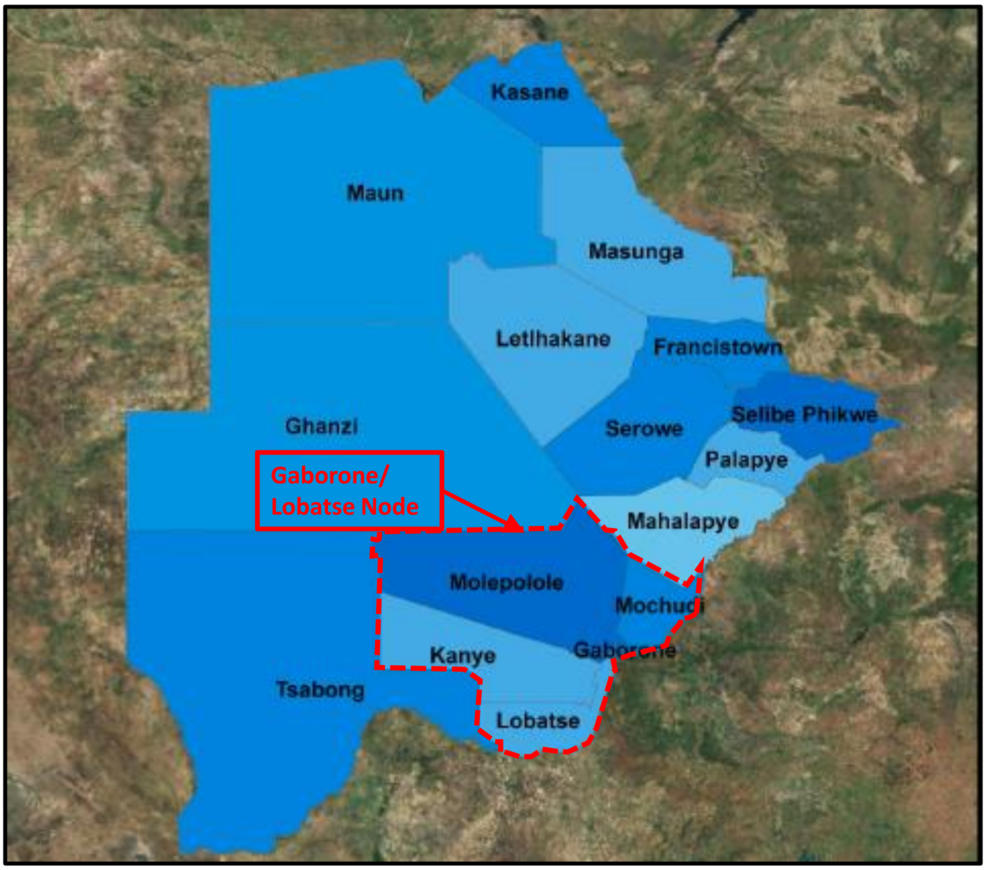


Figure 2-16: Gaborone/Lobatse Node

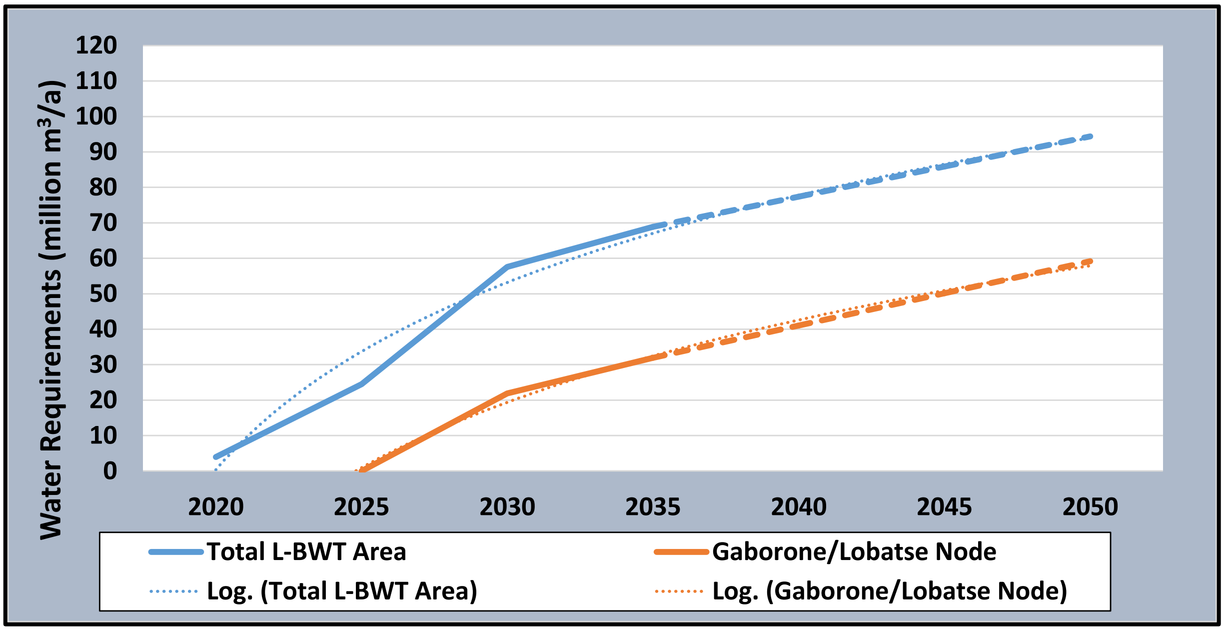


Figure 2-17: Net Augmentation requirements for the two supply areas.

Table 2-7: Botswana net augmentation requirements based on the BNWMPU (million m³/a)

Year	2020	2025	2030	2035	2040	2045	2050
Total L-BWT Area	3.9	24.5	57.6	68.9	77.4	85.9	94.4
Gaborone/Lobatse Node			21.9	32.0	41.0	50.1	59.2

The net augmentation requirements for the two supply areas are shown in Figure 2-17 and summarized in **Table 2-7**. The net augmentation by 2050 is expected to reach 59 million m^3/a and 94 million m^3/a for the Gaborone Lobatse node and for the entire Gaborone/Lobatse Node and North-South Carrier Supply Area respectively. These are the estimates from the updated Botswana National Water Masterplan Update of 2018. Botswana, however, later requested that the previous estimate of 136 million m^3/a should be used rather than the 94 million m^3/a due to uncertainty regarding the long-term sustainability of the groundwater resources. It should be noted that the 136 million m^3/a was determined initially for the realistic scenario as part of round 1 as discussed in **Section 2.3.3**.

2.4.3 South Africa Urban and Industrial Water Requirements

The South Africa water requirements remained as determined from the initial approach. It was however requested at 27-28 May 2019 Gaborone meeting to also add the possibility of supporting the water requirements of the Greater Bloemfontein System from the Lesotho Botswana Transfer pipeline. Current planning is to transfer 43 million m^3/a from Gariep Dam to Bloemfontein. The option to supply this 43 million m^3/a from the Lesotho Botswana Transfer pipeline will thus be an alternative to the planned Gariep – Bloemfontein transfer.

2.5 VALIDATION OF WATER REQUIREMENTS SUMMARY AND CONCLUSIONS

For the purpose of Phase 1 of the pre-feasibility study for the Lesotho Botswana Transfer Scheme a high and a low demand scenario were considered after which it was decided by ORASECOM that only the higher scenario will be taken forward to Phase 2 of the pre-feasibility study. The higher scenario is based on the 136 million m^3/a Botswana net augmentation requirement, details of which are given in **Table 2-8**. The augmentation water requirements for the High Scenario are based on the results as presented at the January 2019 meeting in Maseru for the medium or realistic scenario. The only adjustment was for the Lesotho water requirements, based on the feedback received from the January 2019 meeting as described in **Section 2.1.1.**

Table 2-8: High Scenario L - BWT requirements - Gaborone/Lobatse Node and North-South Carrier Supply Area

Description and Country	2050 Net Augmentation Water Requirements (million m^3/a)	2050 Gross Augmentation Water Requirements (15% losses) (million m^3/a)
Lesotho separate pipeline to Zone 7	11	13
Lesotho via the L-BWT pipeline	8	9
South Africa	18	21
Botswana	136	156
Total L-BWT Demand	**162**	**186**
Total Demand (incl. pipeline to Zone 7)	**173**	**199**

In **Figure 2-18** the percentage split per country is shown of the high demand imposed on Makhaleng Dam. The bulk of the water requirements (about 80%) for the High Scenario is going to Botswana with almost equal parts to RSA and Lesotho.

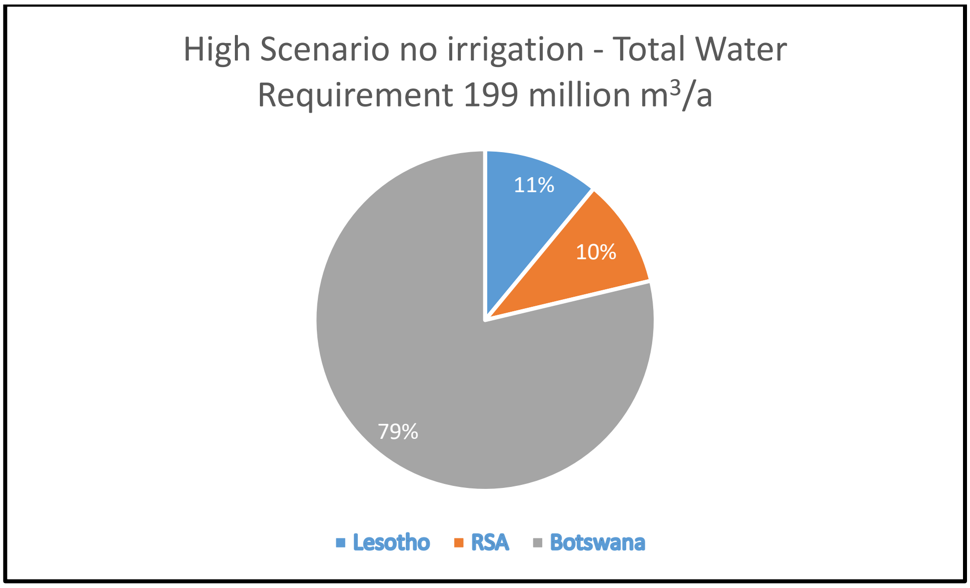


Figure 2-18: High Scenario – no irrigation

The local yield from Makhaleng Dam is estimated to be approximately 400 million m^3/a and should this full yield be utilized at the dam site, an additional intervention option will be required to balance the Orange River Project (ORP) yield. This is the most preferred and logical option given the economical value of diverting as much water as possible from the Makhaleng Dam.

Details of the Low Scenario are given in **Table 2-9**. The only difference between the high and the low scenario is the Botswana augmentation requirement. This however resulted in a significant decrease in the gross requirement from the 199 million m^3/a to 111 million m^3/a.

For the Low Scenario the total water requirement excluding the Lesotho irrigation is 111 million m^3/a, which is less than the incremental yield from Makhaleng Dam of approximately 150 million m^3/a. This will allow for about 40 million m^3/a (±4 500ha) to support irrigation developments from Makhaleng Dam. .

Given the unrealibility and uncertain nature of the groundwater in Botswana to supply the mines, this Scenerio is not support by ORASECOM which has indicated that only the high demand scenario will be taken forward to the Pre-Feasibility Phase of the project..

Table 2-9:Low Scenario L - BWT requirements - Gaborone/Lobatse Node Supply Area

Description and Country	**2050 Net Augmentation Water Requirements (million m^3/a)**	**2050 Gross Augmentation Water Requirements (15% losses) (million m^3/a)**
Lesotho separate pipeline to Zone 7	11	13
Lesotho via the L-BWT pipeline	8	9
South Africa	18	21
Botswana	59	68
Total L-BWT Demand	**85**	**97**
Total Demand (incl. pipeline to Zone 7)	**95**	**111**

In **Figure 2-19** the percentage split per country is shown when the demand imposed on Makhaleng Dam for the Low Scenario is considered, without Lesotho Irrigation. The portion of the water requirements going to Botswana reduced significantly from the almost 80% for the High Scenario to about 60% with almost equal parts to RSA and Lesotho.

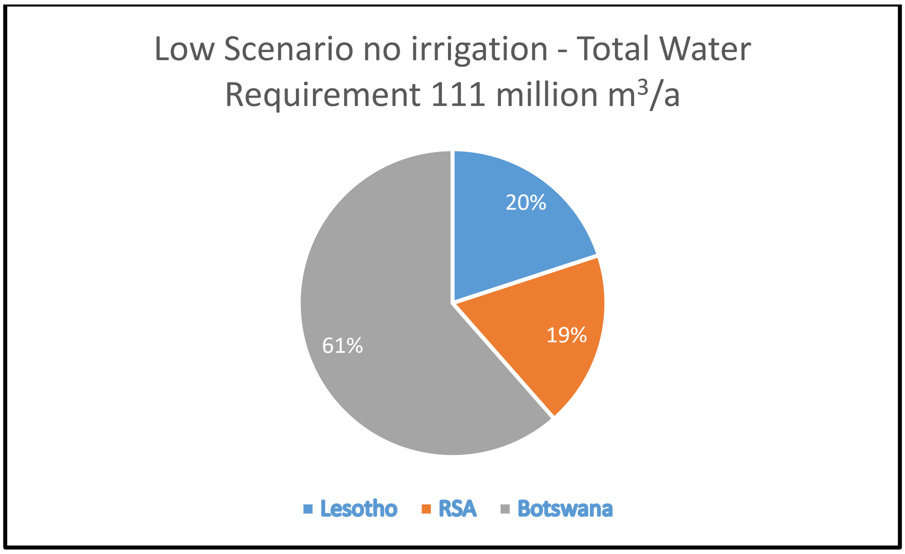


Figure 2-19: Low Scenario – no irrigation

The Low Scenario also allows for the development of irrigation in Lesotho. The net yield from a possible Makhaleng Dam for the Low Scenario allows for the inclusion of about 40 to 49 million m^3/a for irrigation depending on the size and location of Makhaleng Dam. This represents about half of the possible maximum irrigation area downstream of Makhaleng Dam. The change in the distribution of the water requirements between the countries for this option is given in **Figure 2-20**. For this scenario the allocations to Botswana and Lesotho are both over 40% with only 14% to the RSA.

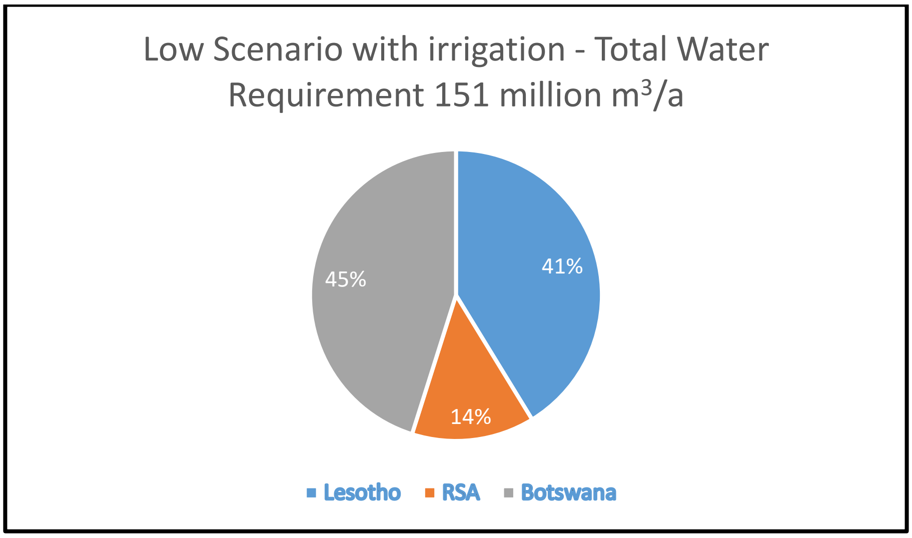


Figure 2-20: Low Scenario with Lesotho irrigation (40 million m^3/a)

DWS RSA requested that the option of augmenting the Greater Bloemfontein System from the L-BWT scheme pipeline also be tested as a possible additional (see **Section 2.2**) RSA water requirement. For this scenario the RSA augmentation requirement from the L-BWT scheme pipeline will increase by another 43 million m^3/a (Mangaung Metro Municipality 2018). Only the Low Scenario could accommodate this additional transfer.

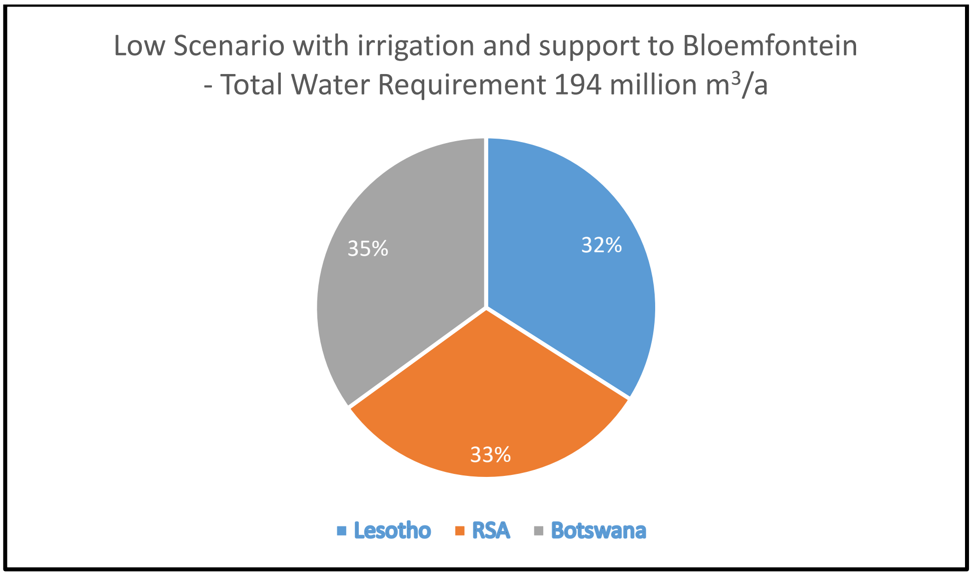


Figure 2-21: Low Scenario with irrigation and support to Greater Bloemfontein

The current RSA planning is to transfer the 43 million m^3/a from Gariep Dam to Greater Bloemfontein. The 43 million m^3/a transfer to Greater Bloemfontein is already part of the future demand for the Orange River Project and can therefore be supplied from either Gariep Dam or from Makhaleng Dam. The impact on the Orange-Senqu system will therefore be more or less the same for both low scenario options and the Lesotho irrigation to be supported from Makhaleng Dam will remain unchanged. When the Low Scenario is also used to augment Greater Bloemfontein, the RSA, Botswana and Lesotho proportions are almost similar being just above 30% each as shown in **Figure 2-21**. The low demand scenario does not allow for water to be supplied to mines located north of Gaboroine which are currently mainly supplied from groundwater. Botswana has indicated that this is a potential problem given uncertainties on the exploitation of the groundwater resources to supply these mines. For this reason, only the higher demand scenario is being taken forward to Pre-Feasibility Phase 2.

<u>It should be noted that:</u>

- The towns in South African to be supplied from the proposed pipeline will be dependent upon the final selected route for the pipeline. The towns and their associated demands can therefore only be confirmed when the preferred pipeline route is finalised.
- The Lesotho requirements for irrigation development in the Makhaleng catchment can differ significantly depending on the demand scenario considered and the incremental yield available from the final selected Makhaleng Dam. The areas to be irrigated in

Lesotho will be confirmed in Phase 2 pending the outcome of the Lesotho Irrigation Masterplan.

- The Botswana water requirements are largely dependent on growth in the mining sector and associated growth in the neighbouring towns and urban centres. The use of groundwater is currently prevalent but its future use is uncertain and cannot be relied upon
- The inclusion of support to the Greater Bloemfontein System will not hamper the extent of irrigation development in the Makhaleng River catchment to be supported from Makhaleng Dam.
- The high Botswana augmentation requirement included in the High Scenario will significantly reduce or even eliminate irrigation development in the Makhaleng River catchment to be supported from Makhaleng Dam unless an additional resource is used to restore the water balance in the ORP. The possible additional resources will be addressed through a separate basin wide integrated reconciliation strategy study.

The Botswana mining sector is predominantly dependent on groundwater and the mining houses have expressed their intention to utilize groundwater resources as far as possible for economic reasons. The mining water augmentation requirements were determined by applying percentage probability to the existing and future mines located in close proximity of the current and planned bulk water distribution infrastructure. A detailed geohydrological and water balance study per mine site should be considered in the Feasibility Phase to determine the sustainable groundwater exploitation potential, derive a water balance, and determine the augmentation requirements.

Due to the significant difference in the incremental and local yield from Makhaleng Dam, other intervention options to balance the deficit in the Orange River Project should be investigated in detail through a separate and independent study.

2.6 EWR DOWNSTREAM OF THE PROPOSED MAKHALENG DAM

For the purpose of this project, only the Ecological Water Requirements (EWR) downstream of the proposed Makhaleng Dam are being investigated. The EWRs for the remaining sites in the Orange/Senqu basin have already been established through numerous other inedpendant studies undertaken by three of the basin states. In terms of the Ecological Water Requirement (EWR) determination, the study area discussed in this report is downstream of the proposed Makhaleng Dam with emphasis on the Makhaleng River.

2.6.1 EWR Site

The Makhaleng River downstream of the proposed dam is a uniform alluvial section and one EWR site sufficiently represents the variety, albeit limited, of habitats in this section. The selected EWR site is situated 7 km downstream of the proposed Makhaleng Dam.

2.6.2 Eco Classification

The Eco Status Level III (Kleynhans and Louw, 2007) method to determine the EC (A to F) was used but adjusted where required based on the available data.

In summary, the D Eco Status represents the response of the biota to the lack of habitat diversity due to sedimentation from overgrazing, erosion, and removal of riparian vegetation as well as the presence of alien vegetation in the riparian zone.

As the Ecological Importance and Ecological Sensitivity is moderate, the Recommended Ecological Category (REC) is set to maintain the PES.

Table 2-10: Present Ecological State Results and Comments

Component	EC	Comment
Instream IHI[1]	D	The instream IHI assessment is based on a site survey and Google Earth information of the catchment. Modelled hydrology was also used to populate the model. The diatom analysis results were used to derive water quality input. The D result is largely due to impacts associated with overgrazing, erosion, sedimentation and alien vegetation.
Riparian IHI	D	The riparian IHI assessment was based on a site survey, Google Earth information of the catchment, photographs of terraces and general area, and a review by a riparian vegetation specialist. The riparian IHI was used as a surrogate for the VEGRAI[2] analysis which will only be undertaken during the Feasibility phase. The D result is largely due to impacts associated with overgrazing, erosion, sedimentation and alien vegetation.
Fish	E	The fish information for the downstream reach D15J-04889 was used to apply a desktop FRAI[3] (without surveyed information). The result is an E Category which is mostly due to the habitat degradation linked to the lack of cover, sedimentation which amongst others affects migration.
Eco Status	D	The Eco Status EC was derived using the Eco Status model. As this is a desktop level study, all the information was not available for the Eco Status model and the following information was used: Instream IHI was used as a surrogate for the MIRAI results which supply the macroinvertebrate EC. The riparian IHI was used as a surrogate for the VEGRAI results which supply the riparian vegetation EC.

1 IHI Index of Habitat Integrity (Kleynhans *et al.*, 2009)

2 Vegetation Response Assessment Index (Kleynhans, 2007)

3 Fish Response Assessment Index (Kleynhans *et al.*, 2007)

2.6.3 EWR Estimate

The Revised Desktop Reserve Model (RDRM, v2) was used to estimate the EWR requirements for the site (refer to Hughes et al., 2012; 2014 and 2018). The time series of natural monthly flows was supplied by WRP Consulting Engineers (Pty) Ltd for the 85-year period 1920 to 2004 and provided a Mean Annual Runoff (MAR) of 575.45 million m^3. For the EWR site, the natural and Present Day (PD) MARs are deemed to be equivalent.

The EWR results are summarised in **Table 2-11**, with the full RDRM ‘report’ provided in **Appendix C**, which includes inter alia EWR assurance ‘rules’ for the range of ECs (viz A to D).

Table 2-11: Summary of EWR Results

Natural/PD Mean Annual Runoff, MAR (10^6 m^3)				575.45
Ecological Category	Low flows		Total flows	
	10^6m^3	% nMAR	10^6m^3	% nMAR
B	213.819	37.2	281.716	49.0
C	144.160	25.1	206.964	36.0
D	95.926	16.7	150.750	26.2

2.6.4 Conclusion

Initially, the "D" ecological category results were used to determine the impacts on yield, which showed minimal impact on the yield. The "B" ecological category was also evaluated; however, this had a significant impact on yield. As explained in **Section 2.6.2**, the "D" ecological category flows, which are considerably less than the present flow regime, are unlikely to maintain the recommended ecological category. It is recommended that various other ecological category ecological water requirements results are evaluated during the Pre-Feasibility Phase 2 as part of a scenario evaluation process to determine the impact of each scenario on the Recommended Ecological Category.

3 DAM SITE SELECTION

The Makhaleng River is the third largest river in Lesotho after the Senqu and Caledon (Mohokare) Rivers. It rises west of Mohale Dam and flows south west to join the Orange River in South Africa. The catchment area of the river is 3 044 km^2. The mean annual runoff at the confluence is estimated as 625 million m^3/a. The elevation of the river falls from 2 070 m above sea level to 1 400 m above sea level at the SA border.

3.1 IDENTIFICATION OF POTENTIAL DAM SITES

Originally, thirteen dam sites were identified using the 2004 Lowlands Study, the Reconnaissance Study for the L-BWT, and the terms of reference, as well as available topographic and geological information. After a stakeholder workshop was held, site Sa was added to the TOR group as well as Site N1a approximately 2 km upstream of site N1 and added because of its narrower valley **Figure 3-1**:

1. Lowlands – 2004 study (Northern) site = Lowlands 2004
2. TOR group of sites (Central) = S1, S2, S3, S4, TOR, N1, N2, N3 and N4.
3. Reconnaissance (Southern) group of sites = D2, D3, and D4.

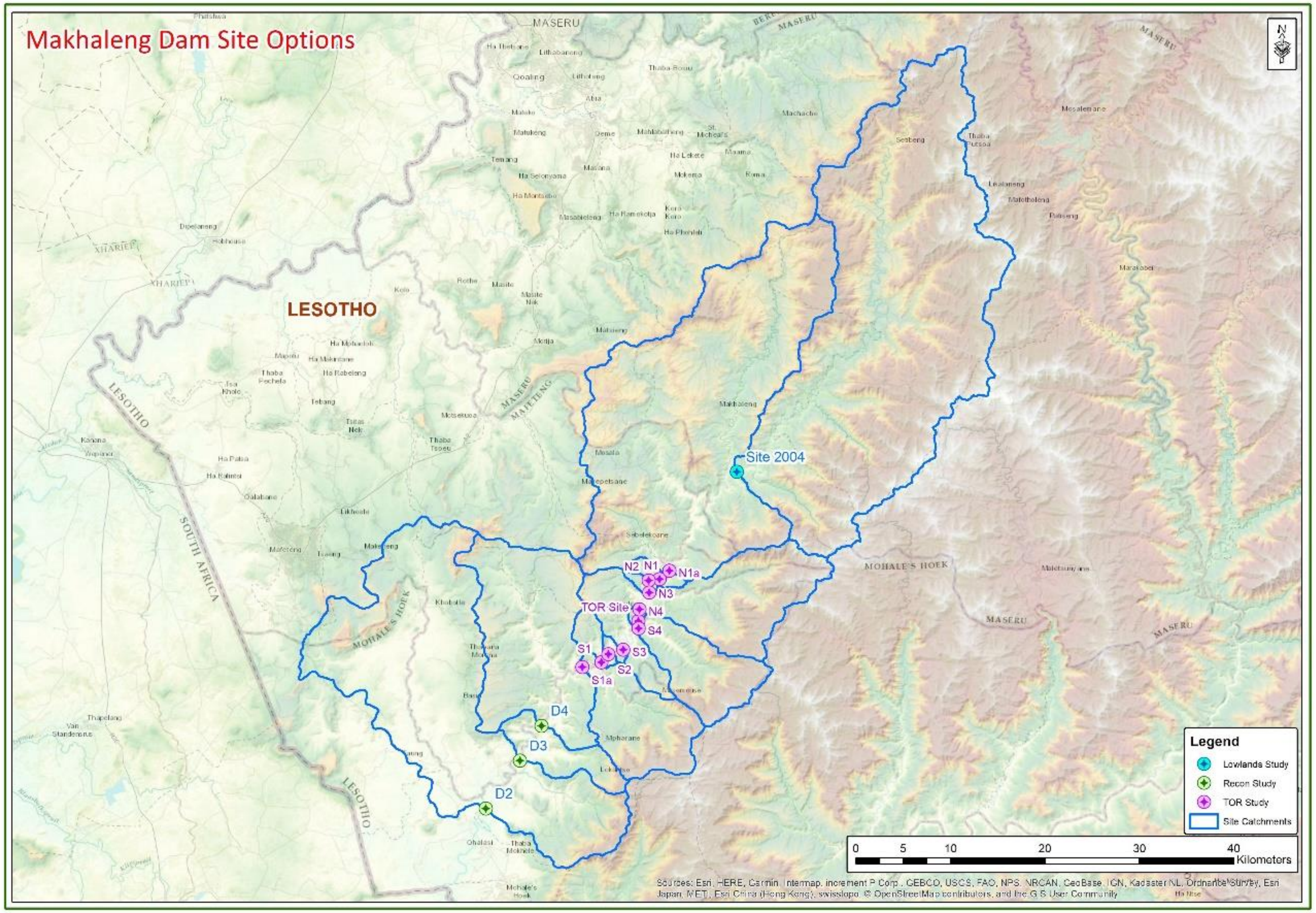


Figure 3-1: Makhaleng River – Fifteen Potential Dam Sites and their Catchments

3.1.1 Lowlands Study (2004)

A dam site was identified during the Lowlands Study in the upper reaches of the Makhaleng River. This site being the most upstream site has the smallest catchment of all the sites identified and therefore lowest run-off.

3.1.2 Terms of Reference (2017)

During the tender stage, ORASECOM indicated; that the probable dam site is within five km upstream or downstream of the coordinates (29º 53′ 06.90″ S and 27º 36′ 54.23″E), however the Consultant is not limited to this stretch of river. The Consultant is required to analyse and assess all possible sites in the Makhaleng River and determine the most suitable site.

Using the available SRTM data, five sites upstream (N1a, and N1 to N4) and five sites downstream (S1a, S1 to S4) were identified. **Figure 3-2** below shows the locations of the ten sites identified in the vicinity of the TOR site.

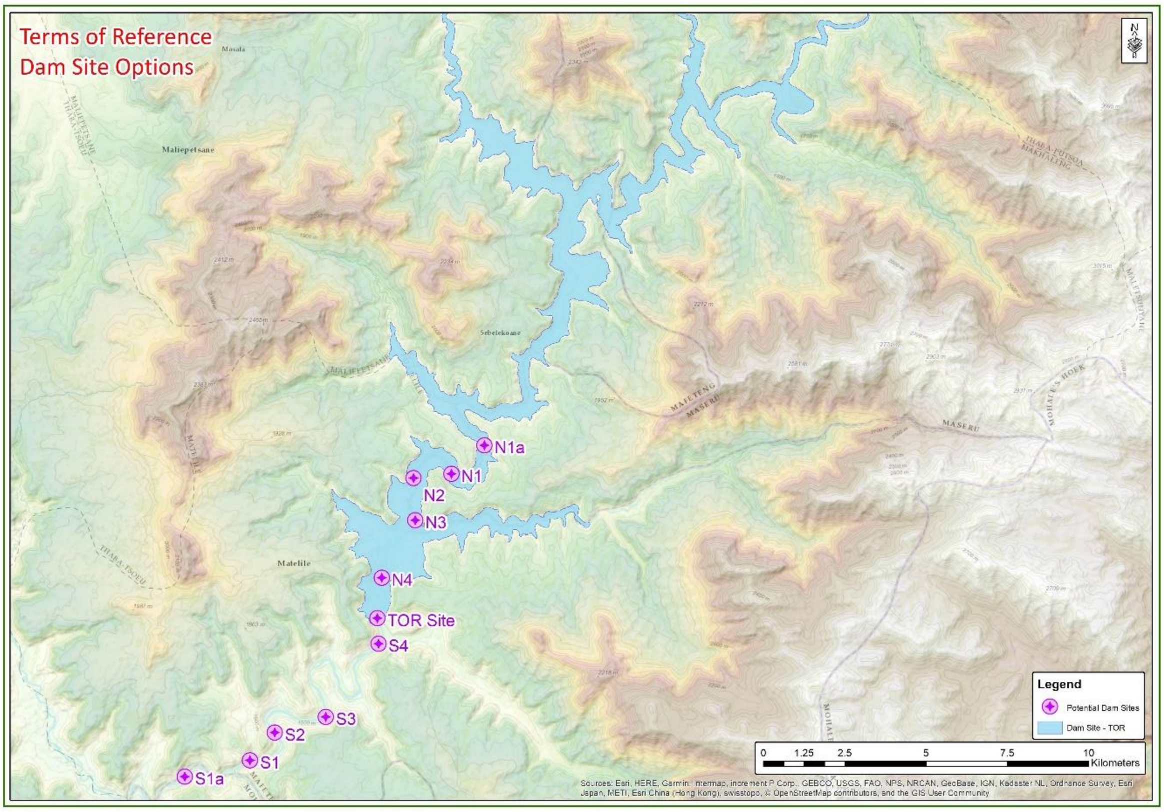


Figure 3-2: Potential Dam Sites near TOR identified point

3.1.3 Three Sites Identified During the Reconnaissance Study (2015)

The reconnaissance study identified three sites in the lower reaches of the Makhaleng River. The first of these sites was D2 which is approximately 2km North of the bridge on the road from Mafeteng to Mohale's Hoek. D3 and D4 are 6km and 10km upstream of the D2 site. The reconnaissance study suggested an RCC gravity dam with a storage capacity in the order of 200 to 400 million m^3. The reconnaissance study also identified the sedimentation risks in the lower Makhaleng River of approximately 6 million m^3/a. The reconnaissance study suggested the use of scour gates to reduce the sedimentation of the reservoir. In addition to the three sites above, the reconnaissance study mentioned another site at the junction of the Makhaleng and Makhalenyane Rivers (29º 49' 49.68" S x 27º 38' 20.95" E). This upstream site is in close proximity to the terms of reference site N1.

3.2 SITE VISITS

A site visit was undertaken on the 14th November 2018 with seven members of the Dam Design Team. A helicopter has hired from MGC Aviation in Lesotho and the team flew from Maseru Airport over all 13 dam sites identified. The team landed and walked over a portion of three of the sites which were prioritised as better dam sites before the visit. These were dam sites N4, S2 and D3.

Photograph of MGC's AS350 B3 Helicopter used for the site visit

The site visit was undertaken by the following study team members from dam engineering, geotechnical, environmental and social disciplines.

- Adam Botha
- Amelia Briel
- Lourie Geldenhuys
- Robert Greyling
- Edwin Lillie
- Lipalesa Malebese
- Gawie Steyn

After the site visit, the dam site options were workshopped by the design team and although it was intended to select a site from the lower catchment as well as the central catchment, the consensus of the team after the workshop was that S1, S2, and N1 were the best three options from what was visible during the site visit. As these sites had the narrowest valley shapes and from the surface geology appeared to had the best founding conditions.

Detailed technical information on each site is provided in **Appendices D and E**.

3.3 DAM SITE CHARACTERISTICS

The main characteristics of each of the dam sites were compiled to make a fair assessment of each site. The characteristics of each site were used to inform the MCA to select the two best options for more detailed investigation at pre-feasibility level of detail.

3.3.1 Dam Size

At this stage of the study, it is premature to determine the optimum size of the dam. As the dam size may influence the optimal site selection, an approach was taken to use <u>two standardised dam sizes for the site selection phase</u>.

The first dam was sized to meet the initial estimate of the 2050 water requirements for the Lesotho to Botswana Transfer, as well as the towns in Lesotho and South Africa on route to Botswana. The initial estimated of the 2050 water requirement is 200 million m^3/a; which includes water losses.

Figure 3-3 shows the process used to determine the dam height at each site. Once the capacity of the dam required to supply the estimated water requirements was determined, the estimated 50-year volume of silt was added to the capacity, and then the height was determined. The freeboard between the full supply level and the non-overspill crest was then added to obtain the final height of the dam.

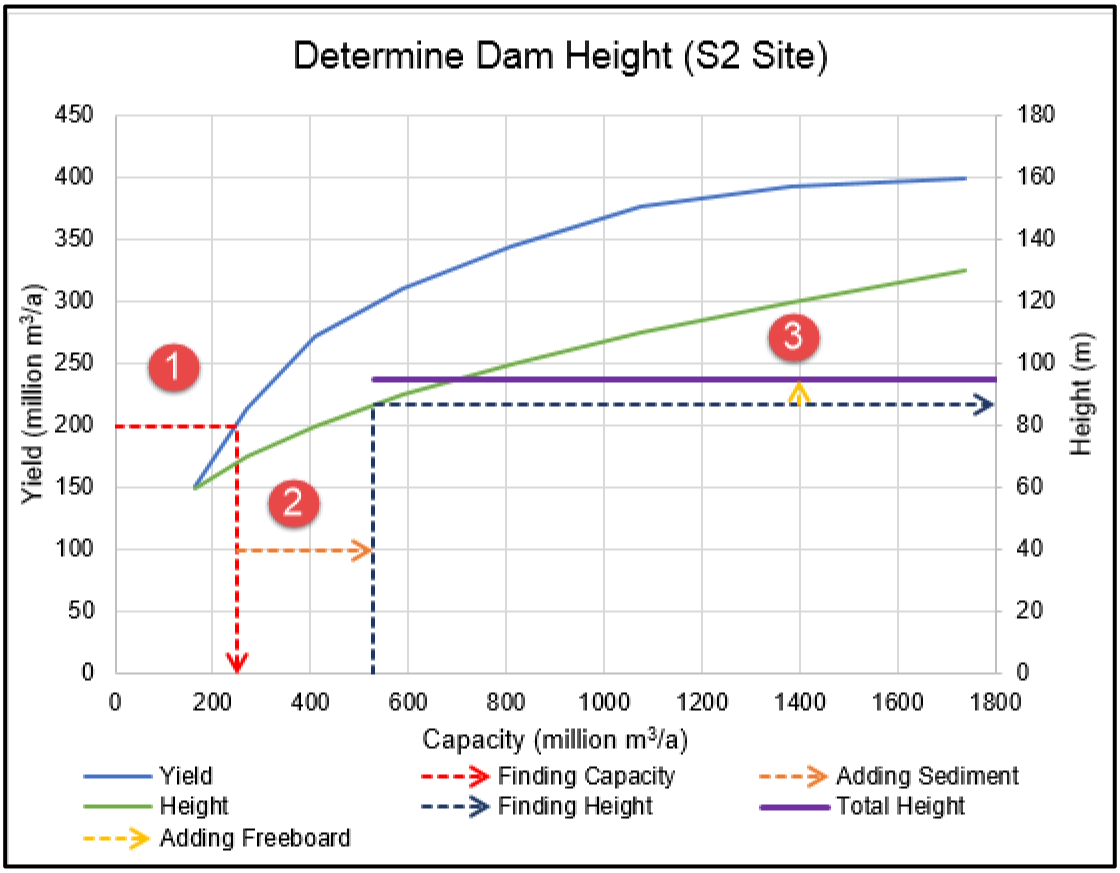


Figure 3-3: Determining the Dam Height at Each Site

The second dam size was selected to target the maximum potential yield from the catchment. The storage-yield relationship obtained from the water resource modelling indicated that the maximum yield is reached at a dam size large enough to store approximately three times the MAR (see **Figure 3-4**). A dam with a volume of three times the Mean Annual Run-off was used as the maximum dam size at each site. The 50-year sediment volume was added onto this storage capacity and the final height, including freeboard, was determined similar to the process used to select the dam size to meet the 2050 water requirements in **Figure 3-3**.

It is important to determine the maximum dam height at each site as it is an objective to minimize the reduction in yield for the downstream Gariep Dam; a larger dam size allows additional yield to be released downstream to support the downstream users. It also offers the opportunity to generate some hydropower with releases from the dam. Additional yield may also be taken up by downstream irrigators in Lesotho. However, it should also be noted that the evaporation from Gariep Dam will be much higher than that from Makhaleng Dam and therefore from an efficient use of water, it will be better to store available water in Makhaleng Dam.

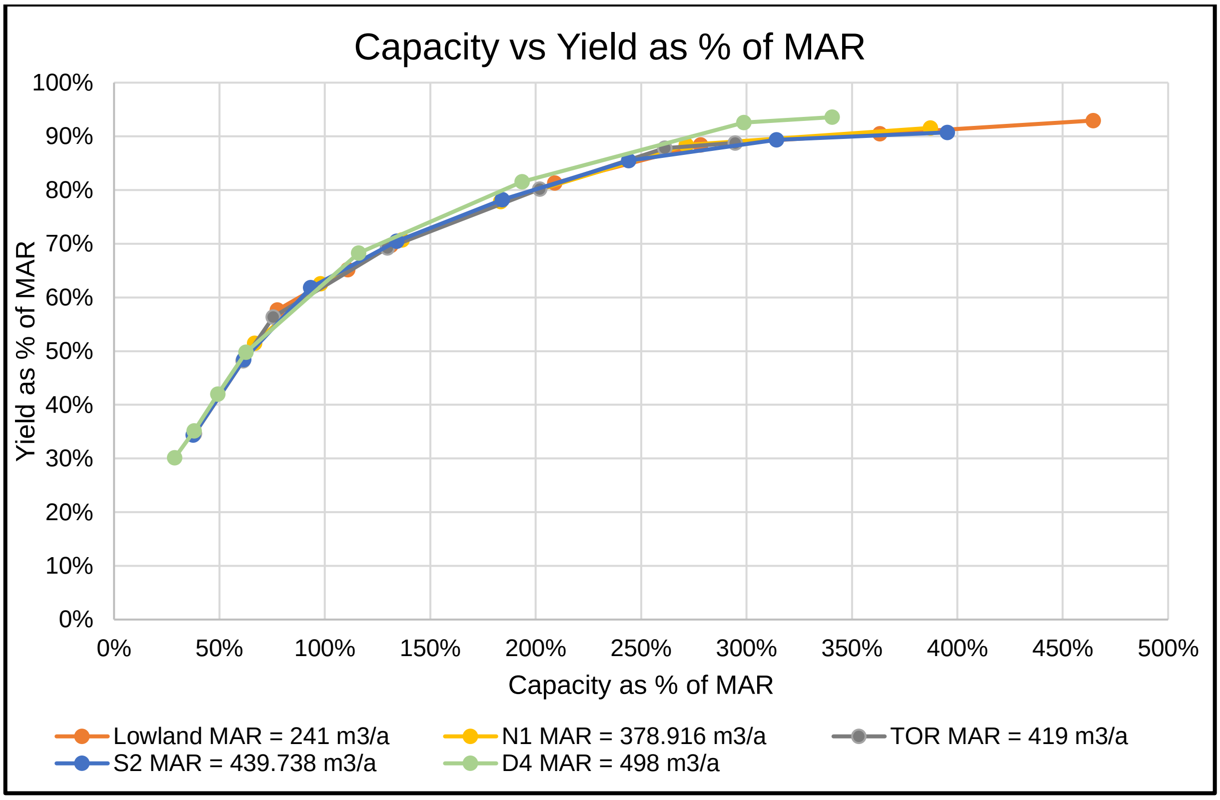


Figure 3-4: Capacity vs Yield to Determine Maximum Dam Capacity

3.3.2 Sedimentation

A high-level estimate of the sedimentation estimate was made using the regionalized sediment yield map of Southern Africa. The Makhaleng River Catchment is in region 7 of the sediment yield map with a medium erodibility index of 10 in the upper catchment and 11 in the lower catchment. The sediment yield map indicates an average sediment yield for this region of 203 tons/km^2/a at a 50% level of confidence. For region 7 the confidence bands are very wide for all ranges of catchment sizes with the 95% confidence band up to 14 times greater than the average sedimentation rate.

From the Google earth image of the catchments, it is clear that the higher Northern catchment areas are less affected by erosion than the lower Southern parts of the catchment, which are subjected to much higher level of agricultural activities. An adjustment factor was added to each of the dam catchments with the factor increasing from higher to lower areas. **Figure 3-5** indicates the sites with high and low sediments characteristics. For the screening assessment of the sites, the 50-year estimated sediment volume was added to the required storage capacity determined from the water resource modelling.

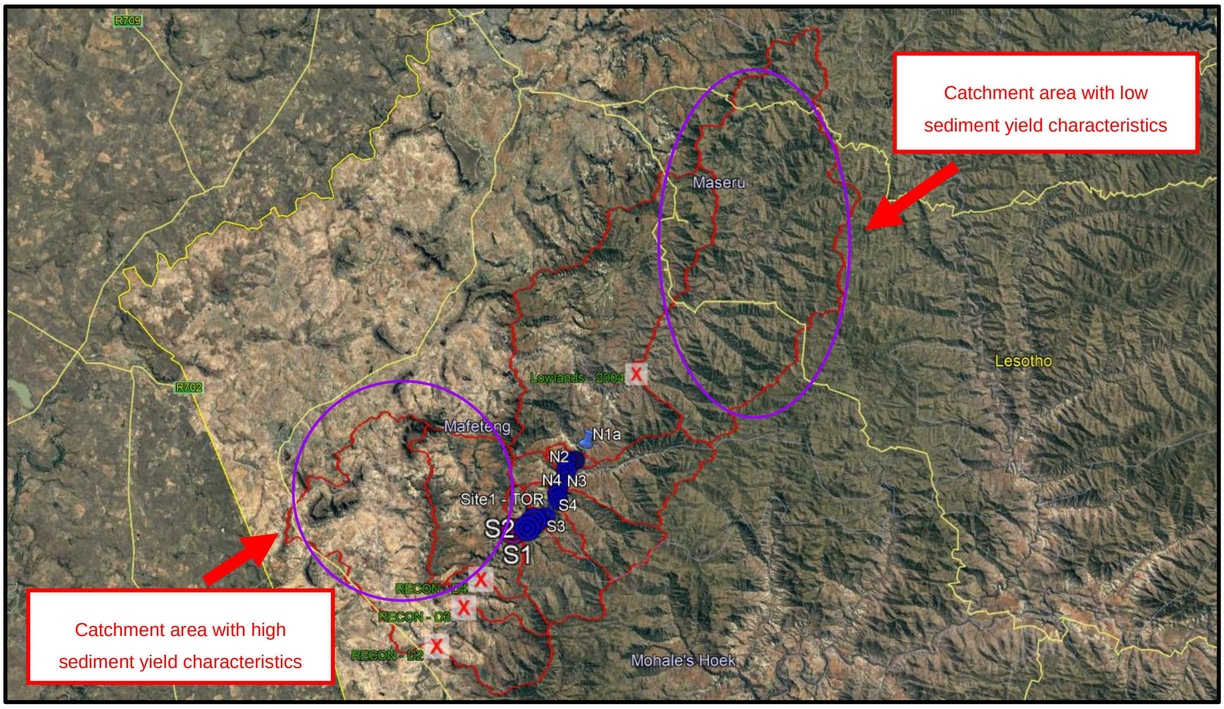


Figure 3-5: Erosion in Western and Southern Lesotho

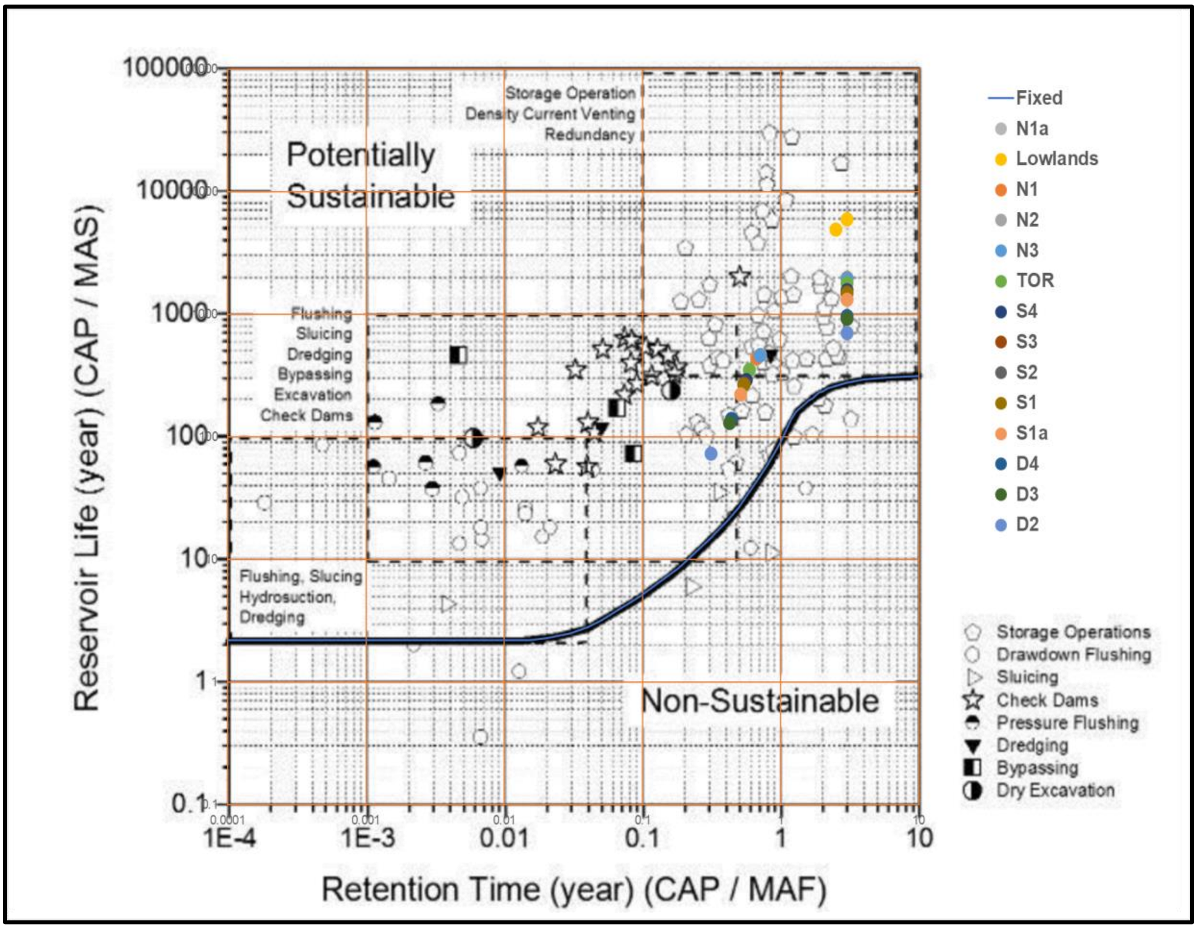


Figure 3-6: Applicability of Sediment Management Techniques In Relation To Reservoir Life and Retention Time (Annandale, Morris, & Karki, 2016)

Figure 3-6 shows the reservoir expected life (CAP/MAS) versus the Retention time (CAP/MAR) for each dam site for the two different sizes. The relationship, by Annandale, indicates a management technique of storage operation, density current venting or redundancy for most of the sites. The exception is for the Southern sites at the maximum storage size; for these developments, Annandale indicates a management technique of flushing, sluicing, dredging, bypassing, excavation, or check dams.

3.3.3 Dam Type Selection

To make a comparison of the different dam sites, a high-level dam type selection for each site was done. Taking into consideration the valley shape, the valley aspect ratios, the geological conditions, the large design floods, and the general lack of obvious side channel chute type spillways at most of the sites, it is assumed that an RCC gravity dam is the most suitable dam type for all of the sites identified except for sites S2 and N1a. For the maximum yield option, Site S2 has an obvious position for a side channel spillway through a low neck on the right bank, should the dam be built large enough to utilize with topographic feature. Site N1a has a narrower valley profile than the other sites and it may be suitable to construct either a single arch gravity dam or a double curvature arch dam. The dam type selection will be revisited during the next phase of the pre-feasibility study, when a more detailed dam type selection study will be undertaken for the two recommended sites.

3.3.4 Dam Cost Estimates and URVs

The RCC, rockfill and concrete quantities for each dam site were measured for the two different sizes. The SRTM data was used to define the topography and estimates were made of the expected founding depths.

Unit rates derived from the Lesotho Highlands Phase II project feasibility study and Neckartal Dam project were applied to the concrete or rockfill quantities to calculate a high-level cost estimate for each dam.

The Unit Reference Value (URV shown in the equation below) of the incremental yield for the dam was calculated by dividing the present value of the life cycle costs of the dam divided by the present value of the water incrementally assured (reference PH van Niekerk). The discount rate used was 8% a year based on the LHWP economic analysis. The LHWP used 6%, 8% and 10%, but a sensitivity analysis was not done during Phase 1 of this study, this will be done during Phase 2. It was assumed that the dam would take five years to construct starting in 2020 and the capital cost would be evenly spread over the five years. The water incrementally assured would be available from 2025 to 2050 in the calculation of the present-day value. The operational and maintenance cost of the dam would be 1% of the capital value per year over the 25-year period of operation, with the duration based on the design horizon of the scheme. The parameters chosen are arbitrary preliminary assumptions for the purpose of screening the options. Residual values and refurbishment costs ignored for now.

$$\text{URV} = \frac{PV\ of\ life\ cycle\ costs}{PV\ of\ quantity\ of\ water\ incrementally\ assured}$$

where

$$PV\ of\ life\text{-}cycle\ cost = PV_{\ capital\ costs} + PV_{\ O\&M\ costs}$$

3.3.5 River Diversion

The river diversion would be via twin diversion tunnels with an upstream and downstream coffer dam, similar to the other large dams constructed or planned in Lesotho for the Lesotho Highlands Water Project Phase I and Phase II. One of the diversion tunnels will be considered to be used as a low-level outlet for releases from the dam and or hydropower generation.

3.3.6 Low-Level Outlet

For the RCC gravity dam options, there will be a multilevel outlet inside an intake tower, which will be attached to the upstream face of the gravity dam. The tower will however be independent of the dam, so that it can be constructed independently from the RCC dam. The tower will include upstream trash racks, fine screens, grooves for maintenance gates, butterfly selector valves, and 3CR12 outlet pipes which will terminate either at the Main Inlet Valve (MIV) for the turbines or at sleeve valves.

For the CFRD option, the outlet works will be a free-standing tower with the pipework included into one of the river diversion tunnels.

3.3.7 Hydropower Potential

Assuming that the pumping station is downstream of the main storage dam, there are two scenarios for which power can be generated at the dam site;

- The first scenario assumes that the releases are continuous
- The second scenario assumes that releases are made to coincide with peak power requirements because of the relatively high value of peak power in Southern Africa. Thus, power would only be generated for five hours per day for five days of the week as shown in **Figure 3-7**.

The size of the power plant will be dependent on which power generation scenario is selected as well as the dam size selected. For the second scenario, downstream balancing storage will be required.

An initial power plant sizing for each power generating scenario and dam size was done and is included in the data sheet for each individual site identified. During the next phase of the pre-feasibility study the sizing and costing of the powerplant will be studied in more detail and the levelized cost of energy will be determined for each option. The powerplant size and type is included in the technical data sheets for each site in **Appendix E**.

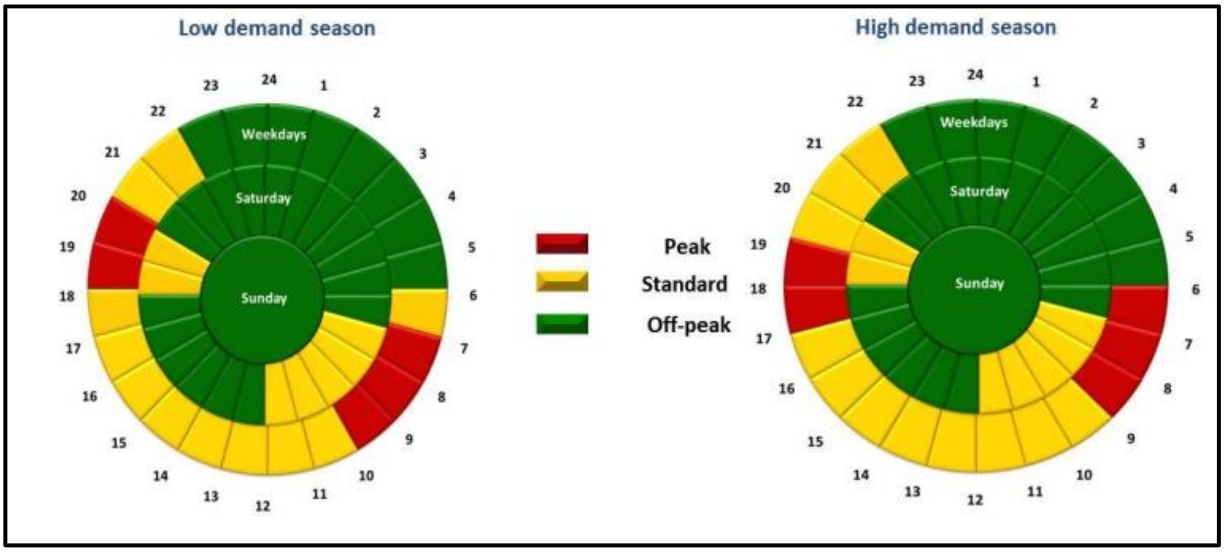


Figure 3-7: Peak, Standard, and Off-Peak Power Times.

3.3.8 Technical Data per Dam Site

The main characteristics of each of the dam sites were compiled to make a fair assessment of each site. A summary of these characteristics is included in a **Table D-1** in **Appendix D** and the technical data sheets provided in **Appendix E**. The characteristics were determined for a dam sized to supply 200 million m^3/a and a dam size equal to three times the MAR in order to maximise the utilisable yield from the Makhaleng River.

The following parameters were determined for each dam site:

- Location
- Catchment Size
- River level
- Design Floods (1:10 year = River diversion, 1:200 year = Design Flood, RMF + Δ = Safety Evaluation Flood)
- MAR

- Dam height to supply a firm yield of 200 million m^3/a
- Dam capacity to supply a firm yield of 200 million m^3/a
- High Level Estimated Dam Cost
- Volume of RCC to construct the dam
- Volume of Rockfill to construct the dam
- Crest length of the dam
- Aspect Ratio = crest length /height
- Unit reference value of water (discount rate = 8%)
- Estimated 50 year loss of storage to sediment
- Distance to construction material
- Social Impact (households affected, Agricultural land and infrastructure)

In addition, to the table containing the technical data per dam site, a technical data sheet per dam was compiled; this included:

- A google earth image of the dam site
- A google earth image of the dam footprint
- A photograph of the site
- Elevation and dam height versus area & capacity relationship
- Storage versus yield relationship
- A profile of the dam valley with the 2 dam size crests plotted across the valley
- Impact on the yield of Gariep Dam
- Likely dam type
- Spillway type
- Outlet arrangement
- River diversion
- Hydropower potential – continuous power & peak power
- Turbine type

The characteristics of each site were used to inform the weighted MCA to select the two best options for more detailed investigation.

3.3.9 River Profile

Figure 3-8 and **Figure 3-9** show the crest elevations of each of the dam options along the river profiles for the 200 million m^3/a and maximum possible yield options. This is to show how the construction of one dam will affect the possible construction of multiple dams based on the inundation along the profile. The construction of the "S" and "D" sites for the 200 million m^3/a option still leaves the possibility of constructing the lowlands option. For the maximum yield option, only the “D” sites will still allow for the construction of the lowlands site.

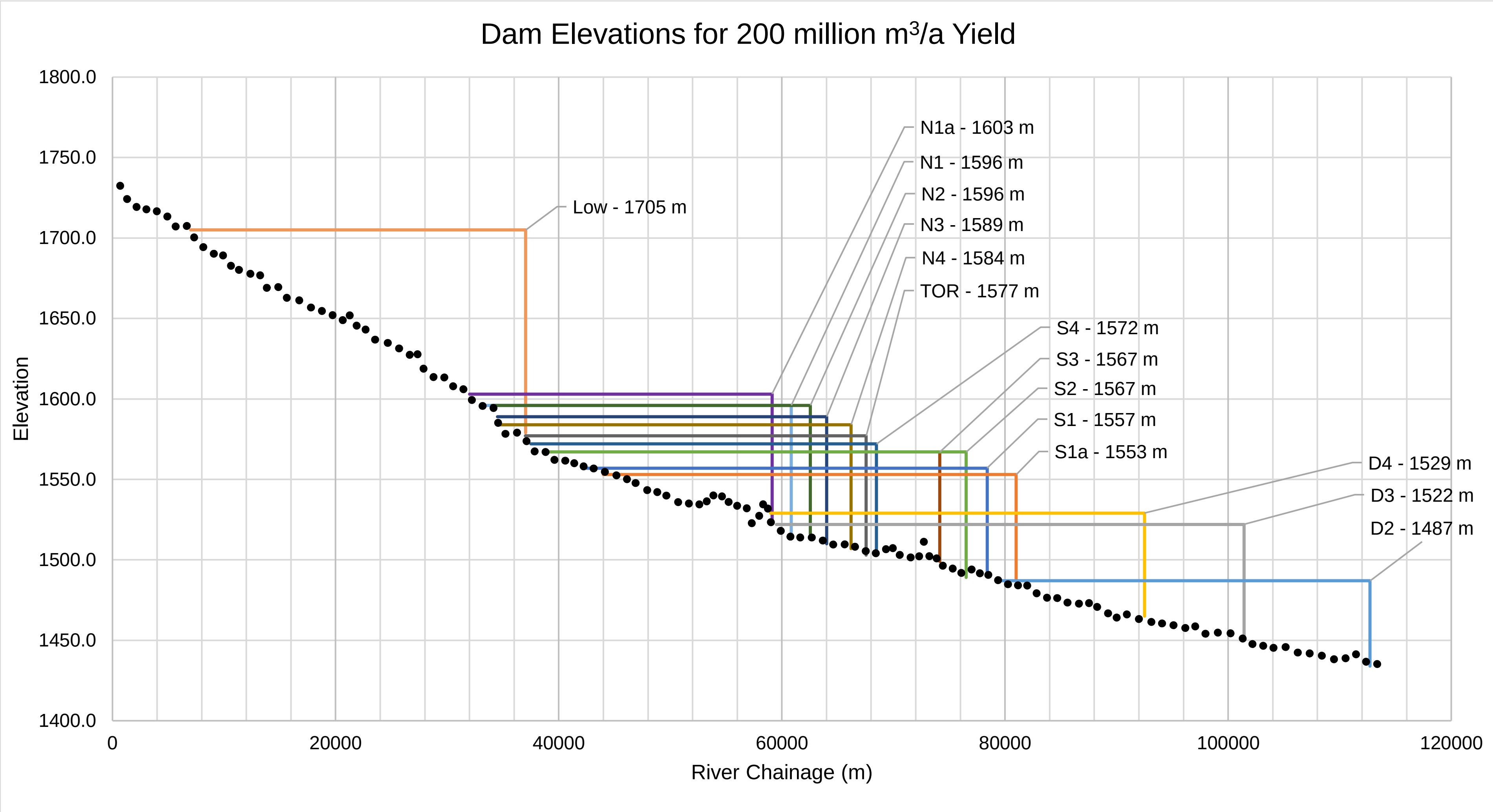


Figure 3-8: River profile showing dam elevations for 200 million m³/aYield

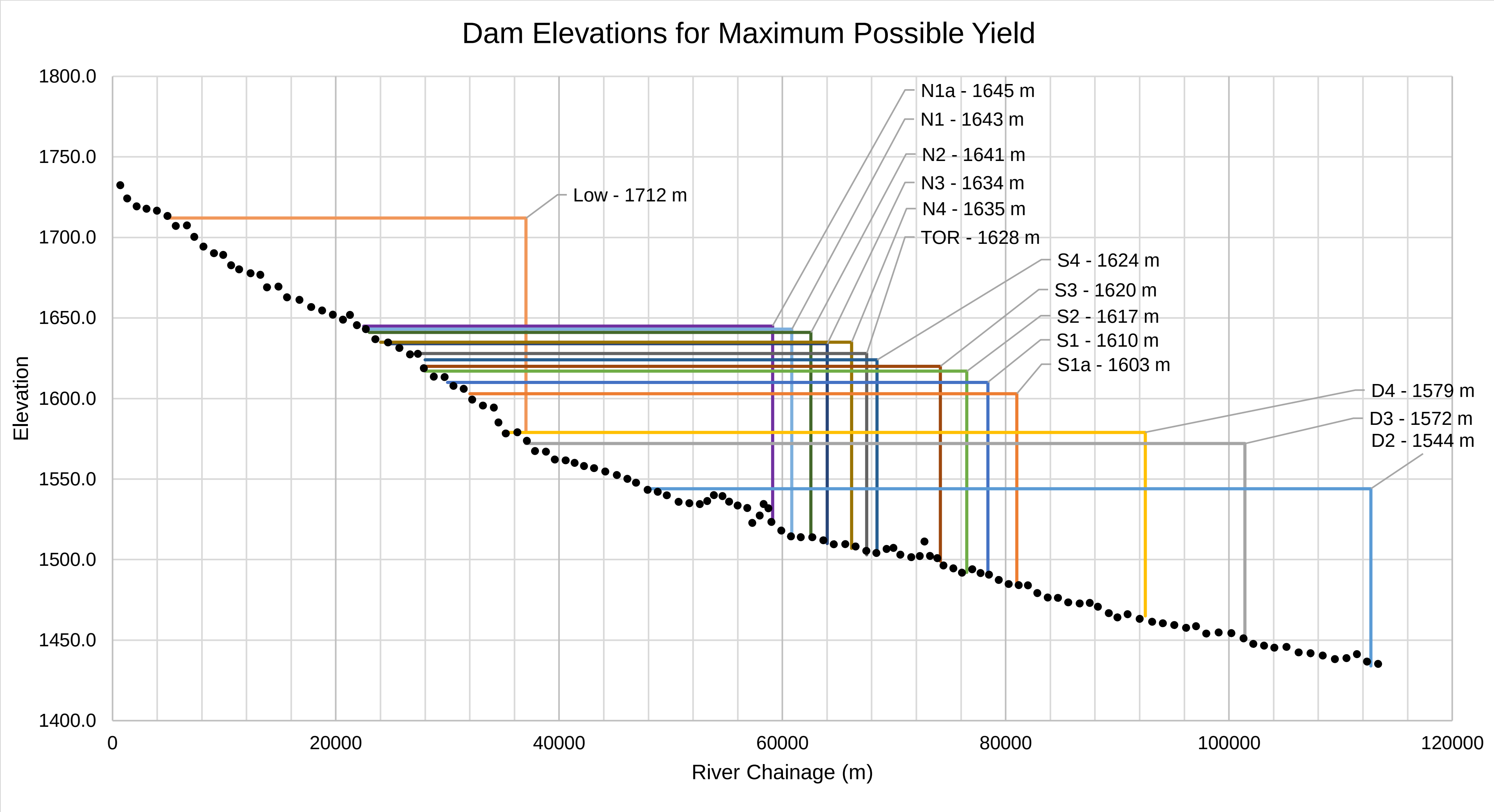


Figure 3-9: River profile showing dam elevations for Maximum Possible Yield

3.4 GEOLOGY AND GEOTECHNICAL CONDITIONS

The thirteen identified sites were plotted on the Geological map of Lesotho Scale 1:250 000 South Sheet.

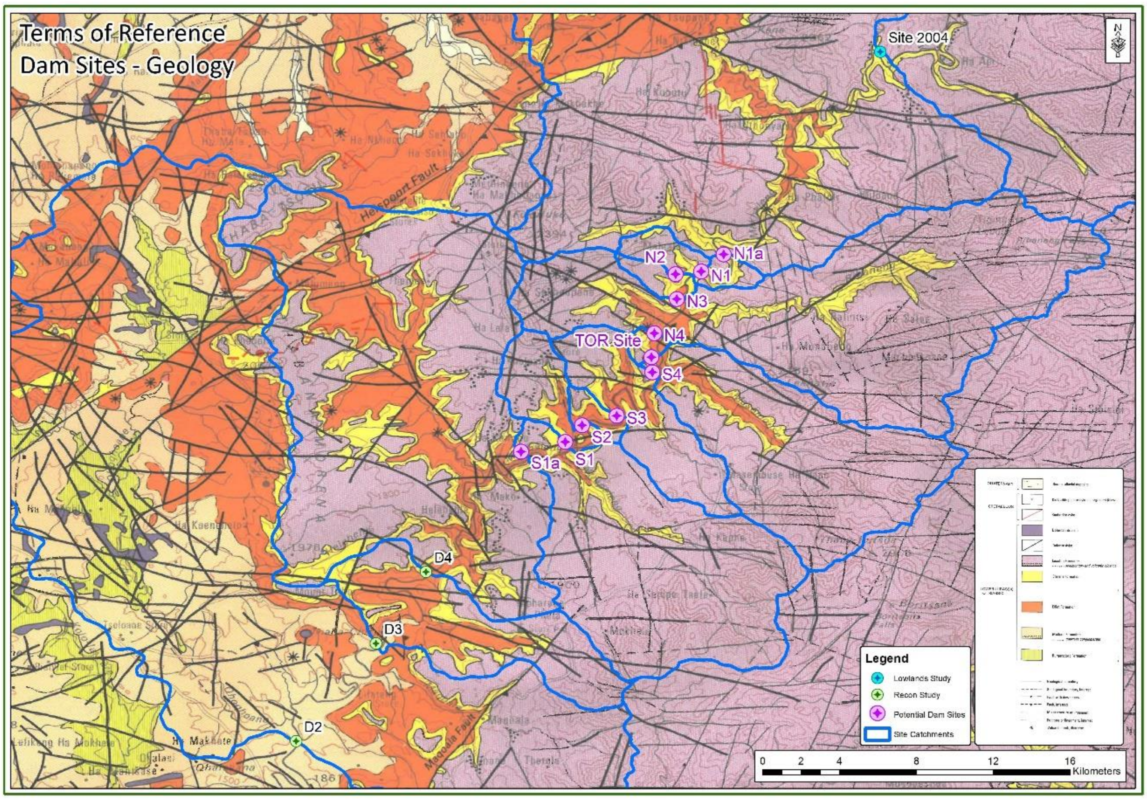


Figure 3-10: Geological Map of Southern Lesotho

3.4.1 Central "N" Dam Sites

The geological conditions at the four sites are similar, with the following geological formations occurring from top to bottom:

- Volcanic rock capping of amygdaloidal basalt;
- Massie fine grained sandstone and siltstone (Clarens Formation);
- Fine and medium grained sandstone with interlayered mudstone and siltstone beds (Elliot Formation).

At sites N1 and N2 the Elliot Formation is expected to be present only below riverbed level. Site N1a was not evaluated at the site visit but is assumed to have a similar geology to Site N1.

N1 appears to be the better dam site, because the river valley is fairly narrow (130 m) with fairly steep slopes (between 1:1.6 and 1:1.8). The river contains alluvial deposits, especially on the righthand side of the river bed, due to the site being on a bend in the river.

At N2 the valley is substantially wider with the left valley slope much flatter, possibly due to the presence of completely weathered mudrock.

At N3 the left valley flank is reasonably steep (1:1.7), but the lower half of the right flank is very flat (1:5.5), most probably due to the presence of mudstone of the Elliot Formation.

At N4 the river valley is fairly wide, and the river section is approximately 175 m wide. The conditions at this site are complicated by the presence of a narrow (10 m wide) dolerite dyke that crosses the river in a north-west to south-east direction. The dolerite at the surface on the right flank is completely to highly weathered and can be expected to be fairly permeable. Near horizontally bedded sandstone rock is present on the riverbanks and expected to be present at shallower than 2 m depth in the river section. The sandstone is covered with a thick layer of completely to highly weathered mudstone on the lower left and right flanks. A single lane concrete road bridge crosses the river diagonally at this site.

Site N1a appears to be the best of the N sites and will most probably require a concrete dam; the issue will then be to find a suitable source of concrete aggregate. The most attractive solution will be to locate a quarry in the basalt lava forming the capping on the high-lying areas. There appears to be possible basalt rock sources within approximately 5 km from the N1a site, but access and environmental issues may be problematic.

3.4.2 Central “S” Dam Sites

The S sites are underlain by similar geological conditions as the N sites, but the rocks of the Elliot Formation are prominent within the river section and on the lower valley flanks at these sites.

At site S4 the left flank of the valley is fairly flat (1:2), but the right flank is much steeper. The site is located approximately 400 m downstream of the confluence of the Makaleng River with a major tributary, hence the river section appears to contain a substantial volume of alluvial material. A dam wall would be located in the residual materials of the Elliot Formation and there appears to be a fairly thick layer of talus and residual materials on the lower portion of the flatter left flank. Due to spillway requirements, the preferred dam at this site should probably be a concrete dam.

At site S3 the left flank is fairly flat (1:2.4) and covered with residual mudrock and sandstone of the Elliot Formation. The site is located on a sharp bend in the river(± 90°), which means that the right flank forms a prominent nose and substantial alluvial deposits on the inside (right) riverbank. This is not a good dam site.

Site S2 is located just downstream of a meander left bend in the river. The valley flank slopes appear to vary between 1:1.8 and 1:2.6 and the river section is fairly narrow at less than 50 m wide. There may be a fault crossing the river at almost 90° in the vicinity of the site, but this should not seriously impact on a fill type dam wall and the dam wall can be positioned off the line of the fault.

A saddle feature is present upstream of the dam site on the right flank, which is capped with a narrow sandstone ridge. It should be possible to position a concrete spillway structure in this saddle, which can feed the water from such a spillway into the adjacent valley of which the floor level appears to be approximately 40 m higher than the Makaleng River bed level. This implies that energy dissipation would be much less complicated. There appears to be a sandstone layer present at the approximate level where a concrete spillway could be founded.

The dam site appears to be suited for a rockfill embankment dam wall and the sandstone ridge on the saddle may be suitable for rockfill construction.

River diversion and the permanent outlet works may be combined by excavating a tunnel (approximately 850 m long) through the left flank downstream of the dam embankment.

Site S2 is the most favourable.

At site S1 the river section is fairly narrow, and the valley flanks vary between 1:1.9 and 1:2.2, although the lower portion of the left flank appears to be covered with talus and residual mudstone soil. Due to spillway considerations, a mass concrete dam wall will probably be required.

Site Sa was not reviewed on the site visit as it was not in consideration at the time. The geology will be assumed to match site S1 for the time being.

3.4.3 Southern “D” Dam Sites

At site D4 the river section is approximately 100 m wide and covered with a significant alluvial layer. Both valley flanks are flatter (approximately between 1:3.5 to 1:5) and the lower right flank is covered with a thick layer of alluvium, talus, and residual mudstone. The presence of thick layers of soil on the lower valley flanks (and the riverbanks) are confirmed by the cultivated fields in these areas. A saddle embankment may be required on the far-left flank to achieve the required dam capacity. A concrete dam would probably be required at this site.

At site D3 the left flank of the valley is sloped at approximately 1:2.3, while the right flank has a very flat plateau at approximately 40 m above the riverbed. The river, and especially the lower portion of the right flank, is covered with a thick layer of alluvium and residual mudrock. It may be possible to consider a spillway on the right flank, but there does not appear to be a good valley with a competent rock floor in the flat adjacent valley, where substantial soil erosion ditches already exist. Therefore, a mass concrete dam should rather be considered.

At site D2 the river section is approximately 70 m wide and filled with alluvial material, while alluvial material, talus and residual mudrock is also present on the lower right flank of the valley. A mass concrete dam should be required at this site, but allowance will have to be made in the dam capacity for substantial silt load storage.

3.4.4 Northern “Lowlands” Site

Located in a narrow valley with river about 45 m wide. The left flank has a flat section (1:10) next to the river, but then steepens to about 1:2.6, but the usable height appears to be only 40m. The right flank is steeper at about 1:1.3.

The riverbed and mid-flanks are in the Clarence Formation and the upper flanks in basalt. The lower left flank is probably covered with alluvium and talus materials.

The site will probably require a concrete dam and the comments on concrete aggregates at N1 are also applicable here.

3.4.5 Central “TOR” Site

This site has a river section of about 100 m wide. The riverbed and lower flanks are in the Elliot Formation and overlain by the Clarens Formation, which is characterised by steep cliffs on the left flank and flatter upper slope on the right flank. Both flaks are capped with basalt at the top.

This is not a good dam site because:

- it is located just downstream of a wide alluvial and residual mudstone on the right plain bank;
- just downstream of the site a major tributary joins the Makhaleng River about 300m downstream of the site and has laid down quite a lot of alluvial material;
- the Richard settlement is located directly downstream on the left lower flank;
- the site is located on a narrow nose on the left bank, while the valley opens up on the right flank and is much wider directly upstream.

3.4.6 Concrete Aggregates

At the N dam sites, the problem will be to find a suitable source of concrete aggregate. The most attractive solution will be to locate a quarry in the basalt lava forming the capping on the high-lying areas. There appears to be possible basalt rock sources approximately 5 km from the N1 site, but access and environmental issues may be problematic.

A source of concrete aggregate for the S and D sites may be more problematic. Basaltic lava may be available approximately 12 km east of the S sites, and 23 km north-east of the D sites. However, access for transport to site will be difficult and environmental clearance may be problematic, because such sources will not be inside any of the dam reservoirs. The quality of the basalt rock will also have to be proved.

A significant dolerite deposit is also present approximately 22 km south-east of the S sites and 13 km north-west of the D sites. The quality of the dolerite rock will have to be confirmed, but transport to the proposed dam sites will be difficult as there are no apparent direct transport routes. Environmental clearance may also be problematic because this source is outside of the dam reservoirs.

On the other hand, suitable sources of suitable sandstone rock for rockfill embankments should be available inside the dam reservoirs of the S and N sites, but possibly not as easily available at the D sites.

3.5 ENVIRONMENTAL AND SOCIAL EVALUATION OF THE DAM SITE OPTIONS

3.5.1 Methodology

Following the site visit, each potential dam site and inundation area was mapped using Google Earth. For each of the sites, the following inundation areas were determined and mapped:

- Dam wall height to meet the scheme requirements
- Dam wall height to obtain the maximum yield from the site.

In evaluating the potential environmental and social impacts, the precautionary principle was applied, and the maximum area of inundation was evaluated. The following attributes were determined:

- Physical displacement: households within the area of inundation
- Economic displacements: crops and rangeland affected by inundation
- Access roads and infrastructure: tar roads, unpaved roads, and bridges
- Relatively undisturbed areas (mainly within tributaries) that could host significant biodiversity
- Erosion
- Overall status of the land (degraded or relatively undisturbed)
- Opportunities for social development (tourism etc.) as part of livelihood restoration or opportunities to utilise water for small-scale irrigation downstream of the dam.

3.5.2 Limitations and Disclaimer

The environmental and social screening for the dam site selection was conducted at a very high level. Only features visible on Google Earth or noted during the brief site visit could be assessed. The estimation of number of households directly affected and agricultural areas affected are an indication only and should be used as a rough guide. Further detailed studies using LiDAR imagery (or similar) coupled with detailed field surveys will be required to quantify the environmental and social impacts. These studies should form part of the Environmental and Social Impact Assessment and Resettlement Action Plan.

3.5.3 Results

The environmental and social aspects were assessed for the maximum inundation scenario only.

At most sites, there is a direct inverse relationship between environmental and social suitability of the sites. The sites that are more developed (by agriculture and used as rangeland) are more degraded from an environmental perspective. The areas in the upper catchment and in the tributaries of the Makhaleng River are less utilised by local communities and therefore have the potential for hosting significant biodiversity areas.

A social and environmental score was given to each site in **Section 6.1** of the report.

3.5.4 Conclusion

Sites D2, D3 and D4 are located in the lower catchment and are extensively developed. The main tar road between Khitsane and Tsoloane will be affected by site D2. These sites are unsuitable or unacceptable from a social perspective, however, the ecological impacts at these sites would be low. Catchment management would, however, be very difficult as the area is extensively utilised. None of these sites are suitable based on environmental and social criteria.

Sites S1a, and S1 to S4 are in the middle catchment. The areas close to the potential dam wall sites are developed and will require significant physical displacement and large-scale economic displacement. The tributaries and tailwaters are less developed and may host areas of potential biodiversity and therefore are moderately favourable from an environmental perspective. More detailed studies will be required to verify or discount biodiversity hotspots in the deep valleys.

Sites TOR, N1a, and N1 to N4 are further up in the Makhaleng River catchment and environmental attributes in these areas may be significant, especially in the relatively undisturbed valleys and tributaries. These attributes increase higher up in the catchment and therefore N1a is likely to be the most sensitive from an environmental perspective. Inversely, Site N1a is the least developed of these sites and therefore social impacts are likely to be moderate. Site N4 will have major social impacts and is therefore considered unfavourable.

The Lowlands site is highly utilised from a socio-economic perspective but could also host significant biodiversity areas due to the irregular topography and deep valleys. This site is less favourable as the tar road between Nkesi and Mantsa will be inundated, causing significant restrictions on accessing the areas to the east of the dam.

Based on this high-level investigation, the following groups of sites can be considered for further investigation from an environmental and socio-economic perspective:

- S1a and S1 to S4
- N1a and N1 to N3.

4 WATER RESOURCE ASSESSMENT

4.1 REVIEW AND VALIDATE HYDROLOGICAL DATA

4.1.1 Initial Hydrology Development

The hydrology representing the Makhaleng River catchment was first produced as part of the Lesotho Lowlands Study (Parkman, 2004). At that time, the simulated hydrology covered the time period 1935 to 1999. Two incremental catchment time series files were applicable and used to assess the water resources of the Makhaleng River catchment for a specified dam site and abstraction point; the two files were titled MAKDAM.INC and MAKABS.INC. Two flow gauging stations were used for calibration purposes, namely MG19 and MG23. **Figure 4-1** provides a locality map of the applicable flow gauges and incremental catchments.

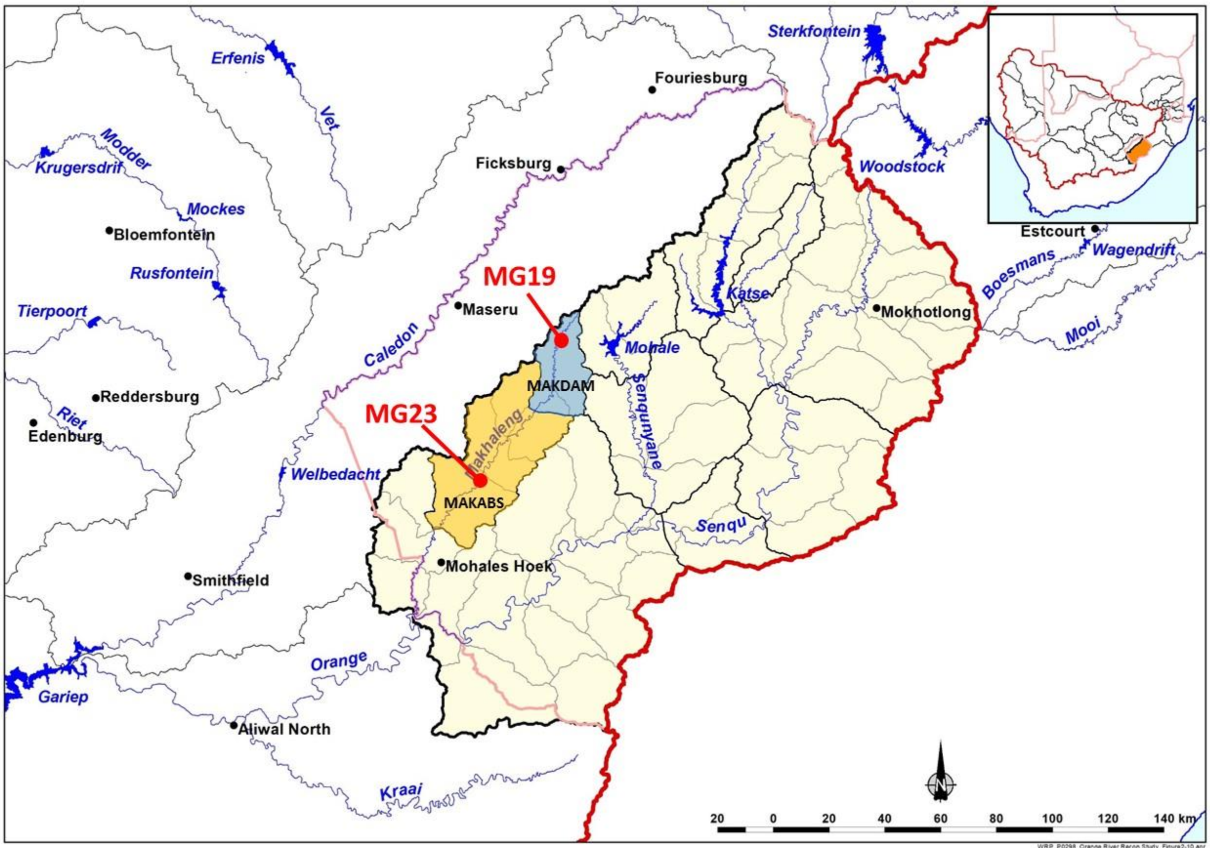


Figure 4-1: Locality of Makhaleng Incremental Catchments and Flow Gauges

Figure 4-2 provides a Table representing a summary of the calibration statistics for the gauging stations and the incremental hydrology. This Table is extracted directly from the Lesotho Lowlands Report (Parkman, 2004).

Lesotho Lowlands Water Supply Scheme - Feasibility Study - Funded by the 8th EDF PARKMAN

Table 3.13 : Statistics of the streamflow sequences in the Makhaleng catchment.

Statistic	Unit	MG19	MG23	Dam site	Abstract-ion site
MAR	million m^3	30.32	388.27	166.85	365.51
Standard deviation of annual flows	million m^3/yr	10.58	161.74	56.99	133.96
Coefficient of variability	%	34.89	41.66	34.16	36.65
Coefficient of skewness	-	0.0989	0.3881	0.3812	0.2759
Range	% MAR	207.81	302.11	341.63	389.59
Autocorrelation coefficient of annual flows	-	0.0542	0.3812	0.0102	0.0798
Mean of logs of annual flows	Million m3	1.4523	2.5504	2.195	2.5307
Standard deviation of logs of annual flows	-	0.1698	0.1951	0.1614	0.1757
Index of seasonal variability	%	23.87	23.61	23.65	22.99

Figure 4-2: Table Extracted from Lesotho Lowlands Report

Figure 4-3 and **Figure 4-4** present the calibration plots of the observed and simulated monthly flows produced using the Pitman Rainfall Runoff Model during the Lesotho Lowlands study.

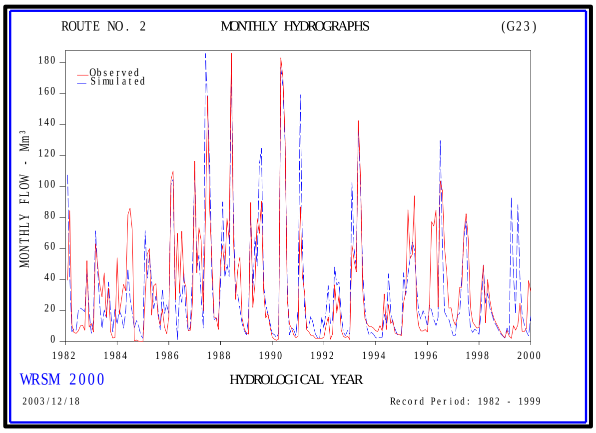


Figure 4-3: Calibration: MG23

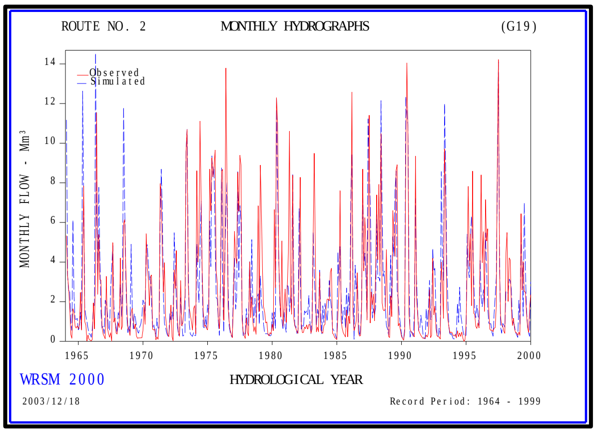


Figure 4-4: Calibration MG19

The calibrations were deemed to be satisfactory at the time based on the statistics of the observed and simulated records.

4.1.2 Hydrology Extension and Incorporation

The initial hydrology representing the Senqu River catchment consisted of eight incremental catchments as presented in **Figure 4-5**. One of the Tasks carried out as part of the ORASECOM Integrated Water Resources Management Plan (ORASECOM, 2014) was to incorporate all available hydrology from other studies and to extend all hydrology to cover the time period 1920 to 2004.

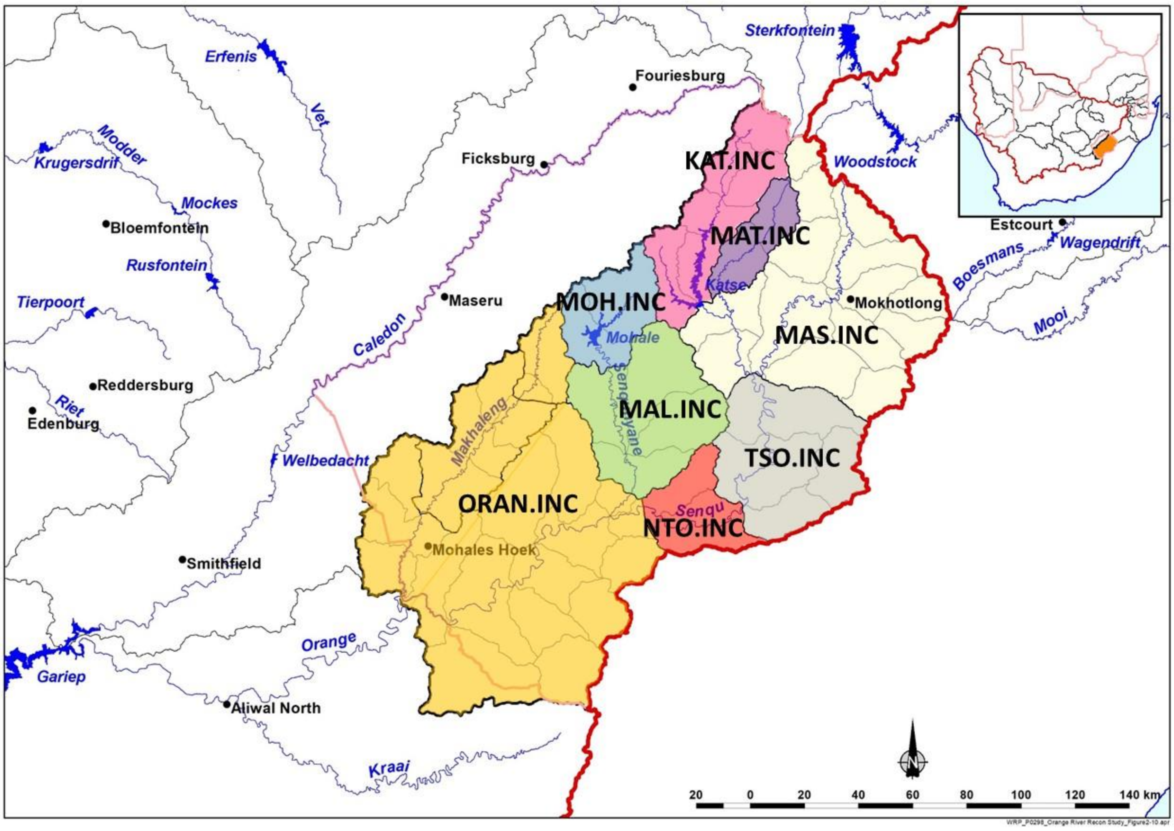


Figure 4-5: Initial Eight Incremental Catchments Representing The Senqu

The actions applicable to the Makhaleng River catchment involved the extension of MAKDAM.INC and MAKABS.INC to cover the required period, and the split in the original ORAN.INC to specifically include the Makhaleng River catchments. Some manipulation of the incremental hydrological files took place such that the overall averages of the combined MAKDAM.INC, MAKABS.INC and ORAN.INC$_{net}$ equalled the original ORAN.INC$_{gross}$. **Table 4-1** provides a summary of this. The table shows that the original MAR of the ORAN.INC catchment (1542.7 million m^3/a) was maintained when the catchment was adjusted to the three subdivisions.

Table 4-1: MAR of incremental catchments for varying time periods

Hydrology	Incremental Catchment Area (km^2)	Time Period (years)	MAR (million m^3/a)
MAKDAM.INC$_{orig}$	535	1935-1999	166.8
MAKABS.INC$_{orig}$	1628	1935-1999	365.5
ORAN.INC$_{orig}$	9269	1920-1995	1542.7
MAKDAM.INC$_{new}$	535	1935-1999	174.5
MAKABS.INC$_{new}$	1628	1935-1999	364.9
MAKDAM.INC$_{new}$	535	1920-1995	169.7
MAKABS.INC$_{new}$	1628	1920-1995	354.8

Hydrology	Incremental Catchment Area (km^2)	Time Period (years)	MAR (million m^3/a)
ORAN.INC$_{new}$	7106	1920-1995	1018.2
Sub-total		1920-1995	1542.7
MAKDAM.INC$_{new}$	535	1920-2004	169.7
MAKABS.INC$_{new}$	1628	1920-2004	354.8
ORAN.INC$_{new}$	7106	1920-2004	1018.2

4.1.3 Updated Observed Flow Data

The approach used to validate the hydrological data that is required for the Makhaleng Dam assessment was to obtain updated observed flow gauge records available since the original calibration took place, and to compare the observed records with model simulations. This was done to determine if the model is still simulating in line with observed records. It was found that flow gauge MG19 had closed and was therefore not used in the assessment. Updated raw flow data was obtained for gauge MG23 from DWA Lesotho Hydrology Division, covering the period 2002 to 2015. An additional flow gauge (D1H006) located approximately 20 km downstream from the MAKABS.INC catchment (Lat: -30.15972; Lon: 27.40138) was identified for potential comparisons, and data from this gauge was also sourced from the DWS RSA data base. It is unclear why this gauge was not used in the original calibrations of the Makhaleng hydrology.

Figure 4-6 to **Figure 4-9** provide pictures of the two flow gauges, and a locality map.

Figure 4-6: Flow Gauge D1H006

Figure 4-7: Flow Gauge D1H006

Figure 4-8: Flow Gauge MG23

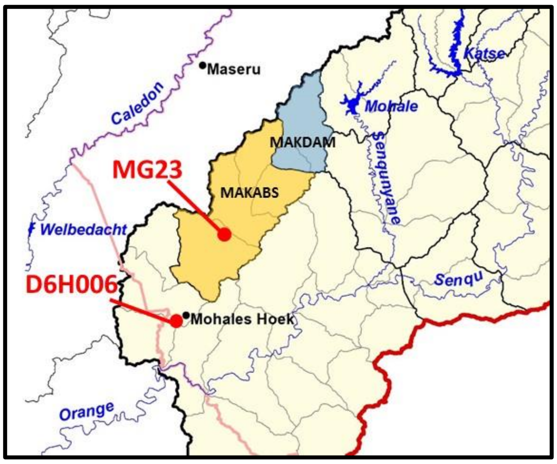


Figure 4-9: Locations D1H006 & MG23

Figure 4-10 and **Figure 4-11** provide plots of the raw flow records. The time series files are presented in **Appendix B**.

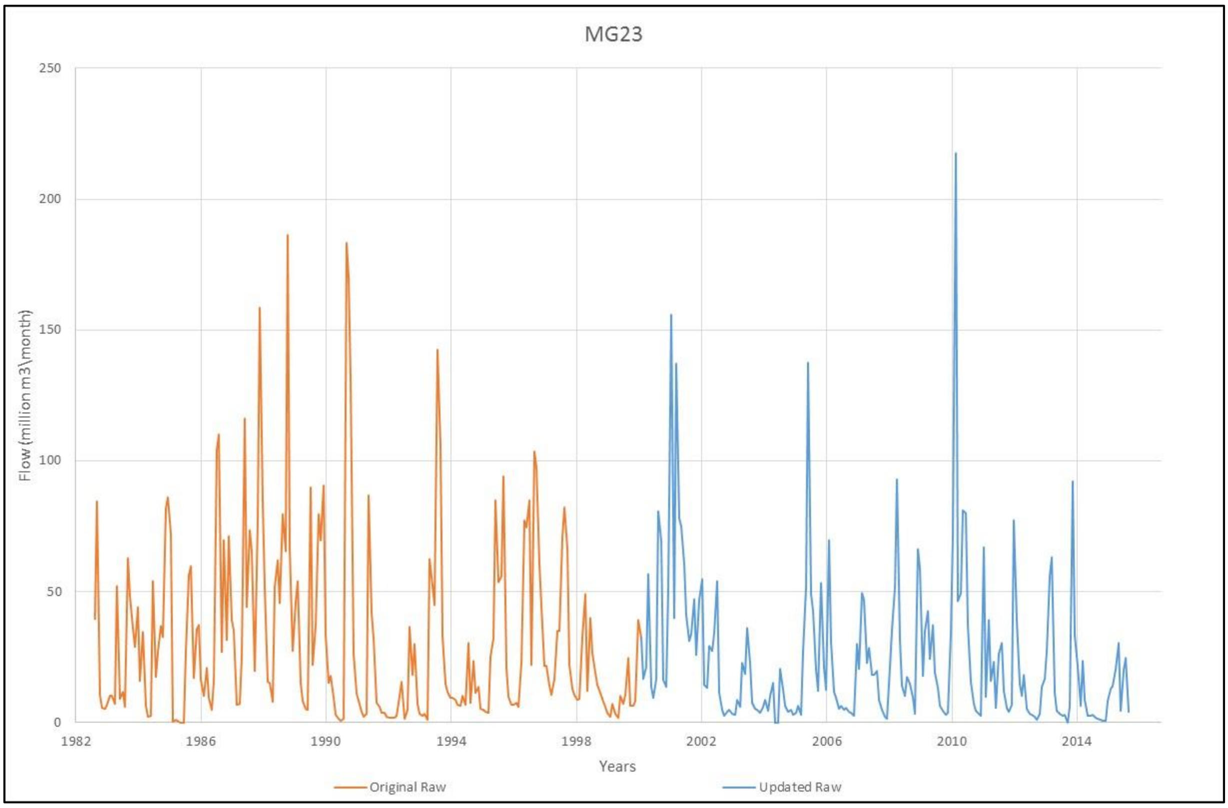


Figure 4-10: Raw Monthly Flows: MG23

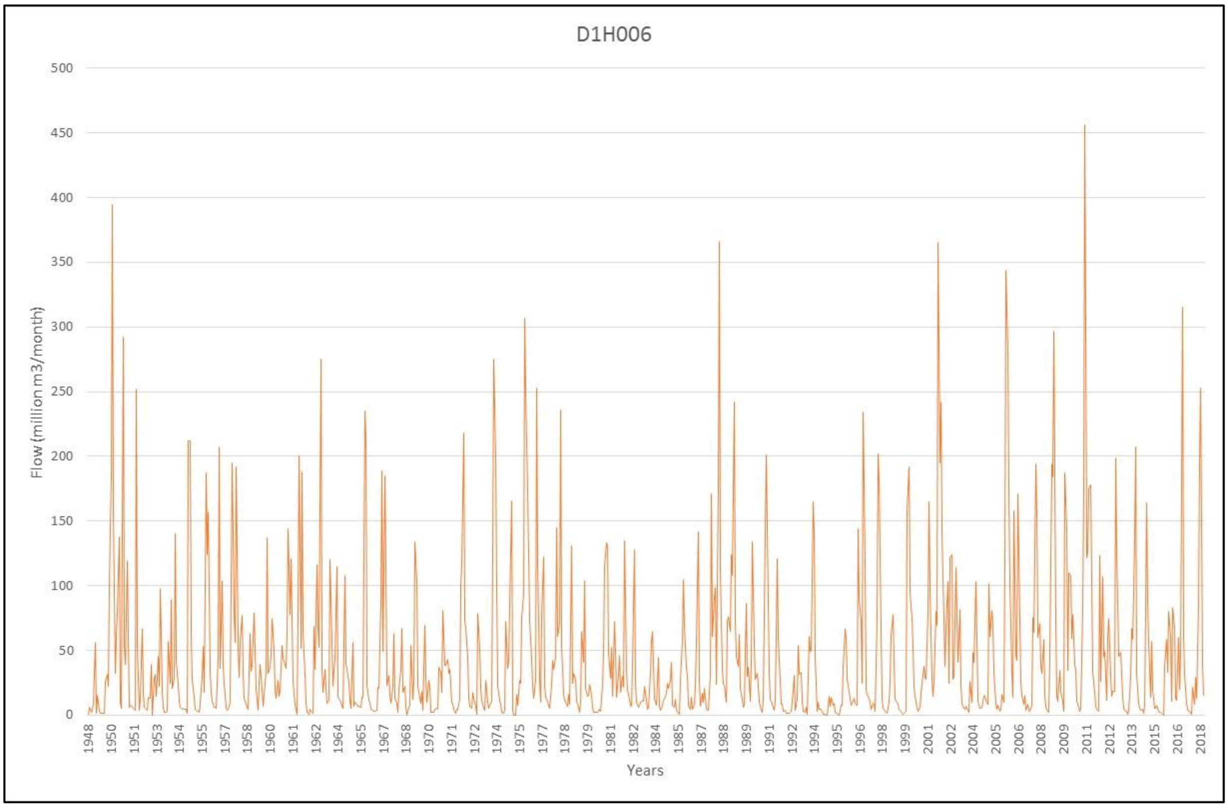


Figure 4-11: Raw Monthly Flows: D1H006

4.1.4 Simulated vs Observed Data

The Water Resources Yield Model (WRYM) and Water Resources Planning Model (WRPM) were configured to represent the present-day catchments and to extract simulated flows from the models at points representing the flow gauges. **Figure 4-12** provides a network diagram of the model configuration.

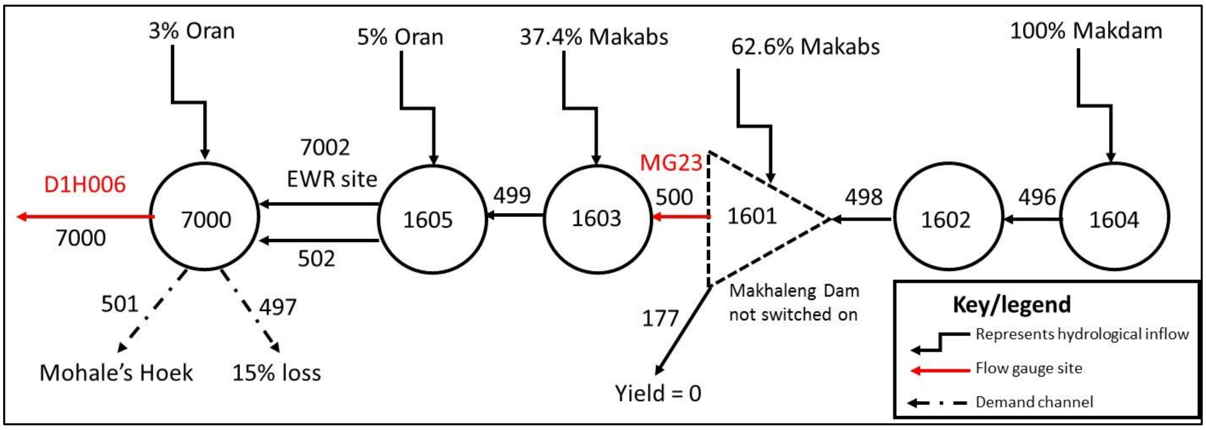


Figure 4-12: Network Diagram of Models Showing Channels Representing Flow Gauges

The WRYM was used to compare the simulated and observed historical flows up until 2004 at the flow gauge points. The WRPM (in stochastic mode) was used to compare the stochastic simulated flows with the observed flows from 2005 to 2018.

Figure 4-13 and **Figure 4-14** provide the results for flow gauges MG23 and D1H006 respectively.

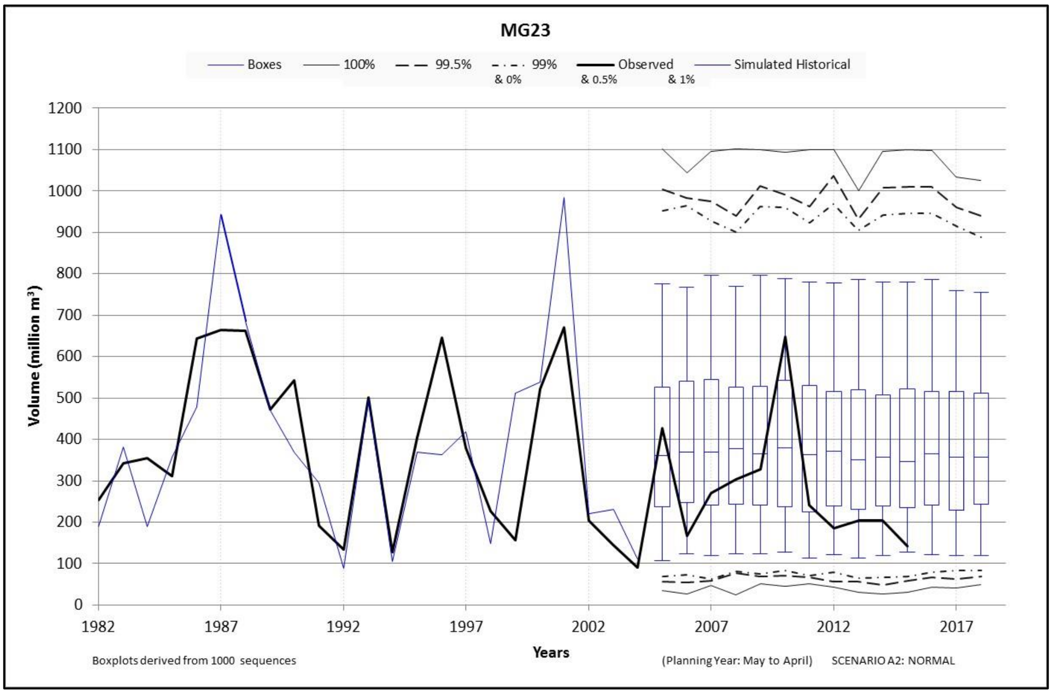


Figure 4-13: Simulated vs Observed Flows: MG23

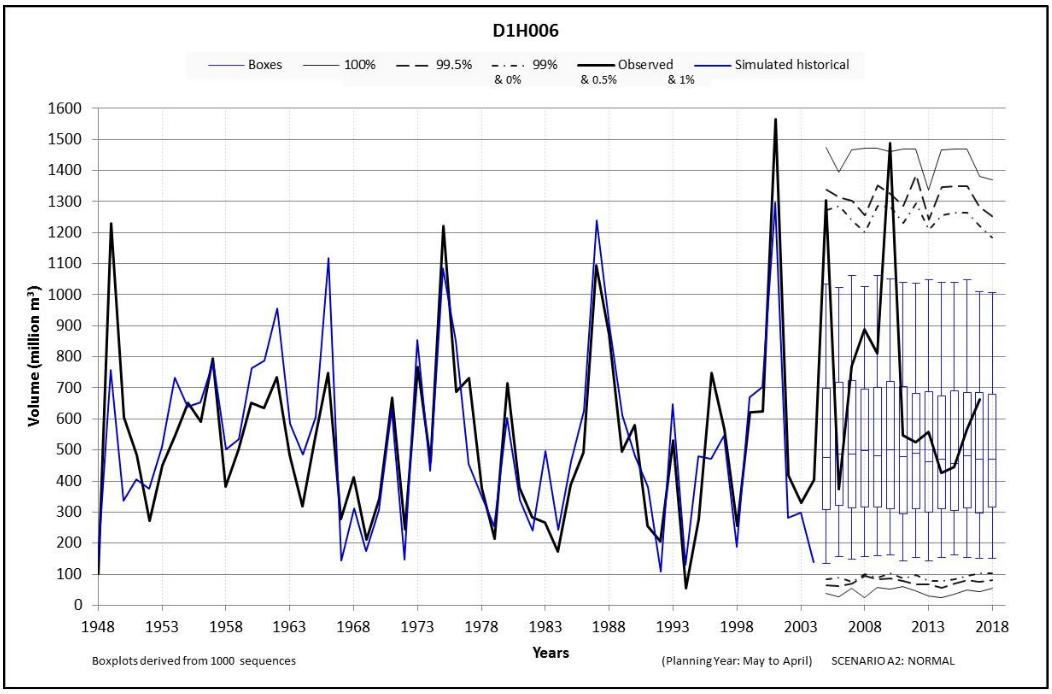


Figure 4-14: Simulated vs Observed Flows: D1H006

The Mean Annual Run-off (MAR) for flow gauge D1H006 and the WRYM simulation over the period 1948-2004 are comparable, with the gauge measuring 525.3 million m^3/a and the WYRM simulating 530.7 million m^3/a. Similarly, the MAR for gauge MG23 for the period 1982-2004 are comparable with the WRYM simulation, with 375.9 million m^3/a measured at the gauge and 388.9 million m^3/a simulated from WRYM. The only noticeable differences on gauge MG23 are the two times where the model simulated higher peaks than observed, in 1987 and 1999. The observed flow gauge records suggest that the gauge measures a maximum flow of approximately 670 million m^3/a, and it is likely that the gauge is not correctly recording the higher flows.

Comparing the simulated stochastic flows of the WRPM between the period 2005 and 2018, indicates that the observed flows fall within the band of stochastic flows. The model does produce some higher flows as well as some lower flows than the observed. The observed flow in January 2011 is greater than the highest stochastic flow generated by the model, but this was known to be a flood of extreme magnitude.

4.1.5 Recommendations Regarding Hydrology

From a yield perspective, low flows are of greater importance when assessing hydrology for dam design. For this reason, it is considered acceptable that the only observed flow that falls slightly outside the band of model generated flows is a high flow. From the observed flow gauging data, it can be seen that the flows included after the original calibration was done, i.e. from 2004 onwards, are never lower than previously measured. There has therefore not been a dryer year since the observed time period that the hydrology spans. The stochastic flows are generated in the models using the historical natural hydrology. Because flows in recent years are higher, it is unlikely that the stochastic flows produced using the extended observed flow data would differ from a low flow perspective. Again, because base flows are considered more important for yield analyses, it is therefore concluded that the original hydrology is suitable for use in the pre-feasibility assessment of the Dam site selection.

Given that flow gauge D1H006 was not included in the original calibration of the hydrology for the Makhaleng River catchment, it is recommended that this be incorporated, and the hydrology reassessed as part of the Dam Feasibility Component. Ideally one would want to consider all available flow gauge data when producing hydrology which should be at a higher confidence level for the Feasibility Phase.

4.2 CATCHMENT WATER RESOURCE MODELLING

When undertaking the water resource assessment there are a few key issues that should be considered which can have a significant impact on the yield and potential viability of any new development. One of the most important and often controversial issues concerns the impact of any new upstream development on the downstream users. In a river basin system that has surplus water resources, a new dam development may not cause any noticeable impact on the downstream users and in such cases, there may be no need to releasew mitigation flows to support the downstream users since they have not experienced any reduction in their supply. This was the situation with the first phase of the Lesotho Highlands Water Project which was planned back in the 1970's and developed in the 1980's. At this time, there was significant surplus water available for new developments in the Orange/Senqu basin with the result that when the major dams and transfer infrastructure was developed in the Lesotho Highlands, there was no need to supply mitigation releases in support of any of the downstream users. Over the past 30 years, the situation has changed and there is no longer any significant surplus water in the Orange/Senqu basin. Water in the basin has become a scarce resource and it is therefore important to evaluate the impact of any new dam development options on the downstream users and if possible to quantify any reduction in water availability that will be experienced by them. It should be noted that if it is considered necessary to mitigate the reduction in water availability to the downstream users, then the reconciliation strategies required, should be included in any financial or technical assessment of the proposed development.

In the case of a new dam anywhere in the upper reaches of the Orange/Senqu river basin, the initial yield assessment will determine the possible maximum yield that can be abstracted from the new dam at the location of the dam, referred to as the local yield at the dam. A second basin-wide assessment will then be undertaken to assess the net or incremental yield from the Orange/Senqu river basin as a whole which will be a positive yield but is likely to be lower than the local maximum yield available at the dam site. It is therefore important to present both the maximum local yield as well as the net additional basin yield also referred to as the incremental yield, for any proposed new development. Another important and sometimes confusing issue concerns the required releases from any proposed new development. The term "compensation releases" is often used to cover the required water to be released from a proposed new dam for environmental purposes. In certain scenarios, an additional volume of water is included to restore the overall balance so that there is no noticeable impact to the downstream users from the proposed development. If both the environmental requirements (usually very small) and the additional mitigation flows (often very large) are combined and shown as "compensation releases" it can create both confusion and some concern as it may appear that much of the benefit of the proposed new dam is being released for no apparent reason. In such cases, the incremental yield from the proposed new dam may be half of the gross maximum local yield which may, in turn, make a potentially viable project appear to be unviable.

Having highlighted the key issues of the maximum local yield as well as the possible incremental yield of a potential new dam development it is also important to mention one more very significant consideration when assessing any new dam development. The maximum local yield given in the report for each possible new development is the actual yield that can be abstracted at the proposed dam site. This water is available high up in the catchment and as such may have significant additional value due to the fact that it can be used to supply specific areas or consumers which cannot be supplied from any downstream dam developments. Even in cases where the incremental yield may be half of the local maximum yield, the full maximum yield can still be used or diverted to external users. In such a case, it may then be necessary to investigate another development to provide additional yield in the river basin to restore the status quo to the existing downstream users. Releasing water from the new Makhaleng Dam high up in the catchment for this purpose is possible but would not be an attractive strategy due to the fact that water higher up in a catchment has greater value and usually experiences low evaporation making it an ideal location to store water.

The various local yields and incremental system yields provided in the remainder of this section will be presented in a manner in which any mitigation flow required by the downstream users is shown as a separate item and is not included in the "compensation flows" which relate specifically to the Environmental Flow.

The water resources yield analyses were carried out in support of the Dam Engineers to provide yields for a range of requested dam sites and sizes. Only a few sites were selected for specific model analyses, and results were extrapolated to make decisions relating to the other sites. The following sub-sections describe the scenarios analysed and the results obtained.

4.2.1 Model Configuration

A simplified WRYM data set focusing on only the Makhaleng River Catchment was configured to carry out the yield analyses of the Makhaleng Dam. Adjustments were made to the incremental hydrology upstream of the Dam, depending on the dam site being assessed. **Figure 4-15** provides the basic WRYM network, with "X" and "Y" used to identify where variations took place.

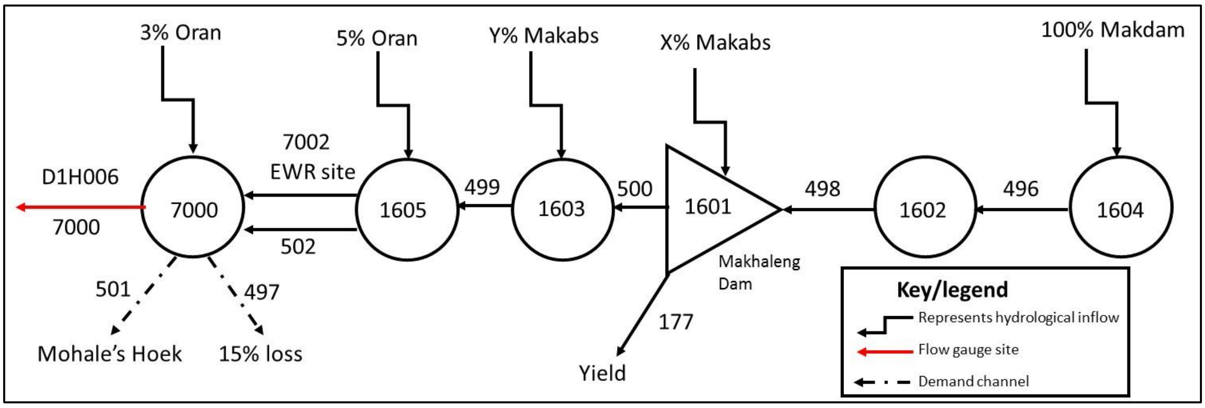


Figure 4-15: Simplified Makhaleng Dam System Network Diagram

Table 4-2 provides the values for X and Y indicated in the diagram for the various dam sites.

Table 4-2: Percentage Hydrology Entering Upstream of The Various Dam Sites Assessed

Dam Site	X% Makabs	Y% Makabs
Lowlands	16.4	83.6
N1	53.5	46.5
TOR	63.7	36.3
S2	70.8	29.2
D4	91.3	8.7

The only other difference between the model configurations for the various dam sites was the height/elevation-capacity relationships for the dams. This was provided by the Dam Engineers and is presented in **Appendix E**.

Additional analyses were carried out to determine the impact of a selected dam size and abstraction on the existing Orange River Project (ORP), namely Gariep and Vanderkloof dams. For these analyses, the larger integrated WRYM configuration was used, incorporating all the catchments upstream of Gariep and Vanderkloof dams. A network layout of this is provided in **Appendix F**. The integrated WRPM was further used to determine the impacts of other systems and sub-systems such as the proposed Noordoewer/Vioolsdrift Dam on the Lower Orange.

4.2.2 Yield Results

The results of the selected yield analyses scenarios are presented in the various Tables and Figures that follow in this subsection. All the results are provided in the form of Historic Firm Yields, i.e. the Dam almost touched empty once in the historic simulation period 1920 to 2004.

Table 4-3: Yield Results of Lowlands Site

Elevation (mamsl)	Capacity (million m^3)	Local Yield (million m^3 /a)
1 715	1 119.61	224
1 705	875.64	218
1 695	670.83	213
1 685	503.98	196
1 670	316.63	168
1 665	267.33	157
1 655	186.92	139

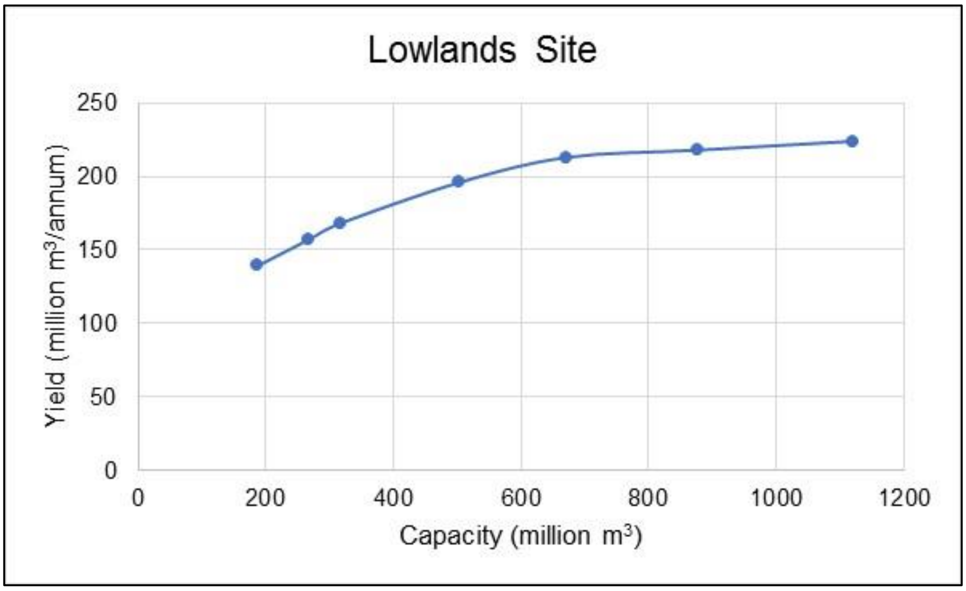


Figure 4-16: Yield Capacity Relationship: Lowlands Site

Table 4-4: Yield results of TOR Site

Elevation (mamsl)	Capacity (million m^3)	Local Yield (million m^3 /a)
1 615	1 234.41	372
1 610	1 094.85	368
1 600	846.14	336
1 585	543.54	290
1 570	316.60	236
1 565	256.61	202
1 555	160.10	145

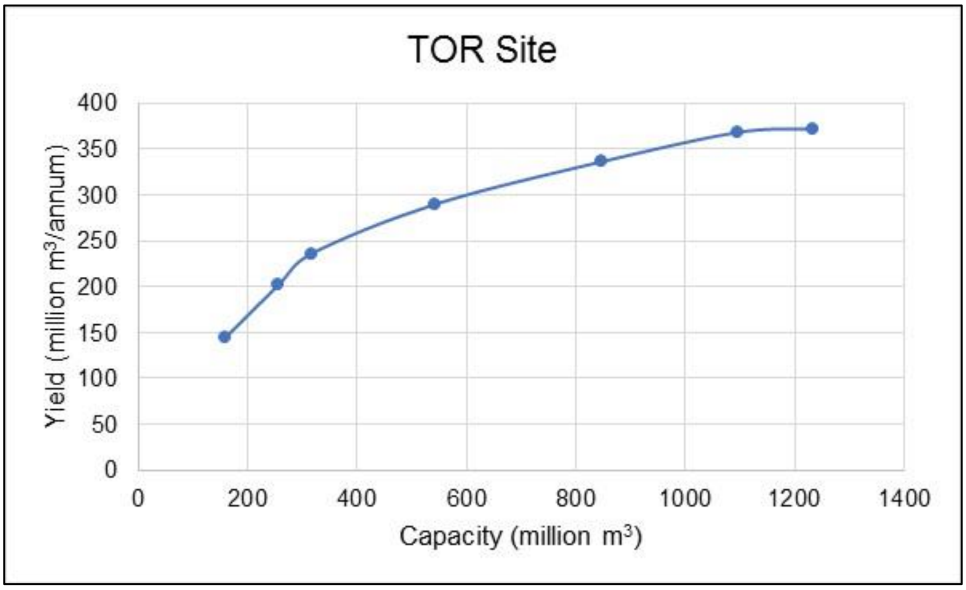


Figure 4-17: Yield Capacity Relationship: TOR site

Table 4-5: Yield Results of Site D4

Elevation (mamsl)	Capacity (million m^3)	Local Yield (million m^3 /a)
1 575	1 696.76	466
1 570	1 488.17	461
1 555	964.03	406
1 540	578.16	340
1 525	312.11	248
1 520	245.44	209
1 515	189.22	175
1 510	143.29	150

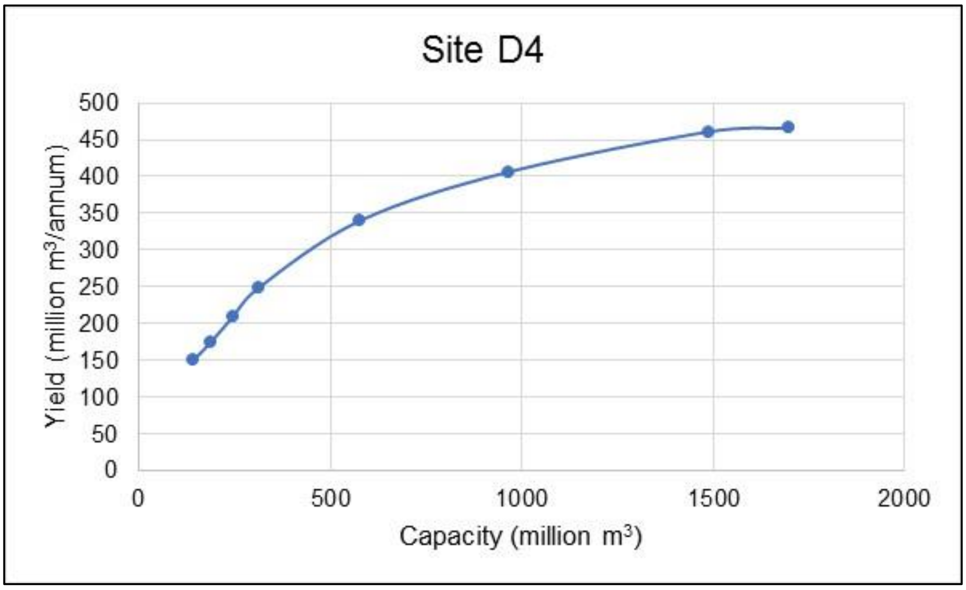


Figure 4-18: Yield Capacity Relationship: Site D4

Table 4-6: Yield Results of Site N1

Elevation (mamsl)	Capacity (million m^3)	Local Yield (million m^3 /a)
1 645	1 467.11	347
1 630	1 028.30	335
1 615	694.74	295
1 605	517.62	268
1 595	371.36	237
1 585	252.74	195

Note: this Yield includes EWR category D

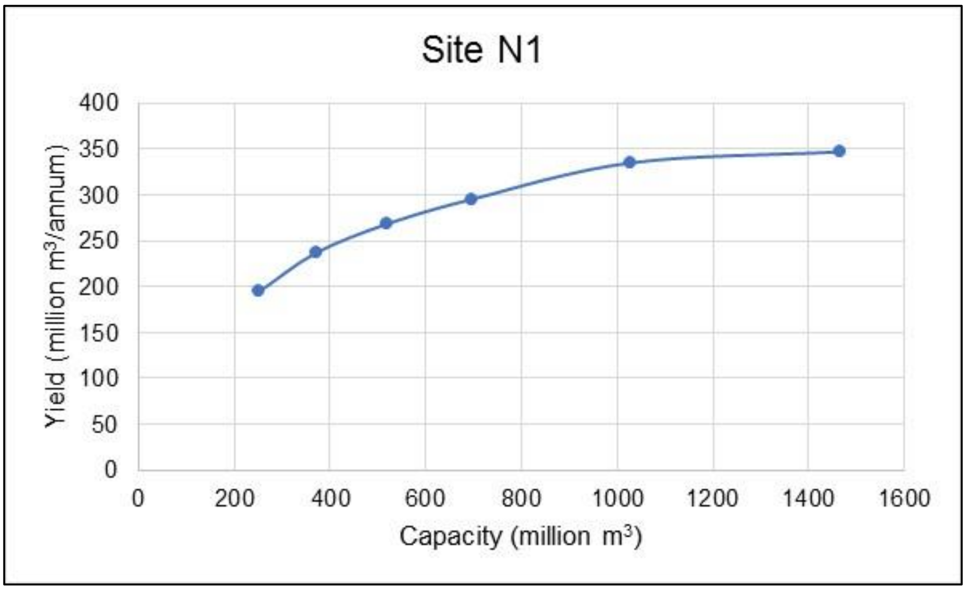


Figure 4-19: Yield Capacity Relationship: Site N1

Table 4-7: Yield Results of Site S2

Elevation (mamsl)	Capacity (million m^3)	Local Yield (million m^3 /a)
1 610	1 738.02	399
1 600	1 381.83	393
1 590	1 073.57	376
1 580	810.02	344
1 570	589.35	310
1 560	409.97	272
1 550	270.35	213
1 540	165.42	151

Note: this Yield includes EWR category D

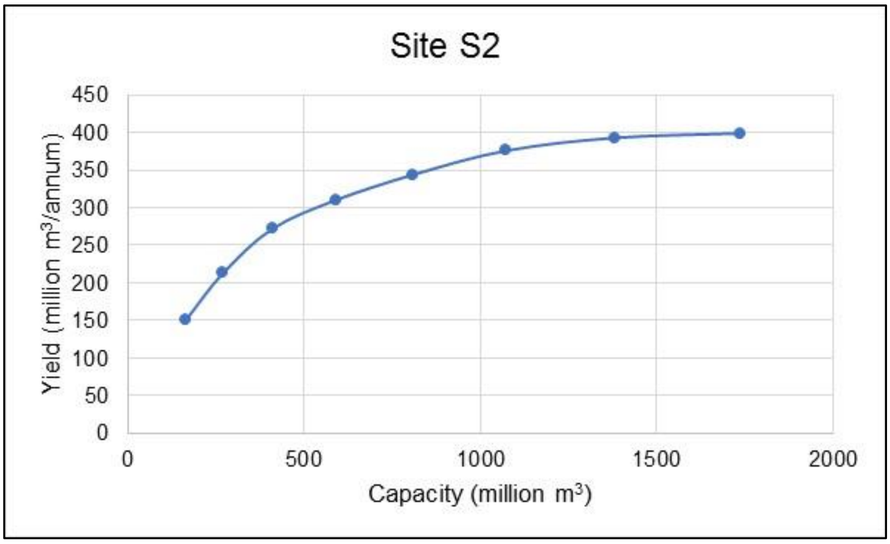


Figure 4-20: Yield Capacity Relationship: Site S2

4.2.3 Impact of Environmental Water Requirements

Additional analyses were carried out for Site 2 including the Environmental Water Requirements provided by the environmental specialists. Two Environmental Water Requirement scenarios were analysed to assess the sensitivity of the available yields on the environmental category (A to D) selected. Originally a category D was selected which is the category that will have the least impact on the resulting yields. This was found to have very little impact on the yields due to the relatively small water volume required under this low category. A second analysis was undertaken using category B to provide an indication of the potential impact of what would most likely be the most demanding category from a yield perspective. It still remains to be seen which category would actually be selected, and this would be assessed in the Feasibility phase. The Environmental Water Requirement requirements based on the natural flows for both category D and category B are included in **Appendix C**.

Table 4-8: Yield Results of TOR Site Excluding and Including EWRs

Elevation (mamsl)	Capacity (million m^3)	Local Yield excl EWR (million m^3 /a)	Local Yield Incl EWR D (million m^3 /a)	Local Yield Incl EWR B (million m^3 /a)
1 615	1 234.41	372	366	282
1 610	1 094.85	368	363	278
1 600	846.14	336	330	256
1 585	543.54	290	284	207
1 570	316.60	236	231	159
1 565	256.61	202	198	147
1 555	160.10	145	140	115

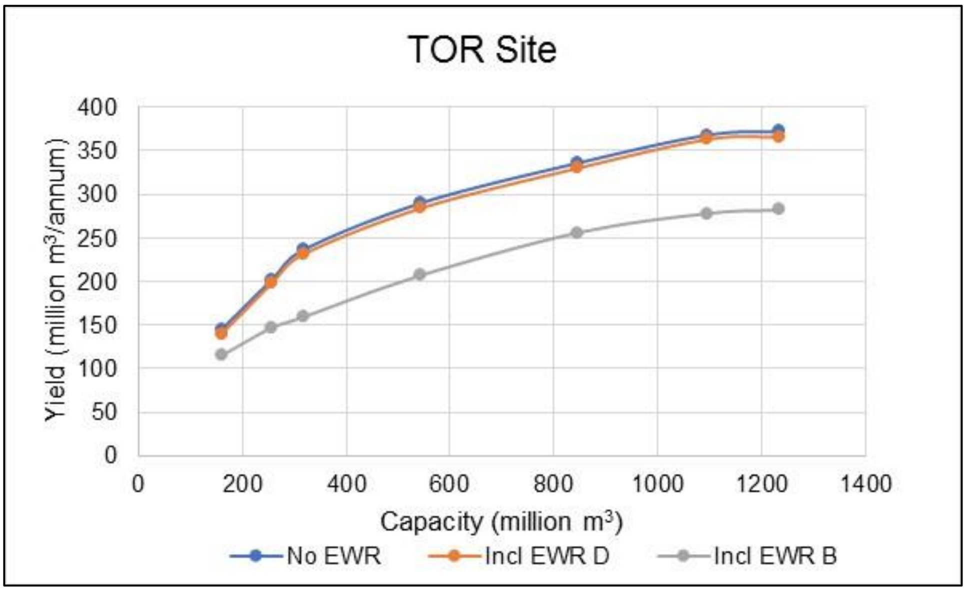


Figure 4-21: Yield Results Including Two EWR Categories

The results show that a category D Environmental Water Requirement requiring a release of approximately 19% of the inflows to the dam has very little impact on the yield. If a category B Environmental Water Requirement is imposed on the system, the impact on the yield is highly significant. Substantial mitigation releases are required from Makhaleng Dam or an alternative development to restore the impact of Makhaleng Dam on the downstream Gariep and Vanderkloof dams. If a category B EWR is later indicated from the Phase II work or the feasibility study, these mitigation releases can be utilised to supply the flow required for the increased Makhaleng EWR.

The reserve for the Upper Orange in the RSA has not yet been determined and was thus not included in the analysis. The Lower Orange Preliminary Reserve was recently determined and signed off by DWS RSA. This Preliminary Reserve was included in the modelling of the system and is part of the water requirements to be supplied from Gariep and Vanderkloof dams.

4.2.4 Impact of Makhaleng on Downstream Water Users

Basin Wide Impacts: As part of the Core Scenario analyses as captured in the Updated Core Scenario Report (ORASECOM, 2019) the Core Scenario was analysed using the Water Resource Planning Model (WRPM). This model takes into account the growth in water requirements over time as well as new development options as developed over the planning period of 2018 to 2050. Results from this model, therefore, provide the basin-wide impacts of growing demands and developments\interventions options over time.

The Core Scenario data sets as defined for the Planning Model include the operating rules and water requirement projections as per the status in 2018. In addition, the current most likely future development and management options of the four basin States which will have an impact on the water resources of the basin were all captured in the data sets. A detailed description of the Core Scenario is given in the Updated Core Scenario Report Section 6 (ORASECOM, 2019). The Core Scenario Planning Model data set represents mainly the surface water resources schemes and users for the entire basin as in 2018 at the start of the analysis, and then added the future developments and increasing water requirements at the date according to current planning. The main future water resource developments included are given in **Table 4-9**.

A large number of Core Scenario and related sensitivity analyses were carried out and documented in the Updated Core Scenario Report (ORASECOM, 2019). For the purpose of this "Pre-feasibility Phase 1" report, only a few selected key scenarios are discussed to illustrate the basin-wide impact of the upstream developments.

The Orange River Project (ORP) is basically the section of the Orange/Senqu river basin which is supplied from the two largest storage reservoirs in Southern Africa, namely Vanderkloof and Gariep. These two dams have a combined storage capacity of some 9 000 million m^3 representing approximately half of all storage capacity in the whole of the Orange/Senqu river basin including all of the Vaal River basin.

Table 4-9: Core Scenario future developments

Cluster 1: Orange River Project Scheme future improvements		Implementation	Project Type
1	Utilise the lower-level storage in Vanderkloof Dam	2019	Dam
2	Real-Time flow modelling and monitoring in the Lower Vaal downstream of Bloemhof Dam and in the Orange River downstream of Vanderkloof Dam to the Orange River mouth;	2020	Dam
3	Building of the Verbeeldingskraal Dam upstream of Gariep Dam;	2032	Dam
4	Formally agreed to Environmental Water Requirements & release to Orange River Mouth	2025	Integrated Water Management
5	Noordoewer/Vioolsdrift Dam used as a resource for Namibia and RSA, and for flow re-regulation for Orange-Senqu River Mouth	2028	Dam
6	Development of 12 000ha for resource-poor farmers of which ± 30% was already developed	Ongoing	Integrated Water Management
7	Polihali Dam (Lesotho Highland Water project (LHWP) Phase ll and connecting tunnel to Katse Dam; using new operating rule	2025	Dam
Cluster 2: L-BWT Scheme			
8	Makhaleng Dam	2030	Dam
9	L-BWT pipeline, transfer pipe to Gaborone/Lobatse and irrigation	2033	Pipeline/Pumping Scheme
Cluster 3: Lesotho Lowlands			
10	Hlotse Dam: Urban/rural demands plus irrigation developments	2029	Dam
11	Ngoajane Dam: Urban/rural demands plus irrigation developments	2034	Dam
Cluster 4: IVRS intervention options			
12	Thukela transfer further phase	2037	Pipeline/Pumping Scheme
13	Desalination and re-use of mine water effluent;	2025	Wastewater Treatment
14	Utilise Croc Return Flows in Tshwane to reduce the load from Rand Water via Vaal	2025	Pipeline/Pumping Scheme
Cluster 5: Caledon to Greater Bloemfontein transfer			
15	Tienfontein pump station capacity increase to 7m^3/s;	2040	Pipeline/Pumping Scheme
16	Increase Tienfontein pumping capacity to 3.87 m^3/s Novo Transfer scheme capacity to 2.2 m^3/s; to Rusfontein Dam	2019	Pipeline/Pumping Scheme
Cluster 6: Greater Bloemfontein internal resource improvements			
17	Raise Mockes Dam to increase storage capacity	2023	Dam
18	Increase Maselport WTW Capacity to 130 Ml/d	2021	Wastewater Treatment
19	Planned indirect reuse from the Bloem Spruit WWTW (± 16 million m^3/a); Maselspoort	2021	Wastewater Treatment
20	Planned direct reuse from the Bloem Spruit WWTW (± 11 million m^3/a); Maselspoort	2030	Wastewater Treatment
Cluster 7: Gariep to Greater Bloemfontein Transfer			
21	Pump station and pipeline from Gariep Dam to Bloemfontein Phase 1	2023	Pipeline/Pumping Scheme
22	Pump station and pipeline from Gariep Dam to Bloemfontein Phase 2	2034	Pipeline/Pumping Scheme
Cluster 8: Neckartal Scheme			
23	Neckartal Dam irrigation demands (large schemes)	2028	Dam
24	Neckartal Dam hydropower releases	2021	Dam
Cluster 9: Integrated Water management options			
25	Removal of unlawful irrigation	Ongoing	IWM
26	WCDM Irrigation	2020	IWM
27	WCDM Urban and Industrial	2018	IWM

These two large storage reservoirs capture water from Lesotho as well as the upper parts of the Orange River basin and provide a reliable and continuous flow of water into the lower Orange River mainly for the large-scale irrigation along the Orange River in South Africa and Namibia.

In the late 1980's and early 1990's, the initial system analysis carried out as part of the Orange River System Analysis study (DWAF,1993) indicated that Phase 1 of the Lesotho Highlands Water Project could be fully implemented without lowering the yield from the Orange River Project below its planned requirements. (See **Figure A-2 in Appendix A**) This analyses highlighted that Phase 1 of the Lesotho Highlands Water Project would not impact negatively on any of the users supplied from the ORP system and no mitigation releases from any of the LHWP Phase 1 dams would be necessary. The analysis further indicated that there was still a small surplus available from the ORP.

The Orange River Reconciliation Strategy Study (DWS, 2015) completed in 2015 clearly indicated that the inclusion of Polihali Dam will impact significantly on the ORP system resulting in deficits that will be experienced in the water supply from the ORP users. DWS (RSA) at the time decided to over the long-term not make any mitigation releases from Polihali Dam to rectify the downstream impact due to the high value of the water in the Vaal River System. Additional storage would rather be created in the Orange River System to make up for the yield lost from the ORP due to Polihali Dam, of which Verbeeldingskraal Dam was one of the selected developments.

Up until approximately the year 2016, there was always surplus water resources in the Orange/Senqu river basin even after including the revised estimates for the environmental requirements. As new dams have been developed and the existing users have increased their water use due to natural population growth etc, the surplus water in the basin has now been utilised to the point that there is basically no surplus water in the basin that can be used without first developing new storage capacity. Any new developments in either Lesotho or the upper reaches of the Orange River basin in South Africa will therefore impact on water availability along the lower reaches of the Orange River. For this reason, any proposed new dam developments must be carefully analysed using the systems models to assess the impacts of the proposed developments, and if necessary, propose some form of additional storage at some point in the system to ensure that the existing water users in the basin are not adversely affected.

In order to carry out the impact assessment of Makhaleng Dam on the Orange River Project, the Water Resource Yield Model (WRYM) data set previously used for Orange River analyses was used. The last analyses undertaken for the Orange River Project date back to 2013 when the model was used in the study for Phase 3 of the ORASECOM Integrated Water Resources Management Plan. From this study, it was found that the total available yield from the Orange River Project was 3 252 million m^3/a.

The final data set used in the 2013 analyses was used as the basic starting point for a new assessment. The first step in the process was to repeat the previous analysis and ensure that the model was producing the same results as in the 2013 study. Having established the same yield results, the model was then modified to first include Polihali Dam followed by Makhaleng Dam which is expected to be in place by approximately 2030. The various water demands throughout the river basin were then updated within the model to the projected 2030 development levels and in addition, Verbeeldingskraal Dam was included together with the utilization of the Vanderkloof Dam Lower-level Storage. It should be noted that Verbeeldingskraal Dam and the Vanderkloof Dam Lower-level Storage are two development options that are required to mitigate the reduction in yield from the Orange River Project due to the construction of the Polihali Dam, which is already underway. From the results given in

Table 4-10, it shows that the reduction in the Orange River Project yield due to the inclusion of Polihali Dam is 200 million m^3/a (Base Scenario A versus Scenario 1). By utilizing these two intervention options (Base Scenario B) it was possible to restore the yield balance in the Orange River Project and provide a small surplus estimated to be in the order of 45 million m^3/a or 1.4%.

The data set was then modified to represent the current configuration of the Makhaleng River catchment as used to carry out the WRYM analyses described under **Section 4.2.2**. The Environmental Water Requirements based on the “D” category were included and the hydrological splits were adjusted. A 3 MAR Makhaleng Dam was included at the S2 dam site (Scenario 2) to determine the 2030 base yield of the Orange River Project. The 2030 Base Scenario B was simulated again with the Environmental Water Requirements and Makhaleng Dam turned off. The yield of the 2030 Base Scenario B was confirmed to be 3 297 million m^3/a which indicates an increase in yield of .45 million m^3/a when compared to the original 2013 yield for the Orange River Project of 3 252 million m^3/a, as mentioned before.

Four additional scenarios were then carried out as shown in **Table 4-10**. It should be noted that the basic data set was identical to the 2030 Base Scenario B with the specific changes itemised in the scenario description. The results presented, therefore, represent the relative changes to the local yield as well as the impacts on the overall system yield.

Table 4-10: Impact on ORP Scenarios and Results

Scenario	Historic Firm Yield (million m^3/a)		Reduction in ORP Yield (million m^3/a)	Overall Incremental Yield Increase (million m^3/a)	Description
	ORP	Other Local Yield/demand			
Scenario1 existing system	3200				The existing infrastructure at 2020 levels but including the system demands as expected in 2030. i.e. it excludes Polihali Dam
Scenario A	3 000	Polihali Local yield 391	200	191	Same as **Scenario 1** but including Polihali Dam with full 391 local yield from the dam.
Scenario B	3 297				Same as **Scenario A** but including Verbeeldingskraal Dam and utilization of Vanderkloof Lower-Level storage
Scenario 2 Large Makhaleng Dam	3 254	Demand imposed on Makhaleng 200	40	160	Same as **Scenario B** with a 3 MAR Makhaleng at site S2. Demand on Makhaleng of 200 and 178 mitigation releases to ORP
Scenario 2g Large Makhaleng Dam	3 297	Demand imposed on Makhaleng 188	0	188	**Scenario 2** with demand from Makhaleng reduced from 200 to 188
Scenario 2h Large Makhaleng Dam	3 045	Demand imposed on Makhaleng 378	252	126	**Scenario 2** with no mitigation releases to ORP and full local yield of 378 from Makhaleng Dam.
Scenario 2j Small Makhaleng Dam	3122	Demand imposed on Makhaleng 218	175	33	**Scenario 2h** with no mitigation releases to ORP and full local yield of 218 from smaller Makhaleng Dam.

The results shown in **Table 4-10** should be considered as preliminary values which may be refined through further stochastic analyses as part of Phase 2 of the Pre-feasibility study. They mainly highlight the key analyses to assess the local yield from the Makaleng Dam for both a large dam (3 MAR = 1 382 million m^3 live storage,) and a smaller dam (0.65 MAR dam with a 298 million m^3 live storage,) that is just sufficient to meet the proposed transfer demands. The dam development will clearly have an impact on the availability of water from the downstream Orange River Project and mitigation measures required to restore the water availability to the downstream users may therefore be required. This have been indicated where appropriate. It should be noted that the mitigation flows can be released directly either from the new Makhaleng Dam or from some other development option in the Orange/Senqu river system, such as the proposed Verbeeldingskraal Dam or the proposed Vioolsdrift Dam for example. Further analyses of the different options for supplying the mitigation flows are discussed in **Section 4.2.5** of this report.

Scenario 2 includes Base Scenario B with the addition of a 3 MAR Makhaleng Dam at the S2 site and a 200 million m^3/a transfer/demand imposed on the dam which resulted in a reduction in yield from the Orange River Project of 40 million m^3/a. **This indicates that the incremental yield increase resulting from this development option is 160 million m^3/a (i.e. 200 million m^3/a - 40 million m^3/a).** Should the full 200 million m^3/a local yield be abstracted from the dam (eg to supply to Gaborone via the pipeline) it will therefore be necessary to provide approximately 40 million m^3/a from some other development lower down in the system to mitigate the yield reduction from the Orange River Project as Makhaleng Dam was not able to supply all the required mitigation releases.

Scenario 2g also includes the 3 MAR Makhaleng Dam at the S2 site and simulates the scenario where the yield from the Orange River Project system is unaffected by the new dam. To avoid the dam having an impact on the yield from the Orange River Project, the operating rules are selected to allow the new dam to provide some support to downstream users when required and the remaining local yield is therefore reduced to some degree. The demand abstracted from Makhaleng Dam in this scenario is reduced from 200 million m^3/a to 188 million m^3/a, which is the maximum local yield that can be abstracted from the Makhaleng Dam without reducing the yield from the Orange River Project. For this scenario, the mitigation releases from Makhaleng Dam were thus sufficient to restore the downstream yield and be able to take 188 million m^3/a from Makhaleng Dam.

Scenario 2h includes the 3 MAR Makhaleng Dam at the S2 site but represents the option where the maximum local yield is abstracted from the new dam and no mitigation releases are made from the dam (the relatively small environmental releases are still being made). This scenario effectively provides an indication of the maximum local yield that can be abstracted from a 3 MAR Makhaleng Dam, but it must be noted that some form of additional development in the system will be required to restore the yield balance at the Orange River Project. **This Scenario indicates that the maximum local yield available at the dam site of the 3 MAR Makhaleng Dam is approximately 378 million m^3/a.** This scenario indicates a reduction of 252 million m^3/a from the yield from the Orange River Project and additional yield would therefore have to be provided to restore the balance to the downstream users. This will be discussed and analysed in more detail in the subsequent Phase 2 of the project

Scenario 2j represents the option when a smaller Makhaleng Dam is considered at site S2 which is just sufficient to supply the full estimated target transfer of 218 million m^3/a. This scenario indicates a reduction of 175 million m^3/a from the yield from the Orange River Project and additional yield would therefore have to be provided somewhere in the system to restore the balance to the downstream users.

Noordoewer/Vioolsdrift Dam

When the various system analyses were undertaken, the results from the combined study by Namibia and the RSA on the Noordoewer/Vioolsdrift Dam were unavailable and the study was still in progress. The study focused on two possible dam size options for the Noordoewer/Vioolsdrift Dam, a large, and a medium size dam. For the purpose of the Core Scenario, the medium size dam was selected although a sensitivity analysis was also undertaken to assess the impacts of a large Noordoewer/Vioolsdrift Dam. The operating rules for both scenarios were identical to ensure that releases from Vanderkloof Dam would be made to support the users between Vanderkloof and Noordoewer/Vioolsdrift dams. Additional water would be released from Vanderkloof Dam only in cases where the proposed Noordoewer/Vioolsdrift Dam could not support the water requirements between the dam and the river mouth.

It is important to note that the Core Scenario indicated in **Table 4-9** includes the Noordoewer/Vioolsdrift Dam from 2028 onwards, Makhaleng Dam from 2030 onwards and the high transfer to Botswana from 2033 onwards. Mitigation releases were made from Makhaleng Dam to restore the balance in the ORP. Hlotse Dam with its demands was included from 2029 and Ngoajane Dam and demands from 2034 onwards.

Results from the planning analyses showed that deficits in the increased Namibia irrigation demand start to occur from 2043 onwards if the medium Noordoewer/Vioolsdrift Dam is considered. With the large Noordoewer/Vioolsdrift Dam in place, no deficits occur until after 2050. In both scenarios, the same expected growth in the Namibia Irrigation requirement was used. These results should be confirmed once the Noordoewer/Vioolsdrift Dam study is completed so that the final dam size and the updated growth in irrigation can be included in the analysis.

In the most recent report of May 2020 for the Noordoewer/Vioolsdrift Dam study, the medium sized dam has been replaced with a small dam. The large dam, however, remains the same size as the dam already analyzed and described above. The revised Namibia demand to be supplied from the large dam also remains the same as previously used and therefore the results presented for the large dam option remain valid.

Orange River Mouth Environmental impacts

The current annual Environmental Water Requirements to be released from Vanderkloof Dam for the Orange River and river mouth amount to 289 million m^3/a, which has more recently been shown to be insufficient. DWS RSA has since reassessed the requirements and approved the new figures which will be released from Vanderkloof Dam from 2022 onwards. These new Environmental Water Requirements for the Preliminary Reserve were included in the modeling of the current Core Scenario.

The final agreed and approved reserve for the Orange River System must therefore still be determined and the figures used in this report may therefore change in future. Previous Environmental Water Requirement studies already indicated that the preferred ecological environmental requirement would result in a decrease in the yield available from the Orange River Project which will obviously have a significant impact on the overall yield balance in the Orange/Senqu system. While it is accepted that the final reserve must still be determined, the preferred ecological environmental requirement was used in the Core Scenario and implemented in the Planning Model by 2028 in association with the large Noordoewer/Vioolsdrift Dam.

With all the planned upstream developments in place, the Planning Model results for the Core Scenario indicated no deficits in the assurance of supply in the Lower Orange until after 2043 on the assumption that agreed Water Conservation and Water Demand measures are implemented successfully. Should these water conservation measures not be implemented successfully, the system yield failures start to occur around the year 2038. The Core Scenario includes the Makhaleng Dam option that releases mitigation water in support of Gariep Dam to have a zero impact on the ORP yield.

As the final Reserve still need to be determined, a sensitivity analysis was carried out using the Preliminary Reserve from 2022 until the end of the simulation (2050). This led to a significant increase in the water supply in the Lower Orange, and subsequently no deficits were experienced. It is expected that the Final Reserve figures will not differ significantly from the

Preliminary Reserve figures used in the Core Scenario in which case the reserve will most probably be supplied at the required level of assurance until at least 2050.

4.2.5 Summary of analysis on Multi-Purpose Dams

This section provides a summary of the work carried out as part of Component I of this study that was executed in parallel with Component III of the study. Component I of the study focusses on the Core Scenario update while Component III addresses the Lesotho/Botswana Transfer Scheme of which this report "Pre-feasibility Phase 1" is the first deliverable.

As part of the Core Scenario Update task and related report from Component I of the study, sub-task 1b6 (assessment of additional multipurpose dams in Lesotho) was carried out and documented in the Core Scenario Update Report (Report number: ORASECOM 003/2019). This section provides a summary of the analyses carried out with the focus on the Makhaleng Dam and restoration of the system water balance after inclusion of the selected Makhaleng Dam. It should be noted that these analyses were carried out at a reconnaissance level and further detailed analyses will be required before final implementation.

The purpose of the Core Scenario is to represent the expected future developments, water management related actions and operating procedures etc. as planned by the four basin countries. One of the key possible future developments is Makhaleng Dam and the Lesotho/Botswana transfer.

It is expected that some deficits will be experienced in future in the downstream sections of the Orange River with the updated Core Scenario in place, since significantly more water is used locally or transferred from the Senqu Basin in support of the Integrated Vaal River System (IVRS) and/or transferred to Botswana.

To be able to overcome the deficit in the Caledon/Mohokare catchment as well as in the main Orange River downstream of Lesotho, additional multipurpose dams in Lesotho were analysed to determine if they can be used to increase the yield available from the basin. The additional yield from these new dams can then be used to balance the deficits that might occur in the system as modelled in the updated Core Scenario.

The two largest future developments in Lesotho are Phase II of the Lesotho Highlands (Polihali Dam and transfer tunnel to Katse Dam) as well as Makhaleng Dam and transfer system to the RSA and Botswana. The impact of the Lesotho Highlands Phase II development significantly impacts on the water supply to the downstream users from the main Orange in Namibia and the RSA.

A map showing the location of the related dams in Lesotho as well as the Lesotho/Botswana transfer route, and the important current water supply systems are included in **Figure 4-22.**

LHWP Phase II Development: The RSA DWS study "Development of Water Reconciliation Strategies for Large Bulk Water Supply Systems: Orange River" was completed in early 2015. This study specifically addressed the impact of Polihali Dam on the main Orange River and provided solutions to restore the water balance in the Orange River to what it was before the inclusion of Polihali Dam. Gariep and Vanderkloof dams also known as the Orange River Project is used to supply all the users (RSA and Namibia) from the main Orange River downstream of the two dams, as well as users in the Eastern Cape via the Orange/Fish tunnel. The inclusion of Polihali Dam resulted in a reduction of 284 million m^3/a in the historic firm yield from the Orange River Project.

Several solutions or intervention options to make up for this reduction in yield were recommended from the DWS RSA Reconciliation Strategy Study, which included the following:

- Utilize the Lower-Level Storage in Vanderkloof Dam
- Real time modelling and monitoring
- Verbeeldingskraal Dam or raising of Gariep Dam
- Vioolsdrift Dam

Not all of the above-mentioned intervention options are required to balance the 284 million m^3/a reduction in the yield from the Orange River Project since some of these options were also used to support the increasing water requirements and revised Environmental Water Requirements. For the purposes of the multipurpose dam analyses, only the first three intervention options were used with Verbeeldingskraal Dam selected as the third option. The yield analyses results clearly show that these three intervention options will be sufficient to maintain the available yield from the ORP system at 3 297 million m^3/a after the inclusion of Polihali Dam, in comparison with the yield of 3 252 million m^3/a, before Polihali Dam was included.

For the purpose of the possible future developments in Lesotho it is important to first distinguish between developments within the Senqu/Makhaleng river catchments and those located in the Mohokare/Caledon River catchment.

Lesotho/Botswana Transfer Scheme: The possible future Lesotho/Botswana Transfer Scheme is one of the key possible future schemes and is located in the Makhaleng River, a tributary of the larger Senqu River. From the work carried out as part of the Prefeasibility Phase I of the current study, the Makhaleng Dam at site S2, is one of the two final recommended sites.

A small (0.65 MAR) and a large (3 MAR) dam were initially considered at site S2. The target water requirement to be supported from the future Makhaleng Dam for the transfer to Botswana plus some small local demands was in the order of 200 million m^3/a. A small dam with a live storage of 298 million m^3/a at site S2 can deliver a historic firm yield of 218 million m^3/a (see

Figure 4-23). Taking the 218 million m^3/a from the small Makhaleng Dam will result in a reduction in the yield of the next downstream major water supply system in the Orange River (referred to as the Orange River project or ORP) of 185 million m^3/a. This means that the incremental yield for the overall system only increases by 33 million m^3/a, which is too small for the intended Lesotho/Botswana transfer Scheme.

The next option evaluated was the large 3 MAR Makhaleng Dam at site S2. From

Figure 4-23 it is evident that the 3 MAR Makhaleng Dam can generate a local firm yield of 378 million m^3/a. Utilizing this full yield for the Lesotho/Botswana transfer system will result in a decrease in the downstream system yield of 252 million m^3/a, providing an incremental system yield increase of approximately 126 million m^3/a (see **Table 4-10)**. The available local yield from the Large Makhaleng Dam exceeds the target requirement of about 200 million m^3/a for the Lesotho/Botswana transfer.

By introducing a different operating rule to the large Makhaleng Dam, the excess yield can be released to downstream users and in this manner most of the impact on the downstream users can be mitigated and the balance restored to the Orange River project. If the full impact of the new Makhaleng Dam on the Orange River Project is restored, then the incremental local yield available for transfer from the dam is approximately188 million m^3/a (see **Table 4-10**). This is higher than the 149 million m^3/a incremental yield obtain for the dam at the TOR site and is due to the larger dam at the S2 site. In this case where 188 million m^3/a is abstracted from Makhaleng Dam to support the Lesotho/Botswana transfer, the impact on the downstream users will be zero, due to the mitigation releases from Makhaleng Dam. These mitigation releases from Makhaleng Dam are over and above the relatively small Environmental Water Requirements which are included in the analyses.

The 188 million m^3/a yield is, however, smaller than the intended demand of approximately 200 million m^3/a for the Lesotho/Botswana transfer, when the high demand scenario is considered. If the low demand scenario is considered, the 188 million m^3/a yield is sufficient to support the intended users and provide up to 78 million m^3/a for irrigation purposes in Lesotho (see Option 3 in **Figure 4-23**).

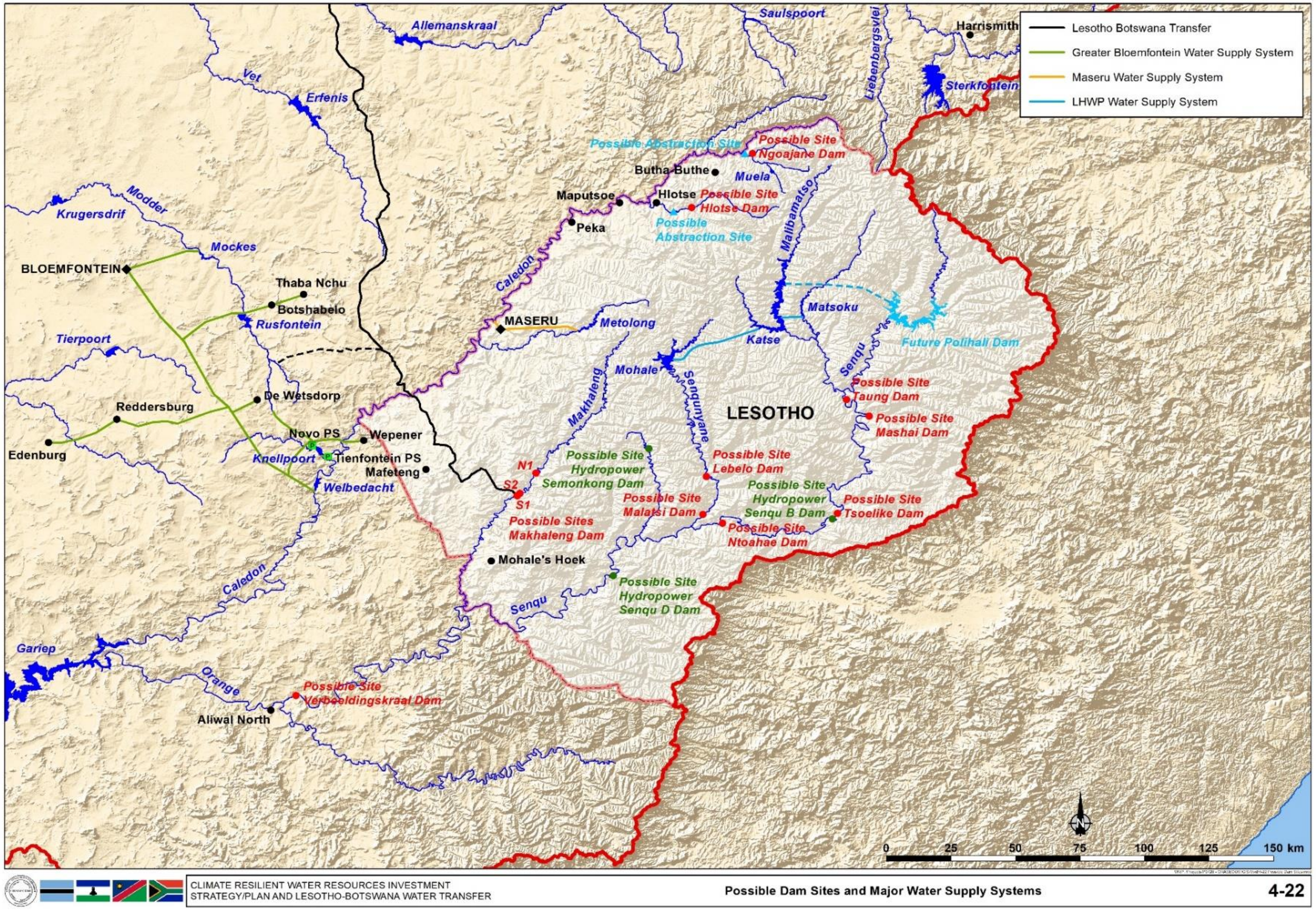
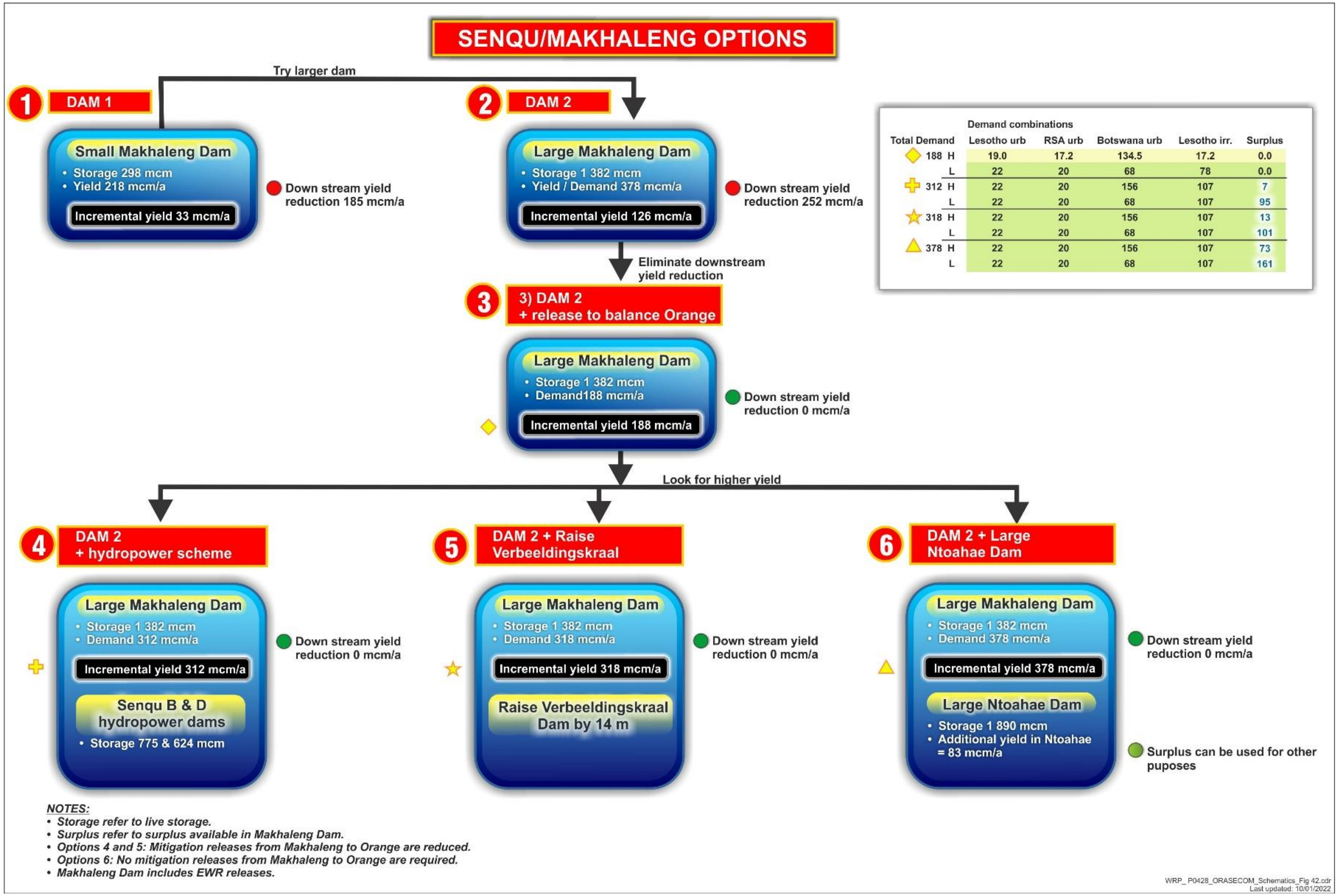


Figure 4-22: Possible Dam Sites and Major Water Supply Systems



Total Demand		Lesotho urb	RSA urb	Botswana urb	Lesotho irr.	Surplus
◇ 188	H	19.0	17.2	134.5	17.2	0.0
	L	22	20	68	78	0.0
✚ 312	H	22	20	156	107	7
	L	22	20	68	107	95
☆ 318	H	22	20	156	107	13
	L	22	20	68	107	101
△ 378	H	22	20	156	107	73
	L	22	20	68	107	161

Figure 4-23: Senqu/Makhaleng Options

If more water is required for the Lesotho/Botswana transfer scheme including the irrigation in Lesotho, it can be provided from the proposed 3 MAR Makhaleng Dam up to the safe limit of 378 million m^3/a as mentioned previously, since this is the maximum local yield that is available at the dam site. Mitigation releases will be required to restore the overall balance so that there is no noticeable impact to the downstream users from the proposed development. Such releases can be supplied from Makhaleng Dam or from some other development, preferably lower down in the system. There are numerous potential projects that can be considered to provide the additional yield such as additional dams in Lesotho or the raising of Gariep Dam or increasing the height of the proposed Verbeeldingskraal Dam etc.

Three possible additional future dams in Lesotho were considered for this purpose and were analysed to determine the potential additional yield they could provide. One of the most attractive options is a new hydropower scheme that is currently already under review by Lesotho. This scheme consists of two new dams (Senqu B and Senqu D dam as shown in

Figure 4-23) in the Senqu River, both located upstream of the confluence of the Makhaleng and Senqu rivers. The live storages of the Senqu B and D dams are 775 and 624 million m^3 respectively. The Senqu B dam is located at about the same site as previously identified for Tsoelike Dam, one of the further phases of the original Lesotho Highlands Water project. The system yield increase from this scheme depends on the operating rules adopted for the scheme. Two possible release patterns were evaluated and analysed. Release pattern 1 followed equal releases every month, to provide a good base power supply. Release pattern 2 followed a monthly distribution pattern equal to that of a typical average monthly flow pattern as produced from the natural flow record, that will benefit the downstream environmental requirements. flow pattern1 and 2 resulted in an increase in the ORP system firm yield of 134 million m^3/a and 124 million m^3/a respectively. This means that the mitigation releases from Makhaleng Dam to the Orange River can be reduced, which in return will increase the net yield (incremental yield) available in Makhaleng Dam to 312 million m^3/a. Although the fairly constant base flow released from the hydropower dams is purely a by-product of the hydropower scheme, it significantly increases the net yield available from Makhaleng Dam (see **Figure 4-24**). For this option the net yield (incremental yield) available in Makhaleng Dam is sufficient to support the high Botswana Transfer option as well as the maximum irrigation development (107 million m^3/a) to be supplied from Makhaleng Dam, leaving a 7 million m^3/a surplus available at the dam.

When selecting one of the previously proposed dams from the original Lesotho Highlands Water Project to increase the system yield, it is important to note that Polihali Dam that will soon be in place. It is therefore important to select one of the most downstream dam sites in order to capture a reasonably large incremental catchment upstream of the selected dam so that there is sufficient inflow to produce the additional yield. For this reason, the Ntoahae dam site was selected, which is the most downstream dam from the original Lesotho Highlands Water Project on the Senqu River and includes the largest incremental catchment downstream of the existing Lesotho Highlands Water Project dams, including the new Polihali Dam.

A large Ntoahae Dam with a live storage of 1 890 million m^3/a was analysed in combination with the 3 MAR Makhaleng Dam. The net yield (incremental yield) generated from Ntoahae Dam was so much, that no mitigation releases were required from Makhaleng Dam for this option, indicating that the full historic firm yield of 378 million m^3/a was now available as the incremental yield from Makhaleng Dam.

The Ntoahae option allows for a fully supplied high Botswana Transfer, as well as the maximum irrigation development (107 million m^3/a) to be supplied from Makhaleng Dam, leaving approximately 73 million m^3/a surplus available in Makhaleng Dam. Over and above this surplus in Makhaleng Dam, there would be an additional yield of 83 million m^3/a available in Ntoahae Dam after restoring the balance in the Orange River.

If the hydropower dams are not developed in future, a viable alternative could be the raising of Verbeeldingskraal Dam, although the dam wall is physically not located in Lesotho. The maximum size of the possible Verbeeldingskraal Dam as considered in the DWS RSA “Reconciliation Strategies for Large Bulk Water Supply Systems: Orange River”, was kept below its optimum height to avoid the reservoir backing up from South Africa into Lesotho. It is possible to develop a larger dam at this site if both South Africa and Lesotho agree that the reservoir can back up into Lesotho during periods when the dam is at or near full supply level. A small increase in height of the dam wall can result in a significant increase in the yield from the dam which could allow the possible Verbeeldingskraal Dam to provide some or all the mitigation releases that is required from Makhaleng Dam. To assess the potential of this option, an analysis was undertaken in which the possible Verbeeldingskraal Dam was raised by an additional 14m. Results from the analysis (see **Figure 2-23** Option 5) indicated that the mitigation releases from Makhaleng Dam can considerably be reduced to be able to increase the incremental yield available from Makhaleng Dam to 318 million m^3/a. This will enable Makhaleng Dam to fully support the high Botswana transfer as well as the maximum irrigation development in Lesotho, with a small surplus yield of approximately 13 million m^3/a. It is likely that the possible Verbeeldingskraal Dam will be able to provide a higher yield than Ntoahae Dam as result of the significantly larger incremental catchment and higher runoff. This option must still be analysed in more detail in a separate study to determine if the dam site can in fact support the larger dam.

Work previously carried out as part of the RSA DWS study “Development of Water Reconciliation Strategies for Large Bulk Water Supply Systems: Orange River” investigated two alternative options to the possible Verbeeldingskraal Dam, both of which are located in Lesotho and were previously part of the original Lesotho Highlands Water Project, namely Malatsi Dam and Ntoahae Dam. The results for the three possible dams were obtained from the Orange River Reconciliation Strategy study and are provided in **Table 4-11**

It should be noted that the costs are very approximate as they exclude any royalties to be paid by South Africa to Lesotho and any further analyses required will be undertaken in a separate study.

Table 4-11: Summary of estimated costs, yields, and URVs

Option	Cost (R million)	Yield (million m^3/a)	URV		
			6%	8%	10%
Verbeeldingskraal FSL 1385	1048	200	R0.39	R0.51	R0.63
Malatsi FSL1652	1373	119	R0.87	R1.11	R1.39
Ntoahae FSL 1645	1370	232	R0.44	R0.57	R0.71

Note: Costs based on 2012 related costs

<u>Mohokare/Caledon River catchment future developments</u>: Other future Lesotho developments to consider as part of the multipurpose dam analyses are Hlotse and Ngoajane dams in the Mohokare/Caledon River catchment. The Lesotho Water Resources Assessment Report from SMEC (2017) recommended that dams be built at Hlotse and Ngoajane with storage capacities of 105 million m^3 and 36 million m^3 respectively. The analyses related to these two dams therefore started with these recommended dam sizes.

Results from the analyses showed that for the proposed dam sizes, the local historic firm yield available from these two dams were sufficient to supply the intended users as well as the Environmental Water Requirements to be supplied from each dam (see **Figure 4-24** options 1 and 3). The impact of these dams and related abstractions on other existing water users from Mohokare/Caledon River, as well as on the Orange River Project (ORP) is significant and must be included in any multipurpose dam analysis. Hlotse Dam is expected to be constructed first, followed by Ngoajane Dam about 4 to 5 years later.

The proposed Hlotse Dam resulted in a reduction in yield of the Orange (ORP) system of 26 million m^3/a. Water users along the Mohokare/Caledon River mainly make use of river runoff abstractions, as dams in the river quickly silts up. Firm yield analyses could thus not be carried out for these sub-systems, and the average water supply to these users were compared for the different scenarios that were simulated. For this purpose, the supply to the main urban/industrial water users were considered, which included:

- Bloemfontein
- Botshabelo
- Thaba Nchu
- Small towns supplied from the Welbedacht Dam sub-system
- Maseru river abstraction
- Maseru rural supply
- Berea
- Mafeteng

The combined supply to these users from the Mohokare/Caledon River on average reduced by 5 million m^3/a with the proposed Hlotse Dam in place. Hlotse Dam also resulted in a decrease in the ORP yield of 26 million m^3/a. The total demand to be supplied from Hlotse Dam is 66 million m^3/a, of which 20 million m^3/a is for domestic use and 46 million m^3/a for irrigation. Due to the downstream impacts the incremental yield from Hlotse Dam is 54 million m^3/a, although the historic firm yield was determined as 85 million m^3/a after releasing the Environmental Flow Requirement. The incremental yield is thus not sufficient to supply the total demand of 66 million m^3/a to be imposed on the dam.

The second option considered to overcome these deficits was to increase the live storage of Hlotse Dam from the initial 96.5 million m^3 to 150 million m^3 (1.5 MAR dam). This resulted in a local yield of 113 million m^3/a at the dam, which can be used to restore or partly restore the downstream negative impacts.

The incremental yield available from the large Hlotse Dam is 62 million m^3/a, almost equal to the intended demand of 66 million m^3/a (see **Figure 4-24** option 2). The bulk of the water demand is to be used for irrigation purposes, which is supplied at lower assurances than urban requirements. The slightly lower firm incremental yield of 62 million m^3/a should most probably be sufficient to support all of the proposed users.

For the purpose of the analyses, it was assumed that the 1.5 MAR Hlotse Dam will already be in place at the time when Ngoajane Dam is to be constructed. Ngoajane Dam with a 36 million m^3 gross storage (31 million m^3/a net storage) was included for the initial Ngoajane system analysis. The incremental yield from this Ngoajane Dam was determined as 10 million m^3/a due to the reduction in supply to downstream users of 20 million m^3/a. Ngoajane Dam can thus not fully support the intended demands of almost 30 million m^3/a to be imposed on the dam. As a second option, a larger Ngoajane Dam (59 million m^3 net storage) was thus considered and analysed, increasing the incremental yield to 15 million m^3/a. Although the Large Ngoajane Dam can be used to balance the negative impact of 24 million m^3/a on the downstream users, it will be able to only supply just over 50% of the demand intended to be supported from the dam.

Two main options (see **Figure 4-24** options 5a and 5b) were suggested to overcome the deficit in supply from the Large Ngoajane Dam:

- 5a: Increase the size of Hlotse Dam further and use the additional yield from Hlotse to provide water for some of the Ngoajane mitigation requirements so that the water balance can be restored.
- 5b: Utilize the surplus yield available in Makhaleng Dam as created by the Makhaleng Dam options 4, 5 or 6, to support part of the Ngoajane mittigation releases and restore the water balance.

Results from the analyses, as well as practical experience from the past clearly indicated that the mitigation releases from Hlotse and Ngoajane dams should not be released into the Mohokare/Caledon River due to extensive losses experienced in the past (in excess of 50%) with flow releases into this river. Due to the high silt load in the river, dams are not constructed in this river, and basically all abstractions to supply users along the river are from river runoff. The only dam built in the Caledon River is the Welbedacht Dam, which has almost totally silted up to the extent that it is effectively a diversion weir.

It will further be very difficult to release the correct mitigation volume at the correct time to satisfy the requirements of the downstream users. There are several irrigation abstractions along the river, some of which may be unlawful which can then abstract water intended for other users. It will therefore be very difficult to ensure that such releases reach their intended targets. It is thus strongly recommended that the mitigation support should take place via pipelines to the impacted users along the Mohokare/Caledon River. Measures to restore the water balance in the main Orange River should rather be achieved through the mitigation options associated with the Makhaleng Dam.

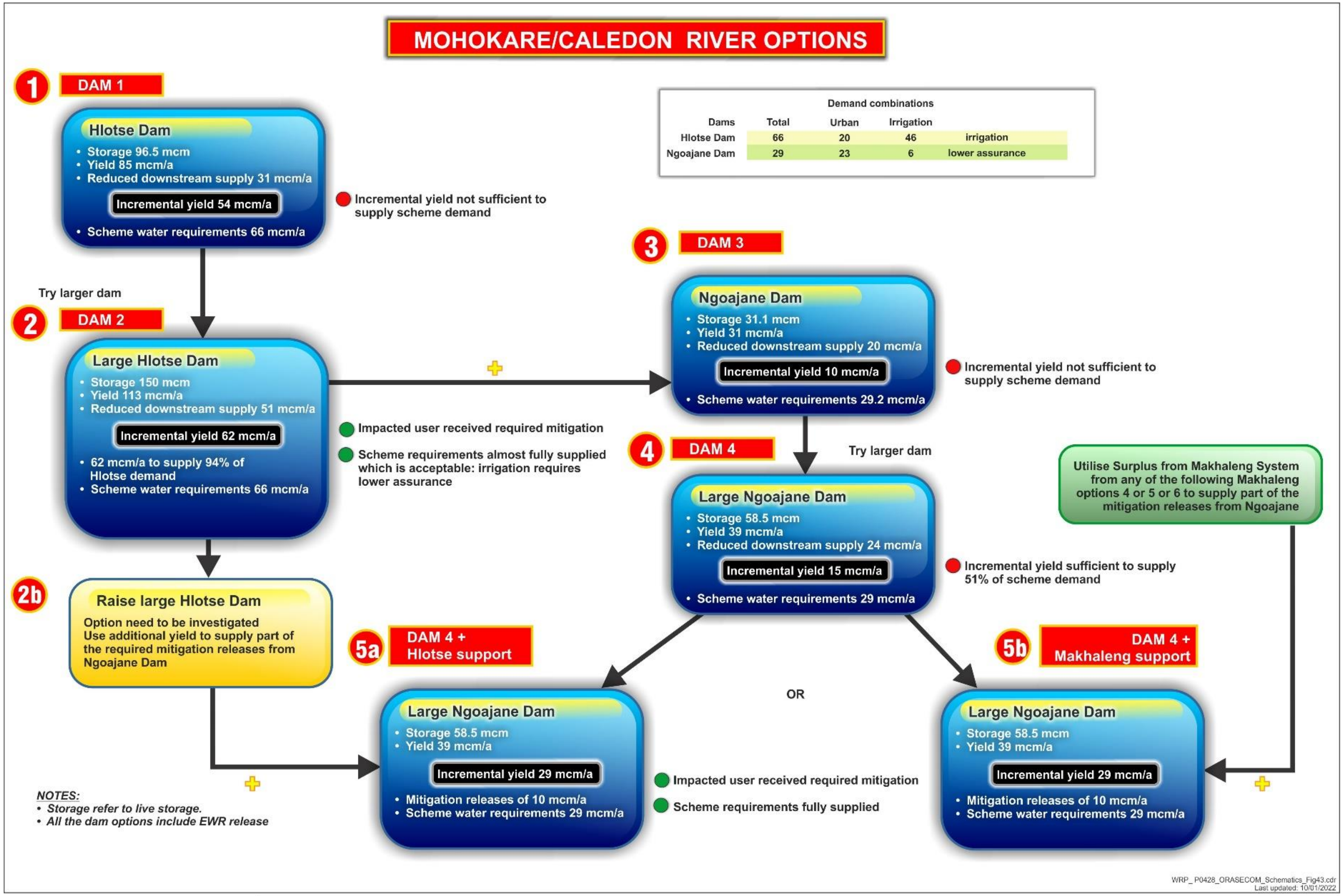


Figure 4-24: Mohokane /Caledon River Options

Conclusions and Recommendations

- It is possible to restore the water balances after the incorporation of Makhaleng, Hlotse and Ngoajane dams and the related target supply areas. This will however have cost implications resulting in higher URV values as well as the cost of water supplied.
- The large 3 MAR Makhaleng Dam will be the most cost-effective option.
- If the Lesotho hydropower scheme in the Senqu River goes ahead, it will increase the net yield in Makhaleng Dam and eliminate the need for further mitigation developments. This option should be included in a separate study for more detailed analysis and by looking at an integrated basin wide approach.
- The possible Verbeeldingskraal Dam offers a cost-effective solution to providing the mitigation releases to downstream users and should be further investigated in a separate study.
- If none of the above-mentioned options are considered, a large Ntoahe Dam can be considered.
- A large Hlotse Dam is a viable option to restore the water balances in the Mohokare/Caledon systems and would be a better option than increasing storage at Ngoajane Dam.
- Support from the Makhaleng Dam surplus as well as the alternative dams analysed in the Senqu River, can also be used to restore the water balance due to the negative water supply impacts on downstream users as result of Hlotse and Ngoajane dams. The alternative dams in the Senqu can to a large extent take over the function of mitigation releases from Makhaleng Dam to downstream users. This will increase the available net (incremental) yield in Makhaleng Dam, which can in turn be used to take over some of the mitigation releases to be made from Hlotse and Ngoajane dams.

4.2.6 Summary of Water Resource findings

The local yield available from the proposed Makaleng Dam (**Section 4.2.2**) at the two final selected dam sites is estimated to be in the order of 380 million m^3/annum which is more than sufficient to supply the required high transfer volume to Botswana as well as to supply the RSA and Lesotho estimated future water requirements imposed on this scheme. Abstracting this water from the proposed Makhaleng Dam, however, will result in a reduction in available yield from the Orange River Project of approximately 200 million m^3/a as highlighted in **Table 4-10**. It is therefore important to ensure that the shortfall to the downstream users is made up from some other resource developments. It can be provided directly from the proposed Makhaleng Dam by additional river releases, however, it may be more efficient to use one of the numerous developments in the system since keeping water in an elevated low evaporation environment is usually a more effective storage strategy.

Using the option to provide all the mitigation releases from Makhaleng Dam will require a reduced transfer volume from Lesotho to Botswana and allow for very limited supply for possile irrigation developments in Lesotho. Combining this option with a relative small additional resource development option to increase the net (incremental) yield available from Makhaleng Dam should be considered.

The results provided in **Table 4-12** therefore indicate that sufficient local yield can be generated at the proposed Makhaleng Dam site to supply the full requirement for the high transfer scenario. Some additional development will, however, be required to mitigate the loss in yield from the downstream resources. **Table A-8** in **Appendix A** provide further details of the demands versus the resource capability for options that includes the possible supply to Greater Bloemfontein.

From **Section 4.2.5** it is clear that there are several promising options that can be used to provide some or all of the required mitigation flows required to restore the water yield to the downstream users. Some of the options that were investigated as part of this study in accordance with the guidelines specified in the Terms of Reference include the following:

- Hydropower schemes in Lesotho. The options in the Senqu River comprise two dams, the Senqu B and Senqu D. By operating these two dams in the correct manner in combination with the large Makhaleng Dam will increase the net yield of the dam from 188 to 312 million m^3/a.
- Raising of the planned Verbeeldingskraal Dam by approximately 14m in combination with the large 3 MAR Makhaleng Dam will increase the net yield of the dam from 188 to 318 million m^3/a.
- Building a large Ntoahae Dam in the Senqu River in combination with the large Makhaleng Dam will increase the net yield of the dam from 188 to 378 million m^3/a.

These options can provide in excess of 100 million m^3/a for other use such as for irrigation developments in Lesotho or support to the Greater Bloemfontein area, etc.

For the high transfer option, the large Makhaleng Dam was not able to provide sufficient mitigation releases as there was still a deficit of 40 million m^3/a yield in the downstream ORP system. For this option Makhaleng Dam was able to supply a maximum of 219 million m^3/a mitigation releases

Table 4-12: Demand versus yield balances for Makhaleng Dam (S2 site)

Description	**Gross Water Requirement imposed on Makhaleng Dam (million m³/a)**	
	High transfer option	**Low transfer option**
Botswana	156	68
RSA	21	21
Lesotho	22	22
Namibia	0	0
Total	**199**	**111**
Yield Resource capability (million m³/a)		
Local yield at dam	378	378
After transfer remaining yield	179	267
Mitigation releases if direct from the dam	219**	190
Remaining Yield	**-40**	**77**
Remaining yield when mitigation releases are supplied from another development	**179**	**267**
Incremental/net Yield	159	188*
Gross requirement	199	111
Remaining Yield	**-40**	**77**

If the Final Reserve for the Orange River is similar in magnitude to the Preliminary Reserve (currently being used), the water supply to the Lower Orange users and river mouth will be supplied at the required assurance of supply even after the large Makhaleng Dam has been commissioned with related mitigation measures in place.

4.3 DESIGN FLOODS

The Francou-Rodier Method was used to determine the maximum regional flood (RMF) at each of the sites. The Makhaleng River catchment is in flood region 5 according to TR137 as shown in **Figure 4-25** below. TR137 appendix 6 was used to determine the ratios for the 1:50, 1:100 and 1:200-year flood events in comparison to the RMF.

According to SANCOLD guidelines, the design flood was estimated to be the 1:200-year event and the Safety Evaluation Flood was estimated to be the RMF plus delta.

For the initial sizing of the river diversion, the 1:10 year flood event was proportioned according to the catchment size based on the flood estimates for Katse Dam, which has a similar size catchment to the central dam sites. The flood estimates for the other dams in Lesotho were taken from the Lesotho Highlands Phase II Feasibility Study.

The estimated flood peaks for each site are shown in **Appendix E**. A summary of the existing dams in Lesotho is given in **Table 4-13**.

The flood hydrology will be revisited and a more detailed analyses will be undertaken during the next phase of the pre-feasibility study by a flood hydrologist, after the selection of the two sites.

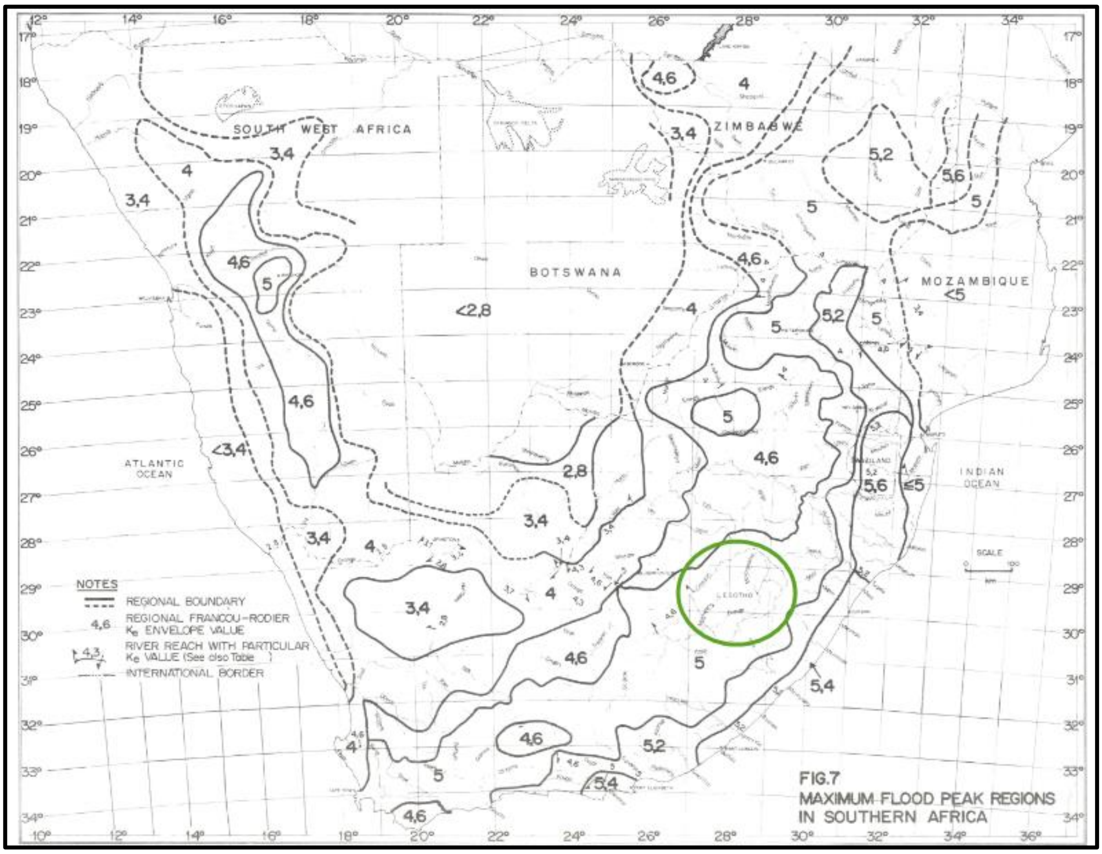


Figure 4-25: TR137 - Maximum Flood Peak Regions in Southern Africa

Table 4-13: Flood Peaks for Each Dam Site for Various Record Periods – Taken from Table E-1 in The Lesotho Highlands Phase II Feasibility Study

Site	Catchment Area (km²)	Flood Discharge Q_t (m³/s) for various Return Periods T (Year)									Extreme Flood		
		2	5	10	20	50	100	200	1000	10000	RMF	RMF +	PMF/Ext. Event
Oxbow	288	140	240	330	440	600	740	930	1 280	1 990	1 690	2 200	3 200
Katse	1867	360	640	900	1 190	1 660	2 060	2 510	3 310	5 170	4 320	5 390	6 010
Polihali	3290	480	870	1 200	1 580	2 210	2 740	3 470	4 320	6 660	5 700	7 100	7 200
Taung/ Mashai	7900	780	1 430	1 970	2 580	3 610	4 460	5 440	6 850	10 600	8 900	10 800	9 600
Tsoelike	10375	850	1 590	2 220	2 930	4 180	5 200	6 350	7 800	12 200	10 200	12 300	10 850
Ntoahae	11 500	900	1 680	2 370	3 110	4 400	5 473	6 700	8 200	12 800	10 700	13 000	11 100
Mohale	938	250	450	620	820	1 140	1 400	1 750	2 320	3 600	3 050	3 900	4 750
Lebelo	3 078	460	840	1 170	1 550	2 160	2 680	3 300	4 230	6 570	5 540	6 900	7 100
Malatsi	3 566	500	900	1 270	1 670	2 340	2 900	3 600	4 560	7 100	6 000	7 400	7 500

4.4 CONFIDENCE BANDS AND CLIMATE CHANGE

As part of the Climate change task, climate change impacts were determined on the yield available from key water supply sub-systems within Orange/Senqu basin. Six climate models were selected among others on the basis that they simulate a realistic ENSO (EL-Nino-Southern Oscillation) signal (Bellenger et al. 2014). This variable exhibits a strong association between South African climate variability.

The six Global Climate Models that were selected and downscaled are:

- Australian Community Climate and Earth System Simulator (ACCESS1-0), hereafter referred to as ACC.
- Geophysical Fluid Dynamics Laboratory Coupled Model (GFDL-CM3), hereafter referred to as GFD.
- National Centre for Meteorological Research Coupled Global Climate Model, version 5 (CNRM-CM5), hereafter referred to as CNR.
- Max Planck Institute Coupled Earth System Model (MPI-ESM-LR), hereafter referred to as MPI.
- Norwegian Earth System Model (NorESM1-M), hereafter referred to as NOR.
- Community Climate System Model (CCSM4), hereafter referred to as CCS.

The climate change models were downscaled, and bias corrected to obtain acceptable regional meteorological trends, correlating with historic data within the accepted Southern African hydrology. The bias corrected climate change rainfall and evaporation data were used to determine their impacts on the natural runoff on each of the sub-catchments used in the Pitman, WRYM and WRPM models. The natural runoff, rainfall and evaporation datasets that were derived based on the output from each of the six climate change models were then used as inputs in the Water Resources Yield Model (WRYM) to determine the related yield impacts.

For the Makhaleng sub-system the average impact from the six climate change models were found to be very small, indicating an increase of 1% above the HFY of 378 million m^3/a. The lowest yield was obtained from the CCS climate change model at 345 million m^3/a with the highest yield of 448 million m^3/a from the GFD climate change model. In all the results from the climate change task it was evident that the GFD climate change model results represented an outlier in comparison with results from the other models. The yield impact results given in **Table 4-14** represented a large dam at the S2 site on the Makhaleng River.

Table 4-14: Firm yield results for Historical and future climate scenarios

Description	**Local Historic Firm Yield for 85year simulation period (million m^3/a)**		**Percentage difference of local Firm Yield results for the climate change scenarios compared to the local Historical Firm Yield**	
CCM	**Scenario 1 (Adjusted rainfall)**	**Scenario 2: (Adjusted rainfall and evaporation)**	**Scenario 1 vs. local Historical Firm Yield**	**Scenario 2 vs. local Historical Firm Yield**
Yield based on the historic flow sequences 378 million m^3/a				0%
ACC	398	379	5%	0%
CCS	367	345	-3%	-9%
CNR	394	388	4%	3%
GFD	446	448	18%	19%
MPI	380	358	1%	-5%
NOR	388	375	3%	-1%
Average	**396**	**382**	**5%**	**1%**

From the analyses carried out as part of the Climate Change task it was found that almost all the results from the six different climate change models were within the range of results produced from the stochastic analyses. This is also evident from the long-term stochastic yield results for the S2 Makhaleng Dam given in **Table 4-15,** although it represents a slightly smaller Makhaleng Dam than the one selected for the climate change impact analyses.

A long-term stochastic yield analysis was also undertaken using the Site S2 option, size 810 million m^3. This dam provided a historic firm yield result of 344 million m^3/a, slightly lower than for the larger Makhaleng Dam used for the Climate Change impact analysis.

The long-term stochastic yield results are presented in **Table 4-15** and the graph provided in **Figure 4-26**. These yield results were determined for the scenario when no mitigation releases were released from Makhaleng Dam to balance the impact of Makhaleng Dam on Gariep and Vanderkloof dams.

Table 4-15: Long Term Stochastic local Yield Results

Recurrence Interval	1 in 20 year	1 in 50 year	1 in 100 year	1 in 200 year
Annual risk of supply failure	5%	2%	1%	0.5%
Yield (million m^3/a)	386	349	329	314

The climate change impact on the yield available from Makhaleng Dam is small and do not require adjustments to the yield results obtained from the historical data. The stochastic analyses are however important to provide a wider range of yield results at different assurance levels. It was found that the range of the stochastic yield results in general includes the range of yield results produced from the climate change impacts, using the six different climate change models.

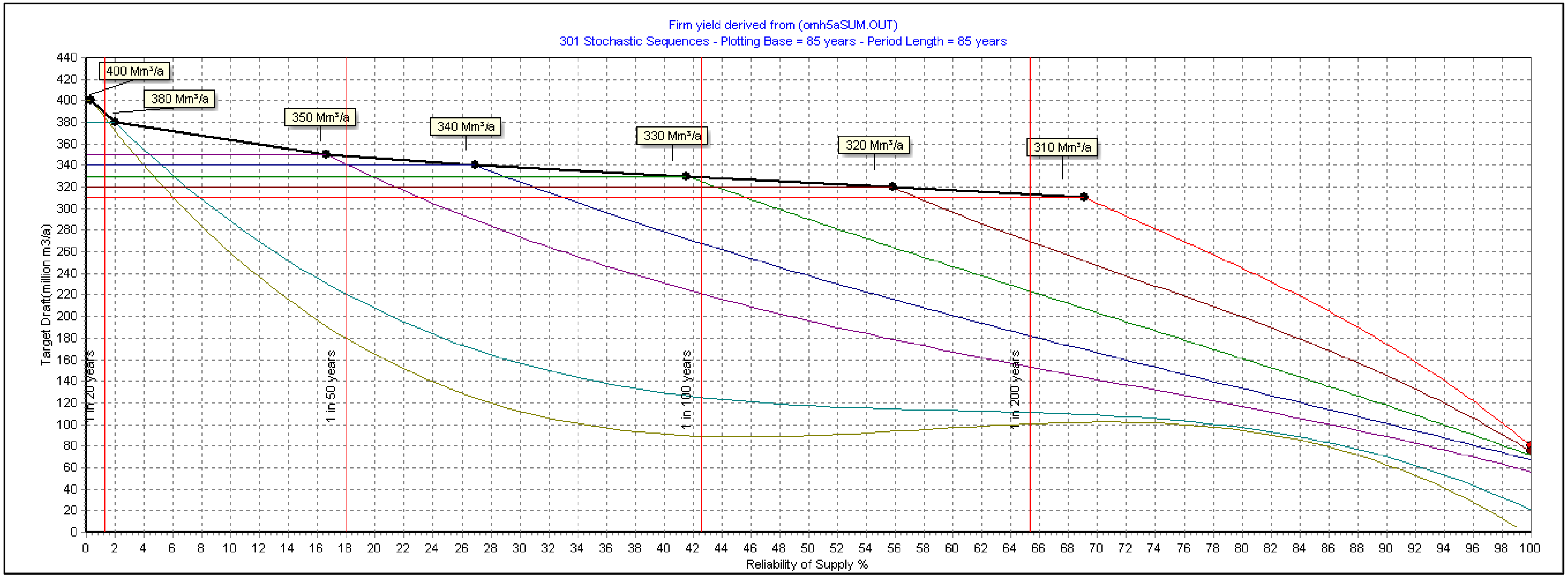


Figure 4-26: Long Term Curve: Site S2, Capacity 810 million m^3

5 CONVEYANCE ROUTE SELECTION

This chapter of the report deals with the proposed conveyance route from Lesotho to Botswana.

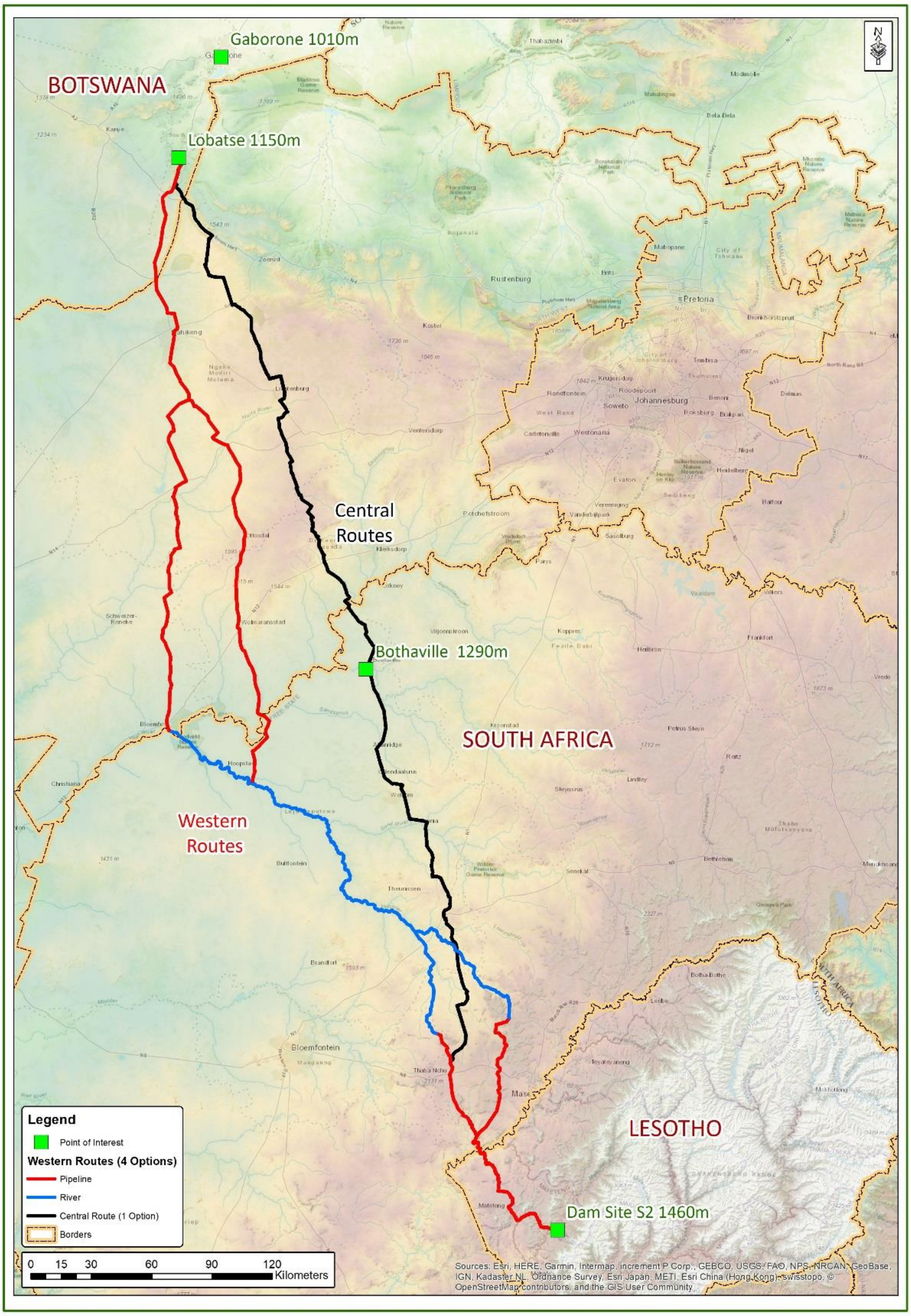


Figure 5-1: **Reconnaissance Study Conveyance Routes**

There are several dam site options in the Makhaleng River presently under consideration. The location of each dam results in changes to the start of the conveyance route which includes changes in the source elevation and pipeline length. The location of each dam therefore impacts the capital and operational cost of the conveyance system. The incremental conveyance costs associated with each dam is evaluated in **Section 5.1**.

Several conveyance route options have been investigated in the Reconnaissance (Recon.) Study and are evaluated in further detail in this report. The purpose of Phase 1 of the PFS (PFS-1) is to narrow down the available routes to two options that will be investigated in greater detail during Phase 2 of the PFS (PFS-2).

Two broad options have been considered: 1) a fully piped option (Central route) and 2) use of river conveyance augmented with piped sections (Western routes).

The Eastern routes investigated in the Recon. Study have been excluded from this PFS study. The reason for this is that the Eastern routes were based on assumption that the water would be taken from the LHWP via the Ash River outfall and various rivers into the Vaal River and thereafter pumped to Lobatse in Botswana. It is understood, due to delays in the implementation of the LHWP and increased uptake of demand in the Gauteng region, that the window of opportunity for supplying Botswana from the Eastern route options has closed.

The Western and Central routes evaluated in the Recon. Study are depicted in **Figure5-1**. All routes connect a water source in Lesotho to the Lobatse region in Botswana.

It is understood that the client, ORASECOM, favours a fully piped conveyance system. It was therefore evident from the outset that the Central route with the requisite modifications recommended in this PFS-1 study, would be taken forward to PFS-2.

The Western routes that involve piped and river conveyance, can be configured in several different ways depending on the pipeline and river routes selected. Given that a significant portion of the Western routes involve river conveyance, the capital costs associated with these routes are likely to be considerably lower than that of the fully piped central route. Once all Western routes have been analysed and a single configuration decided upon, this final configuration will be carried forward to PFS-2 and will be evaluated against the Central route in that phase of the study.

Based on the above, this report has been structured as follows:

- Section 5.1: Input To Dam Site Selection (Conveyance route from each dam to CMP).
- Section 5.2: Evaluation of the Central Route and proposed modifications.

- Section 5.3: Evaluation of the Western Routes, proposed modifications and selection of a single Western route configuration.

The battery limits associated with each section above are noted in **Table 5-1**. It has been agreed that both the Western and Central route options will terminate just downstream of Nnywane Dam near Lobatse in Botswana, from which location it has been assumed that water will flow on to Gaborone Dam via the Nnywane River.

Table 5-1: Battery Limits of Pipeline Routes

Section:	Battery limit at start (upstream):	Battery limit at end (downstream):
Source to Common Point (CMP)	Just downstream of the dam sites: Lowlands, N1a to N4, TOR, S1a to S4 & D2 to D4.	Common Point (CMP)
Central route	Just downstream of dam site S2.	Nnywane River, just downstream of Nnywane Dam, Botswana
Western route	Just downstream of dam site S2.	Nnywane River, just downstream of Nnywane Dam, Botswana

5.1 INPUT TO DAM SITE SELECTION

Pipeline routes were developed from each water source to the Common Point (CMP). The CMP as well as all proposed dam sites considered are indicated in **Figure 5-2**.

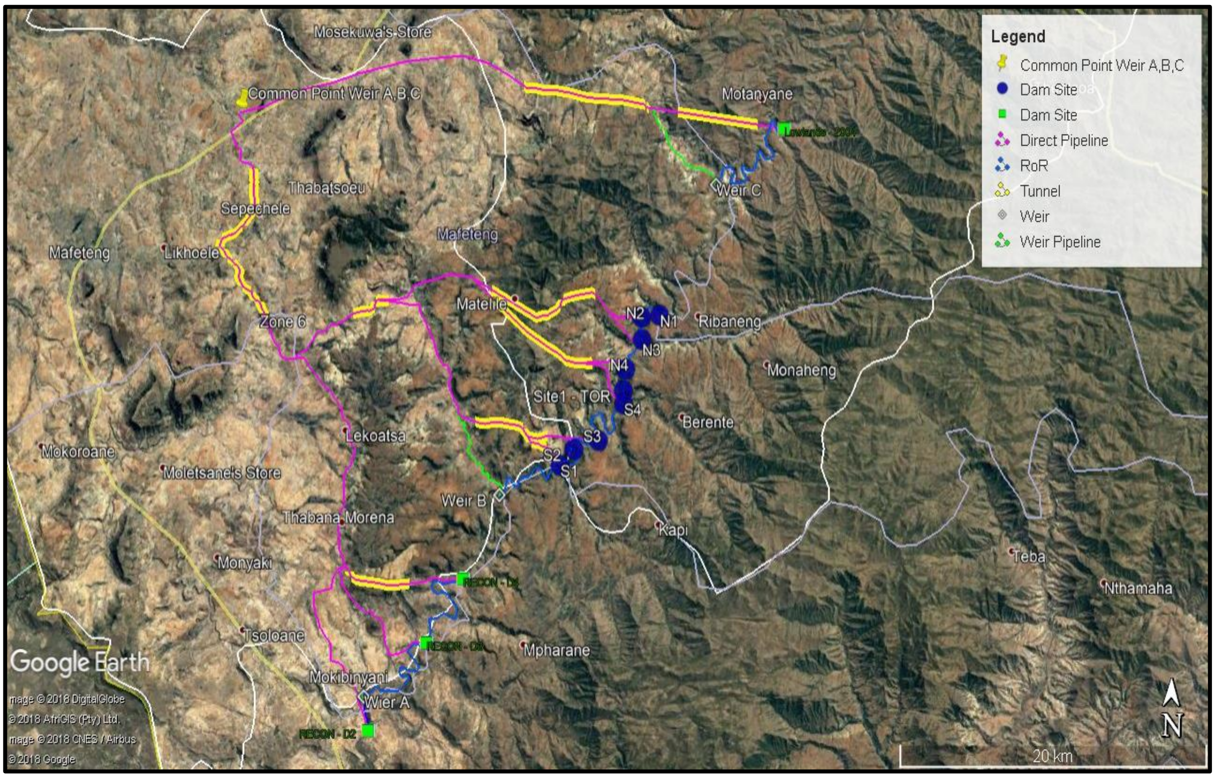


Figure 5-2: Dam Sites and Common Point

The proposed conveyance routes and profiles from each dam site to the CMP are provided in **Appendix G**.

5.1.1 Methodology Used to Develop Incremental Costs

The incremental costs developed in this section were used as inputs to the Multi-Criteria Analysis (MCA) for the selection of two dam sites, as is required in PFS-1.

Two conveyance options were developed for each dam site, (a) a supply directly from the dam, and (b) a supply from a weir/abstraction located downstream of the dam. Technical details of each transfer option are provided in **Appendix G** Conveyances Routes for Dam Options.

The capital costs of the conveyance infrastructure and energy costs to convey the required flow of water to the CMP were calculated for both options at each dam site. Capital costs were based on recently completed large diameter steel pipeline projects, with rates escalated to present day (2018). A contingency of 30% was applied to the estimated capital costs. Energy costs are based on the Eskom Megaflex tariff, estimated at R1.15/kWhr, seasonalised and annualised.

A Unit Reference Value (URV) was then calculated for each option. The URV was calculated as the Net Present Value (NPV) of the capital and energy costs divided by the NPV of the volume of water supplied over the analysis period.

The results of the URV analysis are listed in **Table 5-2**, and are included in the dam site selection MCA. In reference to the colour-coding in **Table 5-2**, green represents a desirable URV while red signifies an undesirable URV.

The infrastructure elements considered in the incremental costing included weirs, pump stations, pipelines, tunnels and break pressure tanks. The NPV's and URV's consider the capital and energy costs for each option. Land acquisition, compensation of affected parties, professional services, taxes etc. are excluded in this exercise.

The following design criteria were applied:

- Rising main maximum velocity: 2 m/s
- Gravity main maximum velocity: 3 m/s
- Pumping main daily operation time: 20 hrs
- Water demand peak factor: 1.2
- Pipeline material: Steel
- Pipeline wall thickness: Based on hoop stress not exceeding 40% of minimum yield strength of Grade X52 steel,
- Gravity tunnels were assumed for the options to supply directly from the dam, to minimise the energy requirements for the direct options.

Table 5-2: Summary of Financial Results for Conveyance Infrastructure up to CMP (High Scenario)

Dam Site	Capital Cost		NPV (8%)		URV (8%)	
	Direct Supply (millions)	RoR Supply (millions)	Direct Supply (millions)	RoR Supply (millions)	Direct Supply	RoR Supply
N1a	R4 126	R3 743	R4 582	R4 286	R3.96	R3.70
N1	R4 126	R3 743	R4 582	R4 286	R3.96	R3.70
N2	R4 036	R3 743	R4 523	R4 286	R3.90	R3.70
N3	R4 073	R3 743	R4 632	R4 286	R4.00	R3.70
N4	R4 013	R3 743	R4 533	R4 286	R3.91	R3.70
TOR	R4 063	R3 743	R4 611	R4 286	R3.98	R3.70
S4	R4 239	R3 743	R4 677	R4 286	R4.04	R3.70
S3	R3 969	R3 743	R3 678	R4 286	R3.17	R3.70
S2	R3 888	R3 743	R3 580	R4 286	R3.09	R3.70
S1	R3 863	R3 743	R3 489	R4 286	R3.01	R3.70
S1a	R3 915	R3 743	R4 418	R4 286	R3.81	R3.70
D4	R3 619	R3 733	R3 747	R4 690	R3.23	R4.05
D3	R3 490	R3 733	R3 885	R4 690	R3.35	R4.05
D2	R3 638	R3 733	R4 233	R4 690	R3.65	R4.05
Lowlands	R3 150	R3 007	R2 589	R3 380	R2.23	R2.92

Table 5-3: Summary of Financial Results for Conveyance Infrastructure up to CMP (Low Scenario)

Dam Site	Capital Cost		NPV (8%)		URV (8%)	
	Direct Supply (millions)	RoR Supply (millions)	Direct Supply (millions)	RoR Supply (millions)	Direct Supply	RoR Supply
N1a	R3 701	R3 301	R3 585	R3 332	R5.23	R4.86
N1	R3 701	R3 301	R3 585	R3 332	R5.23	R4.86
N2	R3 623	R3 301	R3 531	R3 332	R5.15	R4.86
N3	R3 652	R3 301	R3 661	R3 332	R5.34	R4.86
N4	R3 619	R3 301	R3 541	R3 332	R5.17	R4.86
TOR	R3 657	R3 301	R3 596	R3 332	R5.25	R4.86
S4	R3 876	R3 301	R3 713	R3 332	R5.42	R4.86
S3	R3 562	R3 301	R3 016	R3 332	R4.40	R4.86
S2	R3 500	R3 301	R2 944	R3 332	R4.30	R4.86
S1	R3 481	R3 301	R2 887	R3 332	R4.21	R4.86
S1a	R3 405	R3 301	R3 418	R3 332	R4.99	R4.86
D4	R3 215	R3 236	R2 963	R3 530	R4.32	R5.15
D3	R3 003	R3 236	R2 985	R3 530	R4.36	R5.15
D2	R3 117	R3 236	R3 222	R3 530	R4.70	R5.15
Lowlands	R2 787	R2 619	R2 169	R2 597	R3.17	R3.79

5.2 EVALUATION OF CENTRAL ROUTE AND PROPOSED ROUTE MODIFICATIONS

The central route is the most direct route between Lesotho and Botswana. This is to be expected, given that this is a fully piped option. The review of this route considered:

a) Directness of route;

b) Deviations around high elevation points where possible;

c) Identification of structures that may necessitate route deviation;

d) Minimizing the relocation of people, plants and animals where possible;

e) Identification of national, provincial and private roads along conveyance route; and

f) Identification of land use along conveyance route

The Central route is depicted in **Figure 5-3** and in **Figure A1** in **Appendix A**.

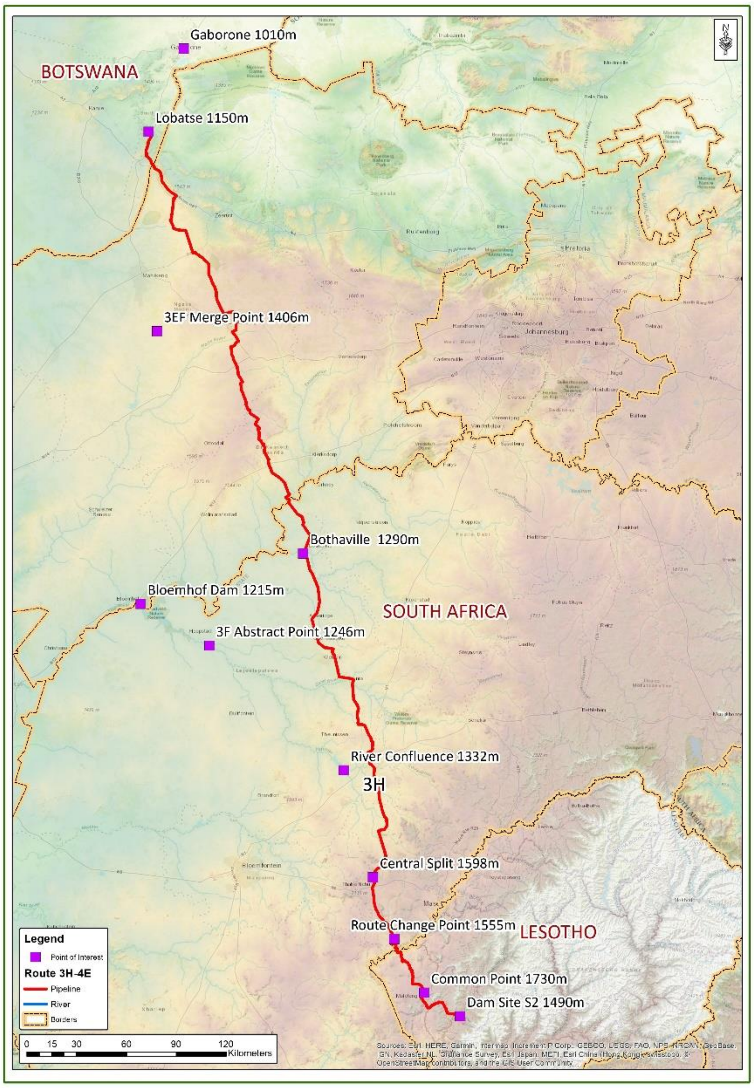


Figure 5-3: Central Route - Plan

5.2.1 Broad overview of the Terrain Along the Route

The central route is approximately 684 km long. This fully piped option will transport water from the proposed dam site in Lesotho to Lobatse in Botswana. The terrain along the route varies in elevation from 1850 mamsl to 1125 mamsl.

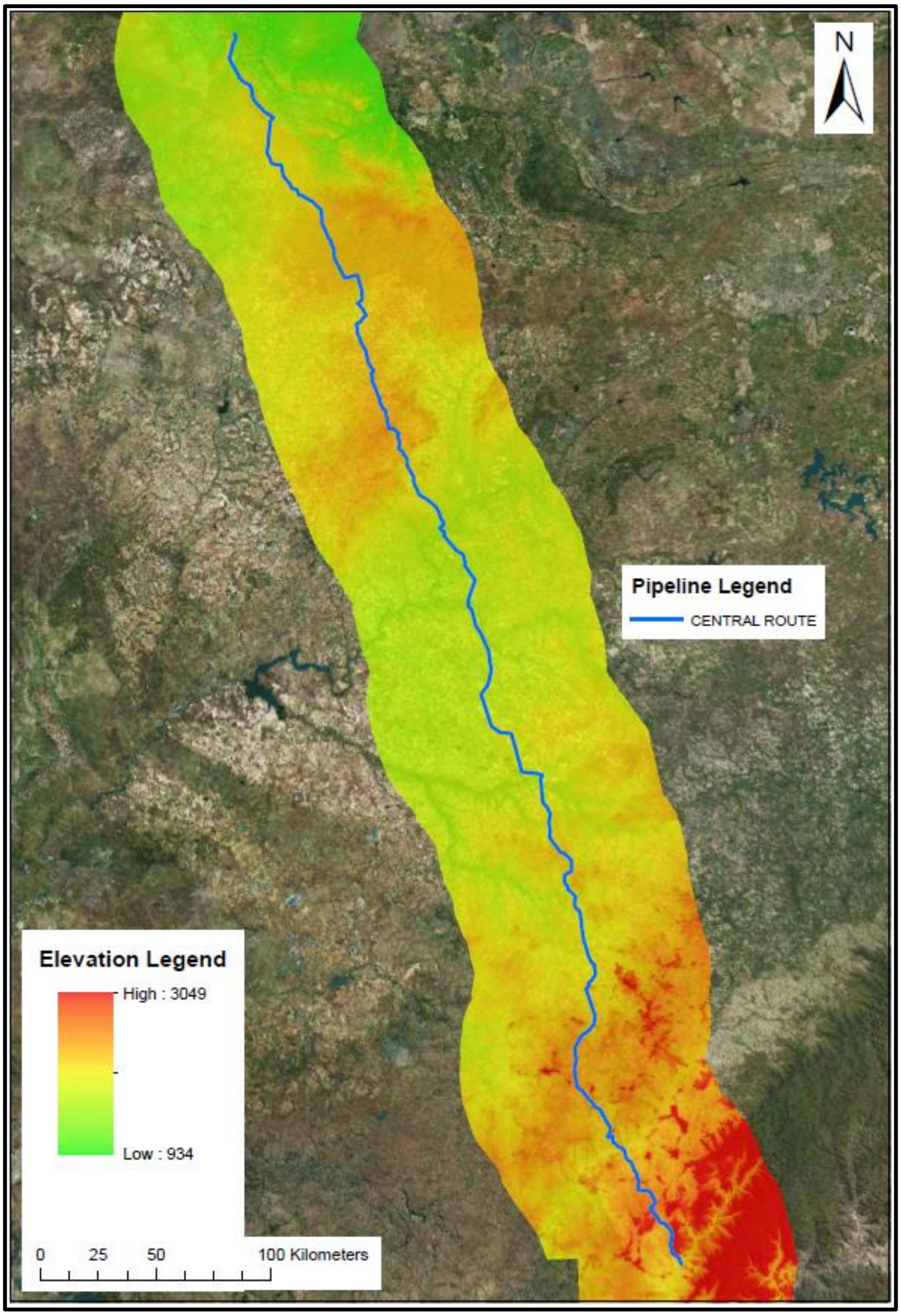


Figure 5-4: Elevation Analysis of Central Route

Figure 5-4 depicts an elevation analysis of the Central Route. Lower elevations, starting from 934 m, are shown in green with the colour indicator changing as the elevation increases, with the highest elevations shown in red.

The Central Route was divided into sections 3H and 4E in the previous study.

The total length of the pipeline required for Route 3H is approximately 400 km, with the route rising steeply from the dam to its highest elevation of approximately 1825 m. The terrain thereafter declines in numerous undulating sections until reaching Bothaville, the commencement of Route 4E.

The total length of the pipeline required for Route 4E is approximately 285 km, with the route climbing to an elevation of around 1575m before falling for the balance of the route to Lobatse.

The Central Route profile is depicted in **Figure 5-10** and **Figure 5-11**.

5.2.2 Review of Section 3H of Central Route

Section 3H of the Central Route runs from Makhaleng Dam to Bothaville in the Free State. The findings of the route review are noted below.

Directness of route

Section 3H generally runs North from Lesotho to Bothaville. When compared to the other routes considered in the Reconnaissance Report, route 3H-4E is the most direct. The fully piped central route option runs parallel to roads and minor deviations were proposed to avoid private land or streams as described in **Section 3.5**.

Zones 5, 6 and 7 were identified as potential recipients of a water supply from Section 3H of the Central route. The following realignment was proposed.

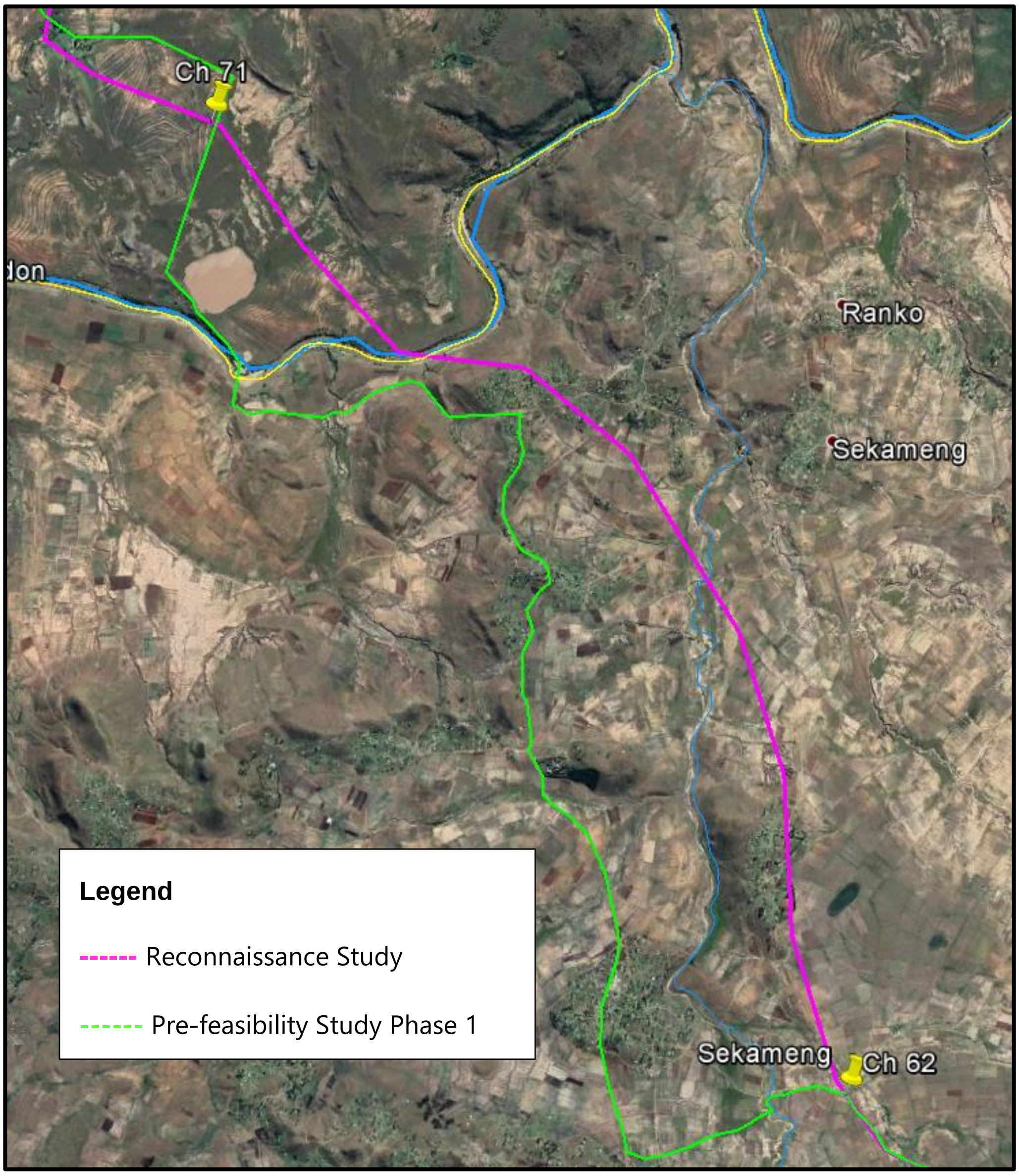


Figure 5-5: Proposed Route Realignment at Sekameng

Route deviations to avoid high elevation clashes with hydraulic grade line

The route has a minimum elevation of 1 250 m and a maximum elevation of 1 825 m. No avoidable high points were identified. The elevation profile is shown in **Figure 5-10** and **Figure 5-11**.

Identification of structures that may require route deviation

Many minor route changes were made. This was necessary primarily to ensure that the length of pipeline was as accurate as possible, i.e. the pipeline length when drawn accurately, may increase by 5 to 10% over the rough initial (Recon.) route. Examples of the changes made are indicated below, however, there are many more such changes.

Where the previous routing was found to encroach on private land and structures, the route was revised and shifted within the road servitude where possible.

The following structures were identified along route 3H:

- Power station parallel to the route in Excelsior, Free State,
- Power station adjacent to route in Winburg, Free State.

Prevention of the relocation of people, plants and animals where possible

Conveyance route 3H required no relocation of people, plants or animals as the route runs parallel to identified roads.

Identification of national, provincial and private roads along conveyance route

Central route 3H runs parallel to the following roads: R709, R30, R70, R73, R26, N8, N5, N1, R708, Fred Osborne Street, Voortrekker Street, and De Villiers Street. The crossing of national roads N1, N5, and N8 will require pipe-jacking.

It is intended that the pipeline will be built on farmland and private land parallel to road reserves and as it is unlikely that road authorities would allow it to be located within the road reserve.

NB. Land acquisition costs have not been estimated. However, it is assumed that the 30% contingency allowed in the overall estimate will also cover the cost of Land acquisition. Therefore, it is deemed to be included in the overall estimate although it has not been specifically measured.

Identification of land use along conveyance route

Land owner information was available for South Africa only. Land use was predominantly private farming and residential properties throughout the route.

5.2.3 Review of Section 4E of Central Route

Section 4E of the Central Route runs from Bothaville, South Africa to Nnywane Dam in Botswana. The findings of the route review are noted in this section.

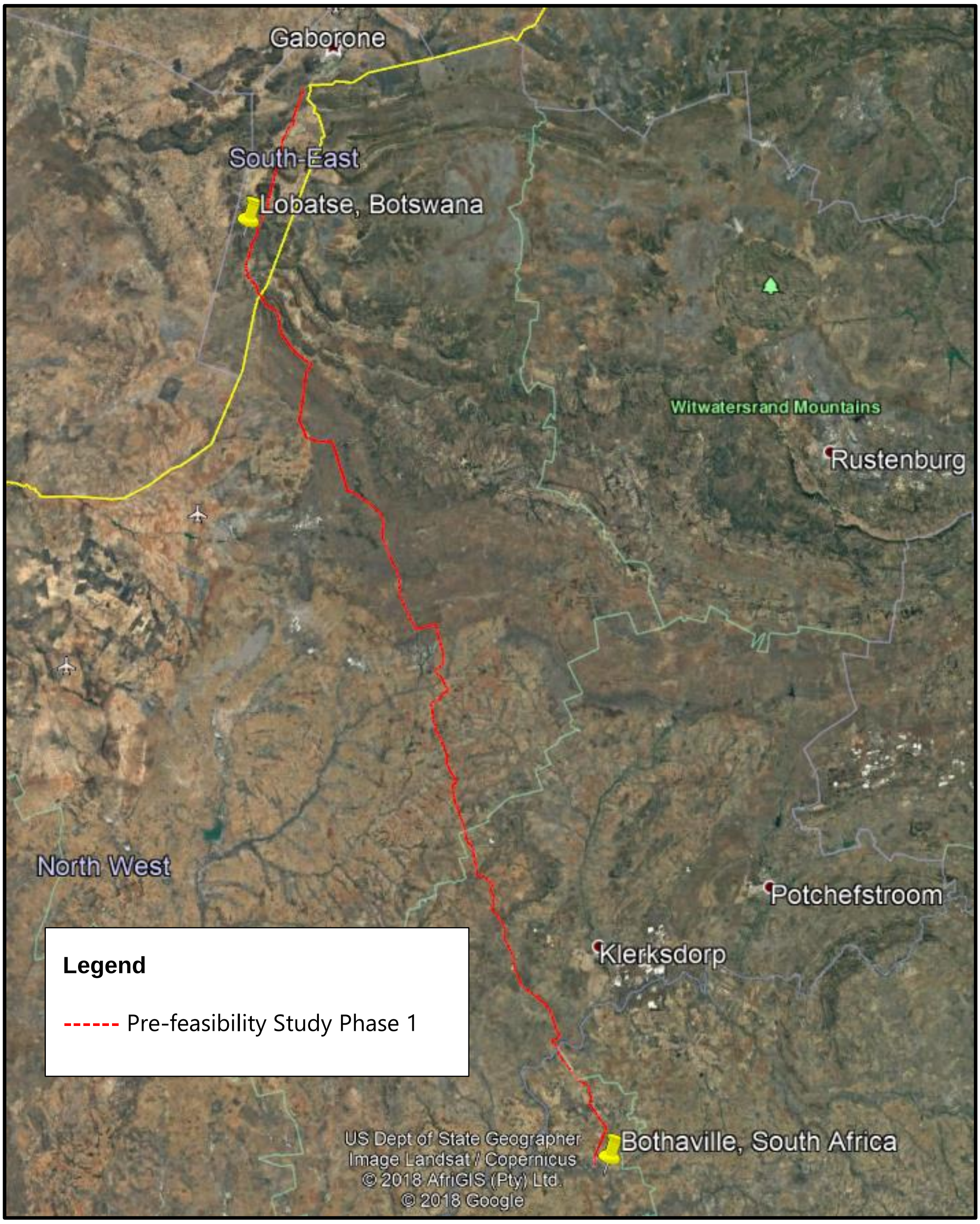


Figure 5-6: Plan View of Route from Bothaville to Lobatse

Directness of route

Section 4E runs generally North from Bothaville, South Africa to Nnywane Dam in Botswana. This section was confirmed as generally being the most direct while running parallel to formal and farm roads.

The following towns were identified as potential recipients of a water supply from Section 4E of the Central route:

- South Africa: Boikhutso, Driehoek, Maipeng, Mahikeng, Miga North, Khunotswane, Zeerust, Dinokana, and Motswedi Gopane.
- Botswana: Lobatse, Pitshane, Good Hope, Kanye, Jwaneng, Ranaka, Moshupa, Lotlhakane, Otse, Ramotswa, Thamaga, Manyana, and Ntlhantlhe/ Magotlhwane.

Route deviations to avoid high elevations

An elevation analysis was undertaken with a view to adjusting the route to avoid high points. Minor route changes were made to avoid high elevations, thereby lowering the energy costs for this route option.

The starting ground elevation at Bothaville is 1 271 m and the end elevation near Lobatse is 1 142 m. The route becomes steeper over the last 100 km before Lobatse. The route has a minimum elevation of 1 143 m and a maximum elevation of 1 575 m. The elevation profile is shown in **Figure 5-10** and **Figure 5-11**.

Identification of structures that may require route deviation

Constructability was considered and where the route was found to encroach on private land and structures, it was revised and shifted within the road reserve where possible as indicated and described below.

Many minor route changes were made. This was necessary primarily to ensure that the length of pipeline was as accurate as possible, i.e. the pipeline length when drawn accurately, may increase by 5 to 10% over the rough initial (Recon.) route. Examples of the changes made are indicated below, however, there are many more such changes.

Figure 5-7: Pipe Route adjusted at Bothaville

The pipe route in the reconnaissance report showed the route going through Bothaville. This route was adjusted to run parallel to the road. There were many areas where the pipeline was adjusted and placed within the road reserve as shown below.

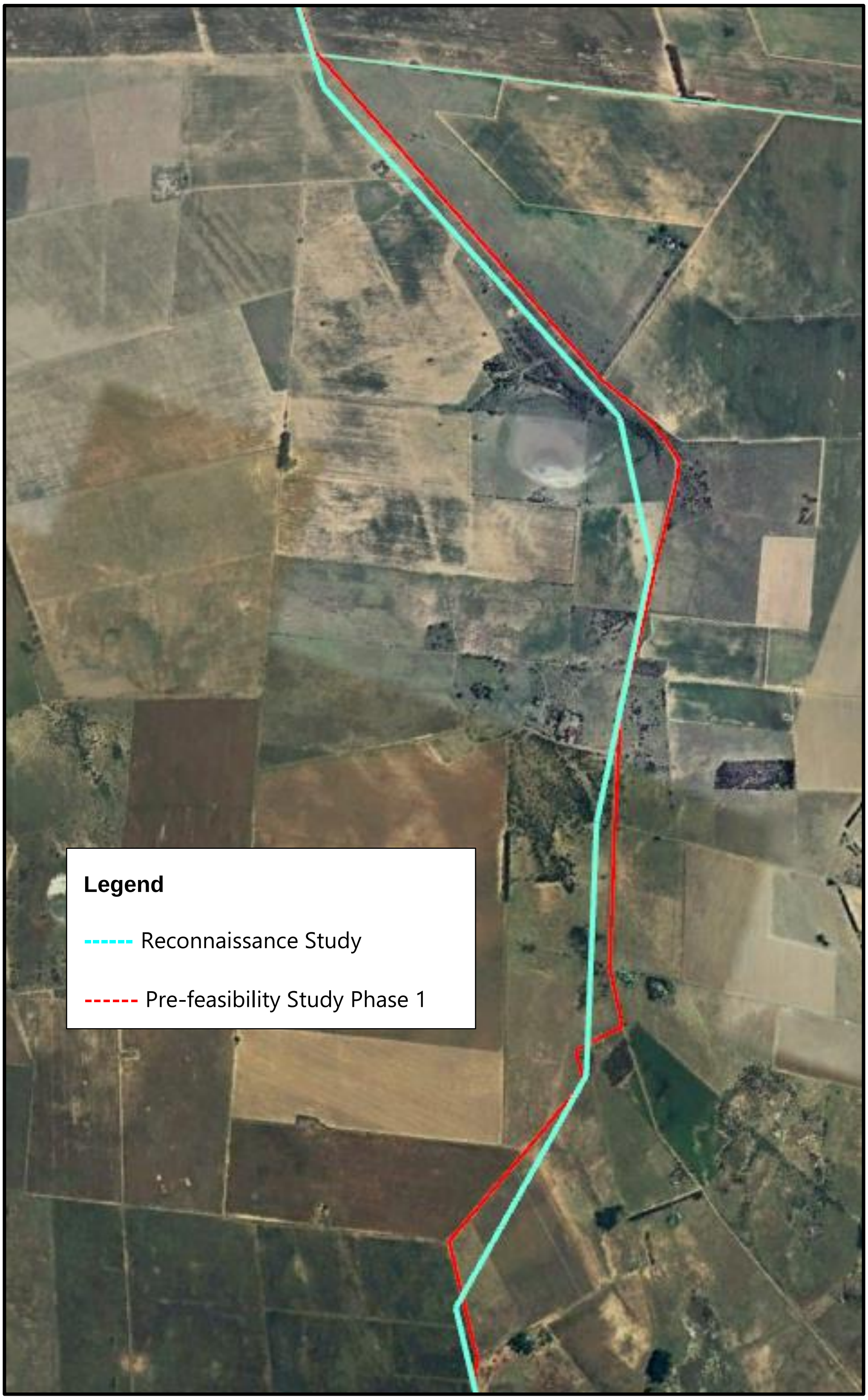


Figure 5-8: CH. 382 000 Route Adjustment

At chainage 382 000 where the previous routing was found to encroach on private land and structures, the route was revised and shifted within the road servitude where possible.

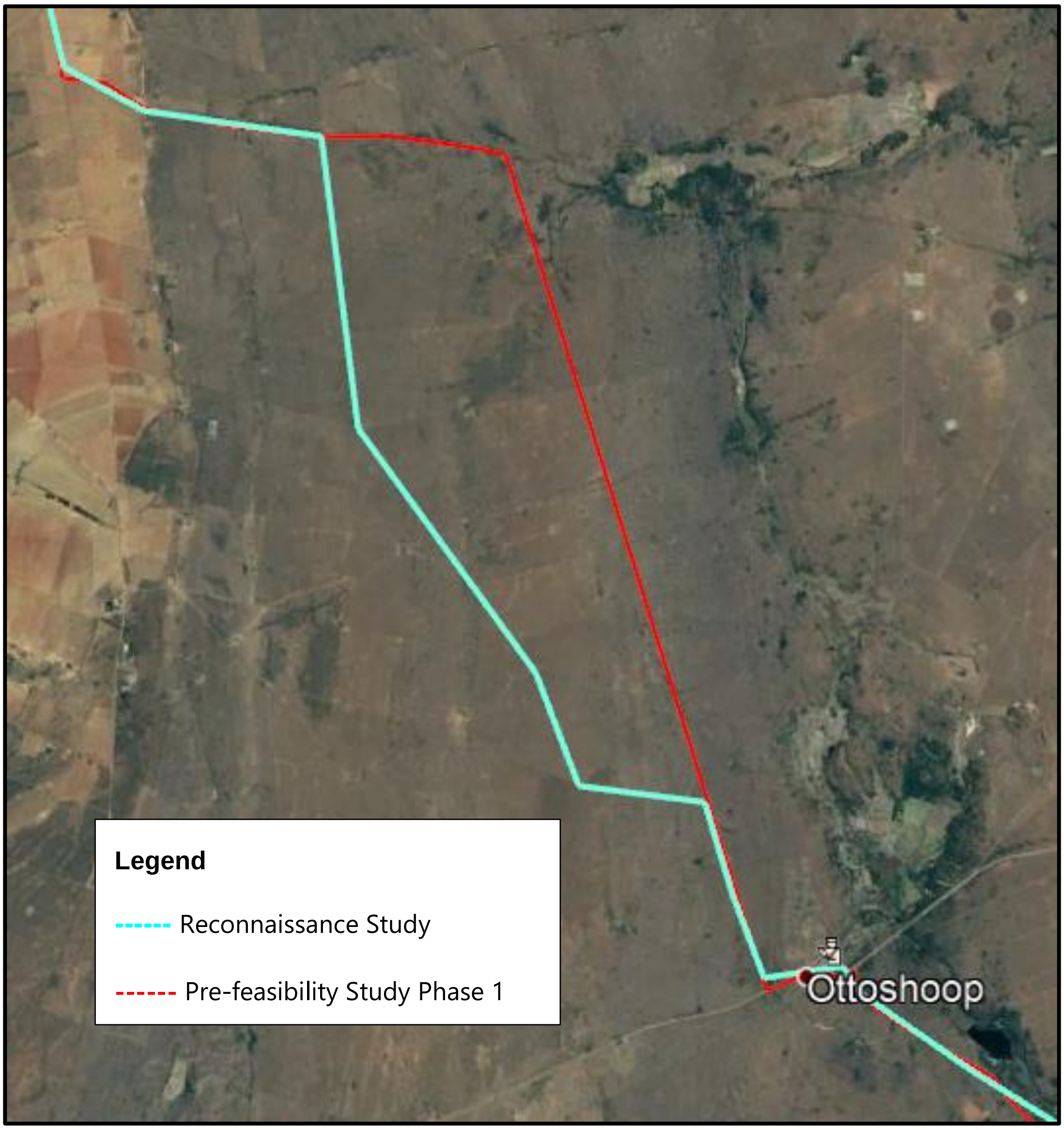


Figure 5-9: Chainage 584 000 Route Adjustment

Figure 5-9 above indicates an adjustment made to minimise the route length and construction time at chainage 584 000.

There were no other significant revisions to the original route and where stream crossings could not be avoided, pipe bridges may be considered.

Prevention of the relocation of people, plants and animals where possible

Conveyance routes 4E requires no relocation of people, plants or animals as the route runs parallel to identified roads.

Identification of national, provincial and private roads along conveyance route

Central route 4E runs parallel along the following roads: N12, N14, N4, R504, R59, R30, R502, R507, R503, R52, R505, R49, and A1.

It is intended that the pipeline will be built on farmland and private land parallel to road reserves and as it is unlikely that road authorities would allow it to be located within the road reserve.

NB. Land acquisition costs have not been estimated. However, it is assumed that the 30% contingency allowed in the overall estimate will also cover the cost of Land acquisition. Therefore, it is deemed to be included in the overall estimate although it has not been specifically measured.

Identification of land use along conveyance route

The route generally runs along farm land and through urban areas. Future detailed pipeline routing exercises are to avoid urban areas where possible.

5.2.4 High-level Hydraulic Analysis of Central Route

This section of the report gives an overview of the pump system options applicable to the central route.

Water Requirements

Two water demand scenarios have been analysed, i.e. Low and High, as noted in **Table 5-4**. The requirements in **Table 5-4** include treatment, bulk transfer and reticulation losses.

Table 5-4: Water Requirements from the L-BWT including losses(million m^3/ a)

Scenario	Lesotho	South Africa	Botswana	**Total**
High	9*	20	156	**185**
Low	9*	20	68	**97**

Note*: This excludes the water requirements to Zone 7 in Lesotho which will not use the same conveyance system.

A design pumping period of 20 hours per day has been used as agreed with the study team. The design flows based on the above demands in litres per second are listed in **Table 5-5**.

Table 5-5: Design Flow Rates Including Peak Factors (litres per second)

Scenario	Lesotho	South Africa	Botswana	Total
High	344	779	5936	7059
Low	344	779	2582	3705

Pipeline Sizing

A high-level hydraulic analysis was carried out using the design flow rates in **Table 5-5**. Steel pipe was assumed to have a Hazen Williams (H-W) friction factor of 130. For the large diameter pipelines being considered, secondary losses have been considered to be insignificant.

Maximum velocities of 2 m/s and 3 m/s have been assumed for pumped and gravity mains respectively, the hydraulic calculations have resulted in water velocities of between 1.7 m/s and 3 m/s.

Figure 5-10 and **Figure 5-11** show the route profile with hydraulic grade lines resulting from an analysis of the High and Low demand scenarios.

The route profile starts at an elevation of 1 490 mamsl and ends at 1 142 mamsl. at Nnywane Dam near Lobatse in Botswana. At the start in Lesotho it covers some mountainous terrain rising to approximately 1 825 mamsl. It then undulates down into South Africa bottoming out at approximately 1 300 mamsl near Bothaville before rising to about 1 575 mamsl. It then descends into Botswana ending at Lobatse.

The conveyance system will have a combination of Pumps, Break Pressure Tanks, Pumped and Gravity Pipelines.

The designs allow for two high lift pump stations to be constructed downstream of the proposed dam site to lift the water up to the high elevations in Lesotho. This will deliver water to a break pressure tank (BPT) approximately 330 m above the abstraction works. The water will flow under gravity from the BPT through a series of steel pipelines and break pressure tanks to an approximate chainage of 415 km. At chainage 415 km and 450 km high lift pump stations will be required to lift the water approximately 200 m at each location and convey it to a BPT at 580 km. From here the water will again flow under gravity through another series of pipelines and break pressure tanks as indicated in **Figure 5-10** and **Figure 5-11**.

The infrastructure required for the Central route option is listed in **Table 5-6**.

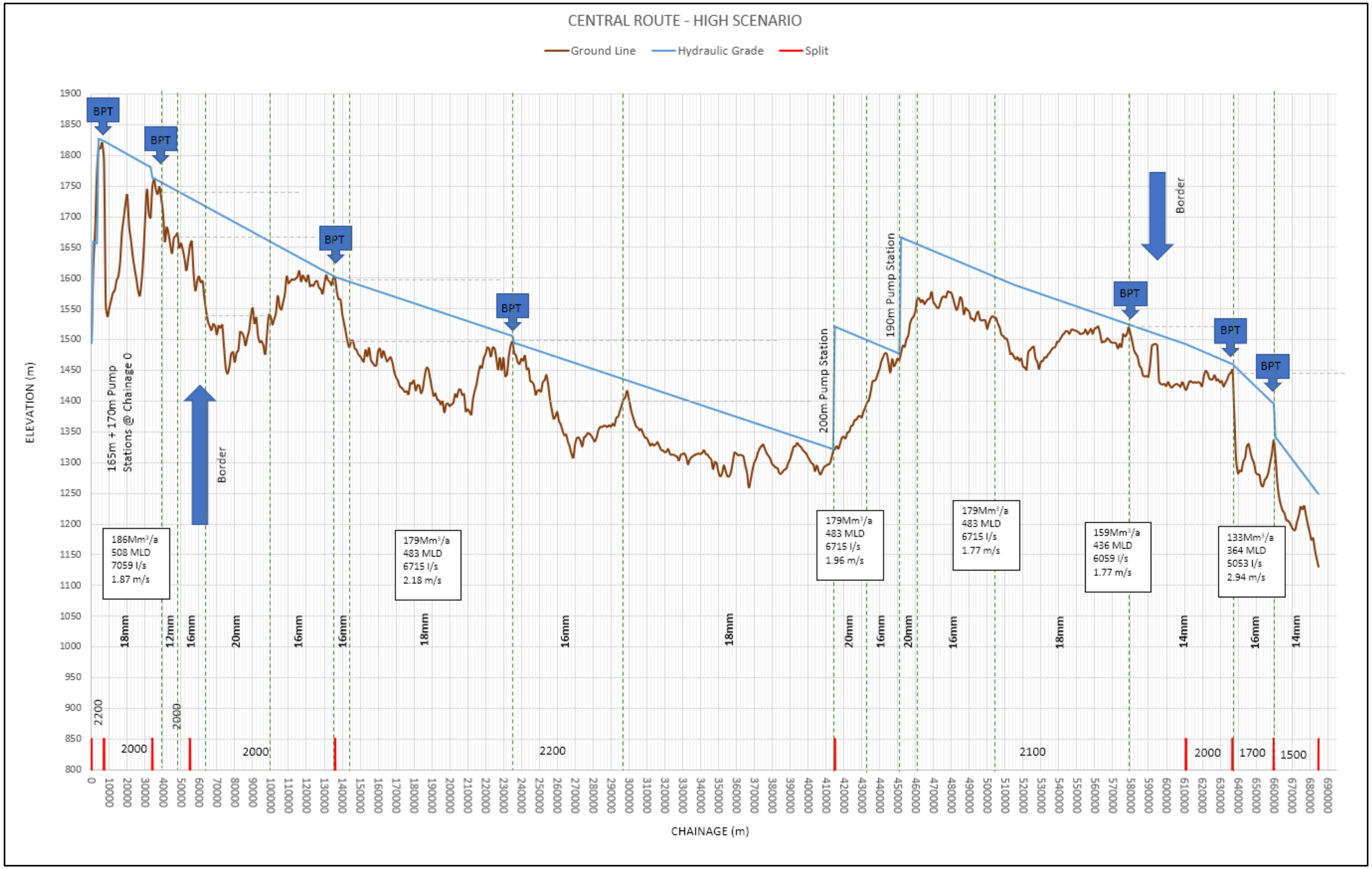


Figure 5-10: Central Route Ground and Hydraulic Profile – High Scenario

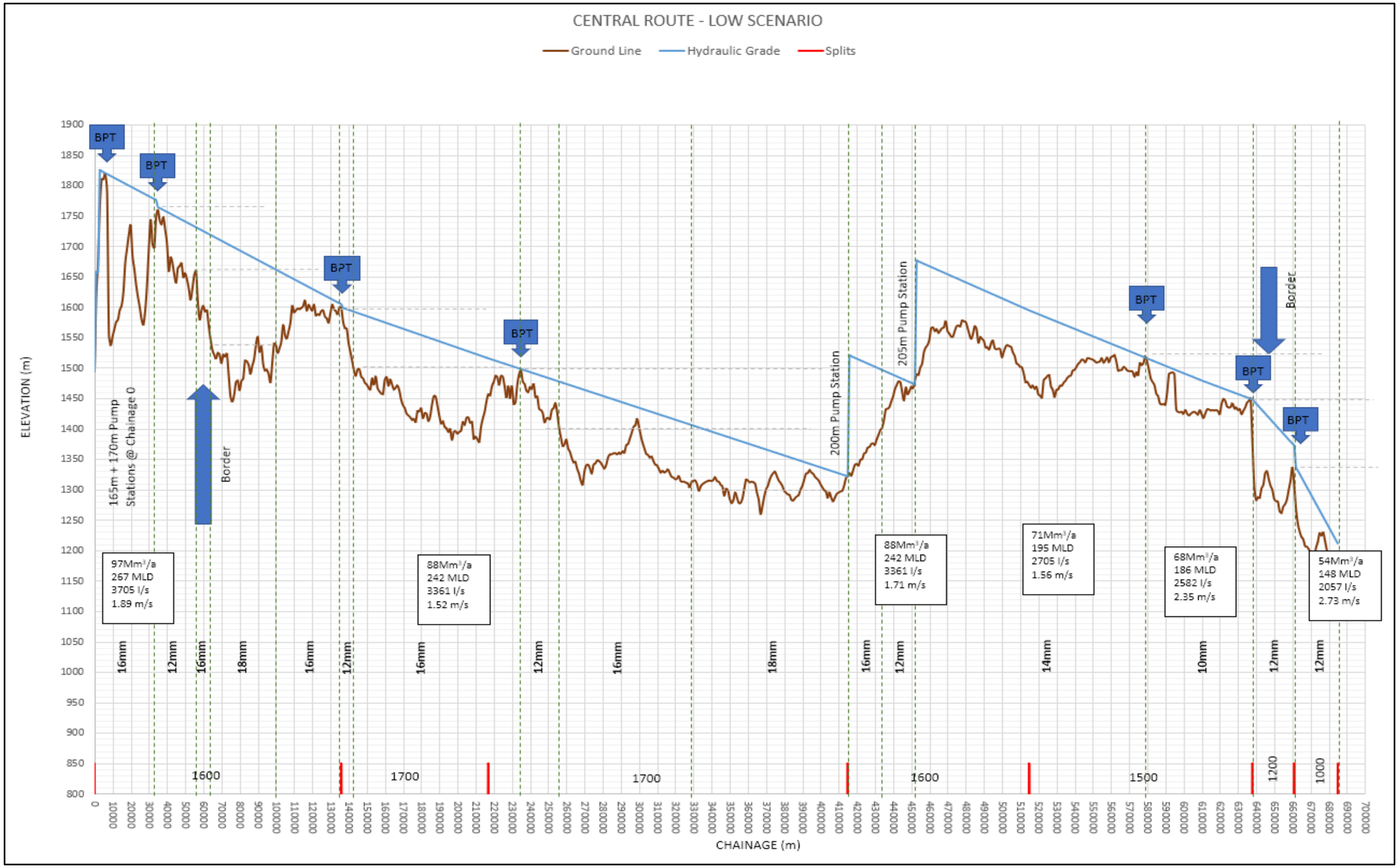


Figure 5-11: Central Route Ground and Hydraulic Profile – Low Scenario

Table 5-6: Central Route Infrastructure Summary

Item:	**High Scenario**		**Low Scenario**	
Pump stations	**Head/ Flow:**	**Power (kW):**	**Head/Flow:**	**Power (kW):**
PS1	165m / 7.1m^3/s	17579	165m / 3.7m^3/s	9226
PS2	170m / 7.1m^3/s	18111	165m / 3.7m^3/s	9506
PS3	200m / 6.7m^3/s	20269	200m / 3.4m^3/s	10145
PS4	190m / 6.7m^3/s	19256	205m / 3.4m^3/s	9638
Pipelines:	**Length:**		**Length:**	
DN2200	288 km		-	
DN2100	195 km		-	
DN2000	157 km		-	
DN1700	20 km		280 km	
DN1600	-		235 km	
DN1500	25 km		125 km	
DN1200	-		20 km	
DN1000	-		25 km	
Abstraction works:	**N/A**		**N/A**	
Reservoirs/ BPT's:	**Size:**		**Size:**	
BPT1:	25ML		15ML	

Item:	High Scenario	Low Scenario
BPT2:	25ML	15ML
BPT3:	25ML	15ML
BPT4:	25ML	15ML
BPT5:	20ML	10ML
BPT6:	20ML	10ML
BPT7:	20ML	10ML

5.2.5 Financial Data

The financial data for the Central Route is noted in **Table 5-7** and **Table 5-8**. It should be noted that these results include all infrastructure between the upstream battery limit at the dam and the downstream battery limit at Lobatse.

Table 5-7: Capital Cost Estimates for Central Route

Item:	High Scenario (millions):	Low Scenario (millions):
Pipelines:	R 36,000	R 25,464
Pump stations:	R 637	R 564
Abstraction works:	N/A	N/A
BPT's:	R 589	R 403
Stilling structures:	R 13	R 13

Table 5-8: Financial Data for Central Route

Scenario:	Capital cost (millions):	NPV (millions):	URV (R/m^3):
High	R37 239.47	R31 782.05	R25.47
Low	R26 443.71	R21 727.27	R33.17

5.3 EVALUATION OF WESTERN ROUTES, PROPOSED CONFIGURATION, AND MODIFICATIONS

5.3.1 Broad Overview of the Terrain Along the Route

The Western route is made up of 4 options labelled 3ACE, 3ACF, 3BDE, and 3BDF as identified in the reconnaissance study. The options are made up of piped and river sections which will transport water from the proposed dam site S2 to the Nnywane Dam near Lobatse in Botswana. The Western routes are depicted in red in **Figure 5-12** and **A1** in **Appendix A**.

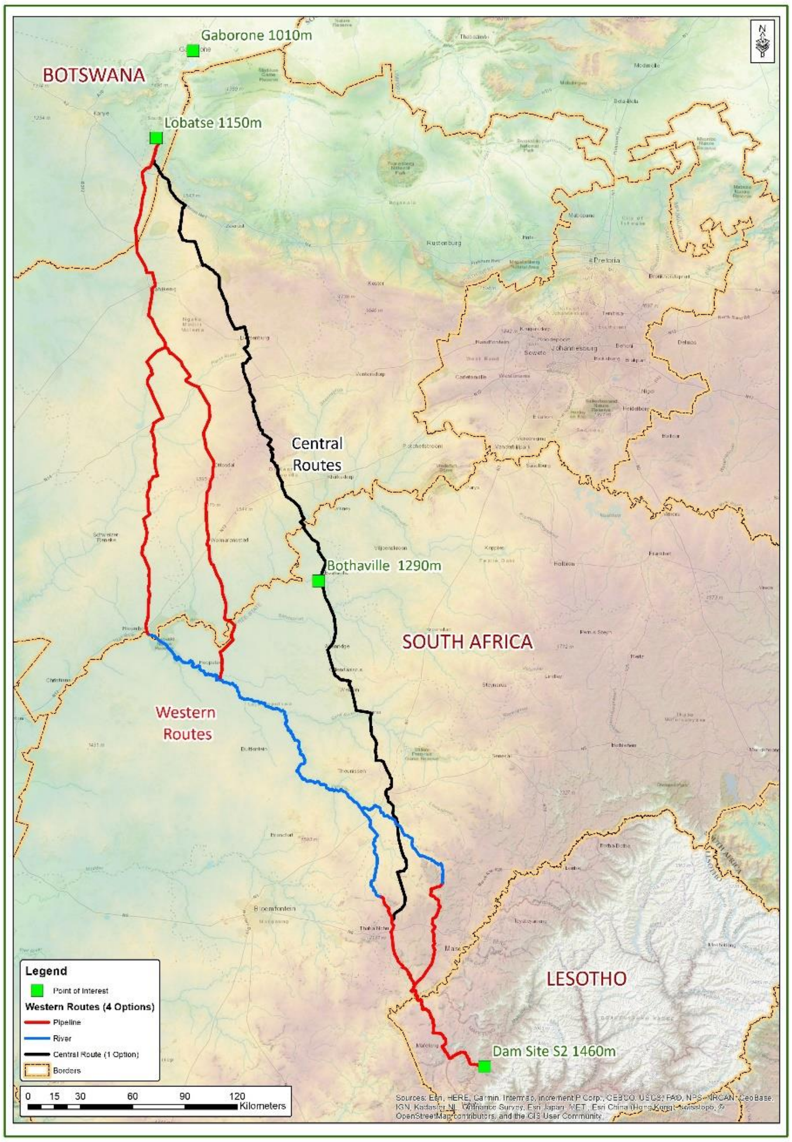


Figure 5-12: Overview of Western Routes

Review of route 3ACE

The total length of the route for 3ACE is approximately 740 km. Water is transferred via two pump stations and pipelines over a distance of 140 km to Saliba Dam. The river is then utilised to transport water for a distance of 280 km before it reverts back to a pipeline system by means of an abstraction works near the Bloemhof Dam wall.

Figure 5-13: Route ACE Plan

The transfer passes through two major dams, Erfenis and Bloemhof Dams. The Groot Vet River flows into Erfenis Dam, which is a DWS dam suppling irrigation downstream. The Vet River flows out of Erfenis Dam and then joins the Sand River before entering Bloemhof Dam. Erfenis Dam has problems with eutrophication caused by upstream farming activities. The Sand River has high chemical and nutrient contents due to mining, urban and agriculture activities in the catchment. Bloemhof Dam has high chemical and nutrients contents due to the urban, mining, industrial and agricultural activities upstream. The pipeline route travels for 320 km to the end of the line in Lobatse in Botswana. This final piped section includes three pump stations for the High demand scenario and two pump stations for the Low demand scenario. Route ACE is depicted in **Figure 5-13**.

The following towns have been identified along the pipeline route: Mokibinyani, Thabana Morena, Lekoatsa, Hellspoort, Mankimane, Letsie, Sepechele, Mapotu, Hobhouse, Connaught, Riversdale, Holfontein, Fort Kelly, Tweespruit, Moroto, Bloemhof, Glaudina, Springbokfontein, Vaalplaats, Mooifontein, Driehoek, Bethel, Lotlhakane, Lotlhakeng, Setlopo, Mahikeng, and Lobatse, The pipeline section runs parallel along the following roads: R26, R709, N8, N12, R504, R507, N14, R375, R503, R49, N18, and A1.

Review of route 3BDE

The total length of the route for 3BDE is approximately 766 km. Water is transferred via three pump stations and pipelines over a distance of 163 km to the river entry at the Klein Vetrivier. The river is then utilised to transport water for a distance of 287 km before it reverts back to a pipeline system at an abstraction works near the Bloemhof Dam wall. The transfer passes through two major dams, Erfenis and Bloemhof Dams. The Klein Vet River flows into Erfenis Dam, which is a DWS dam suppling irrigation downstream. The Vet River flows out of Erfenis Dam and it is then joined by the Sand River before entering Bloemhof Dam. Erfenis Dam has problems with eutrophication caused by upstream farming activities. The Sand River has high chemical and nutrient contents due to mining, urban and agriculture activities in the catchment. Bloemhof Dam has high chemical and nutrients contents due to the urban, mining, industrial and agricultural activities upstream. The pipeline route travels for 316 km to the end of the line in Lobatse in Botswana. This final piped section includes three pump stations for the High demand scenario and two pump stations for the Low demand scenario. Route BDE is depicted in **Figure 5-14**.

The following towns have been identified along the pipeline route: Mokibinyani, Thabana Morena, Lekoatsa, Hellspoort, Mankimane, Letsie, Sepechele, Mapotu, Hobhouse, Commissie Poort, Bloemhof, Glaudina, Springbokfontein, Vaalplaats, Mooifontein, Driehoek, Bethel, Lotlhakane, Lotlhakeng, Setlopo, Mahikeng, and Lobatse. The pipeline section runs parallel along the following roads: R26, N8, R703, N12, R504, R507, N14, R375, R503, R49, N18, and A1.

Figure 5-14: Route BDE Plan

Review of route 3ACF

The total length of the route for 3ACF is approximately 704 km. Water is transferred via two pump stations and pipelines over a distance of 140 km to Saliba Dam. The river is then utilised to transport water for a distance of approximately 215 km before it reverts back to a pipeline system by means of an abstraction works approximately 50 km upstream of Bloemhof Dam. The transfer passes through Erfenis Dam. The Groot Vet River flows into Erfenis Dam, which is a DWS dam suppling irrigation downstream. The Vet River flows out of Erfenis Dam and it is then joined by the Sand River. Erfenis Dam has problems with eutrophication caused by upstream farming activities. The Sand River has high chemical and nutrient contents due to mining, urban and agriculture activities in the catchment. The pipeline route travels for 350 km to the end of line in Lobatse in Botswana. This final piped section includes two pump stations. Route ACF is depicted in **Figure 5-15**.

The following towns have been identified along the pipeline route: Mokibinyani, Thabana Morena, Lekoatsa, Hellspoort, Mankimane, Letsie, Sepechele, Mapotu, Hobhouse, Connaught, Riversdale, Holfontein, Fort Kelly, Tweespruit, Moroto, Makwassie, Wolmaransstad, Ottosdale, Biesiesvlei, Lotlhakane, Lotlhakeng, Setlopo, Mahikeng, and Lobatse. The pipeline section runs parallel along the following roads: R26, R709, N8, R34, R59, R505, R502, N12, R504, R507, N14, R52, R503, R49, N18, A2, A1.

Figure 5-15: Route ACF Plan

Review of route 3BDF

The total length of the route for 3BDF is approximately 735 km. Water is transferred via three pump stations and pipelines over a distance of 162 km to the river entry at the Klein Vetrivier.

The river is then utilised to transport water for a distance of 225 km before it reverts back to a pipeline system by means of an abstraction works approximately 50 km upstream of the Bloemhof Dam wall.

Figure 5-16: Route BDF Plan

The transfer passes through Erfenis Dam. The KleinVet River flows into Erfenis Dam, which is a DWS dam suppling irrigation downstream. The Vet River flows out of Erfenis Dam and it is then joined by the Sand River. Erfenis Dam has problems with eutrophication caused by upstream farming activities. The Sand River has high chemical and nutrient contents due to mining, urban and agriculture activities in the catchment. The pipeline route travels for 387 km to the end of the line in Lobatse in Botswana. This final piped section includes two pump stations. Route BDF is depicted in **Figure 5-16**.

The following towns have been identified along the pipeline route: Mokibinyani, Thabana Morena, Lekoatsa, Hellspoort, Mankimane, Letsie, Sepechele, Mapotu, Hobhouse, Commissie Poort, Makwassie, Wolmaransstad, Ottosdale, Biesiesvlei, Lotlhakane, Lotlhakeng, Setlopo, Mahikeng, and Lobatse. The pipeline section runs parallel along the following roads: R26, N8, R703, R59, R505, R502, N12, R504, R507, N14, R52, R503, R49, N18, A2, and A1.

5.3.2 Comment on Western Pipeline Routes

The western routes comprise alternate sections of pipelines and rivers to transport water to Botswana. In addition to the route making use of rivers to lower cost of construction, the routes pass reasonably close to Delareyville, Driehoek, Maipeng, Mahikeng, and Miga North in the North West Province, which would also benefit from water from the scheme.

Review of route selection considered the following criteria:

a) Directness of route;

b) Route deviation around high elevation points where possible;

c) Identification of structures that may require route deviation;

d) Prevention of the relocation of people, plants and animals where possible;

e) Identification of national, provincial and private roads along conveyance route;

f) Identification of land use along conveyance route; and

g) Confirmation of location of Pump Station/s.

Each of the Western routes comprise of both pipelines and rivers that begin from Makhaleng River in Lesotho to Lobatse Dam in Botswana.

Directness of route

The western routes are alternatives to the central route. They are not direct as they follow the natural gradient of various rivers for large portions of their length. They do, however, benefit other towns out of reach of the central route. The utilisation of rivers to transport water reduces the pipeline length which substantially reduces the overall pipeline construction cost, but the water quality will drop which would increase the potential O&M costs for water treatment.

Minor deviations were proposed to avoid private land or streams, but there were no significant changes to any of the four Western route options.

Route deviation around high elevation points

The Western routes 3ACE, 3BDE, 3ACF, and 3BDF were reviewed to assess whether maximum elevations could be reduced through reasonable rerouting of the pipelines. No avoidable high points that impacted the hydraulic grade line were identified. The long profiles of each of these routes are shown in **Figure 5-19** to **Figure 5-26**.

Identification of structures that may require route deviation

Many minor route changes were made. This was necessary primarily to ensure that the length of pipeline was as accurate as possible, i.e. the pipeline length when drawn accurately, may increase by 5 to 10% over the rough initial (Recon.) route. Examples of the changes made are indicated below, however, there are many more such changes.

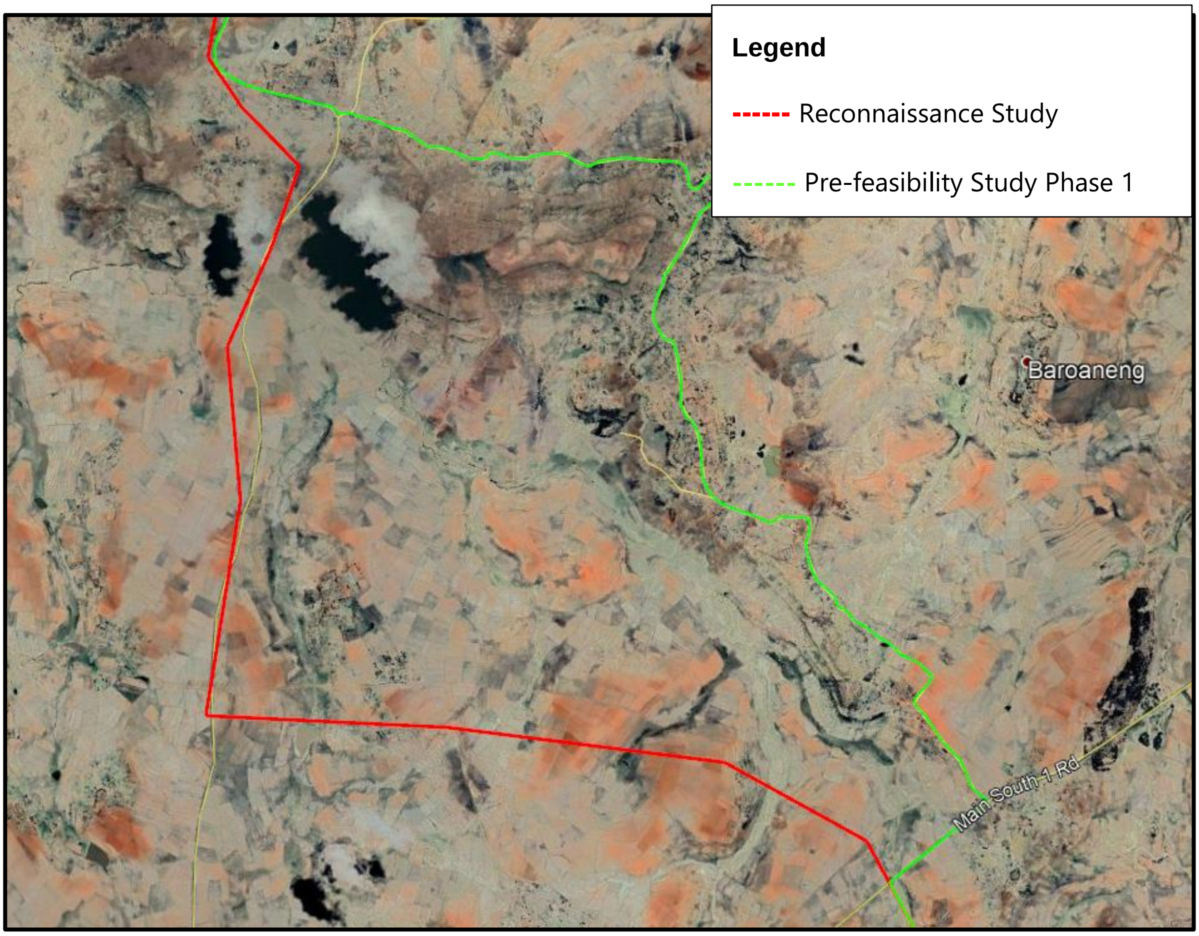


Figure 5-17: Chainage 42 000 Route Adjustment

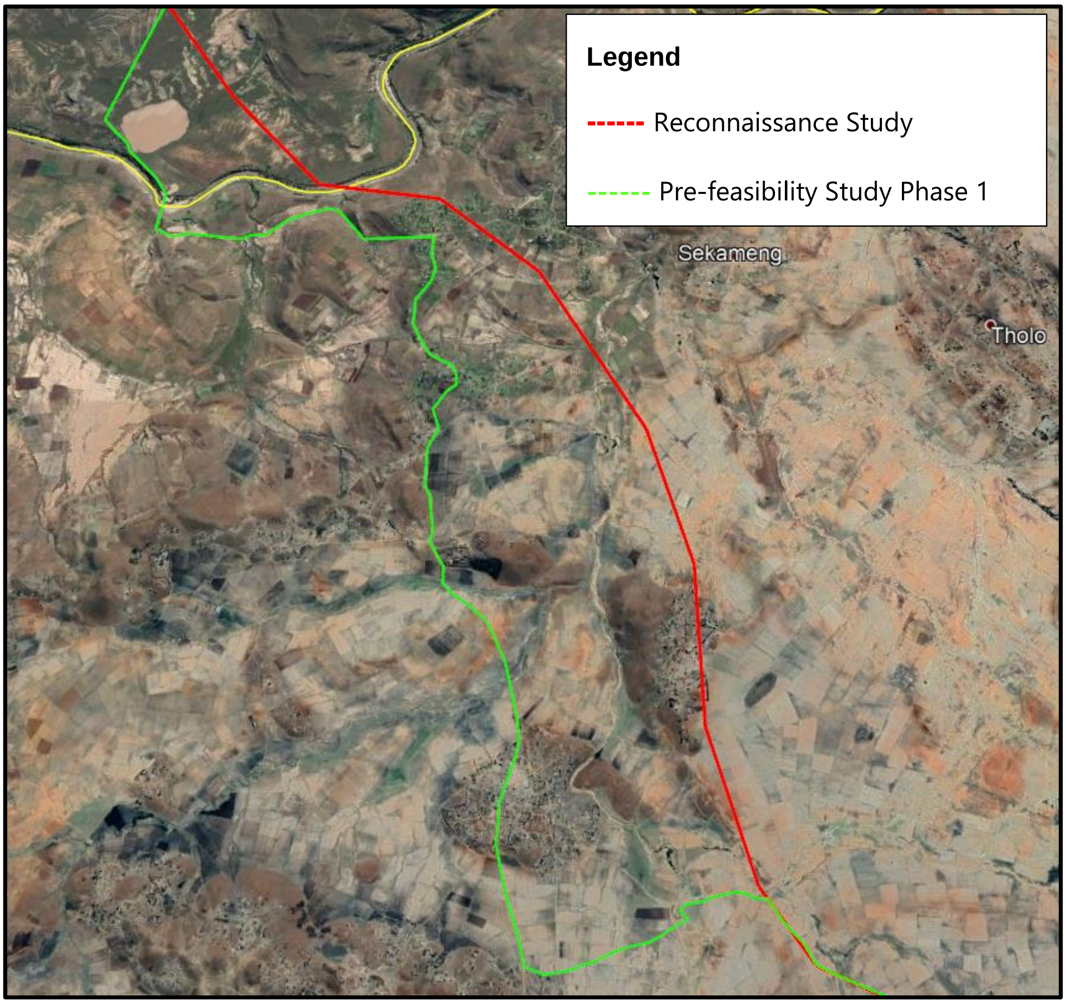


Figure 5-18: Chainage 65 000 Route Amendment

Prevention of the relocation of people, plants and animals where possible

The relocation of people, plants and animals was not necessary.

Identification of national, provincial and private roads along conveyance route

The crossings of national roads N8, N12 and N18 have been identified as requiring pipe-jacking.

Identification of land use along conveyance route

Land owner information was only available for South Africa. The project infrastructure, including pump stations, pipelines, reservoirs, and the associated access roads, is located in both urban and rural areas. In the rural areas the land use is mainly agricultural with a large portion of the land being actively farmed.

5.3.3 High-level Hydraulic Analysis of Western Routes

A high-level hydraulic analysis was carried out using the Low and High demand values. The assumptions used in the Western Routes hydraulic analyses are as noted in **Section 5.2.4** of this report for the Central Route.

The route profiles for the four western route options with hydraulic grade lines resulting from a dynamic flow analysis for the “high” and “low” demand scenario are shown in **Figure 5-19** to **Figure 5-26**. The conveyance system will have a combination of Pumps, Pipelines, River Transport and Break Pressure Tanks.

Two high lift pump station will be required at the new dam site to lift the water up to the high elevations in Lesotho. This will deliver water to a BPT and pipeline system. Some of the Western options require a third pump station in Lesotho due to the elevations encountered along those routes. The water will flow through pumped and gravity pipelines and break pressure tanks to the respective river entry points. Here it discharges into either Saliba Dam or the Klein Vetrivier and flows for up to 287 km in the Vet and Sand rivers. An abstraction works and High Lift Pump Stations located either at or upstream of Bloemhof Dam will be required to lift the water approximately 200 m to 300 m depending on the route option. From here the water will again flow under gravity through another series of pipelines and break pressure tanks, discharging just downstream of Nnywane Dam near Lobatse.

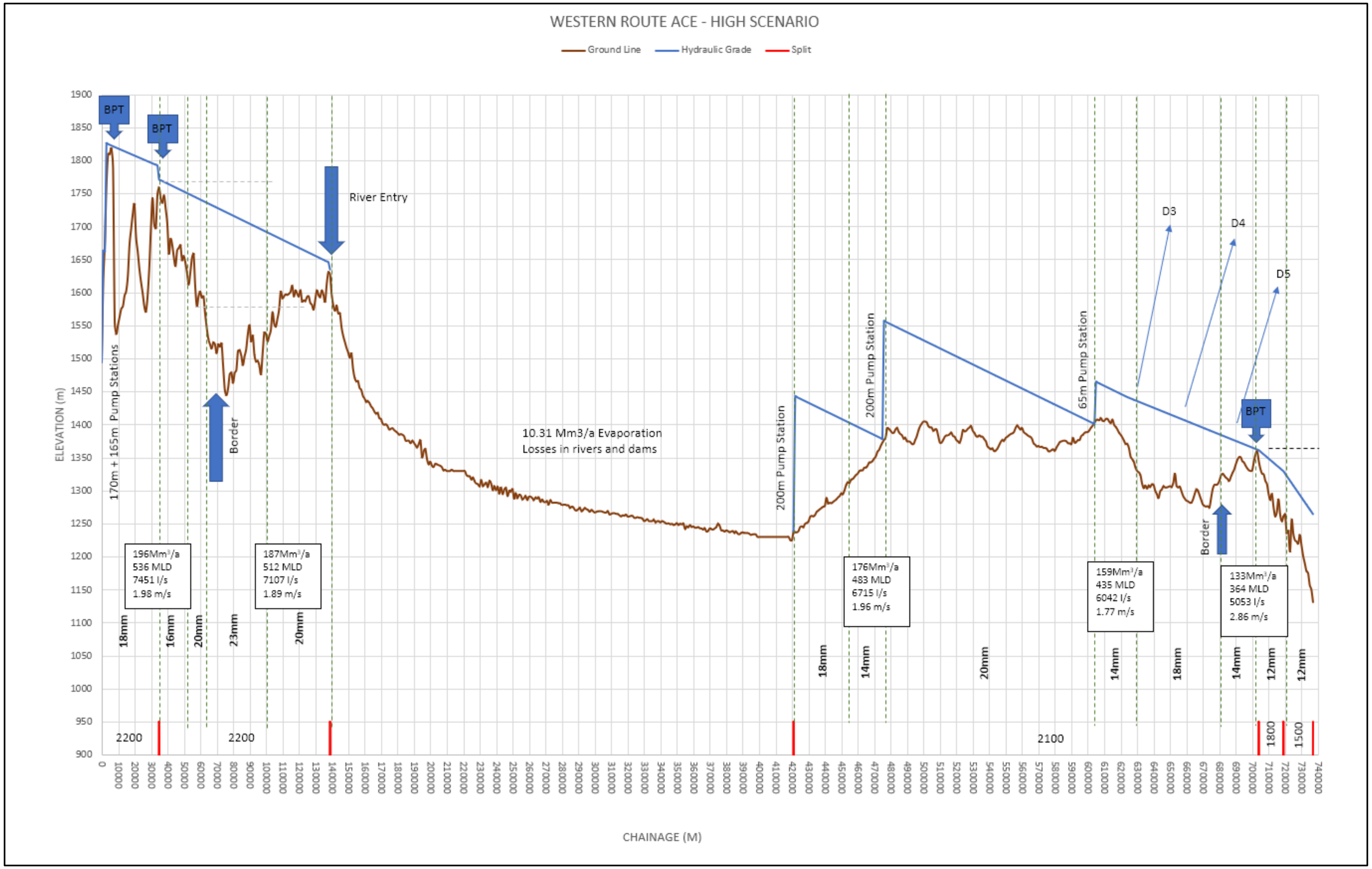


Figure 5-19: Western Route Option ACE Hydraulic Profile – High Scenario

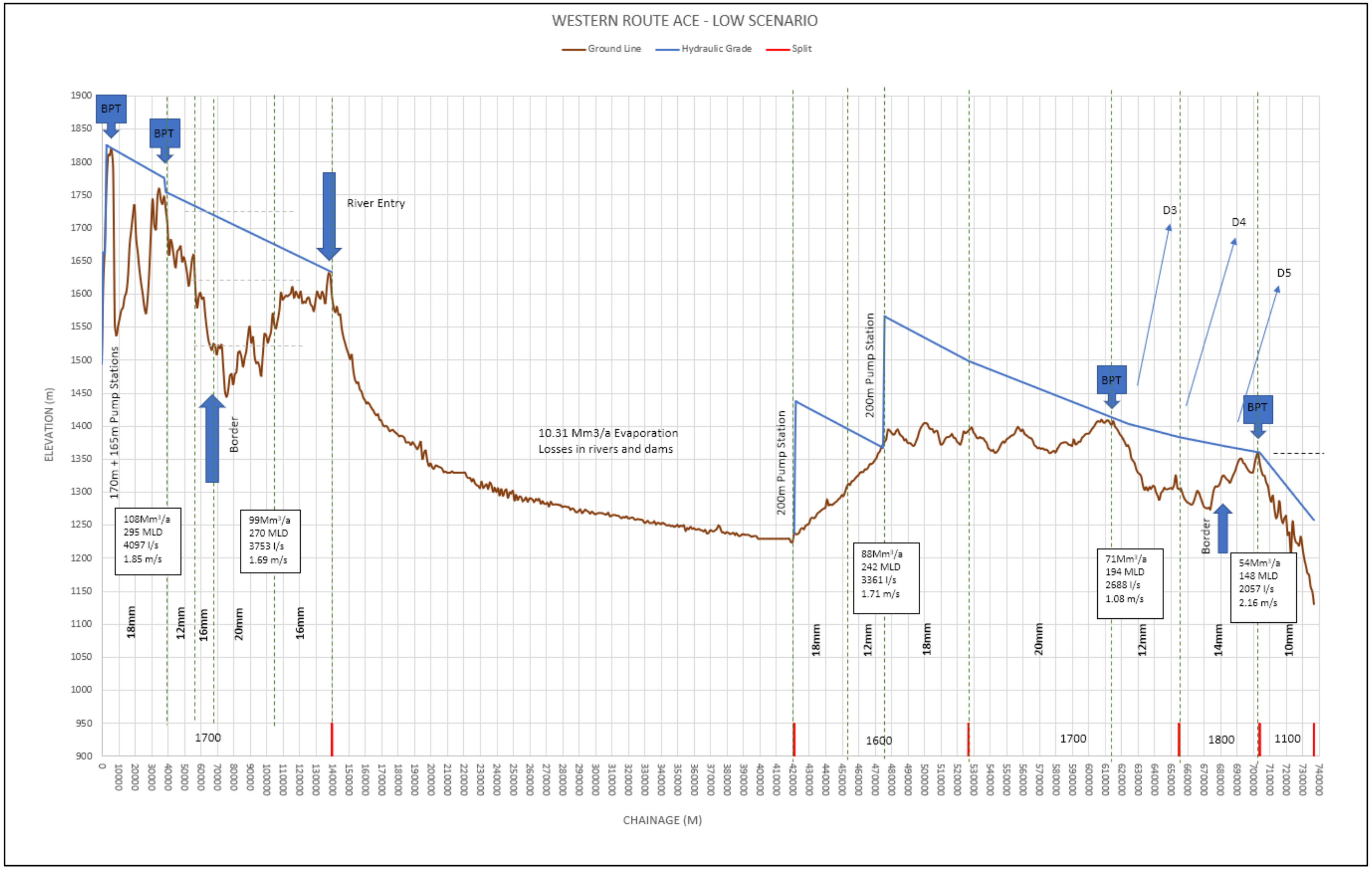


Figure 5-20: Western Route Option ACE Hydraulic Profile – Low Scenario

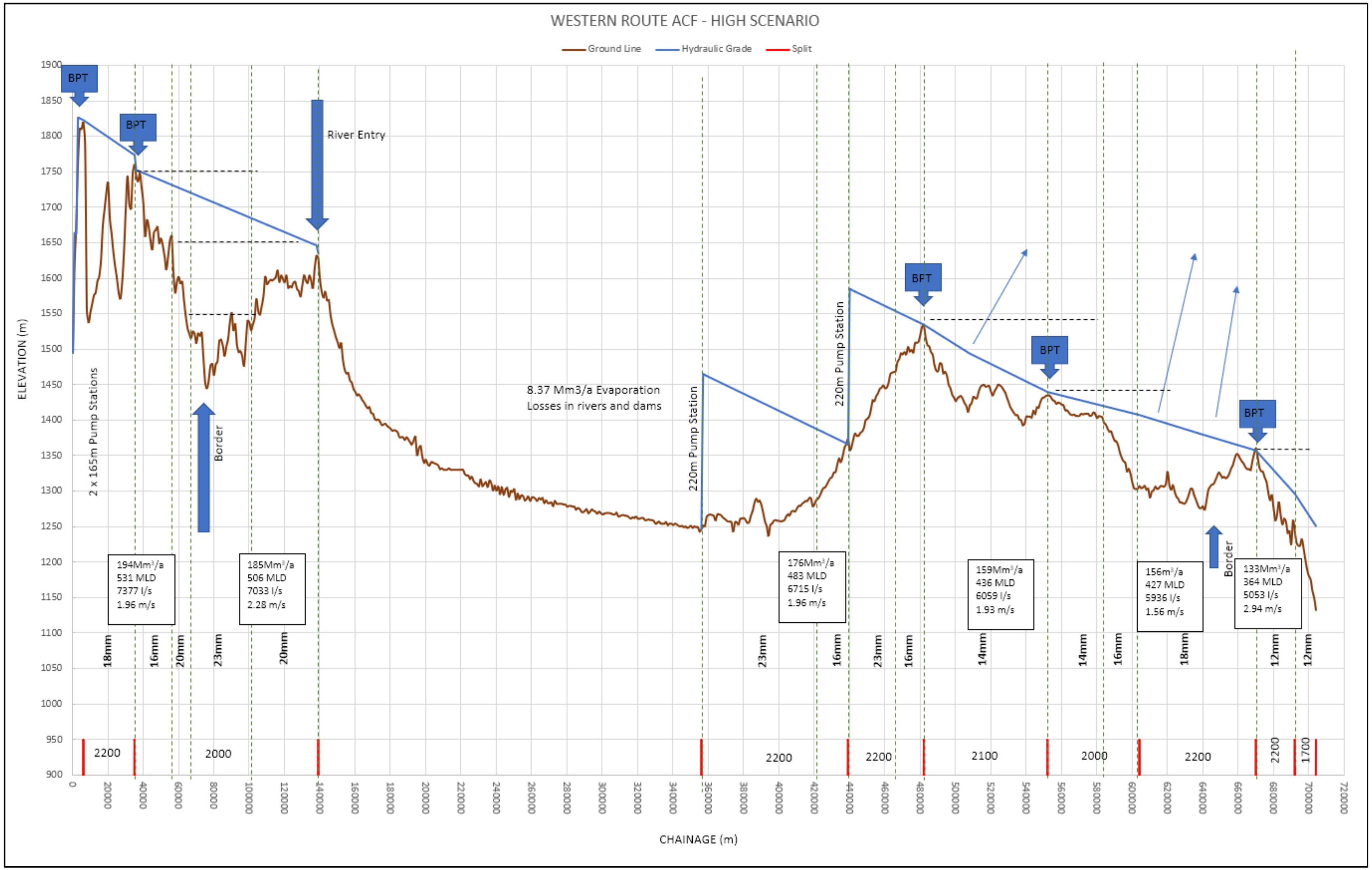


Figure 5-21: Western Route Option ACF Hydraulic Profile - High Scenario

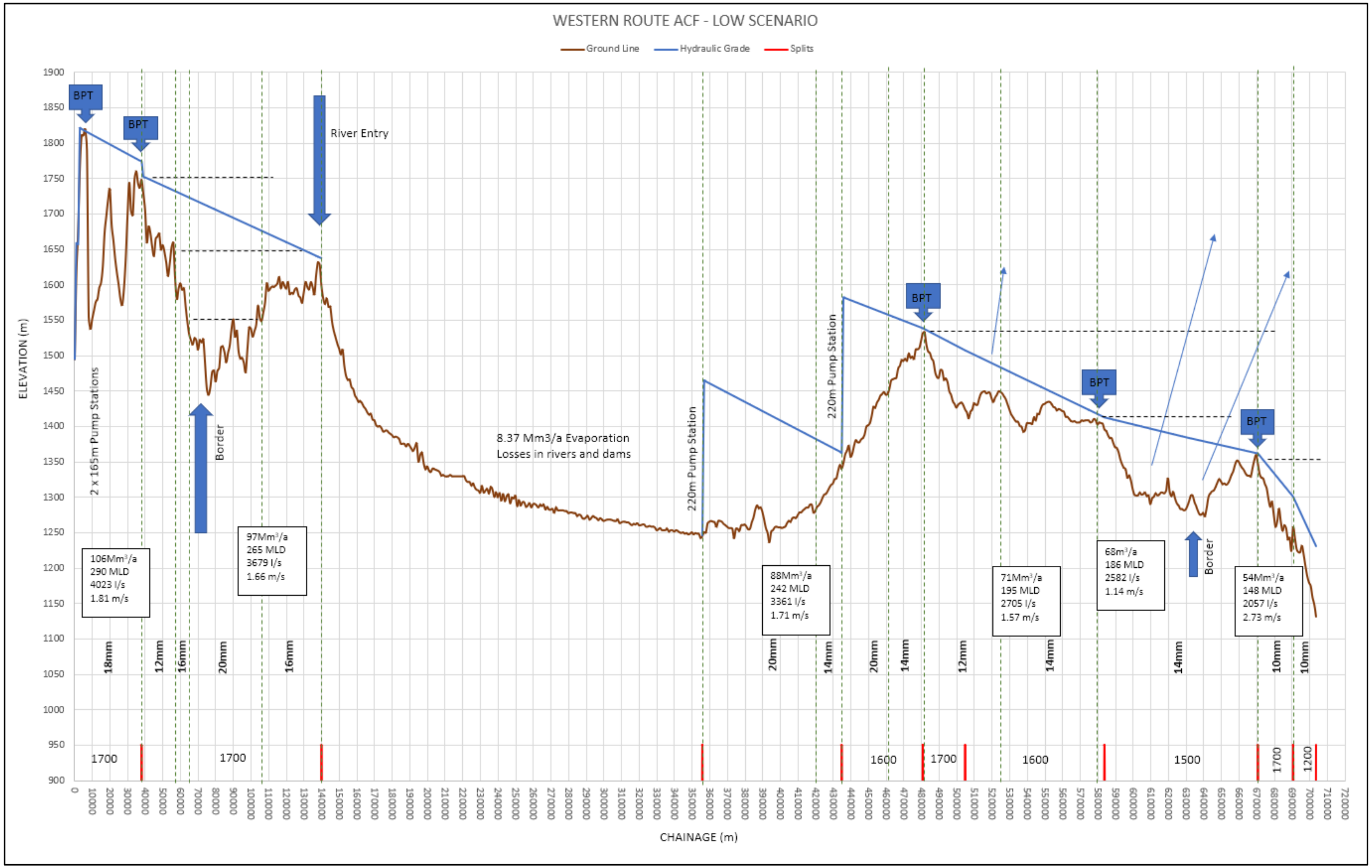


Figure 5-22: Western Route Option ACF Hydraulic Profile - Low Scenario

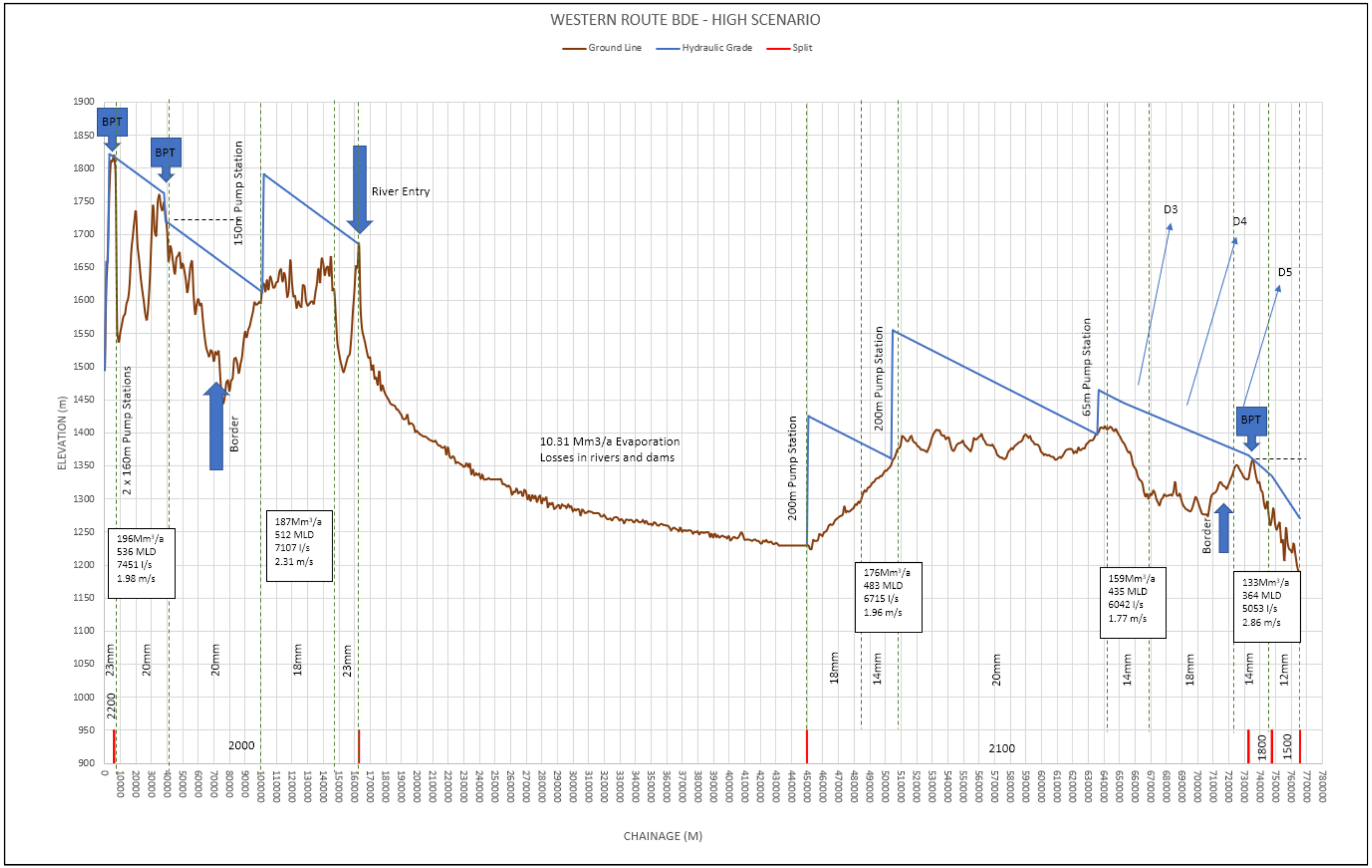


Figure 5-23: Western Route Option BDE Hydraulic Profile - High Scenario

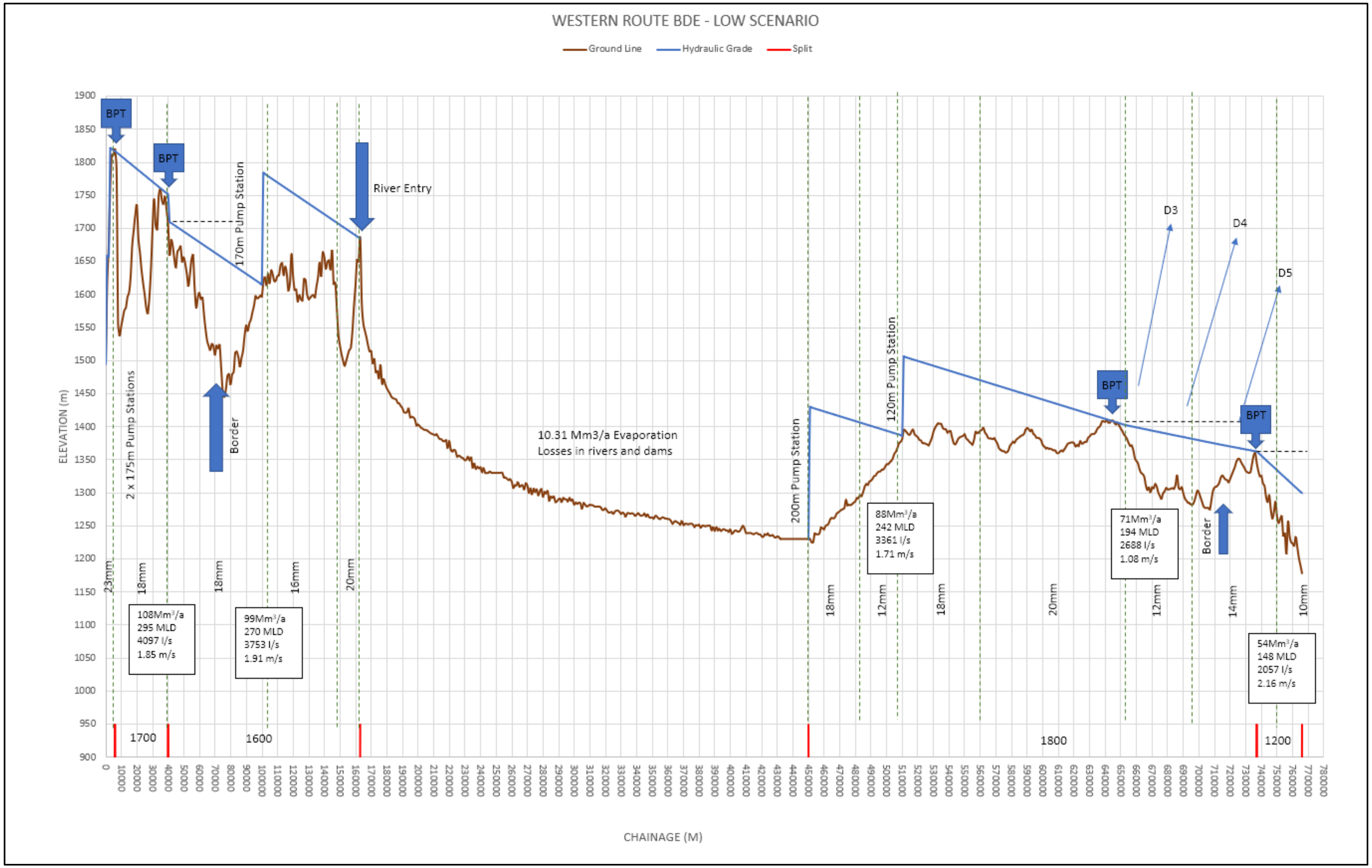


Figure 5-24: Western Route Option BDE Hydraulic Profile - Low Scenario

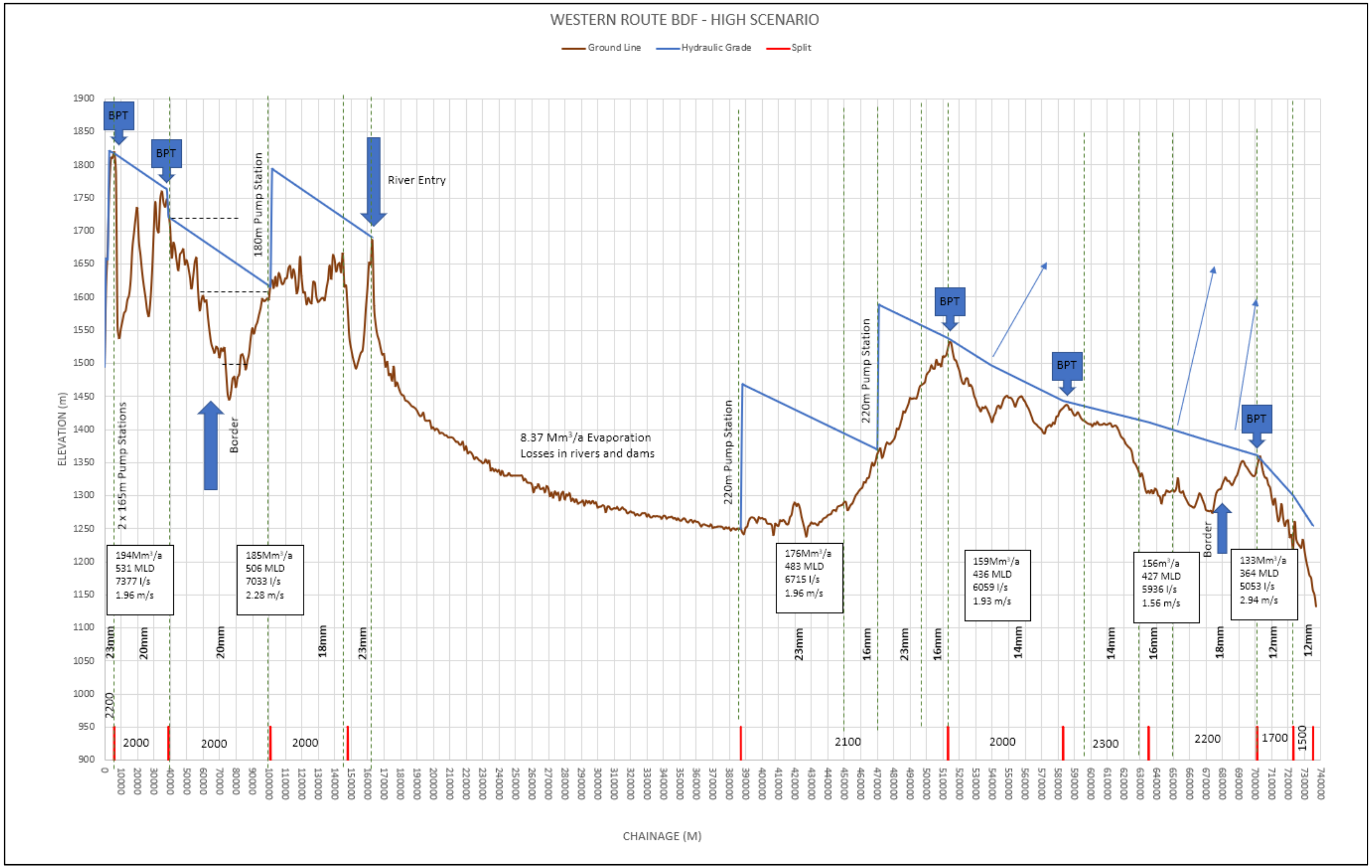


Figure 5-25: Western Route Option BDF Hydraulic Profile - High Scenario

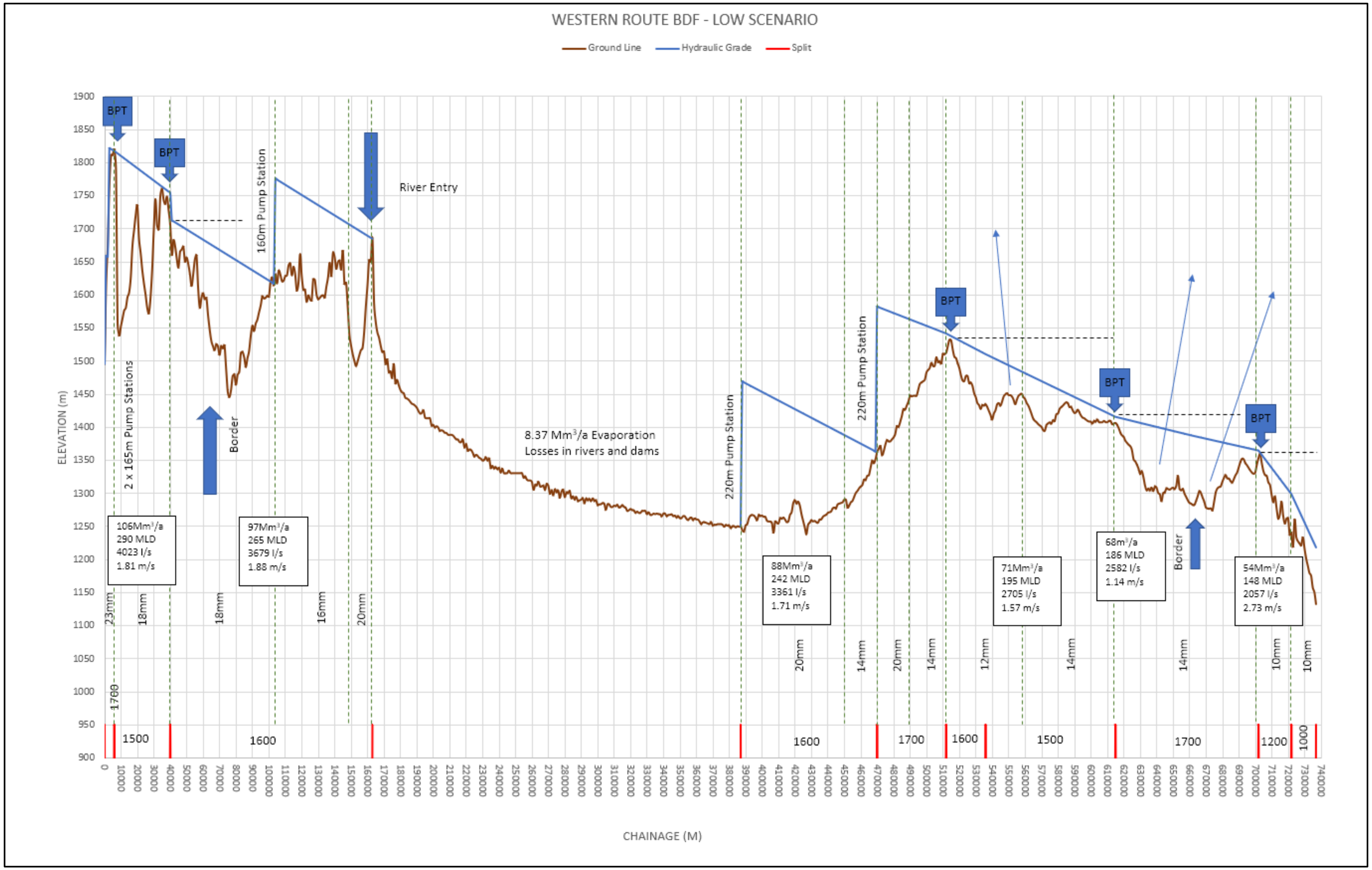


Figure 5-26: Western Route Option BDF Hydraulic Profile - Low Scenario

5.3.4 Financial Results for Western Routes:

Table 5-9: Western Route ACE Infrastructure Summary

Item:	High Scenario		Low Scenario	
Pump stations	**Head/ Flow:**	**Power (kW):**	**Head/Flow:**	**Power (kW):**
PS1	170m/ 7.5m³/s	19116.97	170m/ 4.1m³/s	10511.64
PS2	165m/ 7.5m³/s	18554.71	165m/ 4.1m³/s	10202.48
PS3	200m/ 6.7m3/s	20268.97	200m/ 3.4m3/s	10145.05
PS4	200m/ 6.7m³/s	20268.97	200m/ 3.4m³/s	10145.05
PS5	65m/ 5.9m³/s	5823.22	-	-
Pipelines:	**Length:**		**Length:**	
DN2200	37 km		-	
DN2100	388 km		-	
DN1800	15 km		60 km	
DN1700	-		267 km	
DN1600	-		108 km	
DN1500	19 km		125 km	
DN1200	-		-	
DN1000	-		24 km	
Abstraction works:	6.7 m³/s		3.4 m³/s	
BPT's:	**Size:**		**Size:**	
BPT1:	25ML		15ML	
BPT2:	25ML		15ML	
BPT3:	20ML		15ML	
BPT4:	-		10ML	

Table 5-10: Western Route ACF Infrastructure Summary

Item:	High Scenario		Low Scenario	
Pump stations	**Head/ Flow:**	**Power (kW):**	**Head/Flow:**	**Power (kW):**
PS1	165m/ 7.4m^3/s	18370.43	165m/ 4.0m^3/s	10018.20
PS2	165m/ 7.4m^3/s	18370.43	165m/ 4.0m^3/s	10018.20
PS3	220m/ 6.7m^3/s	22295.87	220m/ 3.4m^3/s	11159.55
PS4	195m/ 6.7m^3/s	19762.25	220m/ 3.4m^3/s	11159.55
PS5	165m/ 7.4m^3/s	18370.43	165m/ 4.0m^3/s	10018.20
Pipelines:	**Length:**		**Length:**	
DN2300	55km		-	
DN2200	176km		-	
DN2100	121km		-	
DN2000	99km		-	
DN1700	20km		274km	
DN1600	-		104km	
DN1500	15km		73km	
DN1200	-		20km	
DN1000	-		15km	
Abstraction works:	6.7 m^3/s		3.4 m^3/s	
BPT's:	**Size:**		**Size:**	
BPT1:	25ML		15ML	
BPT2:	25ML		15ML	
BPT3:	25ML		15ML	
BPT4:	20ML		10ML	
BPT5:	20ML		10ML	

Table 5-11: Western Route BDE Infrastructure Summary

Item:	High Scenario		Low Scenario	
Pump stations	**Head/ Flow:**	**Power (kW):**	**Head/Flow:**	**Power (kW):**
PS1	165m/ 7.4m³/s	18370.43	165m/ 4.1m³/s	10202.48
PS2	165m/ 7.4m³/s	18370.43	165m/ 4.1m³/s	10202.48
PS3	180m/ 7.0m³/s	19105.96	160m/ 3.8m³/s	9062.63
PS4	200m/ 6.7m³/s	20268.97	200m/ 3.4m³/s	10145.05
PS5	200m/ 6.7m³/s	20268.97	200m/ 3.4m³/s	10145.05
PS6	65m/ 5.9m³/s	6587.42	-	-
Pipelines:	**Length:**		**Length:**	
DN2200	33km		-	
DN2100	285km		-	
DN2000	127km		-	
DN1800	15km		60km	
DN1700	-		135km	
DN1600	19km		228km	
DN1500	-		32km	
DN1100	-		24km	
Abstraction works:	6.7 m³/s		3.4 m³/s	
BPT's:	**Size:**		**Size:**	
BPT1:	25ML		15ML	
BPT2:	25ML		15ML	
BPT3:	25ML		15ML	
BPT4:	20ML		10ML	

Table 5-12: Western Route BDF Infrastructure Summary

Item:	High Scenario		Low Scenario	
Pump stations	**Head/ Flow:**	**Power (kW):**	**Head/Flow:**	**Power (kW):**
PS1	165m/ 7.4m³/s	18370.43	165m/ 4.0m³/s	10018.20
PS2	165m/ 7.4m³/s	18370.43	165m/ 4.0m³/s	10018.20
PS3	180m/ 7.0m³/s	19105.96	160m/ 3.7m³/s	8883.94
PS4	220m/ 6.7m³/s	22295.87	220m/ 3.4m³/s	11159.55
PS5	195m/ 6.7m³/s	19762.25	220m/ 3.4m³/s	11159.55
Pipelines:	**Length:**		**Length:**	
DN2300	55km		-	
DN2200	98km		-	
DN2100	121km		-	
DN2000	197km		-	
DN1700	20km		142km	
DN1600	-		224km	
DN1500	15km		105km	
DN1200	-		20km	
DN1000	-		15km	
Abstraction works:	6.7 m³/s		3.4 m³/s	
BPT's:	**Size:**		**Size:**	
BPT1:	25ML		15ML	
BPT2:	25ML		15ML	
BPT3:	25ML		15ML	
BPT4:	20ML		10ML	
BPT5:	20ML		10ML	

The financial results for the Western Routes are noted in **Table 5-13** to **Table 5-18**.

Table 5-13: Capital Cost Estimates for Western Route ACE

Item:	High Scenario (millions):	Low Scenario (millions):
Pipelines:	R 24 395	R 18 754
Pump stations:	R 775	R 564
Abstraction works:	R 260	R 195
BPT's:	R 256	R 241
Stilling structures:	R 26	R 26

Table 5-14: Capital Cost Estimates for Western Route ACF

Item:	High Scenario (millions):	Low Scenario (millions):
Pipelines:	R 26 474	R 18 775
Pump stations:	R 641	R 572
Abstraction works:	R 260	R 195
BPT's:	R 423	R 290
Stilling structures:	R 26	R 26

Table 5-15: Capital Cost Estimates for Western Route BDE

Item:	High Scenario (millions):	Low Scenario (millions):
Pipelines:	R 25 506	R 19 196
Pump stations:	R 932	R 705
Abstraction works:	R 260	R 195
BPT's:	R 346	R 241
Stilling structures:	R 26	R 26

Table 5-16: Capital Cost Estimates for Western Route BDF

Item:	High Scenario (millions):	Low Scenario (millions):
Pipelines:	R 27 081	R 19 279
Pump stations:	R 803	R 708
Abstraction works:	R 260	R 195
BPT's:	R 423	R 290
Stilling structures:	R 26	R 26

Table 5-17: Financial Results for Western Routes – High Scenario

Option	Capital cost (millions):	NPV (millions):	URV:
Western ACE	R25 713.08	R23 757.56	R18.04
Western ACF	R27 823.61	R25 022.49	R19.19
Western BDE	R27 070.21	R25 830.55	R19.81
Western BDF	R28 592.05	R26 669.63	R20.45

Table 5-18: Financial Results for Western Routes – Low Scenario

Option	Capital cost (millions):	NPV (millions):	URV:
Western ACE	R19 844.13	R16 988.17	R23.46
Western ACF	R19 922.49	R17 122.43	R24.08
Western BDE	R20 427.51	R17 913.85	R24.73
Western BDF	R20 563.80	R18 098.30	R25.45

5.4 CONVEYANCE FINANCIAL RESULTS

The combined financial results for the Central and Western routes are noted in **Table 5-19**. These results include all infrastructure required from the battery limit downstream of the dam to the discharge at Lobatse.

Table 5-19: Summarised Financial Results for All Routes – High Scenario

Option	Capital cost (millions):	NPV (millions):	URV:
Central route	R37 239.47	R31 782.05	R25.47
Western ACE	R25 713.08	R23 757.56	R18.04
Western ACF	R27 823.61	R25 022.49	R19.19
Western BDE	R27 070.21	R25 830.55	R19.81
Western BDF	R28 592.05	R26 669.63	R20.45

Table 5-20: Summarised Financial Results for All Routes – Low Scenario

Option	Capital cost (millions):	NPV (millions):	URV:
Central route	R26 443.71	R21 727.27	R33.17
Western ACE	R19 844.13	R16 988.17	R23.46
Western ACF	R19 922.49	R17 122.43	R24.08
Western BDE	R20 427.51	R17 913.85	R24.73
Western BDF	R20 563.80	R18 098.30	R25.45

The effect of evaporation on the river conveyance Western routes has been accounted for by increasing the design flow rates for those routes to compensate for calculated evaporation losses. The increase in the design flow has the effect of increasing the capital and energy costs of the conveyance system. Despite allowing for such evaporation losses, it is clear that over the life span of the project, the Western river conveyance routes are considerably more affordable than the Central fully piped route.

5.5 SUPPLY TO BLOEMFONTEIN

A high-level analysis was undertaken to assess the costs of supplying 43 million m^3/a of water to Bloemfontein via the Rustfontein catchment. The analysis used the Low scenario Western route ACE as a base against which the incremental cost of a supply to Rustfontein was calculated.

The additional demand resulted in an increase in pipe diameters from the start of route ACE to the proposed offtake to Rustfontein, additional pumping volumes and a new pipeline and pump station to Rustfontein. The proposed route of the pipeline from the conveyance to the Rustfontein Catchment is shown on **Figure 5-27** below.

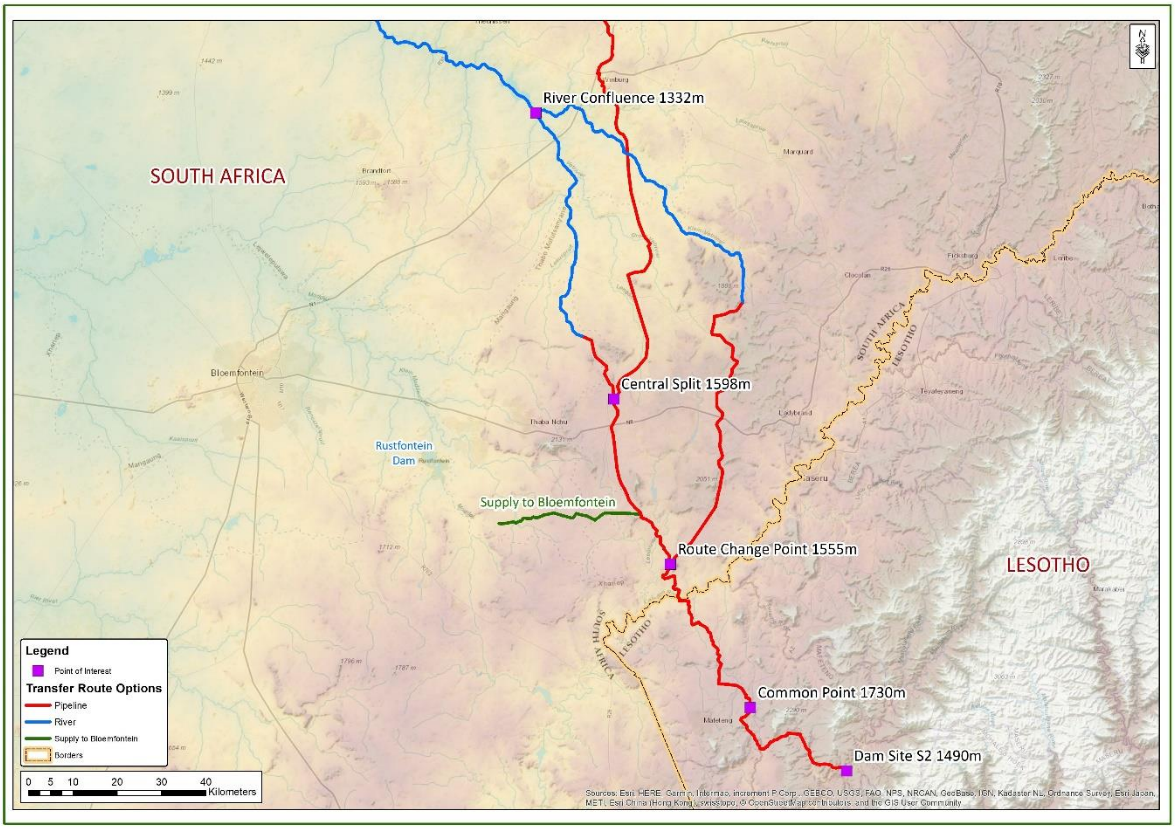


Figure 5-27: Lesotho Lowlands Water Supply Zones (LWC, 2017a)

The incremental capital cost for including the Bloemfontein supply and change in NPV and URV are noted in **Table 5-21**.

Table 5-21: Financial Results Route ACE, Low Scenario including Bloemfontein Supply

Option	Capital cost (millions):	NPV (millions):	URV:
Western ACE excl. Bloemfontein supply	R19 844	R16 988	R23.46
Western ACE incl. Bloemfontein supply	R22 127	R19 297	R20.00
Difference:	R2 283	R2 309	R3.46

5.6 CANAL OPTIONS

The JSMC concluded at the 16th October 2019 meeting in Pretoria that using the river as a conveyance would not be acceptable. The JSMC requested the Consultant to consider another alternative for Phase 2 conveyance.

5.6.1 Broad Overview of the Canal options

The Consultant has considered replacing the river conveyance with a canal along the preferred Western Routes ACE and ACF with the canal running near the river, however outside of the high flood level. In addition to replacing the river conveyance with a canal, canals were also considered for some sections of the gravity pipeline between the Vaal River and Botswana. Canals in place of pipelines may reduce the overall capital cost of the project as the canal has a lower capital cost per km than the pipeline, however the water losses and environmental impacts will be higher with a canal.

Canal options were investigated for routes ACE and ACF for both the high and low water transfer scenarios. The new canal options for routes ACE and ACF are shown on **Figure 5-28** below. The green lines indicate potential canal sections.

Review of route 3ACE with canals

The total length of the route for 3ACE is approximately 775 km with canals only replacing the river conveyance section; if canals are used to also replace the section from Bloemhof Dam to Botswana, the conveyance route will be 873 km.

The river conveyance through the Groot Vet, Sand River, and the Vaal will be replaced with a 316 km canal.

A second option was also to replace some of the existing pipeline from Bloemhof Dam to Botswana where the pipe reaches the top of the catchment divide between the Vaal and Molopo Rivers. This will extend the canal length to 638 km.

Review of route 3ACF with canals

The total length of the route for 3ACE is approximately 712 km with canals only replacing the river conveyance; if canals are used to also replace the section from Vaal River to Botswana, the conveyance route will be 831 km.

The river conveyance through the Groot Vet and Sand River will be replaced with a 226 km canal.

A second option was to also replace some of the existing pipeline from Bloemhof Dam to Botswana where the pipe reaches the top of the catchment divide between the Vaal and Molopo Rivers. This will extend the canal length to 511 km.

Along much of the proposed river conveyance route there is an existing irrigation canal. The canal is approximately 112 km and starts at Erfenis Dam and ends almost at the confluence of the Groot Vet and Sand River. The canal will require upgrading or duplicating to achieve the additional flow requirements needed for the L-BWT.

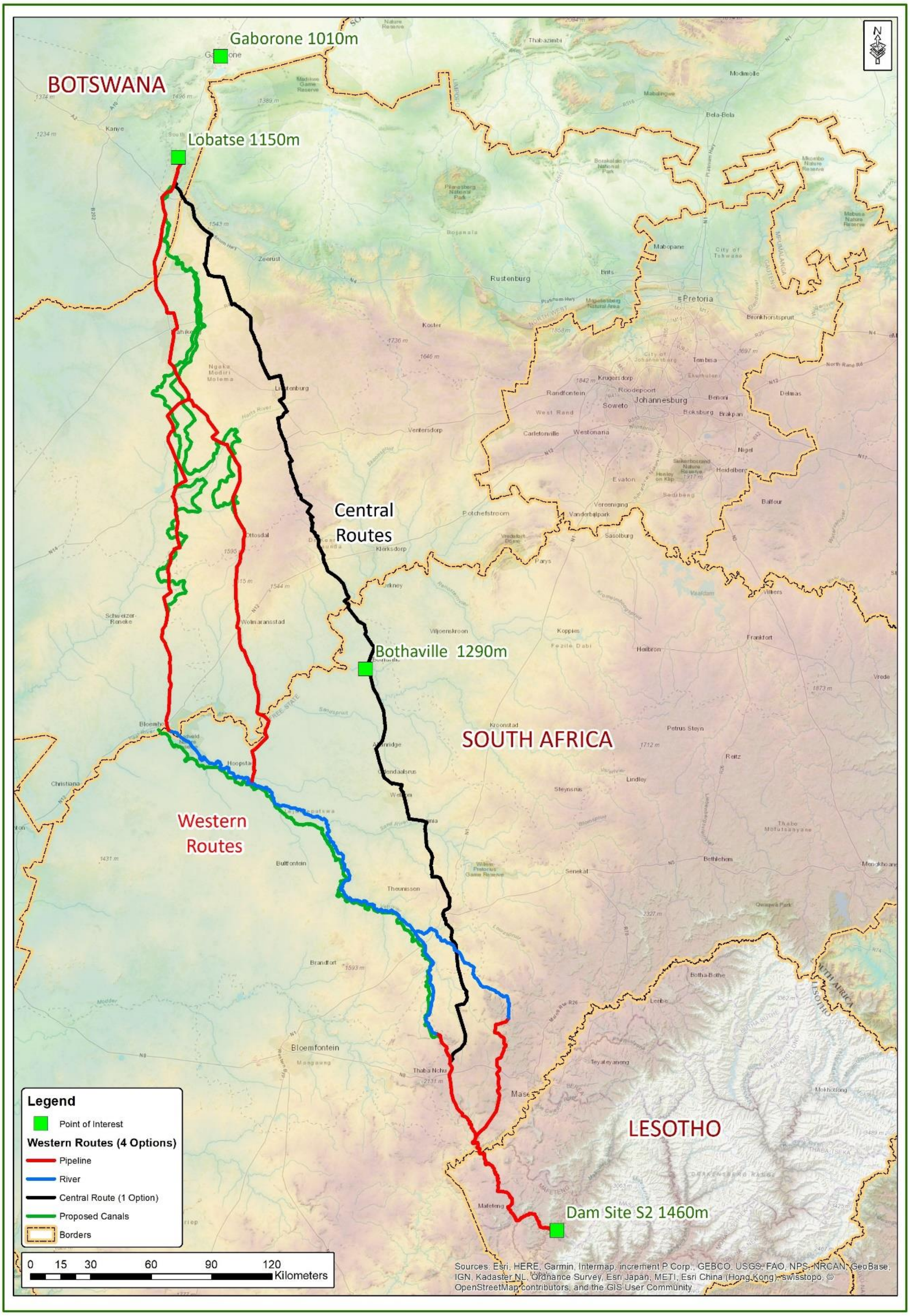


Figure 5-28: L-BWT Conveyances (Canal Options)

5.6.2 Comment on Western Canal Routes

For both the ACE and ACF routes, canal sections were investigated to replace both the river conveyance and section of gravity pipeline as indicated on **Figure 5-29** and **Figure 5-30**.

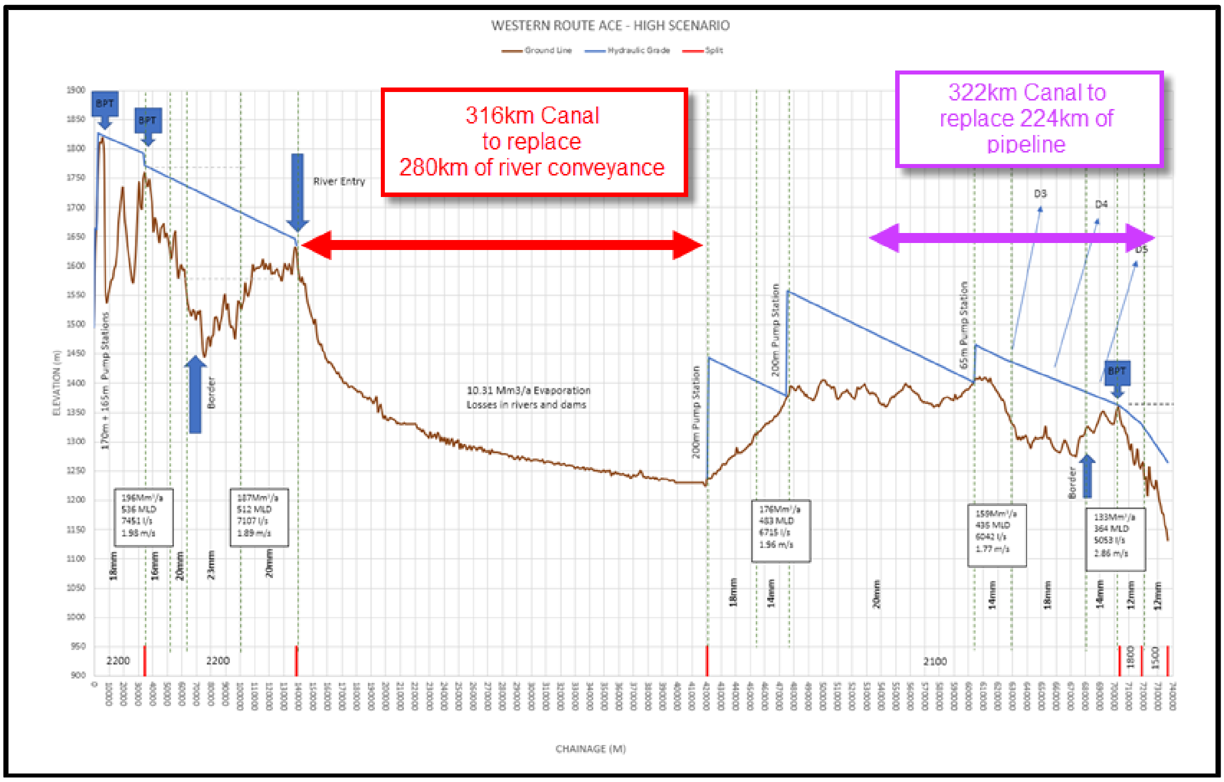


Figure 5-29: Western Route Option ACE Hydraulic Profile – Canal Options

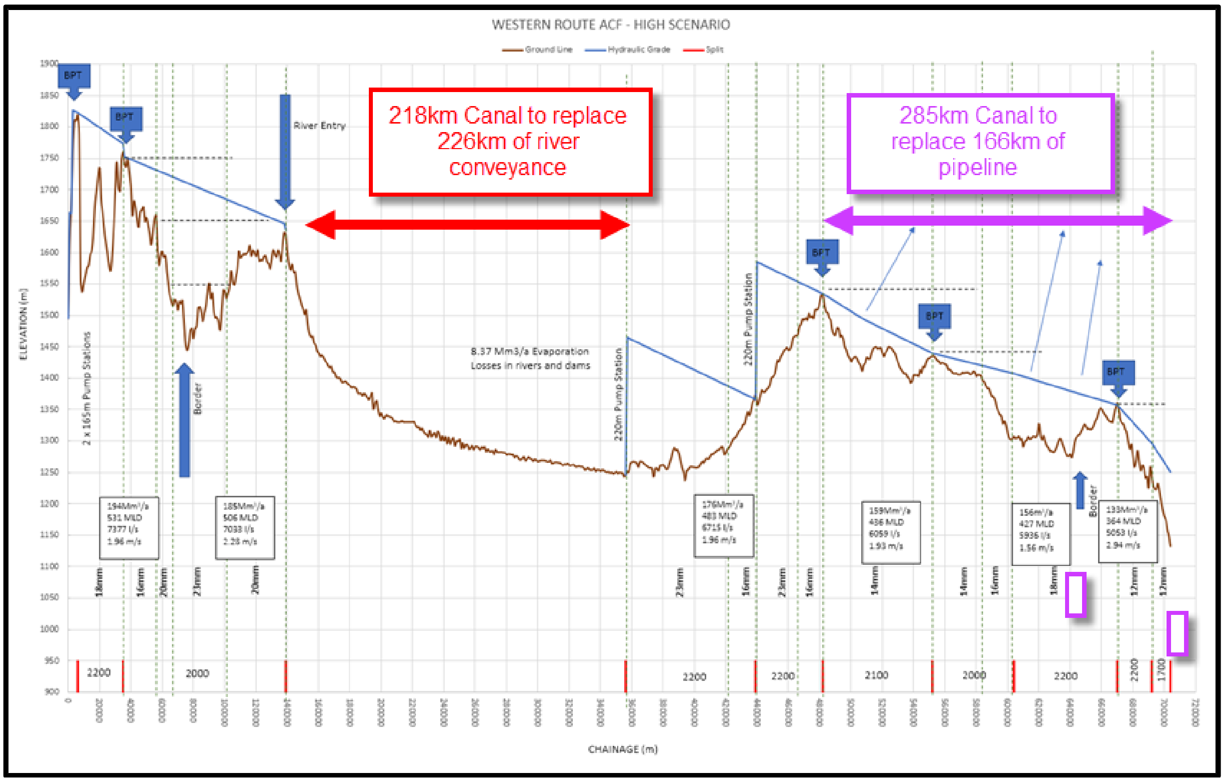


Figure 5-30: Western Route Option ACF Hydraulic Profile – Canal Options

The canal routes were selected based on the SRTM contours with siphons to cross valleys. The main characteristics of the conveyances with the canals are provided in **Table 5-22**.

Table 5-22: Conveyance Route Data with canal options

Conveyance Route Characteristics						
Options	Conveyance Route	Total Length of Pipe	Length of River	Length of canal	Total Length	Total Head Pumped
		(km)	(km)	(km)	(km)	(m)
Pipeline only	Central Route	684	0	0	684	725
Pipeline & River	Western Route ACE	459	280	0	739	735
	Western Route ACF	486	218	0	704	770
New options using canals as conveyances						
Pipeline & canal (instead of river)	Western Route ACE	459	0	316	775	735
	Western Route ACF	486	0	226	712	770
Pipeline & canal (+ end section)	Western Route ACE	235	0	638	873	735
	Western Route ACF	320	0	511	831	770

5.6.3 High-level analysis of canal options

A high-level hydraulic analysis was carried out using the Low and High demand values to determine the canal dimensions. The hydraulic capacity for the canal was determined using the following water demand assumptions;

- High demand = 154 Mm^3/a (Botswana = 136 Mm^3/a, South Africa = 18 Mm^3/a)
- Low demand = 77 Mm^3/a (Botswana = 59 Mm^3/a, South Africa = 18 Mm^3/a)

The following factors were added to these demands to determine the hydraulic capacity;

- 15% losses for water treatment and pipeline losses
- 20 hrs pumping a day
- Net evaporation from the surface of the canal MAE at 1 700 mm & MAP at 550 mm.
- Seepage from the canal at 30 mm per m^2 of lining (USBR guidelines for canal design)

A trapezoidal canal section with a concrete lining was assumed, with a 2 m bottom width and side slopes of 1V:1.5H. A manning n for the concrete lining was assumed to be 0.015 and flow depth was calculated depending on the canal slope. A freeboard allowance of 0.5 m was included in the design as shown in **Figure 5-31** below.

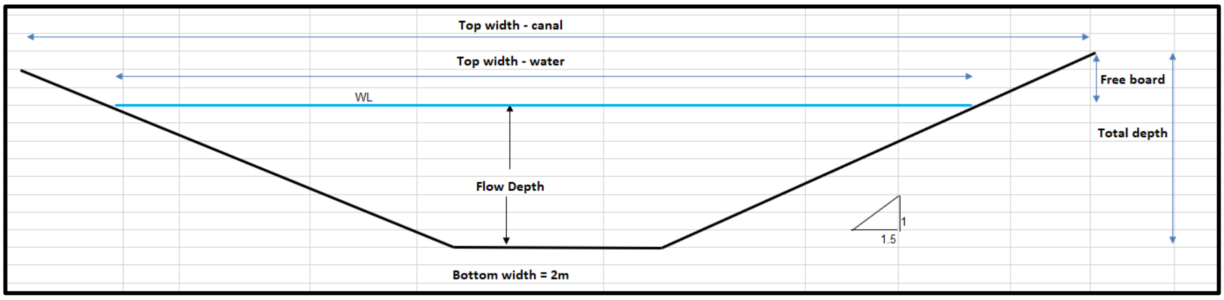


Figure 5-31: Typical Canal Cross section

The design flow capacities and losses for the canals are provided in **Table 5-23**. The design flow is inclusive of the seepage and evaporation losses. The canal losses include both seepage and evaporation losses. The river conveyance in **Table 5-23** only includes evaporation losses from the surface of the river.

Table 5-23: Design capacities and water losses for canal options

Conveyance Route Characteristics		High Scenario - Water Losses				Low Scenario - Water Losses			
Options	Conveyance Route	Design Flow Rate	Losses/km of canal	River/Canal Losses	River/Canal Losses	Design Flow Rate	Losses/km of canal	River/Canal Losses	River/Canal Losses
		(l/s)	(Mm^3/a)	(Mm^3/a)	(%)	(l/s)	(Mm^3/a)	(Mm^3/a)	(%)
Pipeline only	Central Route	7059		0	0	3705		0	0
Pipeline & River	Western Route ACE	7451		*10.31*	*6%*	4097		*10.31*	*12%*
	Western Route ACF	7377		*8.37*	*5%*	4023		*8.37*	*9%*
New options using canals as conveyances									
Pipeline & canal (instead of river)	Western Route ACE	7729	0.0979	30.9	17%	4061	0.0685	21.6	24%
	Western Route ACF	7354	0.0846	19.1	11%	5036	0.0680	15.4	17%
Pipeline & canal (+ end section)	Western Route ACE	8769	0.1000	63.8	36%	3861	0.0822	52.4	59%
	Western Route ACF	8300	0.0957	48.9	28%	4640	0.0781	39.9	45%

5.6.4 Financial Data of the canal options

The cost of the canal was estimated by measuring the quantities and applying unit rates.

The Western route ACE with a canal instead of the river conveyance will add a cost of R 8 billion to ACE option. ACE with canal instead of river conveyance is about R 34 billion. This cost could be reduced to R 30 billion if some of the gravity pipeline is replaced with a canal. However, the water losses will be much higher from the additional canal compared with a pipeline.

The Western route ACF with a canal instead of the river conveyance will add R 5 billion to ACF option. The capital cost will then be about halfway between the fully piped section (R 37 billion) and the route ACF using the river conveyance (R 28 billion). ACF with canal instead of river conveyance is about R33 billion. This cost could be reduced to R 32 billion if some of the gravity pipeline is replaced with a canal. However, the water losses will be much higher from the additional canal compared with a pipeline.

The financial data for the Canal options is provided in **Table 5-24.**

Table 5-24: Capital Cost Estimates for Central Route

Conveyance Route Characteristics		High Scenario - Cost estimates + URVs			Low Scenario - Cost estimates + URVs		
Options	Conveyance Route	Canal Capital Cost	Total Capital Cost	URV	Canal Capital Cost	Total Capital Cost	URV
		(million Rands)	(million Rands)	(R/m^3)	(million Rands)	(million Rands)	(R/m^3)
Pipeline only	Central Route	0	37 239	25.47	0	26444	33.17
Pipeline & River	Western Route ACE	0	25 713	18.04	0	19 844	23.46
	Western Route ACF	0	27 823	19.19	0	19 922	24.08
New options using canals as conveyances							
Pipeline & canal (instead of river)	Western Route ACE	8 089	33 802	23.43	6 267	26 111	29.85
	Western Route ACF	5 341	33 164	23.05	4 162	24 084	27.78
Pipeline & canal (+ end section)	Western Route ACE	16 505	30 038	20.32	13 102	23 475	27.16
	Western Route ACF	12 940	32 331	21.74	10 191	24 339	28.67

6 MULTI CRITERIA ANALYSIS

6.1 DAM SITE SELECTION

As there are multiple parameters which influence the selection of the best dam sites on the Makhaleng River, a weighted multi-criteria analyses (MCA) technique was used to rank the suitability of the sites so that two sites could be for more detailed investigation. This process was used for two dam capacities at each site (200 million m^3/a and a dam capacity equal to 3 times MAR). The criteria selected were weighted according to their relative importance. If the weighting of the criteria changes, so may the optimum site.

The criteria selected for the MCA and their weightings for a dam capacity capable of supplying 200 million m^3/a were:

- Unit reference value of water (dam) (15%)
- Founding Conditions (15%)
- Proximity to Construction Materials (10%)
- Sedimentation Risks (10%)
- Ecological Impacts (10%)
- Socio-economic impact (10%)
- Strategic (15%)
- Conveyance to Common Point (URV) (15%)

The criteria selected for the MCA and their weightings for a dam capacity equivalent to three times the MAR were:

- Unit reference value of water (dam) (15%)
- Yield (10%)
- Founding Conditions (10%)
- Proximity to Construction Materials (10%)
- Sedimentation Risks (10%)
- Ecological Impacts (10%)
- Socio-economic impact (10%)
- Strategic (10%)
- Conveyance to Common Point (URV) (15%)

Each criterion was rated against a five-tier rating system as follows:

Highly favourable	4
Favourable	3
Moderately favourable	2
Unfavourable	1
Unacceptable	0

URV: The dam with the lowest URV received a score of 4. Each other dam with a higher URV received a score relative to the lowest:

$$\text{URV. Score} = \text{URV}_{\text{lowest}} \text{ divided by } \text{URV}_{\text{site}} \times 4$$

Potential Yield: The dam with the highest yield scored a 4 and the other dams scored relative to the highest yield. The potential yield increased as the catchment increased in size. This parameter was not required for the dams which were sized to yield 200 million m^3/a.

Founding Conditions: Founding conditions at each site were based on a Geotechnical Engineer's expert opinion after the site visit and from studying the 1:250 000 geological map of Southern Lesotho. The founding conditions tended to be better in the higher parts of the catchment.

Proximity to Construction Materials: Proximity to Construction Materials at each site was based on a Geotechnical Engineer's expert opinion after the site visit and the 1:250 000 geological map of Southern Lesotho. Access to concrete aggregates also tended to be better in the higher portions of the catchment, were the sites where closer to the Basalt.

Sedimentation Risks: These were based on the sediment yield map of Southern Africa and the satellite images of the catchment. The sedimentation risks increased as the catchment increased in size. The condition of the catchment vegetation deteriorated as you move further down the catchment.

Ecological Impact: Ecological impacts at each site were based on a specialist's opinion after the site visit and after reviewing available satellite images. The ecological condition of the river tended to be better in the higher portions of the catchment.

Socio-economic Impact: Socio-economic impacts at each site were based on a specialist's opinion after the site visit and after reviewing available satellite images. The dam sites in the lower portions of the catchment tended to be impacted more as they had more people and infrastructure, with the exception of the most upstream site which also had significant social issues.

Strategic: The sites higher in the catchment were given a higher score due the advantage of being at a higher elevation which results in more options to transfer the water at lower energy costs via tunnelling options. The evaporation losses are also lower at the higher the dam site. The higher the dam site the greater the potential to develop dam sites downstream at a later stage.

Incremental impact on conveyance route URV: The final parameter selected in the MCA was the incremental cost of the conveyance from the dam site to the common connection point of the water conveyance to Botswana.

$$\text{Score} = \text{URV}_{\text{lowest}} \text{ divided by } \text{URV}_{\text{site}} \times 4$$

Table 6-1 shows the results of the MCA for the dam with a yield of 200 million m^3/a. Site S1 is shown to score the highest followed by site N1. The low URVs are because of the deep valleys with relatively good founding conditions. The “D” sites score very low because of the high URVs, the high social impact, the poor founding conditions and the relative remoteness to construction materials, and the sedimentation potential.

Table 6-2 shows the results of the MCA for the dam which maximises the yield available from the site. Site S2 is shown to score the highest (costed on a CFRD option) followed by site S1 and then by N1 (both costed on RCC gravity dam options). The “D” sites score very low because of the high URVs, the high social impact, the poor founding conditions and the relative remoteness to construction materials. The lower sites also have a significantly higher sedimentation risk as the lower catchment’s land cover is in a much poorer condition as compared to the upstream catchments more in the mountains.

The ranking of the weighted selection criteria for each dam site at two different capacities is summarised in **Table 6-3**.

Table 6-1: Multi Criteria Analyses for Dam with a Yield of 200 million m³/a

DAM SITE	SELECTION CRITERIA for 200 million m³/a Yield Option								
	1. URV (ratio of R/m³)	2. Founding Conditions	3. Proximity to Construction Materials	4.Sedimentation Risks	5. Ecological Impacts	6. Socio-economic impacts	7. Strategic	8. Incremental impact on conveyance route URV (ratio of R/m³)	9. Final Score
Weighting (%)	15	15	10	10	10	10	15	15	-
Lower 2004	0.69	3	3	3	1	1	2	4.00	56.3
N1a	3.35	3	3	2	1	3	2	2.41	62.9
N1	1.95	3	3	2	1	3	2	2.41	57.6
N2	1.60	2	3	2	1	3	2	2.41	52.5
N3	1.85	2	3	2	1	3	2	2.41	53.5
N4	1.84	1	3	2	1	2	2	2.41	47.2
TOR	2.23	2	2	2	2	2	2	2.41	52.4
S4	3.43	2	2	2	2	2	2	2.41	56.9
S3	1.74	1	2	2	2	2	2	2.81	48.3
S2	3.19	2	2	2	2	2	2	2.89	57.8
S1	4.00	2	2	2	2	2	2	2.96	61.1
S1a	2.17	2	2	2	2	2	2	2.41	52.2
D4	1.37	1	1	1	3	1	1	2.76	38.0
D3	2.06	1	1	1	3	1	1	2.66	40.2
D2	3.54	1	1	1	3	0	1	2.44	41.2

Table 6-2: Multi Criteria Analyses for Dam With a Storage Capacity Equivalent to 3 MAR

DAM SITE	SELECTION CRITERIA for Maximum Yield Option (Dam capacity = 3 x MAR)									
	1. URV (ratio R/m³)	2. Yield (ratio of million m³/a)	3. Founding Conditions	4. Proximity to Construction Materials	5. Sedimentation Risks	6. Ecological Impacts	7. Socio-economic impacts	8. Strategic	9. Incremental impact on conveyance route URV (ratio R/m³)	10. Final Score
Weighting (%)	15	10	10	10	10	10	10	10	15	-
Lower 2004	0.9	1.4	3	3	3	1	1	2	4.00	54.3
N1a	3.0	2.2	3	3	2	1	3	2	2.41	60.9
N1	1.7	2.3	3	3	2	1	3	2	2.41	56.1
N2	1.4	2.3	2	3	2	1	3	2	2.41	52.8
N3	1.6	2.3	2	3	2	1	3	2	2.41	53.2
N4	1.5	2.6	2	3	2	1	2	2	2.41	51.1
TOR	1.8	2.6	2	2	2	2	2	2	2.41	52.1
S4	2.6	2.6	2	2	2	2	2	2	2.41	55.5
S3	1.3	2.7	1	2	2	2	2	2	2.81	49.8
S2	4.0	2.6	2	2	2	2	2	2	2.89	62.4
S1	2.9	2.7	2	2	2	2	2	2	2.96	58.6
S1a	1.9	2.6	2	2	2	2	2	2	2.41	52.9
D4	1.3	3.1	1	1	1	3	1	1	2.76	43.0
D3	1.5	3.1	1	1	1	3	1	1	2.66	43.3
D2	1.4	4.0	1	1	1	3	0	1	2.44	40.8

Table 6-3: Dam Site Ranking According to the Weighted Selection Criteria

DAM SITE	Dam Capacity = 200 million m^3/a yield	RANKING	Dam at Max. Capacity	RANKING
Lower 2004	56.3	6	54.3	6
N1a	62.9	1	60.9	2
N1	57.6	4	56.1	4
N2	52.5	8	52.8	9
N3	53.5	7	53.2	7
N4	47.2	12	51.1	11
TOR	52.4	9	52.1	10
S4	56.9	5	55.5	5
S3	48.3	11	49.8	12
S2	57.8	3	62.4	1
S1	61.1	2	58.6	3
S1a	52.2	10	52.9	8
D4	38.0	15	43.0	14
D3	40.2	14	43.3	13
D2	41.2	13	40.8	15

Table 6-3 is presented in graphical form in **Figure 6-1** below.

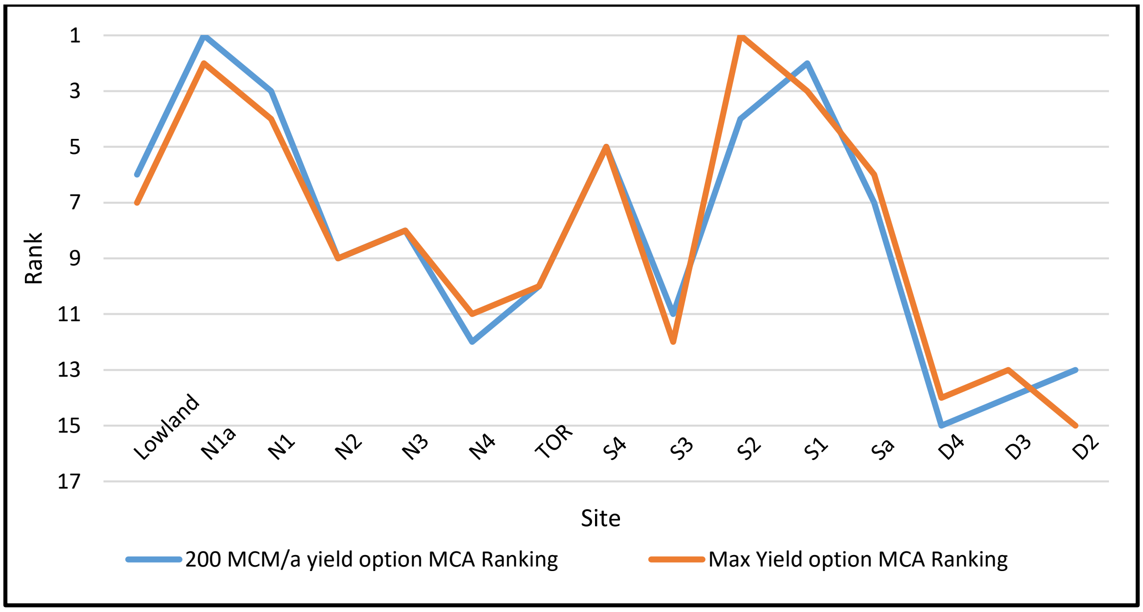


Figure 6-1: MCA Ranking of the Dam Options for Both Yield Options

6.2 CONVEYANCE ROUTE SELECTION

The conveyance route financial results, albeit important, form only one aspect of the assessment of each route. An MCA analysis was undertaken on all routes. The results are presented in **Table 6-4** and **Table 6-5**, with the MCA criteria summarised in **Table 6-8**.

Table 6-4: MCA Results: High Scenario

	URV:	Demand-dist. factor:	Suscep-tible to unauth-orised drawoff	Water Quality	River losses	Energy efficien-cy:	Social impact:	Ecolog-ical impact:	Overall rating:	Rank-ing
Weighting:	*20%*	*10%*	*20%*	*15%*	*5%*	*10%*	*10%*	*10%*	*100%*	
Central route	2.8	2.0	4.0	4.0	4.0	4.0	1.0	3.5	80.4	*1*
Western ACE	4.0	4.0	1.1	1.1	1.1	3.6	3.0	1.5	61.2	*4*
Western ACF	3.8	3.0	2.2	2.2	2.2	3.8	2.0	1.5	66.6	*2*
Western BDE	3.6	4.0	1.0	1.0	1.0	2.9	3.0	2.0	58.0	*5*
Western BDF	3.5	3.0	2.0	2.0	2.0	3.1	2.0	2.0	62.8	*3*

Table 6-5: MCA Results: Low Scenario

	URV:	Demand-dist. factor:	Suscep-tible to unauth-orised drawoff	Water Quality	River losses	Energy efficien-cy:	Social impact:	Ecolog-ical impact:	Overall rating:	Rank-ing
Weighting:	*20%*	*10%*	*20%*	*15%*	*5%*	*10%*	*10%*	*10%*	*100%*	
Central route	2.8	2.0	4.0	4.0	4.0	4.0	1.0	3.5	80.4	*1*
Western ACE	4.0	4.0	1.1	1.1	1.1	3.8	3.0	2.0	62.9	*4*
Western ACF	3.9	3.0	2.2	2.2	2.2	3.6	2.0	2.0	68.1	*2*
Western BDE	3.8	4.0	1.0	1.0	1.0	3.1	3.0	2.5	60.5	*5*
Western BDF	3.7	3.0	2.0	2.0	2.0	3.0	2.0	2.5	64.7	*3*

The MCA was revised with the canal options added to Western Routes ACE and ACF. The results are presented in **Table 6-6** and **Table 6-7**, with the MCA criteria summarised in **Table 6-8**.

Table 6-6: MCA Results with canal conveyances: High Scenario

High Demand Scenario											
Conveyance	River	URV:	Demand-dist. factor:	Susceptible to unauthorised drawoff	Water Quality	River/canal losses	Energy efficiency:	Social impact:	Ecological impact:	Overall rating:	
		20%	*10%*	*20%*	*15%*	*5%*	*10%*	*10%*	*10%*	*100%*	
Central route		2.8	2.0	4.0	4.0	4.0	4.0	1.0	3.5	80.4	*1*
Western ACE	Groot Vet/Sand/Vaal	4.0	4.0	1.1	1.1	1.1	3.6	3.0	1.5	61.3	*8*
Western ACF	Groot Vet/Sand	3.8	3.0	2.2	2.2	2.2	3.8	2.0	1.5	66.6	*6*
Western BDE	Klein Vet/Sand/Vaal	3.8	4.0	1.0	1.0	1.0	2.9	3.0	2.0	58.6	*9*
Western BDF	Klein Vet/Sand	3.6	3.0	2.0	2.0	2.0	3.1	2.0	2.0	63.5	*7*
New options using canals as conveyances for River Section plus additional canal sections											
Western ACE	Canal instead of River Section	3.1	4.0	3.0	3.0	3.0	3.6	2.5	2.5	76.9	*3*
Western ACF	Canal instead of River Section	3.1	3.0	3.2	3.2	3.4	3.8	3.0	3.0	79.9	*2*
Western ACE	Extra canal to replace pipeline	3.6	4.0	2.6	2.6	2.2	3.6	1.5	1.5	69.8	*5*
Western ACF	Extra canal to replace pipeline	3.3	3.0	2.8	2.8	2.6	3.8	2.0	2.0	71.3	*4*

Table 6-7: MCA Results with canal conveyances: Low Scenario

Low Demand Scenario											
Conveyance	River	URV:	Demand-dist. factor:	Susceptible to unauthorised drawoff	Water Quality	River/canal losses	Energy efficiency:	Social impact:	Ecological impact:	Overall rating:	Rank:
		20%	*10%*	*20%*	*15%*	*5%*	*10%*	*10%*	*10%*	*100%*	
Central route		2.8	2.0	4.0	4.0	4.0	4.0	1.0	3.5	80.4	*2*
Western ACE	Groot Vet/Sand/Vaal	4.0	4.0	1.1	1.1	1.1	3.6	3.0	1.5	61.3	*8*
Western ACF	Groot Vet/Sand	3.9	3.0	2.2	2.2	2.2	3.8	2.0	1.5	67.2	*5*
Western BDE	Klein Vet/Sand/Vaal	3.8	4.0	1.0	1.0	1.0	2.9	3.0	2.0	58.7	*9*
Western BDF	Klein Vet/Sand	3.7	3.0	2.0	2.0	2.0	3.1	2.0	2.0	63.7	*7*
New options using canals as conveyances for River Section plus additional canal sections											
Western ACE	Canal instead of River Section	3.1	3.0	3.0	3.0	3.0	3.6	2.5	2.5	74.7	*3*
Western ACF	Canal instead of River Section	3.4	3.0	3.2	3.2	3.4	3.8	3.0	3.0	81.1	*1*
Western ACE	Extra canal to replace pipeline	3.5	3.0	2.6	2.6	2.2	3.6	1.5	1.5	66.8	*6*
Western ACF	Extra canal to replace pipeline	3.3	3.0	2.8	2.8	2.6	3.8	2.0	2.0	71.1	*4*

Table 6-8: Conveyance MCA Criteria

MCA Factor:	Weight:
Unit reference value: The URV is a financial indicator of the value for money in relation to volume of water supplied. The URV is not a tariff.	20%
Water demand – Distance ratio: The water demands for each cluster/region in relation to the distance from each conveyance route centre-line was quantified.	10%
Susceptibility to unauthorised draw-off: River conveyance supply is susceptible to unauthorised draw-off from rivers. This is considered to be a major threat by the Client and has been weighted accordingly.	20%
Water Quality: Water quality may deteriorate dependent on the extent of the route that is piped. For the Western options, the condition of the rivers through which it will be transported play a key role.	15%
River Losses: The Western run-of river options will experience significant losses through evaporation and seepage. This MCA factor accounts for these losses.	5%
Energy efficiency: Energy inflation in Southern Africa is likely to exceed CPI for the foreseeable future. A factor was therefore introduced which ranked the routes in relation to their annual energy requirements.	10%
Social impact: The impact of each route on farming activities and communities was assessed.	10%
Ecological impact: The impact of each route on wetlands and protected areas was assessed. Negative ecological impacts were considered to be mitigated if a conveyance route occurred alongside an existing linear development.	10%

7 CONCLUSIONS

7.1 WATER REQUIREMENTS

The net water requirements for Botswana in 2050 that were selected to be used for Phase 1 of the Prefeasibility Report range from 59 million m^3/a for the low scenario to 136 million m^3/a for the High Scenario. This estimate excludes water treatment losses (10%) and conveyance losses (5%). For the High Scenario, approximately 80% of the water requirement is for Botswana with about 10% each for South Africa and Lesotho.

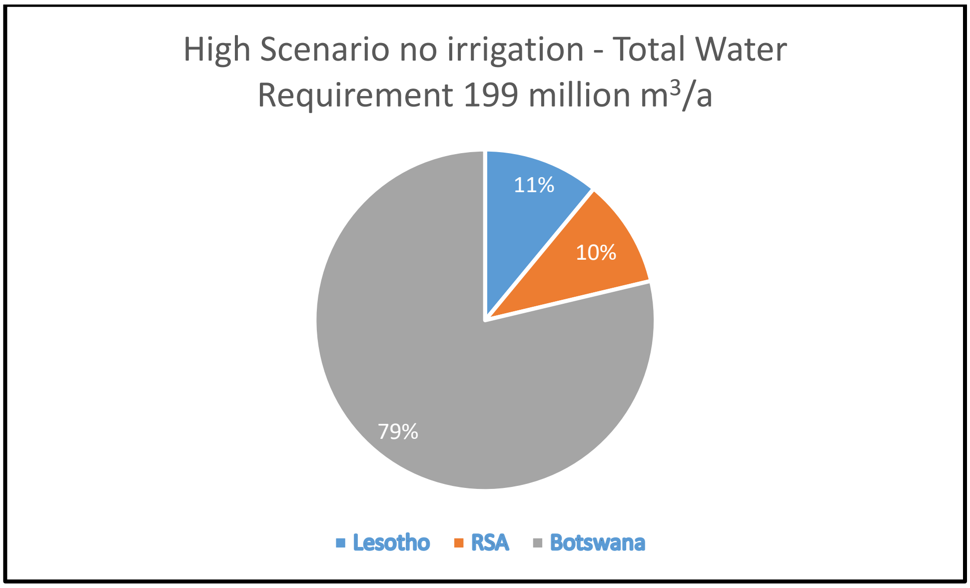


Figure 7-1: L-BWT Project Net Water Requirements 2050 for High Scenario

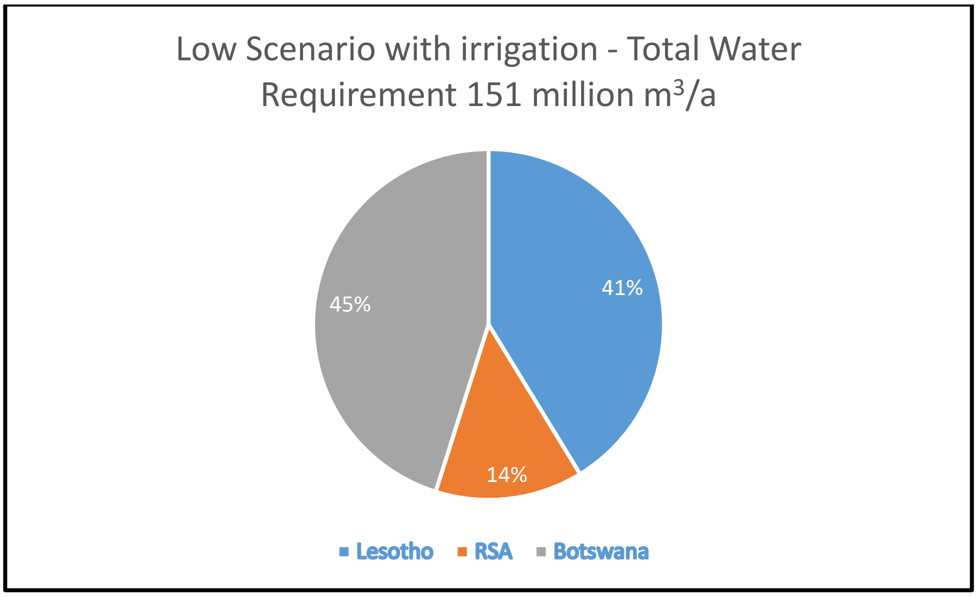


Figure 7-2:L-BWT Project Net Water Requirements 2050 for Low Scenario with Lesotho irrigation

It is important to note that the Low Scenario were considered as an alternative to the option that requires an additional development to supply the mitigation or part of the mitigation releases to restrore the water balance of the downstream users. For the Low Scenario all the required mitigation releases can be made from Mahaleng Dam. The Low Scenario also allows for the development of irrigation in Lesotho. The net yield from a possible Makhaleng Dam for the Low Scenario allows for the inclusion of about 40 million m^3/a for irrigation, which is approximately half of the possible maximum irrigation area downstream of Makhaleng Dam. For this scenario the allocations to Botswana and Lesotho are both over 40% with only 14% to the RSA.

DWS RSA requested that the option of augmenting the Greater Bloemfontein System from the L-BWT scheme pipeline also be tested as a possible additional RSA water requirement. This means that the RSA augmentation requirement from the L-BWT scheme pipeline will then have to be increased by another 43 million m^3/a by 2050. The current RSA planning is to transfer the 43 million m^3/a from Gariep Dam to Bloemfontein. Whether the 43 million m^3/a transfer to the Greater Bloemfontein is taken from Gariep Dam or from Makhaleng Dam, the resulting impact on the ORP will be more or less the same.

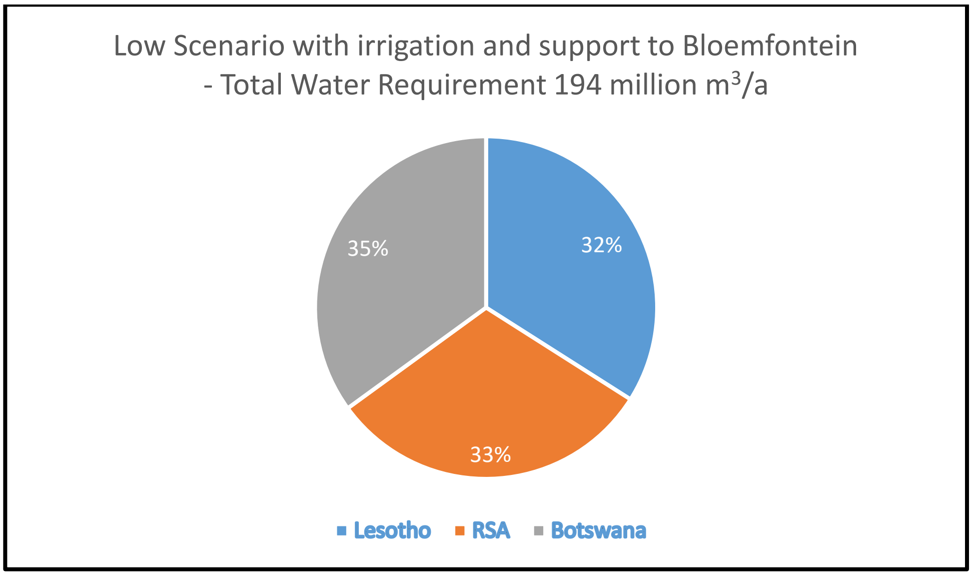


Figure 7-3: Low Scenario with support to Greater Bloemfontein – 2050 Net Water Requirements

This means that the Lesotho irrigation to be supported from Makhaleng Dam can remain the same as determined for the Low Scenario with irrigation as presented in **Figure 7-2**. When the Low Scenario is used to also augment the Greater Bloemfontein, the RSA, Botswana, and Lesotho proportions are almost similar, being just above 30% (**Figure 7-3**).

The Ecological Status was estimated to be a D, which represents the response of the biota to the lack of habitat diversity due to sedimentation from overgrazing, erosion, and removal of riparian vegetation, as well as the presence of alien vegetation in the riparian zone.

The Revised Desktop Reserve Model (RDRM, v2) was used to estimate the EWR requirements for the site. This was done for a B, C, and D Ecological statuses. If releases are made to achieve the B status, it will have a major impact on the yield of the dam, whereas a D would have a minor impact. These impacts will also depend on how Makhaleng Dam is operated. In the case where Makhaleng Dam is also used to mitigate the negative water balance in the Orange River project (ORP) as result of the transfer to Botswana and RSA, significant mitigation releases from Makhaleng Dam will be required to support the ORP. In this case the mitigation releases for support purposes will most probably be sufficient to achieve EWR flows for a B or C ecological class downstream. It is quite possible that this option will be followed, in which case the higher ecological class will not have a significant impact on the net yield available from Makhaleng Dam.

7.2 DAM SITE SELECTION

Fifteen sites were identified for investigation. The sites are divided into three groups;

1. Lowlands – 2004 study (Northern) site = Lowlands 2004
2. TOR group of sites (Central) = S1a, S1, S2, S3, S4, TOR, N1a, N1, N2, N3, and N4.
3. Reconnaissance (Southern) group of sites = D2, D3, and D4.

A site inspection was done on all fifteen sites in Mid-November 2018.

Two dam sizes were investigated at each site:

- A dam capacity set to meet a water requirement of 200 million m^3/a (or the long-term net water requirement)
- A dam capacity set to maximize the available yield from the site equivalent to 3 times the MAR.

For each dam site a complete set of technical data was determined in order to compare the sites for the purpose of selecting two sites for more detailed investigation in the next phase of the feasibility study. These estimations were made on the information available; it should be noted that there is no detailed topographic information (LiDAR survey) or geotechnical information (Site investigations) available at the sites investigated.

The sites in the upper catchment had the advantage of less social impact, better geological conditions, closer proximity to construction materials, lower sedimentation risks, lower conveyance costs, smaller design floods and less evaporation.

The sites in the lower catchment had the advantage of less environmental impact, greater run off at the site and therefore higher yields.

The sites with the narrower valleys had lower unit cost per available yield. Site S2 has the advantage of a natural side channel spillway if the dam is built to a large capacity to reach the elevation of the saddle.

7.3 WATER RESOURCE ASSESSMENT

The latest available data was collected from the streamflow gauge MG23 and D1H006 and compared to the values generated by the WRYM model of the catchment. The latest measured runoff was found to compare reasonably well with the data in the existing catchment model.

A storage yield relationship was developed for the lowlands site, N1, TOR site, S2, and D4. The maximum yield from any of the sites was achieved at about three times the MAR. From these relationships, the height of a dam to achieve a yield of 200 million m^3/a was determined as well as the height of a dam to achieve the maximum yield. In **Table 7-1**, the upstream dams have lower MARs, and require higher dams to achieve a yield of 200 million m^3/a; they also have lower maximum yields.

Table 7-1: Dam Site – MAR, Dam Height to Achieve a 200 million m^3/a Yield, Maximum Yield and Dam Height to Achieve the Maximum Yield

Site	MAR	Dam height for 200 million m^3/a local yield	Maximum Local Yield	Dam height for maximum local yield
	(million m^3/a)	(m)	(million m^3/a)	(m)
Lowlands	241	129	209	136
N1a	378	84	334	126
N1	379	86	335	133
N2	381	78	346	123
N3	382	78	347	123
N4	418	76	380	127
TOR	419	74	381	125
S4	434	69	394	121
S3	439	74	399	127
S2	440	78	389	128
S1	443	74	402	127
S1a	460	79	407	130
D4	498	70	459	120
D3	507	71	467	121
D2	647	53	596	110

The impact on the yield of Gariep Dam was also analysed. If the Makhaleng Dam is constructed to:

- the height required to achieve the 218 million m^3/a transfer with the L-BWT, then the yield of the ORP system (Gariep and Vanderkloof dams) decreases by 175 million m^3/a, or
- the maximum height and 378 million m^3/a are transferred with the L-BWT, then the yield of the ORP system (Gariep and Vanderkloof dams) decreases by 252 million m^3/a, or
- the maximum height and 188 million m^3/a are transferred with the L-BWT, then the yield of the ORP system (Gariep and Vanderkloof dams) remains the same as a

significant portion of the local Makhaleng Dam yield is used to supply all the required mitigation releases.

The original total high scenario demand of 199 million m^3/a cannot be met without negatively impacting the ORP requirements if all the mitigation releases are to be made from Makhaleng Dam. If the demands are tempered with the total demand reduced to 188 million m^3/a, there will be a negligible negative impact on the ORP. Lesotho has expressed interest in new irrigation development, which further reduces the available yield for transfer purposes. If 17.2 million m^3/a is allocated to Lesotho irrigation, the available yield for transfer purposes reduces to 171 million m^3/a, a reduction of 14 %.

There are several different dam development options that have been identified (see

Figure 4-23) that can be used to mitigate the impact on the ORP on behalf of Makhaleng Dam. Results from these analyses showed that sufficient local yield can be generated at the proposed Makhaleng Dam site to supply the full requirement for the high transfer scenario and more (local yield of approximately 380 million m^3/a).

By utilizing any of the above-mentioned development options in combination with the large Makhaleng Dam, it is clear that the high Botswana Lesotho transfer option can easily be supplied from Makhaleng Dam without having negative impacts on downstream users. These options can in fact provide approximately an additional 100 million m^3/a and more for other use such as for irrigation developments in Lesotho or even support to the Greater Bloemfontein, etc.

It should be noted that these options will add to the total cost of the Makhaleng Scheme although the value and benefits from the additional yield from the dam will offset some of these costs and must also be taken into account in any financial analysis.

Table 7-2 provides the estimated capital cost and URV for a dam height to achieve a local yield of 200 million m^3/a and the maximum height at each site. The lowest URVs were achieved at sites N1a for the lower dam height and S2 for the maximum dam height.

Table 7-2: Dam Site – Capital Cost and URVs for Dam Height to Achieve a 200 million m³/a local Yield and Dam Height to Achieve the Maximum local Yield

Site	Dam height for 200 million m³/a yield	Dam height for 200 million m³/a yield	Dam height for maximum yield	Dam height for maximum yield
	(Rand millions)	URV (Rand/m³)	(Rand millions)	URV (Rand/m³)
Lowlands	6 060	3.63	7 117	4.08
N1a	1 247	0.75	3 359	1.21
N1	2 144	1.29	5 917	2.12
N2	2 617	1.57	7 192	2.49
N3	2 262	1.36	6 727	2.32
N4	2 276	1.36	7 555	2.39
TOR	1 871	1.12	6 469	2.04
S4	1 218	0.73	4 534	1.38
S3	2 405	1.44	8 932	2.68
S2	1 311	0.79	2 928	0.90
S1	1 044	0.63	4 212	1.26
Sa	1 927	1.16	6 124	1.86
D4	3 048	1.83	10 516	2.75
D3	2 030	1.22	9 624	2.47
D2	1 179	0.71	12 499	2.52

7.4 CONVEYANCE ROUTE SELECTION

Five conveyance routes were investigated, namely one Central route and four Western river conveyance routes with piped sections. Each route was assessed to determine its directness between source and destination. Sections of pipeline were rerouted to ensure accuracy of location alongside roads and to avoid infrastructure.

Two demand scenarios were considered, i.e. a Low and High demand scenario. For each of the Low and High demand scenarios, a hydraulic model was developed for each route and the conveyance infrastructure required for each option was determined, which included weirs, abstraction works, pump stations, pipelines and break pressure tanks. Capital and energy costs were determined and the NPVs and URVs were calculated.

The use of tunnels was considered, however initial indications are that the high capital cost of a tunnel will not be mitigated by the relatively low additional energy required to pump water over the high elevations in Lesotho.

The fully piped Central conveyance route is the most direct between Lesotho and Botswana and was calculated to have a capital cost of R 37.2 billion and a URV of R 25.47 /m^3 for the High scenario. The capital cost and URV for the Low scenario were R 26.4 billion and R 33.17 /m^3 respectively.

Western routes ACE, ACF, BDE, and BDF were assessed. Each route had variations in terms of location, length of pipe, length of river conveyance sections, and energy requirements. In addition, losses due to evaporation from the river conveyance sections were allowed for in the capital and operational costs of the Western routes. Route ACF was found to be the optimum route of the Western routes with a capital cost of R 27.8 billion and a URV of R 19.19 /m^3 for the High scenario. The capital cost and URV for the Low scenario were R 20.4 billion and R 24.08 /m^3 respectively for Route ACF.

If river conveyances are not acceptable, then the Western route ACF, with a 226 km canal, was found to be the optimum route. This route has a capital cost of R 33.2 billion and a URV of R 23.43 /m^3 for the High scenario. The capital cost and URV for the Low scenario were R 24.1 billion and URV of R 27.78 /m^3 respectively for Route ACF with canal.

Table 7-3: Summary of Western Routes with the Canal Considered for the High Demand Scenario

High Demand Scenario								
Conveyance	**River**	**Abstraction Point**	**Capital Cost**	**URV**	**Pipe km**	**River km**	**Canal km**	**Total km**
Central route			R 37 239	R 25	684	**0**	**0**	**684**
Western ACE	Groot Vet/Sand/Vaal	d/s Bloemhof	R 25 713	R 18	459	280	0	**739**
Western ACF	Groot Vet/Sand	u/s Bloemhoef	R 27 824	R 19	486	218	0	**704**
Western BDE	Klein Vet/Sand/Vaal	d/s Bleomhof	R 27 070	R 19	474	287	0	**761**
Western BDF	Klein Vet/Sand	u/s Bloemhoef	R 28 592	R 20	505	225	0	**730**
New options using canals as conveyances for River Section plus additional canal sections								
Western ACE	Canal instead of River Section		R 33 802	R 23	459	0	316	**775**
Western ACF	Canal instead of River Section		R 33 164	R 23	486	0	226	**712**
Western ACE	Extra canal to replace pipeline		R 30 038	R 20	235	0	638	**873**
Western ACF	Extra canal to replace pipeline		R 32 331	R 22	320	0	511	**831**

Table 7-4 Summary of Western Routes with the Canal Considered for the Low Demand Scenario

Low Demand Scenario								
Conveyance	**River**	**Abstraction Point**	**Capital Cost**	**URV**	**Pipe km**	**River km**	**Canal km**	**Total km**
Central route			R 26 444	R 33	684	**0**	**0**	**684**
Western ACE	Groot Vet/Sand/Vaal	d/s Bloemhof	R 19 844	R 23	459	280	0	**739**
Western ACF	Groot Vet/Sand	u/s Bloemhoef	R 19 922	R 24	486	218	0	**704**
Western BDE	Klein Vet/Sand/Vaal	d/s Bleomhof	R 20 428	R 25	0	287	0	**287**
Western BDF	Klein Vet/Sand	u/s Bloemhoef	R 20 564	R 25	0	225	0	**225**
New options using canals as conveyances for River Section plus additional canal sections								
Western ACE	Canal instead of River Section		R 26 111	R 30	459	0	316	**775**
Western ACF	Canal instead of River Section		R 24 084	R 28	486	0	226	**712**
Western ACE	Extra canal to replace pipeline		R 23 475	R 27	235	0	638	**873**
Western ACF	Extra canal to replace pipeline		R 24 339	R 29	320	0	511	**831**

7.5 MCA FOR DAM SITE SELECTION

The weighted MCA included URVs, yield potential, founding Conditions, Proximity to Construction Materials, Sedimentation Risks, Ecological Impact, Socio-Economic Impact, Strategic Factors, and the URV of the Conveyance.

For a dam with a height to achieve a yield of 200 million m^3/a, the MCA indicated that the N1a is the best site followed by S2.

For a dam set to a size to maximise the yield from the Makhaleng River, S2 is the best site followed by N1a.

7.6 MCA FOR CONVEYANCE ROUTE SELECTION

The weighted MCA considered URVs, demand-distance factors, unauthorised abstraction risk, water quality, river losses, energy efficiency, and social and environmental impacts. The MCA criteria are summarised in **Table 6-8**.

The MCA indicates that the Central fully piped route is the most favourable when compared with other routes against a basket of weighted factors for the high scenario.

The Western Route ACF is the most favourable piped/river conveyance routes.

The ranking of the Central and Western Route ACF is valid for both the Low and High scenarios.

The MCA was later revised to include the canal options for Western Routes ACE and ACF.

For the high scenario for the options including the canals, the most favourable route was the Central Piped Route and the second ranked route was the ACF with a canal only replacing the river conveyance.

For the low scenario for the options including the canals, the most favourable route was the ACF with a canal only replacing the river conveyance and the second ranked route was Central Piped Route

7.7 SUMMARY OF RECOMMENDED DAM OPTIONS

A summary of the key characteristics for the recommended dam options is presented in **Table 7-5** below (prices relevant to 2018).

Table 7-5: Key Characteristics of the Recommended Dam Options

Site	Height	Storage	Maximum local Yield	Maximum incremental Yield	Capital Cost	Local yield URV	Incremental yield URV
	(m)	(million m^3)	(million m^3/a)	(million m^3/a)	(million Rands)	(R/m^3)	(R/m^3)
N1a	126	1 133	334	137	3 359	1.21	3.01
N1	133	1 137	335	138	5 917	2.12	5.29
S2	128	1 319	389	158	2 928	0.90	2.26
S1	127	1 328	402	160	4 212	1.26	3.14

7.8 SUMMARY OF RECOMMENDED CONVEYANCE OPTIONS

A summary of the high scenario and the low scenario are presented in **Table 7-6** and **Table 7-7** respectively, with the high scenario supplying 185 million m^3/a and the low scenario supplying 97 million m^3/a.

Table 7-6: Key Characteristics of the Preferred Conveyance Routes for the High Scenario

Conveyance option	Maximum Pipe Diameter	Total Length of Pipe	Length of Canal	Total Head Pumped	Capital Cost	URV
	(mm)	(km)	(km)		(million Rands)	(R/m^3)
Central Route	2 200	685	0	725	37 239	25.47
Western Route ACF with canal	2 300	486	226	910	33 164	23.43

Table 7-7: Key Characteristics of the Preferred Conveyance Routes for the Low Scenario

Conveyance option	Maximum Pipe Diameter	Total Length of Pipe	Length of Canal	Total Head Pumped	Capital Cost	URV
	(mm)	(km)	(km)		(million Rands)	(R/m^3)
Central Route	1 700	685	0	735	26 443	33.17
Western Route ACF with canal	1 700	486	226	935	24 084	27.78

8 RECOMMENDATIONS

The Botswana water requirements are largely dependent on growth in the mining sector and associated growth in the neighbouring towns and urban centres.

The Botswana mining sector is predominantly dependent on groundwater and the mining houses have expressed their intention to utilize groundwater resources as far as possible for economic reasons. A detailed geohydrological and water balance study per mine site should be considered in the Feasibility Phase to determine the sustainable groundwater exploitation potential, derive a water balance, and then determine the final augmentation requirements for the mines.

It is recommended that a large Makhaleng Dam (approx. 3 MAR) should be built to provide more flexibility in the system as well as to support additional irrigation in Lesotho. It should be noted that water supplied in a northerly direction from the Makhaleng Dam will be used predominantly for urban and industrial purposes. Such water carries a very high value which will typically be in the order of R10/m^3 but can be as high as R70/m^3 at 2022 tariffs.

The conveyance route from Lesotho to Botswana should be sized to meet the high scenario water requirements.

The proposed Makhaleng Dam can supply more than the full requirement for the high transfer scenario (local yield of approximately 380 million m^3/a). Some additional development will, however, be required to mitigate the loss in yield from the downstream resources which should be investigated in a separate study. Several promising options have been identified in this study and should be investigated in a separate study running in parallel with the Feasibility Study.

The cost of the dam and the relative URV is an order of magnitude smaller than that of the conveyance infrastructure. This further supports the recommendation for the large dam that maximises the yield from the Makhaleng River, provides a higher assurance of supply and more flexibility with regard to mitigating downstream users. It provides more hydropower potential and will also be similar to the existing and planned development of the other transfer dams in the Lesotho Highlands which are all relatively large with respect to their catchment run-off.

An MCA workshop was held with the JSMC to decide on the MCA factors and their weighting factors in Botswana on the 26th & 27th May 2019. From the MCA, it is recommended that S1/S2 are retained as the downstream sites and N1a/N1 sites are retained as the upstream sites for the pre-feasibility study. It should be noted that the selection is based on limited topographic, geotechnical, social and environmental information.

It is recommended that the Central fully piped route and the Western Route ACF with canal to replace river conveyance are retained for Phase 2 of the pre-feasibility study.

It is recommended that a critical review of the rating curves and the accuracy of the flow records from gauges MG19, MG23, and D1H006 be undertaken by a river gauging expert and the level of reliability be determined.

Flow gauge D1H006 was not included in the original calibration of the hydrology for the Makhaleng River catchment, it is recommended that this be incorporated, and the hydrology reassessed and extended to 2018 as part of the Dam Feasibility Component.

The environmental requirements determined for Makhaleng Dam during the Phase 1 study were carried out at a desktop level. It is thus recommended that various other EWRs are determined focused on the final location of the Makhaleng Dam. These results should be evaluated during Phase 2 and or at the start of the Feasibility Phase as part of a scenario evaluation process to determine the impact of each scenario on the yield available from the dam as well as on the Recommended Ecological Category (REC).

Due to the significant difference in the incremental and local yield from Makhaleng Dam, other intervention options to balance the deficit in the Orange River Project should be investigated in detail through a separate and independent study.

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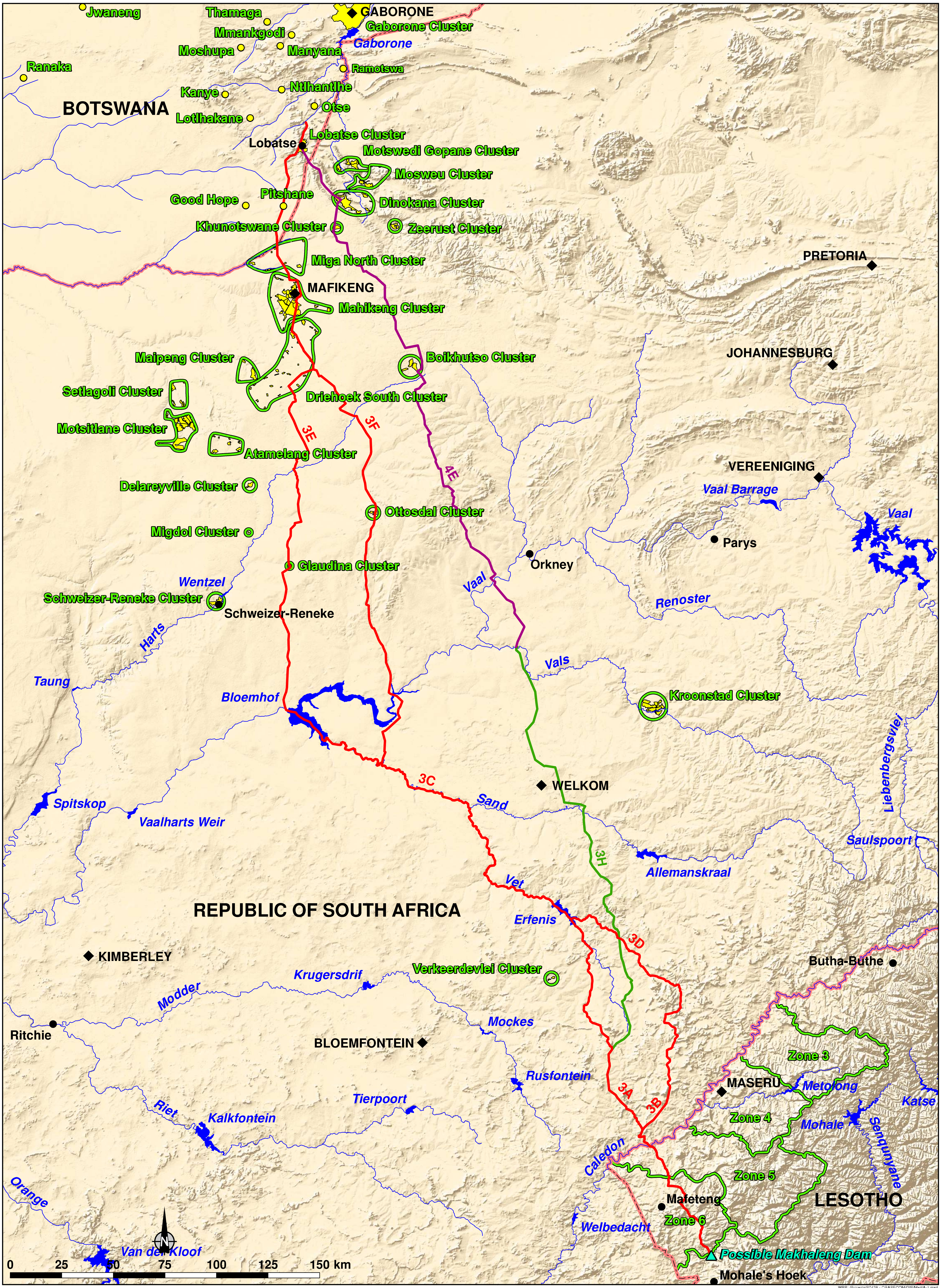
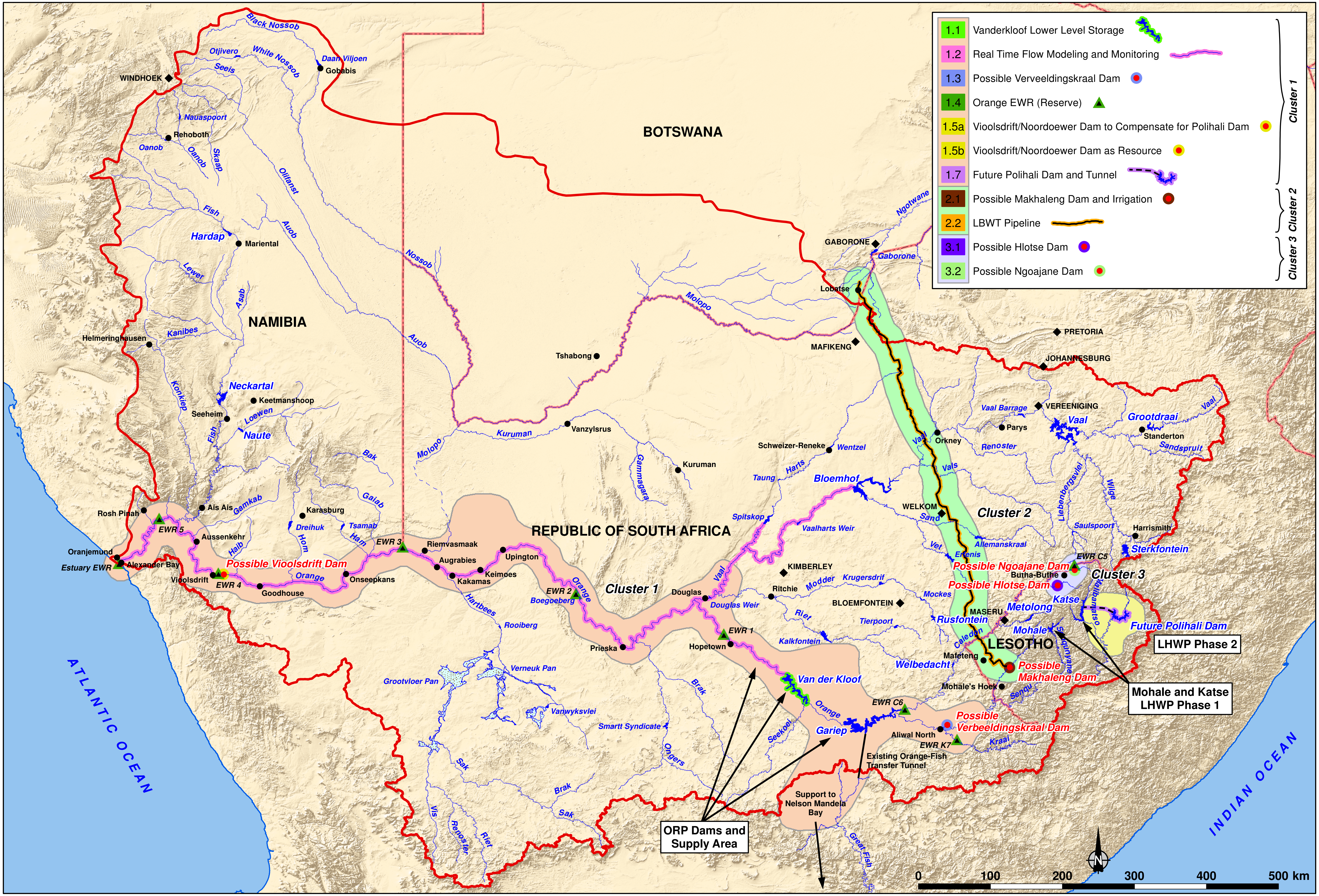
APPENDIX A: Water Requirement Map and Tables



CLIMATE RESILIENT WATER RESOURCES INVESTMENT STRATEGY/PLAN AND LESOTHO-BOTSWANA WATER TRANSFER

Lesotho-Botswana Transfer Selected Supply Areas

A-1



CLIMATE RESILIENT WATER RESOURCES INVESTMENT STRATEGY/PLAN AND LESOTHO-BOTSWANA WATER TRANSFER

Key Existing and Possible Future Dams in the Orange Senqu Basin

A-2

Table A-1: Lesotho net water requirements for Zones 3-6: Realistic Scenario

	Realistic Scenario: Lesotho L-BWT Nett Demands (million m3/a)																																
Lesotho Zone	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
Zone 3 Peka/ Mapoteng/ TY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zone 4 Maseru/ Mazenod/ Roma	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.891	1.946	3.001	4.056	5.111	6.166	7.222	8.277	9.332	10.387
Zone 5 Morija/ Matsieng	1.547	1.552	1.558	1.565	1.572	1.580	1.587	1.594	1.601	1.608	1.615	1.623	1.630	1.637	1.644	1.651	1.658	1.666	1.673	1.680	1.687	1.694	1.701	1.708	1.716	1.723	1.730	1.737	1.744	1.751	1.759	1.766	1.773
Zone 6 Mafeteng	3.388	3.585	3.783	3.831	3.880	3.928	3.977	4.025	4.074	4.122	4.171	4.219	4.268	4.316	4.365	4.413	4.462	4.510	4.559	4.607	4.656	4.704	4.753	4.801	4.850	4.898	4.947	4.995	5.044	5.092	5.141	5.189	5.238
Total	**4.935**	**5.138**	**5.341**	**5.396**	**5.452**	**5.508**	**5.563**	**5.619**	**5.675**	**5.730**	**5.786**	**5.842**	**5.897**	**5.953**	**6.009**	**6.064**	**6.120**	**6.176**	**6.231**	**6.287**	**6.343**	**6.398**	**6.454**	**7.401**	**8.512**	**9.622**	**10.733**	**11.844**	**12.954**	**14.065**	**15.176**	**16.287**	**17.397**

Table A-2: Lesotho net water requirements for Zones 3-6: High Scenario

	High Scenario: Lesotho L-BWT Nett Demands (million m3/a)																																
Lesotho Zone	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
Zone 3 Peka/ Mapoteng/ TY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zone 4 Maseru/ Mazenod/ Roma	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.759	2.474	4.188	5.903	7.957	10.011	12.065	14.119	16.173	18.227	20.281	22.335	24.389	26.443
Zone 5 Morija/ Matsieng	1.547	1.552	1.558	1.565	1.572	1.580	1.587	1.594	1.603	1.611	1.620	1.629	1.638	1.648	1.659	1.669	1.679	1.690	1.702	1.714	1.726	1.738	1.751	1.765	1.779	1.794	1.808	1.822	1.837	1.851	1.865	1.880	1.894
Zone 6 Mafeteng	3.388	3.585	3.783	3.831	3.880	3.928	3.977	4.025	4.082	4.139	4.196	4.253	4.310	4.376	4.443	4.510	4.577	4.643	4.722	4.801	4.880	4.958	5.037	5.130	5.223	5.316	5.409	5.502	5.596	5.689	5.782	5.875	5.968
Total	**4.935**	**5.138**	**5.341**	**5.396**	**5.452**	**5.508**	**5.563**	**5.619**	**5.685**	**5.750**	**5.816**	**5.882**	**5.947**	**6.025**	**6.102**	**6.179**	**6.256**	**6.333**	**6.424**	**7.274**	**9.080**	**10.885**	**12.691**	**14.852**	**17.013**	**19.175**	**21.336**	**23.498**	**25.659**	**27.821**	**29.982**	**32.143**	**34.305**

Table A-3: Lesotho net water requirements for Zones 5,6 & 7: Realistic Scenario

Water Requirements	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
Zone 5 Morija/ Matsieng (SMEC, 2017)	1.65	1.65	1.66	1.66	1.67	1.68	1.68	1.69	1.70	1.70	1.71	1.72	1.73	1.74	1.75	1.75	1.77	1.78	1.79	1.80	1.81	1.82	1.83	1.84	1.86	1.87	1.88	1.90	1.91	1.92	1.94	1.95	1.97	1.98	2.00	2.01
Zone 6 Mafeteng (SMEC, 2017)	3.82	4.02	4.21	4.41	4.61	4.81	4.85	4.90	4.95	5.00	5.05	5.10	5.16	5.22	5.28	5.33	5.40	5.47	5.53	5.60	5.67	5.74	5.82	5.90	5.98	6.06	6.15	6.25	6.34	6.43	6.53	6.62	6.71	6.80	6.90	6.99
Zone 7 Mohale's Hoek (SMEC 2017)	7.67	8.06	8.45	8.84	9.23	9.61	9.65	9.68	9.71	9.75	9.78	9.82	9.86	9.89	9.93	9.97	10.02	10.06	10.11	10.15	10.20	10.25	10.30	10.36	10.41	10.47	10.53	10.59	10.65	10.72	10.78	10.84	10.91	10.97	11.03	11.10
Total Requirement	**13.14**	**13.73**	**14.32**	**14.91**	**15.50**	**16.09**	**16.18**	**16.27**	**16.36**	**16.45**	**16.54**	**16.64**	**16.75**	**16.85**	**16.95**	**17.06**	**17.18**	**17.30**	**17.43**	**17.55**	**17.67**	**17.81**	**17.96**	**18.10**	**18.25**	**18.39**	**18.56**	**18.73**	**18.90**	**19.08**	**19.25**	**19.42**	**19.59**	**19.76**	**19.93**	**20.10**
Resources																																				
Zone 5 (WTW & Boreholes/Springs)	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
Zone 6 Mafeteng (WTW & Boreholes/Springs)	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02
Zone 7	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41
Total Resources	**1.55**	**1.55**	**1.55**	**1.55**	**1.55**	**1.55**	**1.55**	**1.55**	**1.55**	**1.55**	**1.55**	**1.55**	**1.55**	**1.55**	**1.55**	**1.55**	**1.55**	**1.55**	**1.55**	**1.55**	**1.55**	**1.55**	**1.55**	**1.55**	**1.55**	**1.55**	**1.55**	**1.55**	**1.55**	**1.55**	**1.55**	**1.55**	**1.55**	**1.55**	**1.55**	**1.55**
Lesotho net requirement	**11.58**	**12.18**	**12.77**	**13.36**	**13.95**	**14.54**	**14.63**	**14.72**	**14.81**	**14.90**	**14.98**	**15.09**	**15.19**	**15.30**	**15.40**	**15.51**	**15.63**	**15.75**	**15.87**	**16.00**	**16.12**	**16.26**	**16.41**	**16.55**	**16.70**	**16.84**	**17.01**	**17.18**	**17.35**	**17.52**	**17.69**	**17.86**	**18.03**	**18.21**	**18.38**	**18.55**

Table A-4: South Africa L-BWT net water requirements: Realistic Scenario

												Realistic Scenario: South Africa Towns L-BWT Nett Demands (million m^3/a)																								
Province	**District Municipality**	**Local Municipality**	**Town**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
Free State	Lejweleputswa	Masilonyana	Verkeerdevlei	0.132	0.147	0.161	0.169	0.177	0.185	0.193	0.201	0.208	0.216	0.224	0.232	0.240	0.248	0.256	0.264	0.272	0.280	0.287	0.295	0.303	0.311	0.319	0.327	0.335	0.343	0.351	0.359	0.366	0.374	0.382	0.390	0.398
	Dr Ruth Segomotsi Mompati	Mamusa	Glaudina	0.029	0.033	0.037	0.040	0.043	0.046	0.049	0.052	0.056	0.059	0.063	0.066	0.070	0.074	0.077	0.081	0.084	0.088	0.092	0.095	0.099	0.102	0.106	0.110	0.113	0.117	0.120	0.124	0.128	0.131	0.135	0.138	0.142
			Migdol	0.282	0.296	0.310	0.324	0.338	0.352	0.366	0.380	0.396	0.412	0.428	0.444	0.460	0.476	0.492	0.508	0.524	0.540	0.556	0.572	0.588	0.604	0.620	0.636	0.652	0.668	0.684	0.700	0.716	0.732	0.748	0.764	0.780
		Ditsobotla	Lichtenburg	0.000	0.000	0.000	0.054	0.107	0.161	0.214	0.268	0.309	0.351	0.392	0.434	0.475	0.516	0.558	0.599	0.641	0.682	0.723	0.765	0.806	0.848	0.889	0.930	0.972	1.013	1.055	1.096	1.137	1.179	1.220	1.262	1.303
North West	Ngaka Modiri Molema	Mahikeng	Mahikeng	6.439	6.436	6.433	6.490	6.547	6.605	6.662	6.719	6.773	6.827	6.880	6.934	6.988	7.046	7.104	7.162	7.220	7.278	7.356	7.434	7.511	7.589	7.667	7.745	7.823	7.900	7.978	8.056	8.134	8.212	8.289	8.367	8.445
			Driehoek South Cluster	1.396	1.409	1.422	1.429	1.436	1.442	1.449	1.456	1.462	1.468	1.475	1.481	1.487	1.493	1.499	1.506	1.512	1.518	1.524	1.530	1.537	1.543	1.549	1.555	1.561	1.568	1.574	1.580	1.586	1.592	1.599	1.605	1.611
			Miga North Cluster	0.157	0.167	0.176	0.182	0.189	0.195	0.202	0.208	0.213	0.218	0.224	0.229	0.234	0.239	0.244	0.250	0.255	0.260	0.265	0.270	0.276	0.281	0.286	0.291	0.296	0.302	0.307	0.312	0.317	0.322	0.328	0.333	0.338
		Ramotshere Moiloa	Motswedi Gopane	0.003	0.004	0.005	0.011	0.017	0.024	0.030	0.036	0.038	0.041	0.043	0.046	0.048	0.050	0.053	0.055	0.058	0.060	0.062	0.065	0.067	0.070	0.072	0.074	0.077	0.079	0.082	0.084	0.086	0.089	0.091	0.094	0.096
			Khunotswane	0.257	0.264	0.271	0.274	0.278	0.281	0.285	0.288	0.288	0.289	0.289	0.290	0.290	0.290	0.291	0.291	0.292	0.292	0.292	0.293	0.293	0.294	0.294	0.294	0.295	0.295	0.296	0.296	0.296	0.297	0.297	0.298	0.298
			Dinokona	1.082	1.145	1.208	1.234	1.260	1.285	1.311	1.337	1.345	1.352	1.360	1.367	1.375	1.383	1.390	1.398	1.405	1.413	1.421	1.428	1.436	1.443	1.451	1.459	1.466	1.474	1.481	1.489	1.497	1.504	1.512	1.519	1.527
			Zeerust	0.062	0.083	0.104	0.119	0.133	0.148	0.162	0.177	0.181	0.185	0.190	0.194	0.198	0.202	0.206	0.211	0.215	0.219	0.223	0.227	0.232	0.236	0.240	0.244	0.248	0.253	0.257	0.261	0.265	0.269	0.274	0.278	0.282
		Ratlou	Maaipeng / Mareetsane	0.030	0.032	0.034	0.035	0.036	0.038	0.039	0.040	0.042	0.043	0.045	0.046	0.048	0.050	0.051	0.053	0.054	0.056	0.058	0.059	0.061	0.062	0.064	0.066	0.067	0.069	0.070	0.072	0.074	0.075	0.077	0.078	0.08
			Delareyville	0.036	0.048	0.060	0.074	0.088	0.102	0.116	0.130	0.140	0.150	0.160	0.170	0.180	0.190	0.200	0.210	0.220	0.230	0.240	0.250	0.260	0.270	0.280	0.290	0.300	0.310	0.320	0.330	0.340	0.350	0.360	0.370	0.38
			Atemelang	1.078	1.104	1.130	1.156	1.182	1.208	1.234	1.260	1.286	1.312	1.338	1.364	1.390	1.416	1.442	1.468	1.494	1.520	1.546	1.572	1.598	1.624	1.650	1.676	1.702	1.728	1.754	1.780	1.806	1.832	1.858	1.884	1.91
			Motsitlane	0.008	0.010	0.013	0.015	0.018	0.021	0.024	0.027	0.030	0.032	0.035	0.038	0.041	0.044	0.047	0.050	0.052	0.055	0.058	0.061	0.064	0.067	0.070	0.072	0.075	0.078	0.081	0.084	0.087	0.089	0.092	0.095	0.098
			Setlagole	0.016	0.019	0.022	0.025	0.029	0.032	0.036	0.039	0.042	0.045	0.048	0.051	0.054	0.057	0.060	0.063	0.066	0.069	0.072	0.075	0.078	0.081	0.084	0.087	0.090	0.093	0.096	0.099	0.102	0.105	0.108	0.111	0.114

Table A-5: South Africa L-BWT net water requirements: High Scenario

Province	District Municipality	Local Municipality	Town	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
				High Scenario: South Africa Towns L-BWT Nett Demands (million m^3/a)																																
Free State	Fezile Dabi	Moqhaka	Kroonstad	3.619	3.847	4.076	4.305	4.534	4.762	4.991	5.220	5.449	5.677	5.906	6.135	6.363	6.592	6.821	7.050	7.278	7.507	7.736	7.964	8.193	8.422	8.651	8.879	9.108	9.337	9.565	9.794	10.023	10.252	10.480	10.709	10.9378
	Lejweleputswa	Masilonyana	Verkeerdevlei	0.132	0.147	0.161	0.169	0.177	0.185	0.193	0.201	0.208	0.216	0.224	0.232	0.240	0.248	0.256	0.264	0.272	0.280	0.287	0.295	0.303	0.311	0.319	0.327	0.335	0.343	0.351	0.359	0.366	0.374	0.382	0.390	0.398
North West	Dr Ruth Segomotsi Mompati	Mamusa	Glaudina	0.029	0.033	0.037	0.040	0.043	0.046	0.049	0.052	0.056	0.059	0.063	0.066	0.070	0.074	0.077	0.081	0.084	0.088	0.092	0.095	0.099	0.102	0.106	0.110	0.113	0.117	0.120	0.124	0.128	0.131	0.135	0.138	0.142
			Migdol	0.282	0.296	0.310	0.324	0.338	0.352	0.366	0.380	0.396	0.412	0.428	0.444	0.460	0.476	0.492	0.508	0.524	0.540	0.556	0.572	0.588	0.604	0.620	0.636	0.652	0.668	0.684	0.700	0.716	0.732	0.748	0.764	0.78
	Ngaka Modiri Molema	Ditsobotla	Lichtenburg	0.000	0.000	0.000	0.054	0.107	0.161	0.214	0.268	0.309	0.351	0.392	0.434	0.475	0.516	0.558	0.599	0.641	0.682	0.723	0.765	0.806	0.848	0.889	0.930	0.972	1.013	1.055	1.096	1.137	1.179	1.220	1.262	1.303
		Mahikeng	Mahikeng	6.439	6.436	6.433	6.490	6.547	6.605	6.662	6.719	6.773	6.827	6.880	6.934	6.988	7.046	7.104	7.162	7.220	7.278	7.356	7.434	7.511	7.589	7.667	7.745	7.823	7.900	7.978	8.056	8.134	8.212	8.289	8.367	8.445
			Driehoek South Cluster	1.396	1.409	1.422	1.429	1.436	1.442	1.449	1.456	1.462	1.468	1.475	1.481	1.487	1.493	1.499	1.506	1.512	1.518	1.524	1.530	1.537	1.543	1.549	1.555	1.561	1.568	1.574	1.580	1.586	1.592	1.599	1.605	1.611
			Miga North Cluster	0.157	0.167	0.176	0.182	0.189	0.195	0.202	0.208	0.213	0.218	0.224	0.229	0.234	0.239	0.244	0.250	0.255	0.260	0.265	0.270	0.276	0.281	0.286	0.291	0.296	0.302	0.307	0.312	0.317	0.322	0.328	0.333	0.338
		Ramotshere Moiloa	Motswedi Gopane	0.003	0.004	0.005	0.011	0.017	0.024	0.030	0.036	0.038	0.041	0.043	0.046	0.048	0.050	0.053	0.055	0.058	0.060	0.062	0.065	0.067	0.070	0.072	0.074	0.077	0.079	0.082	0.084	0.086	0.089	0.091	0.094	0.096
			Khunotswane	0.257	0.264	0.271	0.274	0.278	0.281	0.285	0.288	0.288	0.289	0.289	0.290	0.290	0.290	0.291	0.291	0.292	0.292	0.292	0.293	0.293	0.294	0.294	0.294	0.295	0.295	0.296	0.296	0.296	0.297	0.297	0.298	0.298
			Dinokona	1.082	1.145	1.208	1.234	1.260	1.285	1.311	1.337	1.345	1.352	1.360	1.367	1.375	1.383	1.390	1.398	1.405	1.413	1.421	1.428	1.436	1.443	1.451	1.459	1.466	1.474	1.481	1.489	1.497	1.504	1.512	1.519	1.527
			Zeerust	0.062	0.083	0.104	0.119	0.133	0.148	0.162	0.177	0.181	0.185	0.190	0.194	0.198	0.202	0.206	0.211	0.215	0.219	0.223	0.227	0.232	0.236	0.240	0.244	0.248	0.253	0.257	0.261	0.265	0.269	0.274	0.278	0.282
		Ratlou	Maaipeng / Mareetsane	0.030	0.032	0.034	0.035	0.036	0.038	0.039	0.040	0.042	0.043	0.045	0.046	0.048	0.050	0.051	0.053	0.054	0.056	0.058	0.059	0.061	0.062	0.064	0.066	0.067	0.069	0.070	0.072	0.074	0.075	0.077	0.078	0.08
			Delareyville	0.036	0.048	0.060	0.074	0.088	0.102	0.116	0.130	0.140	0.150	0.160	0.170	0.180	0.190	0.200	0.210	0.220	0.230	0.240	0.250	0.260	0.270	0.280	0.290	0.300	0.310	0.320	0.330	0.340	0.350	0.360	0.370	0.38
			Atemelang	1.078	1.104	1.130	1.156	1.182	1.208	1.234	1.260	1.286	1.312	1.338	1.364	1.390	1.416	1.442	1.468	1.494	1.520	1.546	1.572	1.598	1.624	1.650	1.676	1.702	1.728	1.754	1.780	1.806	1.832	1.858	1.884	1.91
			Motsitlane	0.008	0.010	0.013	0.015	0.018	0.021	0.024	0.027	0.030	0.032	0.035	0.038	0.041	0.044	0.047	0.050	0.052	0.055	0.058	0.061	0.064	0.067	0.070	0.072	0.075	0.078	0.081	0.084	0.087	0.089	0.092	0.095	0.098
			Setlagole	0.016	0.019	0.022	0.025	0.029	0.032	0.036	0.039	0.042	0.045	0.048	0.051	0.054	0.057	0.060	0.063	0.066	0.069	0.072	0.075	0.078	0.081	0.084	0.087	0.090	0.093	0.096	0.099	0.102	0.105	0.108	0.111	0.114

Table A-6: Botswana L-BWT net water requirements: Low Scenario

Botswana Node	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
												Low Scenario: Botswana L-BWT Nett Demands (million m3/a)																					
Lobatse Node																																	
Lobatse	3.320	3.467	3.618	3.771	3.930	4.094	4.263	4.437	4.616	4.799	4.988	5.183	5.383	5.589	5.801	6.014	6.045	6.474	6.711	6.955	7.206	7.465	7.731	8.005	8.286	8.576	8.874	9.181	9.471	9.761	10.051	10.341	10.631
Pitshane	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036
Good Hope	0.127	0.131	0.135	0.138	0.142	0.146	0.151	0.155	0.159	0.164	0.169	0.174	0.180	0.186	0.191	0.197	0.203	0.209	0.215	0.222	0.229	0.236	0.243	0.250	0.258	0.266	0.274	0.282	0.290	0.298	0.305	0.313	0.321
School at Good hope	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117
Moshupa	1.418	1.463	1.509	1.557	1.606	1.657	1.709	1.763	1.819	1.877	1.936	1.994	2.054	2.116	2.179	2.244	2.312	2.381	2.451	2.523	2.597	2.674	2.752	2.833	2.916	3.002	3.090	3.181	3.267	3.353	3.438	3.524	3.610
NWMPR Jwaneng	0.444	0.448	0.451	0.455	0.458	0.462	0.465	0.469	0.473	0.477	0.481	0.485	0.489	0.494	0.498	0.503	0.508	0.512	0.517	0.522	0.526	0.531	0.536	0.540	0.545	0.550	0.555	0.560	0.565	0.570	0.574	0.579	0.584
Jwaneng Diamond Mine	0.000	0.000	0.000	0.000	0.000	0.000	0.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Mmamashia/Gaborone Node																																	
Lotlhakane	0.269	0.281	0.293	0.302	0.314	0.327	0.34	0.353	0.363	0.377	0.391	0.406	0.421	0.415	0.431	0.447	0.463	0.479	0.49	0.502	0.514	0.526	0.539	0.552	0.565	0.579	0.593	0.607	0.6206	0.6342	0.6478	0.6614	0.675
Ranaka	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046
Otse	0.465	0.491	0.514	0.533	0.557	0.581	0.606	0.632	0.653	0.679	0.706	0.734	0.762	0.879	0.814	0.84	0.847	0.883	0.906	0.929	0.953	0.978	1.003	1.029	1.056	1.083	1.111	1.14	1.1674	1.1948	1.2222	1.2496	1.277
Ramotswa Station Taung	0.061	0.061	0.061	0.061	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062
Ramotswa	2.915	2.99	3.086	3.119	3.195	3.273	3.353	3.432	3.513	3.594	3.676	3.759	3.843	3.927	4.013	4.1	4.188	4.277	4.365	4.455	4.548	4.642	4.738	4.836	4.936	5.038	5.143	5.249	5.3512	5.4534	5.5556	5.6578	5.76
Thamaga	1.255	1.347	1.447	1.554	1.668	1.791	1.923	2.065	2.218	2.381	2.557	2.659	2.766	2.876	2.991	3.111	3.235	3.365	3.479	3.597	3.719	3.845	3.975	4.11	4.25	4.394	4.543	4.697	4.8414	4.9858	5.1302	5.2746	5.419
Manyana	0.096	0.097	0.099	0.1	0.101	0.102	0.104	0.105	0.107	0.108	0.11	0.111	0.113	0.115	0.117	0.118	0.12	0.122	0.124	0.126	0.128	0.13	0.132	0.134	0.136	0.138	0.14	0.142	0.144	0.146	0.148	0.15	0.152
Ntlhantlhe, Magotlhwane,	0.121	0.122	0.124	0.125	0.127	0.128	0.13	0.131	0.133	0.135	0.136	0.138	0.14	0.142	0.146	0.146	0.148	0.15	0.152	0.154	0.156	0.158	0.16	0.163	0.165	0.167	0.169	0.172	0.1744	0.1768	0.1792	0.1816	0.184
Mmamashia/Gaborone Node and North (Letsibogo, Palapye & Mahalapye Ndes and Mines)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.125	0.381	1.229	2.004	2.840	3.757	4.619	8.738	9.564	10.402	11.252	12.113	12.988	13.875	14.774	15.688	16.615	17.557	18.471	19.384	20.298	21.212	22.126
Total	**10.69**	**11.10**	**11.54**	**11.91**	**12.36**	**12.82**	**13.31**	**21.80**	**22.32**	**22.85**	**23.54**	**24.29**	**25.64**	**27.00**	**28.28**	**29.74**	**30.95**	**35.85**	**37.23**	**38.65**	**40.09**	**41.56**	**43.06**	**44.59**	**46.15**	**47.74**	**49.37**	**51.03**	**52.62**	**54.22**	**55.81**	**57.41**	**59.00**

Table A-7: Botswana L-BWT net water requirements: High Scenario

Realistic Scenario: Botswana L-BWT Nett Demands (million m3/a)																																
Botswana Node	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
Lobatse Node																																
Lobatse	3.320	3.467	3.618	3.771	3.930	4.094	4.263	4.437	4.616	4.799	4.988	5.383	5.589	5.801	6.014	6.045	6.474	6.711	6.955	7.206	7.465	7.731	8.005	8.286	8.576	8.874	9.181	9.471	9.761	10.051	10.341	10.631
Pitshane	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036
Good Hope	0.127	0.131	0.135	0.138	0.142	0.146	0.151	0.155	0.159	0.164	0.169	0.180	0.186	0.191	0.197	0.203	0.209	0.215	0.222	0.229	0.236	0.243	0.250	0.258	0.266	0.274	0.282	0.290	0.298	0.305	0.313	0.321
School at Good hope	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117
Kanye	3.038	3.152	3.269	3.391	3.518	3.649	3.785	3.927	4.073	4.225	4.383	4.650	4.789	4.933	5.081	5.234	5.391	5.540	5.694	5.852	6.015	6.182	6.353	6.530	6.711	6.897	7.089	7.270	7.452	7.633	7.815	7.996
Moshupa	1.418	1.463	1.509	1.557	1.606	1.657	1.709	1.763	1.819	1.877	1.936	2.054	2.116	2.179	2.244	2.312	2.381	2.451	2.523	2.597	2.674	2.752	2.833	2.916	3.002	3.090	3.181	3.267	3.353	3.438	3.524	3.610
NWMPR Jwaneng	0.444	0.448	0.451	0.455	0.458	0.462	0.465	0.469	0.473	0.477	0.481	0.489	0.494	0.498	0.503	0.508	0.512	0.517	0.522	0.526	0.531	0.536	0.540	0.545	0.550	0.555	0.560	0.565	0.570	0.574	0.579	0.584
Jwaneng Diamond Mine	0.000	0.000	0.000	0.000	0.000	0.000	0.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Mmamashia/Gaborone Node																																
Lotlhakane	0.269	0.281	0.293	0.302	0.314	0.327	0.34	0.353	0.363	0.377	0.391	0.421	0.415	0.431	0.447	0.463	0.479	0.49	0.502	0.514	0.526	0.539	0.552	0.565	0.579	0.593	0.607	0.6206	0.6342	0.6478	0.6614	0.675
Ranaka	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046
Otse	0.465	0.491	0.514	0.533	0.557	0.581	0.606	0.632	0.653	0.679	0.706	0.762	0.879	0.814	0.84	0.847	0.883	0.906	0.929	0.953	0.978	1.003	1.029	1.056	1.083	1.111	1.14	1.1674	1.1948	1.2222	1.2496	1.277
Ramotswa Station Taung	0.061	0.061	0.061	0.061	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062
Ramotswa	2.915	2.99	3.086	3.119	3.195	3.273	3.353	3.432	3.513	3.594	3.676	3.843	3.927	4.013	4.1	4.188	4.277	4.365	4.455	4.548	4.642	4.738	4.836	4.936	5.038	5.143	5.249	5.3512	5.4534	5.5556	5.6578	5.76
Thamaga	1.255	1.347	1.447	1.554	1.668	1.791	1.923	2.065	2.218	2.381	2.557	2.766	2.876	2.991	3.111	3.235	3.365	3.479	3.597	3.719	3.845	3.975	4.11	4.25	4.394	4.543	4.697	4.8414	4.9858	5.1302	5.2746	5.419
Manyana	0.096	0.097	0.099	0.1	0.101	0.102	0.104	0.105	0.107	0.108	0.11	0.113	0.115	0.117	0.118	0.12	0.122	0.124	0.126	0.128	0.13	0.132	0.134	0.136	0.138	0.14	0.142	0.144	0.146	0.148	0.15	0.152
Ntlhantlhe, Magotlhwane,	0.121	0.122	0.124	0.125	0.127	0.128	0.13	0.131	0.133	0.135	0.136	0.14	0.142	0.146	0.146	0.148	0.15	0.152	0.154	0.156	0.158	0.16	0.163	0.165	0.167	0.169	0.172	0.1744	0.1768	0.1792	0.1816	0.184
Mmamashia/Gaborone Node Remainder and Northern Nodes (Letsibogo, Palapye & Mahalapye Nodes and Mines)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	2.038	5.133	11.375	15.624	18.483	21.542	24.871	28.049	41.466	44.512	47.611	50.759	53.964	57.225	60.542	63.917	67.353	70.853	74.416	77.854	81.292	84.730	88.168	91.606
Total	**13.728**	**14.249**	**14.805**	**15.305**	**15.877**	**16.471**	**17.090**	**25.730**	**28.426**	**32.210**	**39.169**	**44.686**	**48.272**	**51.917**	**55.933**	**59.613**	**73.970**	**77.723**	**81.551**	**85.448**	**89.425**	**93.477**	**97.608**	**101.821**	**106.118**	**110.503**	**114.977**	**119.277**	**123.576**	**127.876**	**132.176**	**136.476**

Table A-8: Water requirement versus Resource capability at S2 dam site

Gross Water Requirement scenarios to be imposed on Makaleng Dam (million m^3/a)					
Description	**Reconnaissance Study**	**High**	**Low**	**High including Bloemfontein**	**Low including Bloemfontein**
Botswana	150	156	68	156	68
RSA	25	21	21	64	64
Lesotho (urb/ind)	25	22	22	22	22
Lesotho (irrigation)	0	0	76	0	76
Namibia	0	0	0	0	0
Total	**200**	**199**	**187**	**242**	**230**
Resource capability (million m^3/a) – Implications for scenarios at S2 dam site					
Description		**High**	**Low**	**High including Bloemfontein**	**Low including Bloemfontein**
Local Yield		378	378	378	378
Mitigation requirement *		219	190	176	147
Incremental/Net yield		159	188	202	231
Treatment losses		20	19	24.2	23
Conveyance loss		10.0	9	12.1	12
Remaining yield (1)		**129**	**160**	**165**	**196**
Remaining yield (2)		**348**	**350**	**341**	**343**
Net Water Requirement (million m^3/a) before losses (conveyance + treatment)					
Botswana		133	58	133	58
Lesotho urb/ind		18	19	19	19
RSA		19	18	55	55
Total net demand excluding irrigation		**169**	**95**	**207**	**132**
Net deficit/Surplus (3)		**-40**	**65**	**-41**	**65**
Net deficit/Surplus (4)		**179**	**255**	**135**	**212**
Lesotho irrigation (5)			65	0	65
Other users (6)		179	190	135	147

Notes: *- The mitigation requirements can be supplied by means of releases directly from Makhaleng Dam or by means of releases from another resource, for example the Lesotho possible hydro-power dams or a combination of the two.

(1) - Remaining yield if mitigation releases are supplied from Makhaleng Dam only

(2) – Remaining yield if mitigation releases are supplied from another source

(3) – Deficit or surplus in the overall system when mitigation releases are supplied from Makhaleng only

(4) - Surplus in the overall system but also available at Makhaleng Dam when mitigation releases are supplied from another resource

(5) – The surplus from the Low transfer scenario can for example be used for irrigation in Lesotho or by any of the other users.

(6) – This is the maximum surplus available at Makhaleng Dam and can be used for any users to be supplied from this dam on the condition that all the mitigation releases are supplied from another resource.

APPENDIX B: Water Resources

Flow Gauge Data

D1H006: Monthly flow (million m3)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	
1948	0.67	5.77	2.26	4.55	8.96	56.1	1.65	15	3.31	1.7	1.36	1.14	102.47
1949	1.46	25.7	31.2	22.2	101	187	395	155	32.2	62	79.7	138	1230.46
1950	9.84	5.17	292	52.5	39	119	57.6	6.33	7.74	6.53	5.15	4.07	604.93
1951	252	52.3	3.63	13.5	67.1	15.7	6.13	4.55	3.89	14	12.6	38.9	484.3
1952	0	28.5	31.8	14.2	45	22.3	98.1	18	6.24	2.25	2.06	3.32	271.77
1953	56.7	24.8	89.1	20.7	28.2	140	41.4	23.1	11	6.02	4.6	5.52	451.14
1954	4.31	4.33	1.42	211.55	211.84	58.42	26.95	13.91	4.75	4.05	3.07	2.41	547.01
1955	9.82	29.86	53.31	17.58	187.42	124	157	32	17.3	10.9	6.09	5.73	651.01
1956	4.97	44.3	207	36.4	104	36.9	24.6	5.97	3.79	4.15	9.9	108	589.98
1957	195	76.4	56	192	52.6	29	57.2	77.2	31.8	13.1	8.52	5.72	794.54
1958	4.67	62.9	33.6	38.9	79.2	48.3	20.2	3.59	26.3	39.3	19.5	6.98	383.44
1959	15.7	33.7	137	31.9	37.1	47.6	75	49.3	18.9	12.7	26.7	14.7	500.3
1960	19	54	44.1	41.6	35.9	65.3	144	77.7	121	25.5	16.7	7.76	652.56
1961	0.49	81.4	200	51.6	188	63.7	30.6	9.86	2.31	0.8	4.6	2.99	636.35
1962	1.63	68.8	35	116	68.2	52.5	275	34.8	17.7	35.4	20.7	9.34	735.07
1963	11.2	120	87.7	22.4	35.7	43.9	115	13.8	13	10.2	6.51	5.23	484.64
1964	108	39.4	35.7	24.2	11.3	5.53	56.4	7.13	9.69	8.56	6.62	6.94	319.47
1965	5.77	13.4	13.7	235	213	23.3	11.6	9.93	4.82	4.06	3.28	2.57	540.43
1966	4	21.1	20.9	88.7	189	48.83	185.18	111.33	23.2	31	15.4	9.21	747.85
1967	22.2	63.1	12.8	9.25	2.09	20.1	35.4	67.1	17.6	22	5.88	0	277.52
1968	6.06	7.41	53.6	12.1	27.9	134	102	22.2	17.4	8.99	18.6	3.4	413.66
1969	69.1	28.1	9.98	26.5	20.9	2.26	2.01	2.18	4.28	5.56	4.13	37.2	212.2
1970	33.9	17.7	80.7	38.7	38.6	43.2	32.6	35	9.88	8.3	4.71	1.52	344.81
1971	4.21	4.49	13	101	117	218	73.3	67	44.8	13	6.81	5.52	668.13
1972	17.9	13.3	6.72	0.31	78.7	50.9	20	11.6	4.93	3.69	26.9	10.2	245.15
1973	5.18	7.47	10.4	131	275	198	94.2	22.4	11.5	7.97	2.16	1.6	766.88
1974	4.72	72.4	36.1	42	86.1	166	3.79	0	0	15.9	7.52	26.8	461.33
1975	24.6	75.8	93.9	307	247	172	122	72.4	42.9	22.6	12.7	27.6	1220.5
1976	253	115	27	10.1	77.5	122.8	22	13.7	10.7	7.78	5.3	23.9	688.78
1977	42.1	35.2	44.4	145	61	70.9	236	53.2	16	11.1	9.52	7.18	731.6
1978	15.7	8.08	131	24.7	32.3	27.3	9.97	9.03	2.56	10.5	64.8	41.1	377.04
1979	104	21	14.7	15.1	23.5	15.6	6.24	2.18	2.34	2.07	2.04	4.56	213.33
1980	3	23.8	48.3	115	133	130	47.3	28.7	52.5	14.6	72	47.7	715.9
1981	13.6	31.8	46.1	17.5	30.2	21.8	135	33.6	18.8	15.8	7.8	6.55	378.55
1982	39.3	128	24.7	10.1	5.89	7.29	9.8	11.5	10.5	21.9	10.6	4.4	283.98
1983	6.36	33.2	56.7	64.9	11.9	10.3	7.58	44.7	6.6	3.94	7.6	11.6	265.38
1984	12.3	16.6	24.6	20.6	26.7	40.7	7.25	5.87	12.5	3.46	1.37	0.6	172.55
1985	26.5	57.5	105	68.8	36.4	30.8	7.31	4.4	14.1	4.74	8.36	22.7	386.61
1986	57.1	142	25.6	6.51	16.7	9.85	20.5	5.27	3.8	3.71	31.2	171	493.24
1987	60.6	91	98.5	24	180	366	110	35.2	24.1	22.8	9.93	72	1094.13
1988	76.1	64.6	124	108	242	71.6	45.3	37.6	62.7	20.7	12.1	6.16	870.86
1989	7.58	85.9	30.2	36.9	11	42.9	134	54	27.3	32.4	22	9.99	494.17
1990	3.49	2.04	12.5	145	201	142	31.2	12.1	10.5	6.34	4.06	11.2	581.43
1991	121	58.4	42.4	8	8.52	2.65	3.92	1.52	1.64	1.68	2.33	2.62	254.68
1992	19.2	30.7	3.42	12.1	54	31.3	32.9	10.9	3.03	2.15	6.4	0.7	206.8
1993	60.5	49	49.7	165	138	43.6	2.87	9.68	4.73	4.43	2.8	0.98	531.29
1994	0.33	0.07	0.16	14.4	6.54	13.8	7.2	9.46	2.21	1.39	0.33	0	55.89
1995	7.59	7.68	36.68	67.24	58.64	27.68	18.48	12.84	7.95	10.96	12.91	9.08	277.73
1996	7.86	144	89	72.4	24.3	234	115	19.23	15.75	13.34	9.69	4.12	748.69
1997	9.26	8.13	3.08	77.06	202.07	178.65	63.53	12.45	5.05	2.96	1.94	1.77	565.95
1998	9.7	26.5	61.76	77.69	40.84	12.33	10.13	8.27	4.57	2.65	1.41	0.41	256.26
1999	2.34	2.8	157.9	192.18	94.64	74.27	51.73	20.34	9.64	5.96	3.06	6.29	621.15
2000	17.19	24.76	37.61	28.93	27.4	79.74	165.14	95.58	26.52	14.55	27	79.9	624.32
2001	69.1	365	195	242	140	72.7	38	68.8	103	24.5	122	124	1564.1
2002	27.3	29.6	114	73.2	40.4	81.6	22.6	8.83	5.22	4.76	6.7	3.89	418.1
2003	2.31	25.8	9.75	48.8	40.7	103	57.9	10.5	5.09	5.04	5.9	14.43	329.22
2004	15.16	11.52	8.5	102	60.8	80.8	69.4	32.4	8.06	4.76	7.38	2.66	403.44
2005	4.51	16.1	10.1	127	344	280	170	102	32.7	13.9	158	46.8	1305.11
2006	41.9	171	69.2	25.1	15.2	8.12	15	4	8.68	4.01	3.05	7.94	373.2
2007	75.7	63.6	194	154	60.2	71.1	38.3	31.9	58.4	14.3	6.07	3.11	770.68
2008	2.5	48.2	194	184	297	69.2	14.8	11	34.2	18.7	10.8	3.1	887.5
2009	187	142	34.8	110	108	59.4	77.6	39.3	34.6	11	5.78	2.63	812.11
2010	5.49	84.3	184	456	122	126	175	178	101	32.7	16.7	7.12	1488.31
2011	4.76	3.07	123	26.1	107	45.2	49.4	11.4	60.7	74.7	28.9	14.2	548.43
2012	18.6	18.1	199	123	45.1	46.9	48.5	14	5.28	3.97	2.7	0.932	526.082
2013	3.86	29.9	67.2	58.7	136	207	30.9	9.23	5	3.88	4.29	1.69	557.65
2014	7.96	164	85.4	57.2	13.7	56.8	18.8	4.96	5.56	7.69	3.18	1.88	427.13
2015	2.11	0.428	0	38.3	58.4	32.9	80	60.2	10.8	83.3	67.2	12.6	446.238
2016	11.6	59.9	20.3	49.3	315	59.6	30.8	9.05	4.32	3.26	1.92	0.814	565.864
2017	21.4	8.07	29.1	13.2	86.6	198	253	38.4	15.2	0	0	0	662.97

	MG23: Monthly flow (million m3)												
1982	39.50	84.41	10.68	5.67	5.18	6.82	10.05	10.33	7.24	52.09	9.22	11.59	252.78
1983	6.02	62.97	48.47	36.24	28.79	44.21	15.76	34.44	6.23	2.21	2.41	53.93	341.68
1984	17.43	26.84	36.79	32.73	81.81	86.04	72.11	0.16	0.87	0.12	0.05	0.00	354.95
1985	26.97	56.29	59.82	17.02	35.92	37.21	16.45	10.21	20.98	9.36	4.98	15.77	310.98
1986	104.22	110.06	26.91	69.80	31.51	71.07	39.29	35.04	6.91	7.11	24.98	116.31	643.21
1987	44.30	73.38	65.17	19.76	77.41	158.28	84.26	51.60	15.70	15.33	7.74	51.90	664.83
1988	61.85	45.80	79.62	65.50	186.18	66.70	27.21	46.05	54.20	15.07	8.38	5.22	661.78
1989	4.71	89.68	21.96	37.40	79.46	69.73	90.45	33.46	15.16	18.01	9.31	2.88	472.21
1990	1.33	0.72	1.52	183.16	169.97	130.49	26.33	11.13	8.42	4.11	2.35	3.33	542.86
1991	86.88	41.92	31.99	7.56	6.10	3.76	3.69	2.05	1.98	1.84	1.86	2.74	192.37
1992	10.34	15.72	1.42	4.68	36.58	18.24	30.07	7.30	3.29	2.41	3.32	1.16	134.53
1993	62.28	52.06	44.92	142.56	105.00	33.08	14.89	11.59	9.45	9.56	8.55	6.88	500.82
1994	6.33	10.24	6.89	30.57	7.65	23.64	11.53	13.53	5.40	4.83	4.28	3.77	128.66
1995	25.10	32.19	84.94	53.69	56.05	93.98	21.00	9.93	6.72	6.71	7.63	6.11	404.05
1996	23.18	77.30	74.45	84.78	22.17	103.61	97.34	60.64	44.51	21.52	21.68	13.94	645.12
1997	10.50	16.61	34.98	34.98	70.67	82.40	66.12	22.19	12.71	10.45	8.60	8.88	379.09
1998	32.62	49.10	11.98	39.92	26.74	19.11	14.54	11.52	8.96	6.05	3.78	2.34	226.66
1999	6.98	3.39	1.95	10.11	7.22	10.55	24.65	6.45	6.33	8.36	39.23	32.20	157.42
2000	16.50	21.33	56.65	13.71	9.38	16.78	80.74	69.32	16.22	13.55	51.40	155.93	521.50
2001	39.93	136.99	77.86	74.91	60.63	41.19	30.97	33.83	47.23	25.89	46.95	54.85	671.24
2002	14.42	13.19	29.33	27.40	34.37	53.92	11.45	4.70	2.73	4.19	5.03	3.41	204.15
2003	2.80	8.61	5.83	22.74	18.40	36.29	22.48	7.38	5.38	4.81	3.74	6.16	144.59
2004	8.85	4.33	10.34	15.21	0.00	0.00	20.53	12.48	6.20	4.06	4.68	3.02	89.70
2005	3.75	6.22	3.08	27.27	51.57	137.59	49.09	42.45	20.25	11.92	53.11	21.06	427.36
2006	12.33	69.65	30.91	11.63	9.38	5.07	6.51	4.91	5.60	4.19	3.59	2.65	166.44
2007	30.02	20.49	49.39	46.82	22.71	28.61	18.22	18.27	19.54	8.77	4.68	2.27	269.79
2008	1.55	21.10	35.52	51.85	93.04	31.55	13.94	10.12	17.32	14.93	9.39	3.50	303.81
2009	66.29	58.71	17.84	34.95	42.62	24.37	37.30	19.05	13.06	6.37	4.61	3.00	328.17
2010	3.64	34.06	71.49	217.62	46.57	49.44	81.21	79.87	37.27	15.48	7.27	4.29	648.22
2011	3.25	2.73	66.80	9.89	39.22	16.08	22.98	5.74	26.18	30.27	12.24	5.50	240.87
2012	4.12	6.79	77.30	38.60	14.89	10.02	18.32	5.32	3.46	2.78	2.19	1.24	185.02
2013	3.24	13.77	16.70	27.40	55.82	63.05	11.23	4.61	3.27	2.72	2.87	0.00	204.67
2014	6.22	92.09	33.61	21.29	6.23	23.47	8.80	2.49	2.69	3.12	1.69	1.36	203.06
2015	0.92	0.79	0.49	8.43	12.90	13.95	20.61	30.56	4.40	20.21	24.79	4.17	142.22

APPENDIX C: EWR Desktop Report

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LIST OF ACRONYMS

DWS	Department of Water and Sanitation
EC	Ecological Category
EI	Ecological Importance
EIS	Ecological Importance and Sensitivity
ES	Ecological Sensitivity
EWR	Ecological Water Requirements
MAR	Mean Annual Runoff
nMAR	Natural Mean Annual Runoff
PD	Present Day
PES	Present Ecological State
PESEIS	Present Ecological State Ecological Importance and Sensitivity
RDRM	Revised Desktop Reserve Model
REC	Recommended Ecological Category
SQ	Sub-Quaternary
WMA	Water Management Area
WWTW	Waste Water Treatment Works

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1 INTRODUCTION

1.1 Study Area

In terms of the Ecological Water Requirement (EWR) determination, the study area is downstream of the proposed Makhaleng Dam with emphasis on the Makhaleng River. The EWRs in the Orange River are defined through the recent Preliminary Reserve determination and the agreed Preliminary Ecological Reserve Category (DWS, 2017).

1.2 EWR Site

The Makhaleng River downstream of the proposed dam is a uniform alluvial section and one EWR site sufficiently represented the variety (albeit limited) habitats in this section. The selected EWR site is situated 7 km downstream of the proposed Makhaleng Dam (**Figure 1-1** and **1-2**). Siltation and sedimentation, due to overgrazing and erosion, is evident at the EWR site which is also characterised by mostly alien vegetation growth.

1.3 Approach

The desktop analysis entails the determination of the Present Ecological State and the estimation of environmental flows and flood releases for various different ecological states. To estimate the flooding regime, specialist input is required and forms part of the analysis to further increase the confidence in the desktop output.

In order to determine the types of releases that may be required for the environmental flow requirements of the riverine system downstream of the proposed Makhaleng Dam, an extended desktop study, which included fieldwork, was undertaken in October 2018. The fieldwork entailed a site visit to the study area where an EWR site was selected that provided sufficient indicators to assess environmental flows and assess the condition of biophysical components (drivers such as hydrology, geomorphology and physico-chemical conditions) and biological responses (*viz*. fish, macroinvertebrates and riparian vegetation). For hydraulic modeling purposes, a cross-sectional survey was undertaken at the EWR site in order to convert requirements in terms of hydraulic parameters to flow. Using the measured hydraulics, the Revised Desktop Reserve Model (RDRM) (Hughes *et al*., 2012; 2014; 2018) was applied at the EWR site to quantify the environmental flows, ensuring that the desktop model output is of significantly higher confidence than a Desktop assessment where field data is excluded.

1.4 Purpose and Outline of this Report

The purpose of the report is to document the process and results of the EcoClassification and EWR estimates for the EWR site.

Figure 1-1: Location of the EWR site - EWR_Makhaleng

Figure 1-2: EWR_Makhaleng in relation to the proposed Makhaleng Dam

2 ECOCLASSIFICATION

The sub-quaternary (SQ) river reaches as indicated in http://www.dwa.gov.za/iwqs/gis_data /river/rivs500k.html and http://www.dwa.gov.za/iwqs/gis_data/river/River_Report_01.pdf, form the basic delineation unit of the desktop Present Ecological State, Ecological Importance and Ecological Sensitivity (referred to as PESEIS) assessment undertaken for the Department of Water and Sanitation (DWS) and the Water Research Commission (DWA, 2014) for all Water Management Areas (WMAs) across South Africa, including parts of Lesotho. According to the data, the EWR site is situated in SQ reach D15G-04805, however, no assessment was undertaken for this reach. D15H-04889, situated downstream of the EWR site in the Makhaleng River, is the first reached assessed and the EcoClassification process therefor had to be adjusted to determine the Ecological Categories (ECs). The process followed is described below.

EcoClassification consists of three basic steps as follows (Kleynhans and Louw, 2007):

- Determination of Present Ecological State (PES) (DWS, 2016).
- Determination of Ecological Importance and Sensitivity (EIS) (DWS, 2016).
- Deriving the Recommended Ecological Category (REC).

The following steps were followed to determine the REC. It must be noted that this process forms part of the desktop level of EcoClassification (Kleynhans and Louw, 2007) and therefore the restoration capability could only be determined based on this level of information.

- Determine the PES and provide an Ecological Category for the EcoStatus.
- Provide the reasons for the PES. Focus on whether the issues are flow or non-flow related. Flow related implies that the direct source and causes of the problem are in flow changes (e.g., decreased flow due to pumping for irrigation) or non-flow related which implies e.g., the presence of alien vegetation.
- Determine the Ecological Importance (EI) and Ecological Sensitivity (ES).
- Derive the REC according to the following guidelines:
    - Improve the PES if the EIS is High or Very High and the PES is lower than a B Category.
    - Maintain the PES if the EIS is Moderate or Low or the PES is a B Category or higher.

EWR estimation is based on the REC (**Section 2.3**). However, in the cases where the REC is an improvement of the PES, an assessment must be made whether that improvement can be achieved by means of increasing the flow. If the improvement requires *non-flow related* measures, e.g. vegetation removal or improvement of Waste Water Treatment Works (WWTW) operation, the EWRs are estimated for the PES.

2.1 Present Ecological State

The EcoStatus Level III (Kleynhans and Louw, 2007) method to determine the EC (A to F) were used but adjusted where required based on the available data. The results are provided below (**Table 2-1**). The EcoClassification as used in this study has been used in various other studies for Lesotho (LHDA, 2016; Louw *et al*., 2013) and is therefore an acceptable approach.

Table 2-1 Present Ecological State results and comments

Component	EC	Comment
Instream IHI[1]	**D**	The instream IHI assessment is based on a site survey and Google Earth information of the catchment. Modelled hydrology was also used to populate the model. The diatom analysis results were used to derive water quality input. The D result is largely due to impacts associated with overgrazing, erosion, sedimentation and alien vegetation.
Riparian IHI	**D**	The riparian IHI assessment was based on a site survey, Google Earth information of the catchment, photographs of terraces and general area, and a review by a riparian vegetation specialist. The riparian IHI was used as a surrogate for the VEGRAI[2] analysis which will only be undertaken during the Feasibility phase. The D result is largely due to impacts associated with overgrazing, erosion, sedimentation and alien vegetation.
Fish	**E**	The fish information for the downstream reach D15J-04889 was used to apply a desktop FRAI[3] (without surveyed information). The result is an E Category which is mostly due to the habitat degradation linked to the lack of cover, sedimentation which amongst others affects migration.
EcoStatus	**D**	The EcoStatus EC was derived using the EcoStatus model. As this is a desktop level study, all the information was not available for the EcoStatus model and the following information was used: Instream IHI was used as a surrogate for the MIRAI results which supply the macroinvertebrate EC. The riparian IHI was used as a surrogate for the VEGRAI results which supply the riparian vegetation EC.

1 IHI Index of Habitat Integrity (Kleynhans *et al*., 2009)
2 Vegetation Response Assessment Index (Kleynhans, 2007)
3 Fish Response Assessment Index (Kleynhans *et al*., 2007)

In summary, the D EcoStatus represents the response of the biota to the lack of habitat diversity due to sedimentation from overgrazing, erosion and removal of riparian vegetation as well as the presence of alien vegetation in the riparian zone.

2.2 Ecological Importance and ecological sensitivity

The desktop EI and ES results of the downstream reach (D15H-04889) were used for the EWR_Makhaleng site. Both the EI and ES is Moderate and as the habitat of these two reaches are so similar, it is unlikely that any metrics would rate higher and change the outcome. A more detailed EIS will be undertaken during the Feasibility phase.

2.3 Recommended Ecological Category (REC)

As the EI and ES is MODERATE, the REC is set to maintain the PES.

Flow is not the driving factor for the deteriorated ecological condition and the biological response is not based on flow related issues. A D EWR would diminish the current buffering effect of good flows resulting in a further deterioration in the PES. EWR results for a D EWR would therefore be too stringent, as decreasing the flow significantly from the present flow conditions will not maintain the REC due to the other impacts on the system. During a scenario evaluation in the Feasibility Phase, the impacts on the EC would therefore have to be determined for various categories to determine which will maintain the REC considering impacts such as sedimentation.

3 EWR ESTIMATION AND RESULTS

3.1 Approach

The Revised Desktop Reserve Model (RDRM, v2) was used to estimate the EWR requirements for the site (refer to Hughes *et al.*, 2012; 2014 and 2018). The timeseries of natural monthly flows was supplied by WRP Consulting Engineers (Pty) Ltd for the 85-year period 1920 to 2004, and provided a Mean Annual Runoff (MAR) of 575.45 $10^6 m^3$. For the EWR site, the natural and Present Day (PD) MARs are deemed to be equivalent.

A field trip to the EWR site on the Makhaleng River took place on 18 October 2018. Topographical and hydraulic information were collected to improve the confidence of the default 'desktop' hydraulics of the RDRM, through the survey of a cross-sectional profile the modelling of the rating (or stage-discharge) relationship. The discharge at the time of the survey was 2.9 m^3/s (calculated using the velocity-area method). Site detail and the cross-sectional profile of EWR_Makhaleng is provided in **Figure 3-1**.

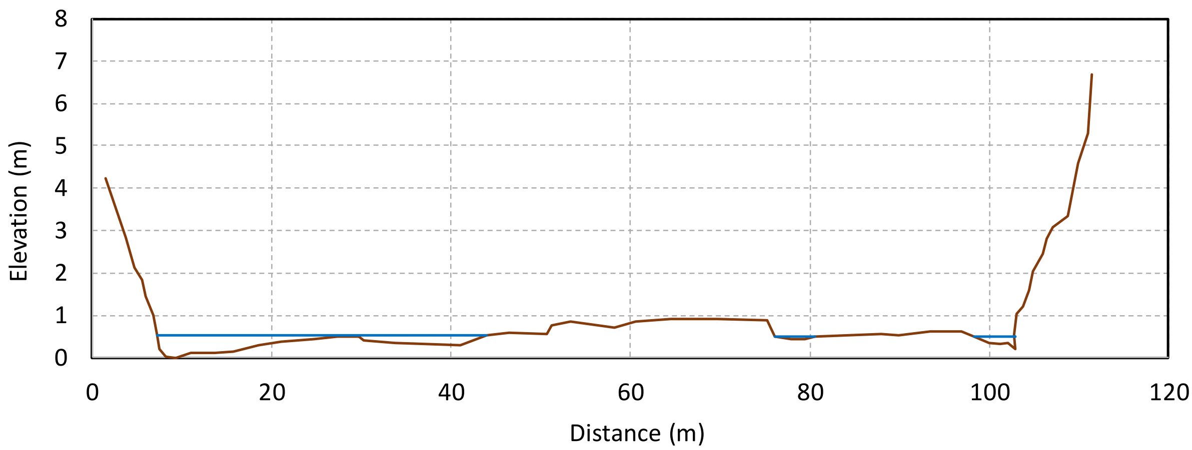

Figure 3-1: Top: photographs of EWR_Makhaleng; bottom: surveyed cross-sectional profile

Velocity-depth class weighting factors and stress index values at zero fast flow were derived from predicted fish species for the river reach, as described by Hughes *et al.* (2018). Default (i.e. 'desktop') shifts were applied to compute stress-duration and hence discharge-duration relationships (for the various ECs) relative to natural. The default high-flow component was used, but checked using riparian indicators - described in the next section.

3.2 Results

3.2.1 Riparian Indicators to affirm desktop EWR

The presence of riparian indicators at this site was scant and did not therefore add much confidence to the results. However, some species were used, even though these included terrestrial and alien species:

- Pine trees (*Pinus* species) were found growing within the riparian zone. These are unlikely to have been planted but would likely be tended for timber. Not only is this an alien species (usually an escapee from forestry plots) but it is also a terrestrial species that will easily succumb to flooding. Its presence in the riparian zone was therefore used to determine the larger more infrequent flood with a return period of about once every two years. These floods would serve to prevent further encroachment of *Pinus* into the riparian zone and even cause mortality of these existing specimens. Based on this, the 1-in-2-year flood would therefore have an approximate stage level of 2.76 m which corresponds to a discharge of about 290 m^3/s. The desktop estimation for the same frequency flood was 205 m^3/s, which would suffice. No change is therefore required based on this indicator.
- *Diospyros lyceoides*, which is an indigenous terrestrial shrub common along rocky ridges close to rivers in this area, also occurred within the riparian zone. This species is expected for this reach, and although a terrestrial species, can be used as an indicator of the annual flood which would serve to limit the occurrence of this species lower down within the riparian zone. Using this indicator at this site suggests an annual flood of about 120 m^3/s. This is slightly lower than the 138 m^3/s desktop estimation, but either will serve the purpose. No change is needed to the desktop estimation based on this indicator.
- The sedge *Cyperus marginatus* occurred in the marginal and lower zones of the riparian zone. This indigenous indicator is expected at the site albeit in greater abundance (reduced by grazing). The lower limit of the sedge population can be used as an indicator for the wet season base flow which should activate the population which occurs at about 5 m^3/s. The sedge population is also an indicator for within-year, smaller, more frequent floods.

Based on the indicator and the placement of terraces this flooding range would be between 25-60 m^3/s, and would be required 4 or more times a year. The range of similar floods was estimated between 72-76 m^3/s, 7 times per year, by the desktop approach, which will perform the same required functions.

3.2.2 Desktop EWR results

The EWR results are summarised in **Table 3-1**, with the full RDRM ‘report’ provided in **Appendix A**, which includes *inter alia* EWR assurance ‘rules’ for the range of ECs (*viz* A to D)

Table 3-1 Summary of EWR results

Natural/PD Mean Annual Runoff, nMAR (10^6m^3)				575.45
Ecological Category	**Low flows**		**Total flows**	
	10^6m^3	**% nMAR**	**10^6m^3**	**% nMAR**
B	213.819	37.2	281.716	49.0
C	144.160	25.1	206.964	36.0
D	95.926	16.7	150.750	26.2

3.3 CONCLUSION

Initially, the D EC results were used to determine the impacts on yield, which showed minimal impact on the yield. The B EWR was also evaluated; however this had a significant impact on yield. As explained in **Section 2.3**, the D EWR flows which, are considerably less than the present flow regime, is unlikely to maintain the REC. It is recommended that various other EC EWR results are evaluated during the Feasibility Phase as part of a scenario evaluation process to determine the impact of each scenario on the REC.

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APPENDIX D: Dam Site Summary Table

Site		Lowlands	N1a	N1	N2	N3	N4*	TOR	S4	S3	S2*	S1	S1a	D4	D3*	D2
Location	Latitude	29°44'31.40"S	29°50'13.46"S	29°50'40.87"S	29°50'45.77"S	29°51'27.89"S	29°52'25.33"S	29°53'5.80"S	29°53'31.17"S	29°54'41.63"S	29°54'59.79"S	29°55'30.64"S	29°55'44.80"S	29°59'7.10"S	30° 1'7.63"S	30° 3'52.37"S
	Longitude	27°43'10.26"E	27°38'45.31"E	27°38'10.13"E	27°37'25.50"E	27°37'27.70"E	27°36'49.60"E	27°36'44.86"E	27°36'46.27"E	27°35'46.90"E	27°34'47.34"E	27°34'14.27"E	27°33'5.02"E	27°30'24.84"E	27°29'0.68"E	27°26'45.99"E
Catchment Size	(km^2)	803	1402	1406	1412	1416	1570	1572	1653	1684	1688	1703	1803	2021	2069	2554
Lowest Ground Level	(m)	1576	1519	1516	1518	1511	1508	1503	1503	1493	1489	1483	1488	1459	1451	1434
MAR	(million m^3/a)	241	378	379	381	382	418	419	434	439	440	443	460	498	507	647
Estimated Flood peaks for initial design	QRMF (m^3/s)	2 833	3 744	3 749	3 757	3 763	3 962	3 965	4 066	4 103	4 108	4 126	4 247	4 496	4 549	5 053
	QRMF + Δ (m^3/s)	3 582	4 682	4 688	4 698	4 704	4 943	4 947	5 067	5 112	5 118	5 140	5 283	5 581	5 644	6 244
	1:10 (m^3/s)	779	1 030	1 031	1 033	1 035	1 090	1 090	1 118	1 128	1 130	1 135	1 168	1 236	1 251	1 390
	1:50 (m^3/s)	1 246	1 713	1 715	1 719	1 722	1 827	1 828	1 881	1 901	1 904	1 913	1 977	2 110	2 138	2 410
	1:100 (m^3/s)	1 539	2 094	2 097	2 102	2 106	2 229	2 231	2 293	2 317	2 320	2 331	2 406	2 563	2 596	2 916
	1:200 (m^3/s)	1 857	2 504	2 508	2 513	2 517	2 661	2 663	2 735	2 762	2 766	2 779	2 866	3 047	3 085	3 453
Fatal Flaw	(Yes/No)	No	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes
Dam height for 200 million m^3/a yield	(m)	129	84	86	78	78	76	74	69	74	78	74	79	70	71	53
Dam capacity for 200 million m^3/a yield	(million m^3)	602	270	253	270	269	248	248	242	239	236	238	224	217	215	200
Dam Cost for 200 million m^3/a yield	(million Rands)	R 6 060	R 1 247	R 2 144	R 2 617	R 2 262	R 2 276	R 1 871	R 1 218	R 2 405	R 1 311	R 1 044	R 1 927	R 3 048	R 2 030	R 1 179
Concrete Dam volume for 200 million m^3/a yield	(m^3)	2 020 165	415 668	714 539	872 493	753 928	758 815	623 576	406 076	801 511	436 976	348 110	642 246	1 016 003	676 659	393 123
Embankment Dam volume for 200 million m^3/a yield	(m^3)	8 009 595	1 642 775	2 832 774	3 453 775	2 975 513	2 999 003	2 462 135	1 599 772	3 150 580	1 718 362	1 366 464	2 537 359	3 996 493	2 615 717	1 522 856
Crest Length for 200 million m^3/a yield	(m)	943	259	367	505	521	496	439	325	673	343	311	412	790	881	531
Aspect Ratio for 200million m^3/a yield	(crest/height)	7.3	3.1	4.3	6.5	6.7	6.5	5.9	4.7	9.1	4.4	4.2	5.2	11.3	12.4	10.0
URV of yield assured (i = 8%) for 200 million m^3/a yield		3.6	0.7	1.3	1.6	1.4	1.4	1.1	0.7	1.4	0.8	0.6	1.2	1.8	1.2	0.7
Maximum Yield	(million m^3/a)	209	334	335	346	347	380	381	394	399	389	402	407	459	467	596
Capacity at maximum yield	(million m^3)	723	1133	1137	1143	1147	1254	1258	1301	1318	1319	1328	1381	1494	1520	1940
Ratio max capacity over MAR		3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Dam height for maximum yield	(m)	136	126	133	123	123	127	125	121	127	128	127	130	120	121	110
Dam Cost for maximum yield	(million Rands)	R 7 117	R 3 359	R 5 917	R 7 192	R 6 727	R 7 555	R 6 469	R 4 534	R 8 932	R 2 928	R 4 212	R 6 124	R 10 516	R 9 624	R 12 499
Concrete Dam volume for maximum yield	(m^3)	2 372 370	1 119 549	1 972 415	2 397 463	2 242 203	2 518 354	2 156 303	1 511 229	2 977 179	1 471 413	1 403 860	2 041 314	3 505 171	3 207 938	4 166 319
Embankment Dam volume for maximum yield	(m^3)	9 397 168	4 450 591	7 859 719	9 548 394	8 922 170	10 028 769	8 589 658	6 016 608	11 843 647	5 856 101	5 583 665	8 130 717	13 957 162	12 732 192	16 281 741
Crest Length for maximum yield	(m)	1205	400	514	655	723	720	608	466	965	466	493	559	994	1361	4276
Aspect Ratio for maximum yield		8.9	3.2	3.9	5.3	5.9	5.7	4.9	3.9	7.6	3.6	3.9	4.3	8.3	11.3	38.9
URV of yield assured (i = 8%) for maximum yield		4.1	1.2	2.1	2.5	2.3	2.4	2.0	1.4	2.7	0.9	1.3	1.9	2.7	2.5	2.5
Estimated Sediment Load over 50 years	(m^3)	6 034 274	28 567 074	28 710 512	28 931 995	29 090 111	34 876 568	35 055 881	41 135 154	43 445 285	43 759 807	44 859 631	52 433 861	80 804 652	86 230 015	140 846 580
Distance to construction materials	(km)	+5km	+5km	+5km	+5km	+5km	+5km	12 km E or 22 km SE	12 km E or 22 km SE	12 km E or 22 km SE	12 km E or 22 km SE	12 km E or 22 km SE	12 km E or 22 km SE	22 km SE or 13 km NW of site	22 km SE or 13 km NW of site	22 km SE or 13 km NW of site
Social impact	No. of households	Approx. 230	Approx. 90	Approx. 80	Approx. 90	Approx. 130	Approx. 130	Approx. 210	Approx. 160	Approx. 160	Approx. 160	Approx. 160	Approx. 170	Approx. 180	Approx. 160	Approx 450
	Agricultural land	Major economic displacement (crops, rangeland)	Moderate economic displacement (crops, rangeland)	Moderate economic displacement (crops, rangeland)	Moderate economic displacement (crops, rangeland)	Large-scale farming areas near dam wall, moderate economic displacement elsewhere	Large-scale farming areas near dam wall, moderate economic displacement elsewhere	Moderate economic displacement (crops, rangeland)	Moderate economic displacement (crops, rangeland)	Moderate economic displacement (crops, rangeland)	Moderate economic displacement (crops, rangeland)	Moderate economic displacement (crops, rangeland)	Moderate economic displacement (crops, rangeland)	Major economic displacement (crops, rangeland)	Major economic displacement (crops, rangeland)	Major economic displacement (crops, rangeland) Inundation area almost entirely developed
	Roads/Bridges	Various access roads, 3 km of main unpaved road, at least one major bridge	750 m of main unpaved road affected in western tailwater, detour possible via gravel road, 1 foot bridge just upstream of site N1a	750 m of main unpaved road affected in western tailwater, detour possible via gravel road, 1 foot bridge just upstream of site N1a	1 foot bridge just upstream of site N1a	1 foot bridge just upstream of site N1a	Bridge near dam wall 3 km of main road near dam wall, 1 foot bridge just upstream of site N1a 1.4 km of access road near dam wall Small section of main road in western tailwater 1 foot bridge just upstream of site N1a	Approx 4.5 km of main road Small bridges Bridge near Richard Village Approx 2 km of unpaved road Small section of main road in western tailwater	Approx 7.5 km of main road Small bridges Bridge near Richard Village Approx 2 km of unpaved road Small section of tar road in western tailwater	Approx 7.5 km of main road Small bridges Bridge near Richard Village Approx 2 km of unpaved road	Approx 7.5 km of main road Small bridges Bridge near Richard Village Approx 2 km of unpaved road	Approx 7.5 km of main road Small bridges Bridge near Richard Village Approx 2 km of unpaved road	Approx 7.5 km of main road Small bridges Bridge near Richard Village Approx 2 km of unpaved road	Approx 5 km of main road Small bridges Bridge near Richard Village Approx 1 km of unpaved road	Approx 4.5 km of main road Small bridges Bridge near Richard Village Approx 4.5 km of unpaved road	Approx 15 km of main road Small bridges Bridge near Richard Village Approx 12 km of unpaved road
Environmental Impact		Deeply incised valleys Erosion not very significant High potential for areas with significant biodiversity – main river channel and especially in tributary valleys	Incised valleys, Moderate erosion, Moderate potential for areas with significant biodiversity – mainly in tributary valleys Western tributary largely uninhabited – potential biodiversity areas Western tailwater largely uninhabited – potential biodiversity areas Eastern tailwater largely uninhabited, but extensive agriculture – potential biodiversity areas	Incised valleys, Moderate erosion, Moderate potential for areas with significant biodiversity – mainly in tributary valleys Western tributary largely uninhabited – potential biodiversity areas Western tailwater largely uninhabited – potential biodiversity areas Eastern tailwater largely uninhabited, but extensive agriculture – potential biodiversity areas	Incised valleys, Moderate erosion, Moderate potential for areas with significant biodiversity – mainly in tributary valleys Western tributary largely uninhabited – potential biodiversity areas Western tailwater largely uninhabited – potential biodiversity areas Eastern tailwater largely uninhabited, but extensive agriculture – potential biodiversity areas	Incised valleys, Moderate erosion, Moderate potential for areas with significant biodiversity – mainly in tributary valleys Western tributary largely uninhabited – potential biodiversity areas Western tailwater largely uninhabited – potential biodiversity areas Eastern tailwater largely uninhabited, but extensive agriculture – potential biodiversity areas	Incised valleys, Moderate erosion Moderate potential for areas with significant biodiversity – mainly in tributary valleys Western tributary largely uninhabited – potential biodiversity areas Western tailwater largely uninhabited – potential biodiversity areas Eastern tailwater largely uninhabited, but extensive agriculture – potential biodiversity areas	Wider valley at dam wall site, Moderate erosion Moderate potential for areas with significant biodiversity, especially in tributaries Marginal vegetation is comprised of trees, probably alien / invasive Pine plantations on hillsides	Wider valley at dam wall site, Moderate erosion Moderate potential for areas with significant biodiversity, especially in tributaries Marginal vegetation is comprised of trees, probably alien / invasive Pine plantations on hillsides	Wider valley at dam wall site, Moderate erosion Moderate potential for areas with significant biodiversity, especially in tributaries Marginal vegetation is comprised of trees, probably alien / invasive Pine plantations on hillsides	Narrow valley at dam wall site, Moderate erosion Moderate potential for areas with significant biodiversity, especially in tributaries Marginal vegetation is comprised of trees, probably alien / invasive Pine plantations on hillsides	Narrow valley at dam wall site, Moderate erosion Moderate potential for areas with significant biodiversity, especially in tributaries Marginal vegetation is comprised of trees, probably alien / invasive Pine plantations on hillsides	Eastern tributary will be inundated (additional to S1) Narrow valley at dam wall site, Moderate erosion Moderate potential for areas with significant biodiversity, especially in tributaries Marginal vegetation is comprised of trees, probably alien / invasive Pine plantations on hillsides	Wide valley at dam wall site Moderate erosion Degraded land Large inundation surface area – evaporation Catchment management will be difficult	Wide valley at dam wall site Moderate erosion Degraded land Large inundation surface area – evaporation Catchment management will be difficult	Very wide valley at dam wall site Major erosion Degraded land, especially eastern tributary Large inundation surface area – evaporation Catchment management will be difficult

APPENDIX E: Dam Site Technical Data Sheets

LOWLANDS

1.1 LOCATION

The Lowlands dam site is located at 29°44'31.40"S and 27°43'10.26"E in the West of Lesotho.

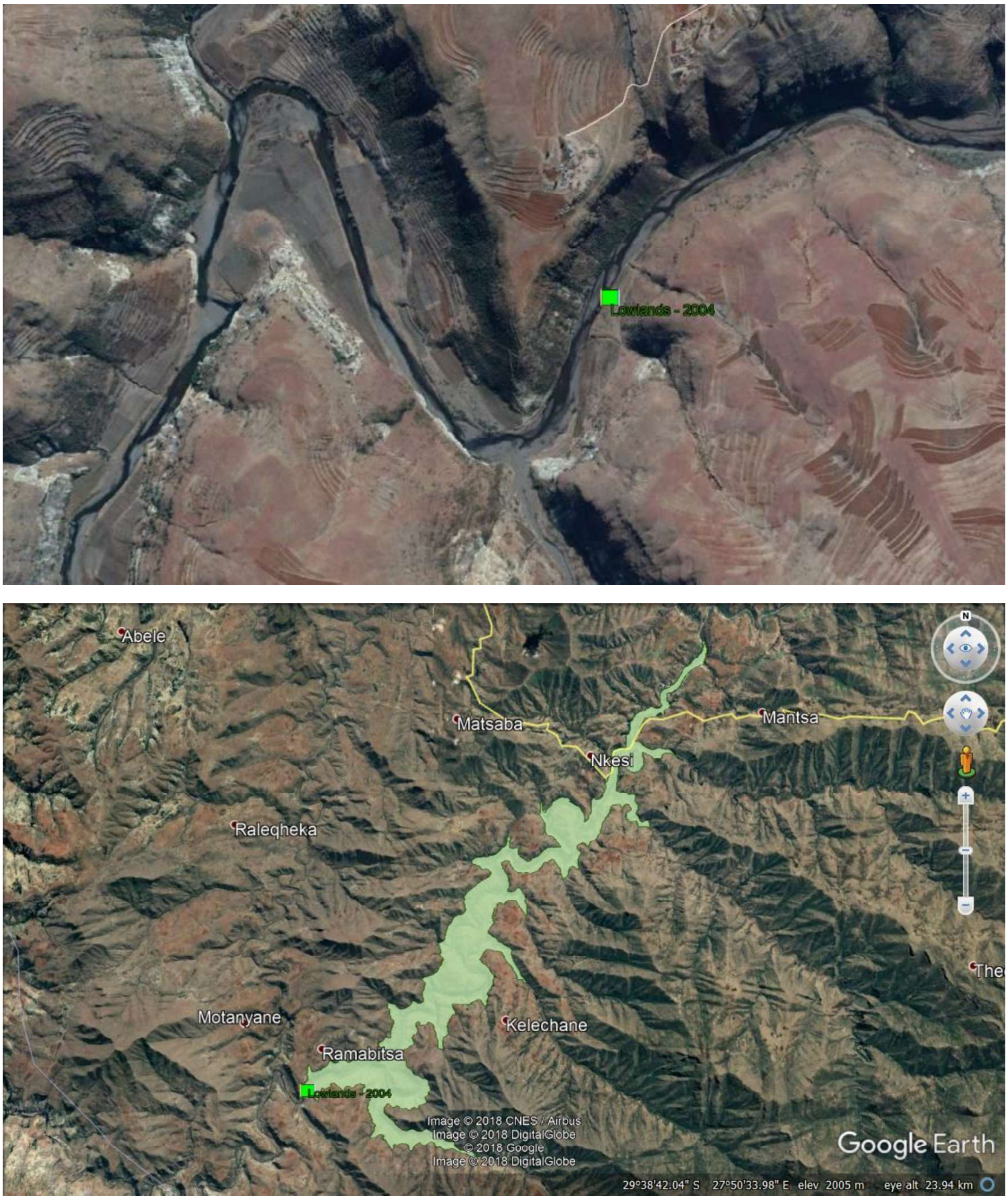


Figure 1: Map of Dam Site Location

1.2 GENERAL

• Catchment Size (km^2):	803
• MAR (MCM/a):	240
• Design Floods (m^3/s):	
• 1:10 year (River diversion):	780
• 1:200 (Design Flood):	1 855
• RMF + ∆ (Safety Evaluation):	3 580
• Distance to Construction material	+ 5 km
• Expected 50-year Sediment Volumes (million m^3)	6.03

Figure 2: Photograph of Dam Site

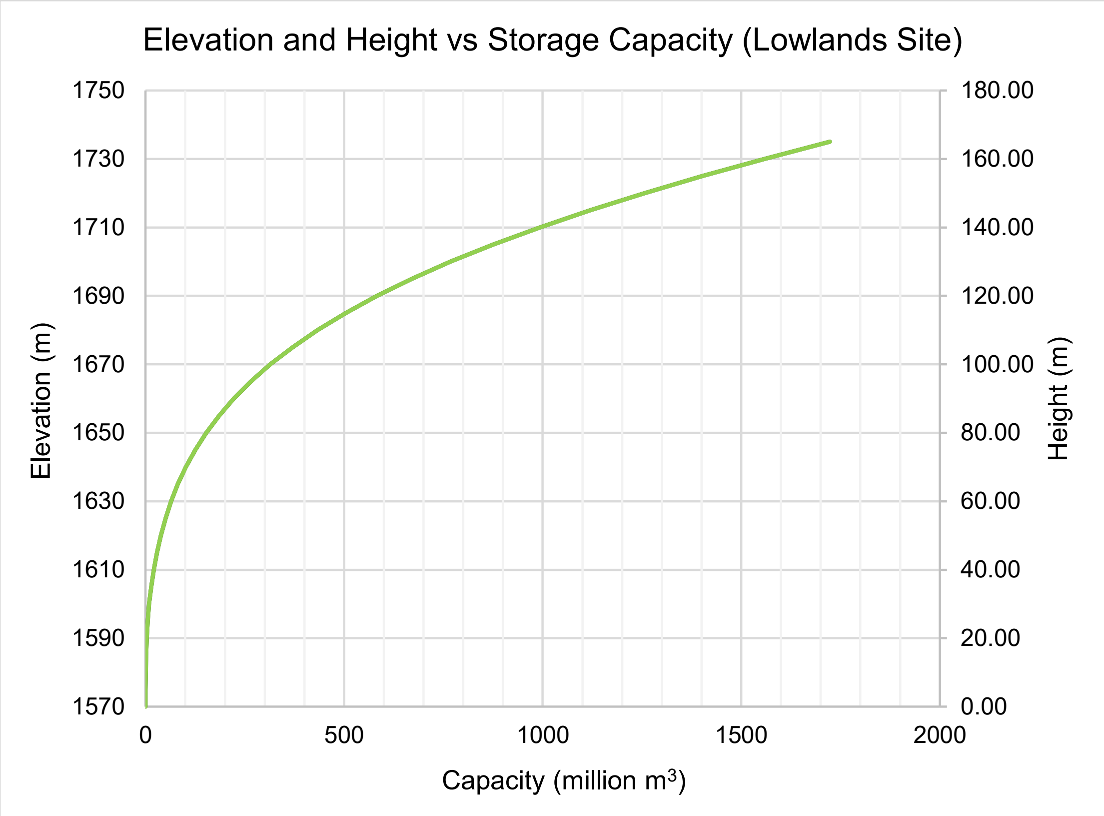


Figure 3: Elevation and Height vs Storage Capacity Graph

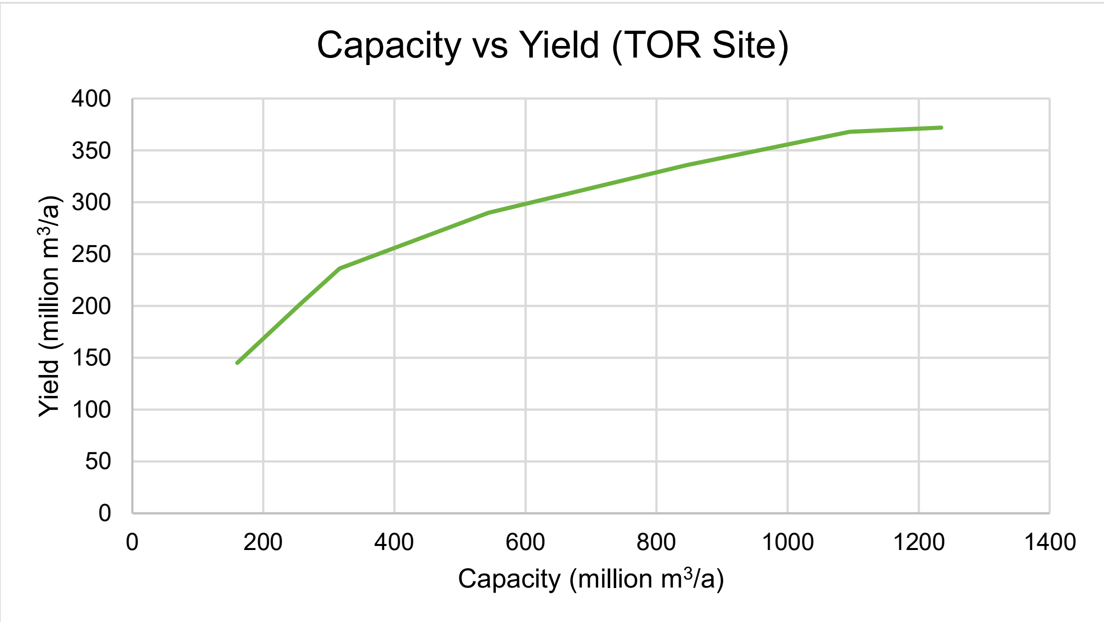


Figure 4: Capacity vs Yield Graph

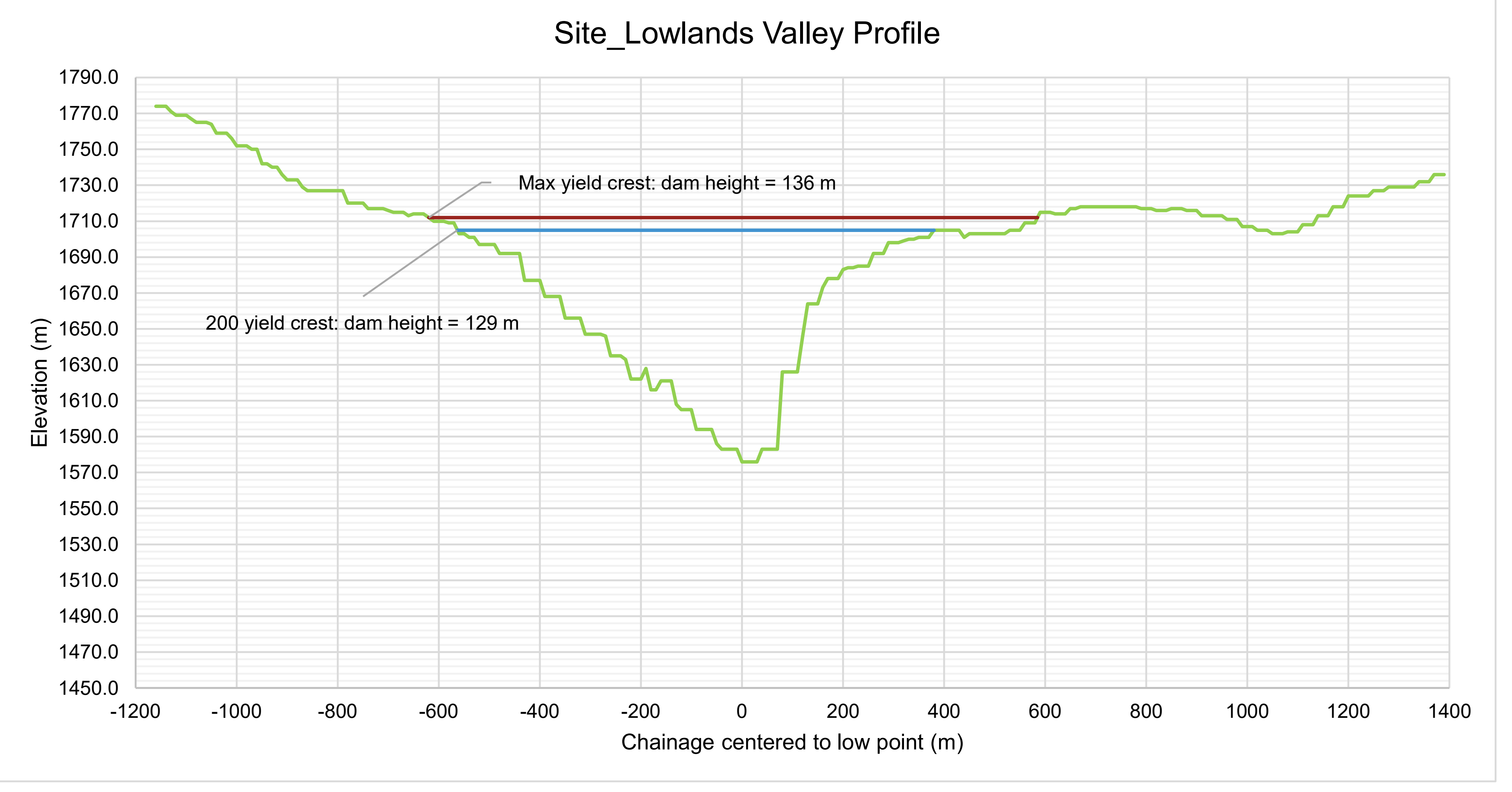


Figure 5: Dam valley profile with dam heights for a dam with 200 MCM/a yield and for a maximum a yield that equates to a capacity of 3 MAR

1.3 DAM HEIGHT OPTIONS

Scenarios	Dam Height to meet 200MCM/a Yield (Scenario 1)	Dam Height for 3 MAR Capacity (Scenario 2)
Height (m)	129	136
Capacity (MCM)	605	729
Yield (MCM/a)	200	209
Impact on the yield of Gariep Dam (MCM/a)	-165	-159
Aspect Ratio	7.3	8.9
Likely Dam Type	RCC Gravity Dam	RCC Gravity Dam
River Diversion	Coffer dam, with twin diversion tunnels	Coffer dam, with twin diversion tunnels
Spillway type	Free ogee over crest	Free ogee over crest
Outlet arrangement	Multi-level outlet, with tower against upstream face	Multi-level outlet, with tower against upstream face
Dam material volumes (m^3)	2 020 165	2 372 370
Hydropower potential - continuous flow (MW)	7.55	8.93
Hydropower potential - peak power (MW)	50.7	60.0
Turbine type - continuous flow	Horizontal Francis	Horizontal Francis
Turbine type - peak power	Vertical Francis	Vertical Francis
Dam Capital Cost Estimate (million R)	R 6 060	R 7 117
URV of yield assured (i = 8%)	3.6	4.1

N1A

1.1 LOCATION

The N1a dam site is located at 29°50'13.46"S and 27°38'45.31"E in the West of Lesotho.

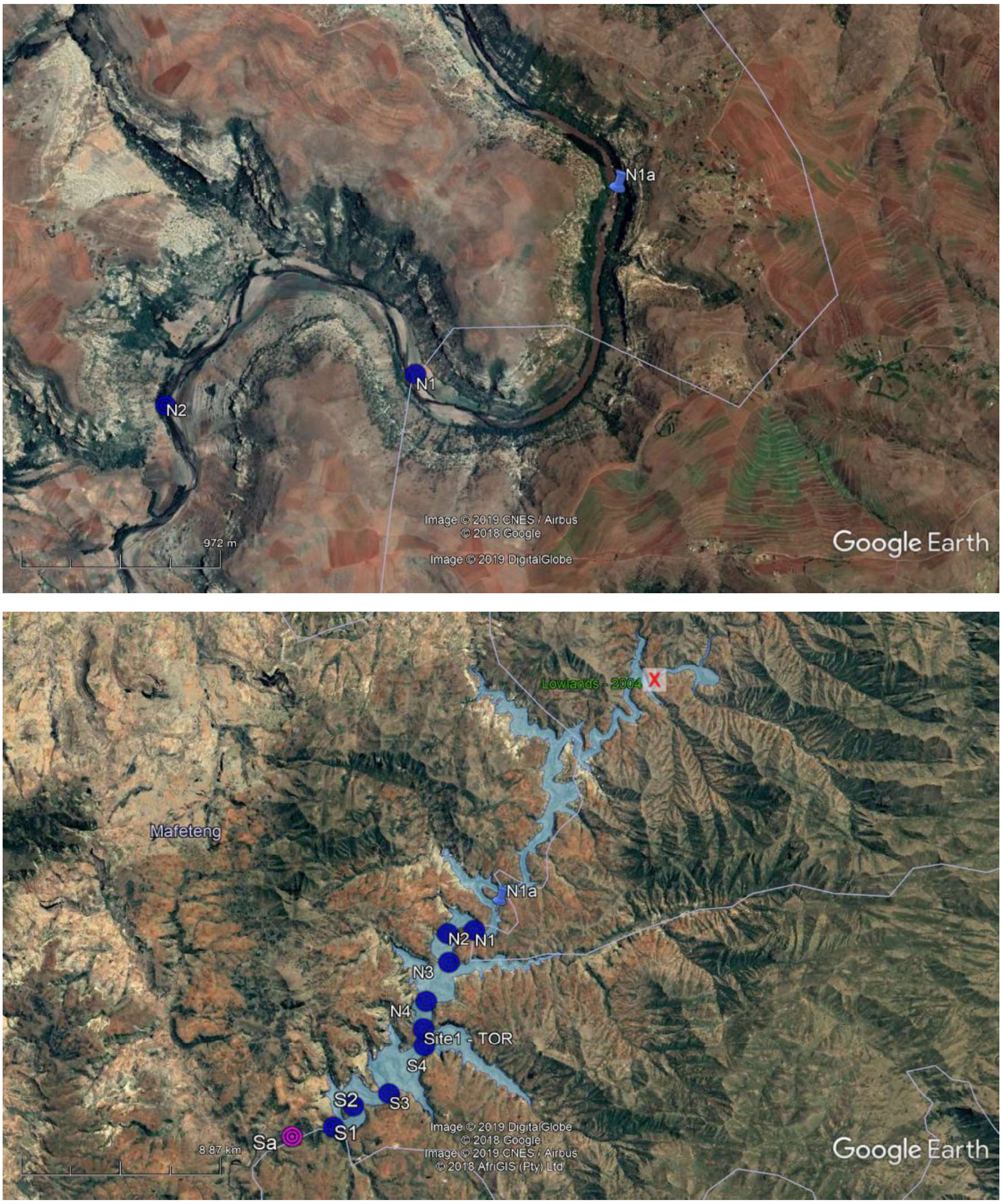


Figure 1: Map of Dam Site Location

1.2 GENERAL

• Catchment Size (km^2):	1 402
• MAR (MCM/a):	378
• Design Floods (m^3/s):	
• 1:10 year (River diversion):	1 030
• 1:200 (Design Flood):	2 504
• RMF + Δ (Safety Evaluation):	4 682
• Distance to Construction material	+ 5 km
• Expected 50-year Sediment Volumes (million m^3)	28.57

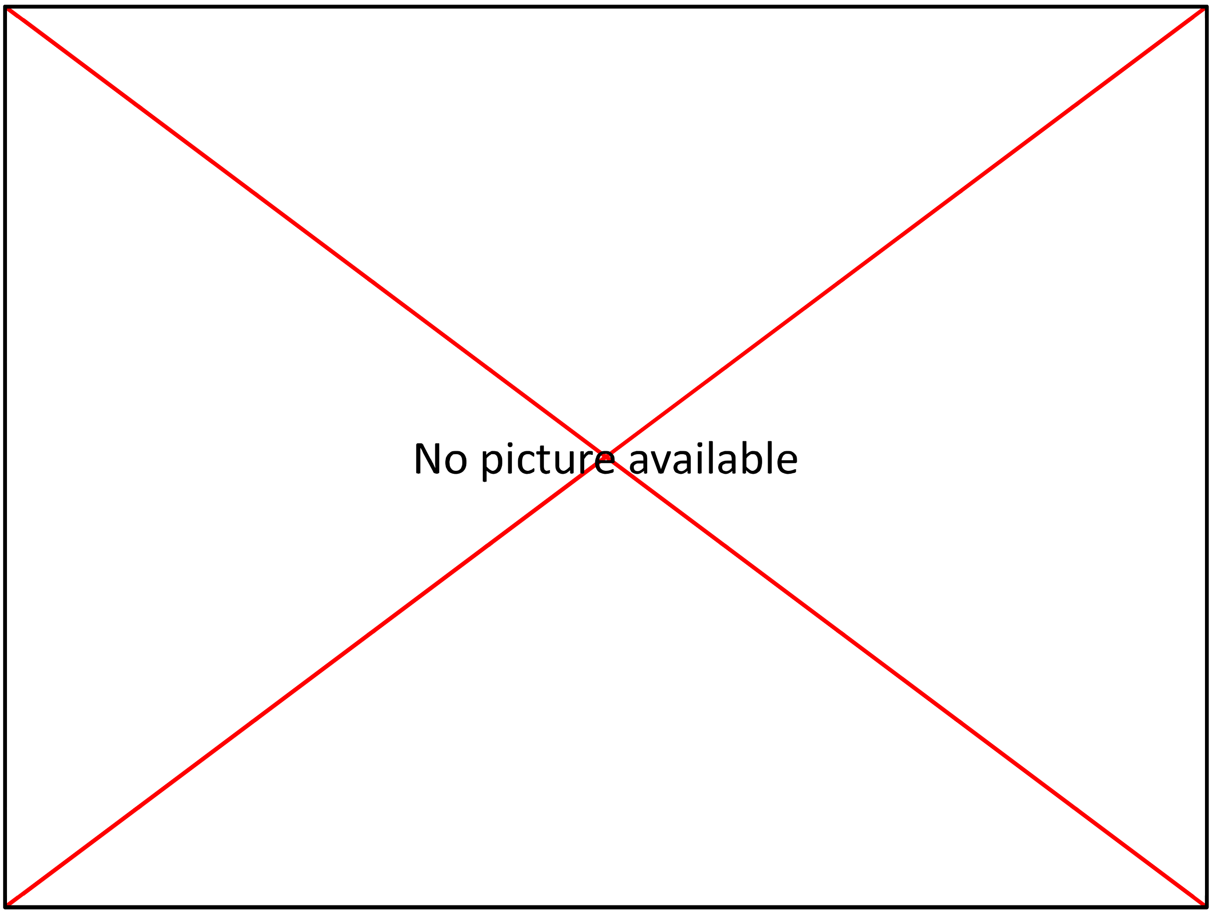


Figure 2: Photograph of Dam Site

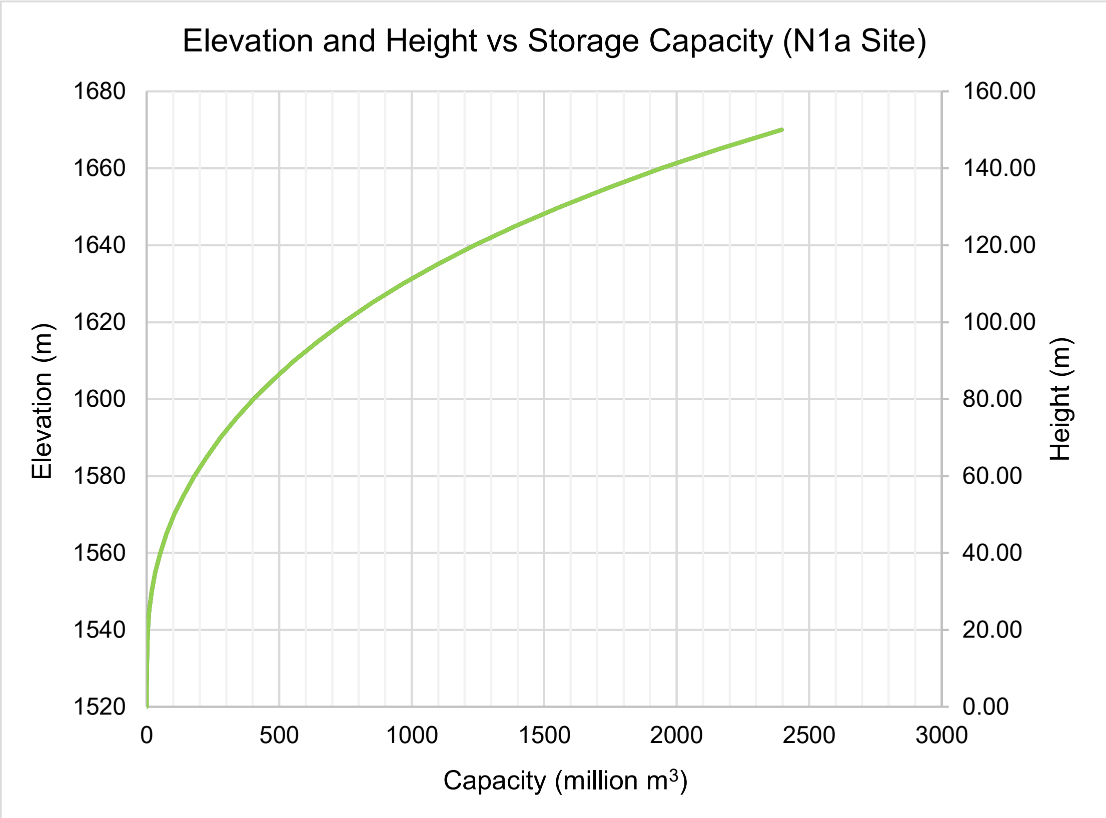


Figure 3: Elevation and Height vs Storage Capacity Graph

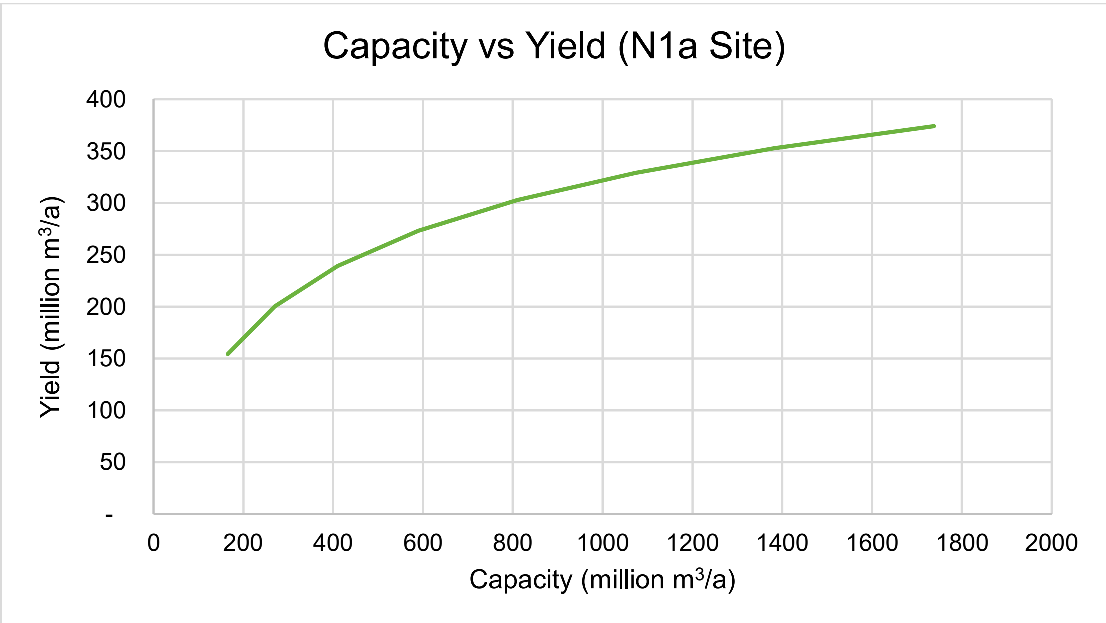


Figure 4: Capacity vs Yield Graph

Figure 5: Dam valley profile with dam heights for a dam with 200 MCM/a yield and for a maximum a yield that equates to a capacity of 3 MAR

1.3 DAM HEIGHT OPTIONS

Scenarios	Dam Height to meet 200MCM/a Yield (Scenario 1)	Dam Height for 3 MAR Capacity (Scenario 2)
Height (m)	84	126
Capacity (MCM)	270	1 133
Yield (MCM/a)	200	334
Impact on the yield of Gariep Dam (MCM/a)	-165	-74
Aspect Ratio	3.1	3.2
Likely Dam Type	RCC Gravity Dam	RCC Gravity Dam
River Diversion	Coffer dam, with twin diversion tunnels	Coffer dam, with twin diversion tunnels
Spillway type	Free ogee over crest	Free ogee over crest
Outlet arrangement	Multi-level outlet, with tower against upstream face	Multi-level outlet, with tower against upstream face
Dam material volumes (m^3)	415 668	1 119 549
Hydropower potential - continuous flow (MW)	4.74	12.33
Hydropower potential - peak power (MW)	31.90	82.90
Turbine type - continuous flow	Horizontal Francis	Horizontal Francis
Turbine type - peak power	Vertical Francis	Vertical Francis
Dam Capital Cost Estimate (million R)	R 1 247	R 3 359
URV of yield assured (i = 8%)	0.7	1.2

N1

1.1 LOCATION

The N1 dam site is located at 29°50'40.87"S and 27°38'10.13"E in the West of Lesotho.

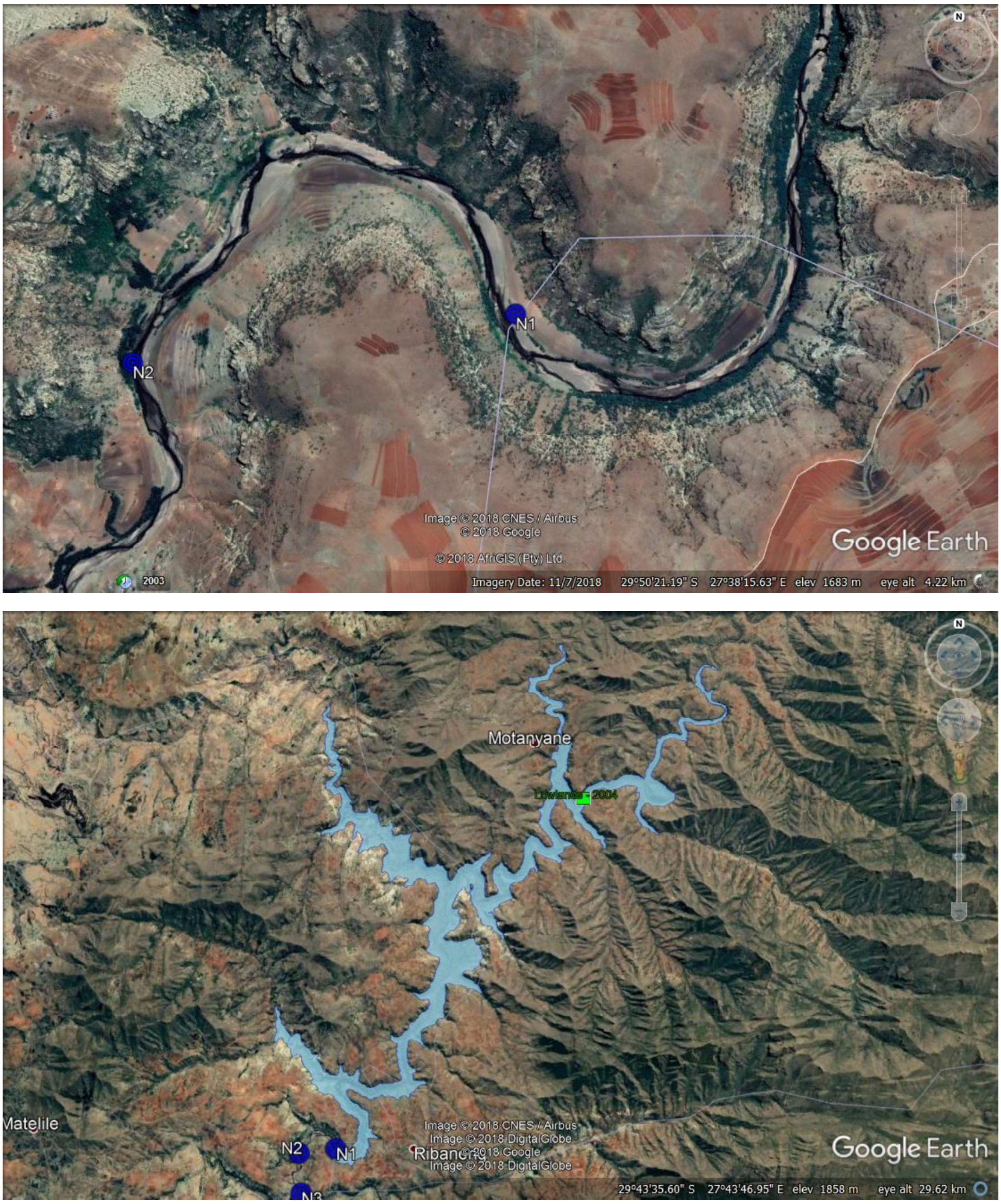


Figure 1: Map of Dam Site Location

1.2 GENERAL

• Catchment Size (km^2):	1 406
• MAR (MCM/a):	380
• Design Floods (m^3/s):	
• 1:10 year (River diversion):	1 030
• 1:200 (Design Flood):	2 510
• RMF + ∆ (Safety Evaluation):	4 690
• Distance to Construction material	+ 5 km
• Expected 50-year Sediment Volumes (million m^3)	28.71

Figure 2: Photograph of Dam Site

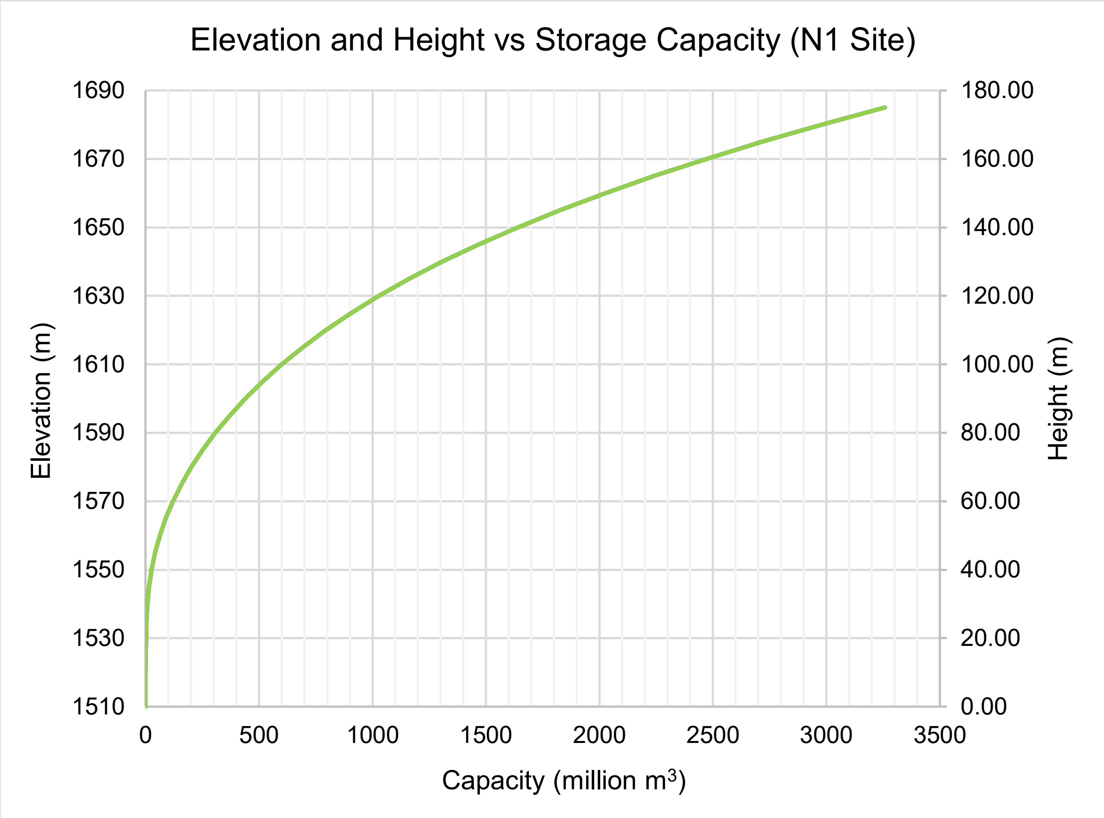


Figure 3: Elevation and Height vs Storage Capacity Graph

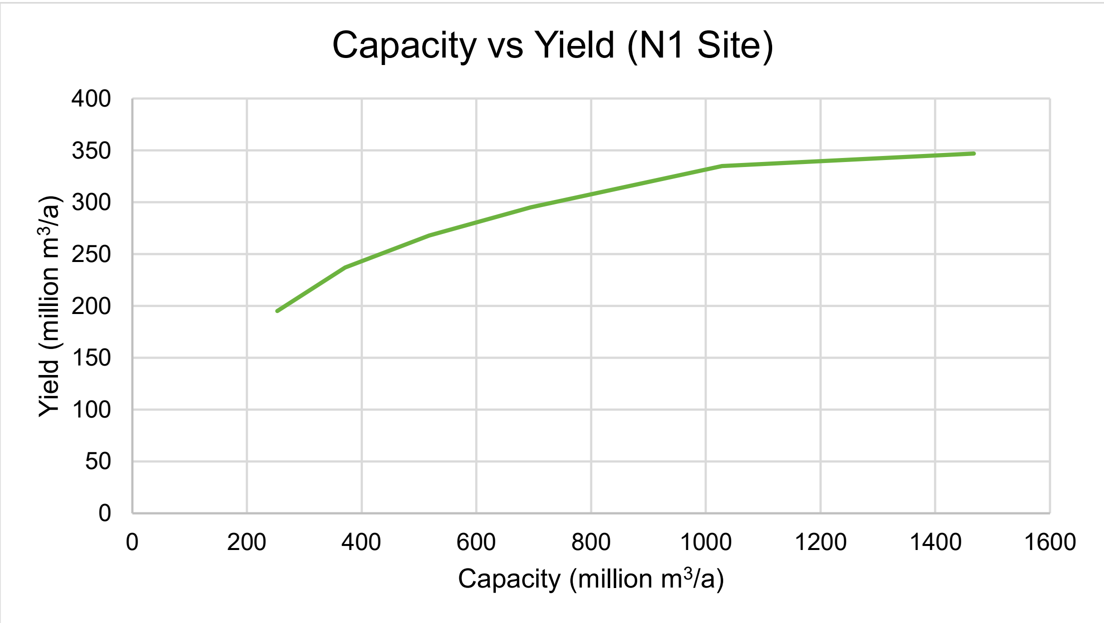


Figure 4: Capacity vs Yield Graph

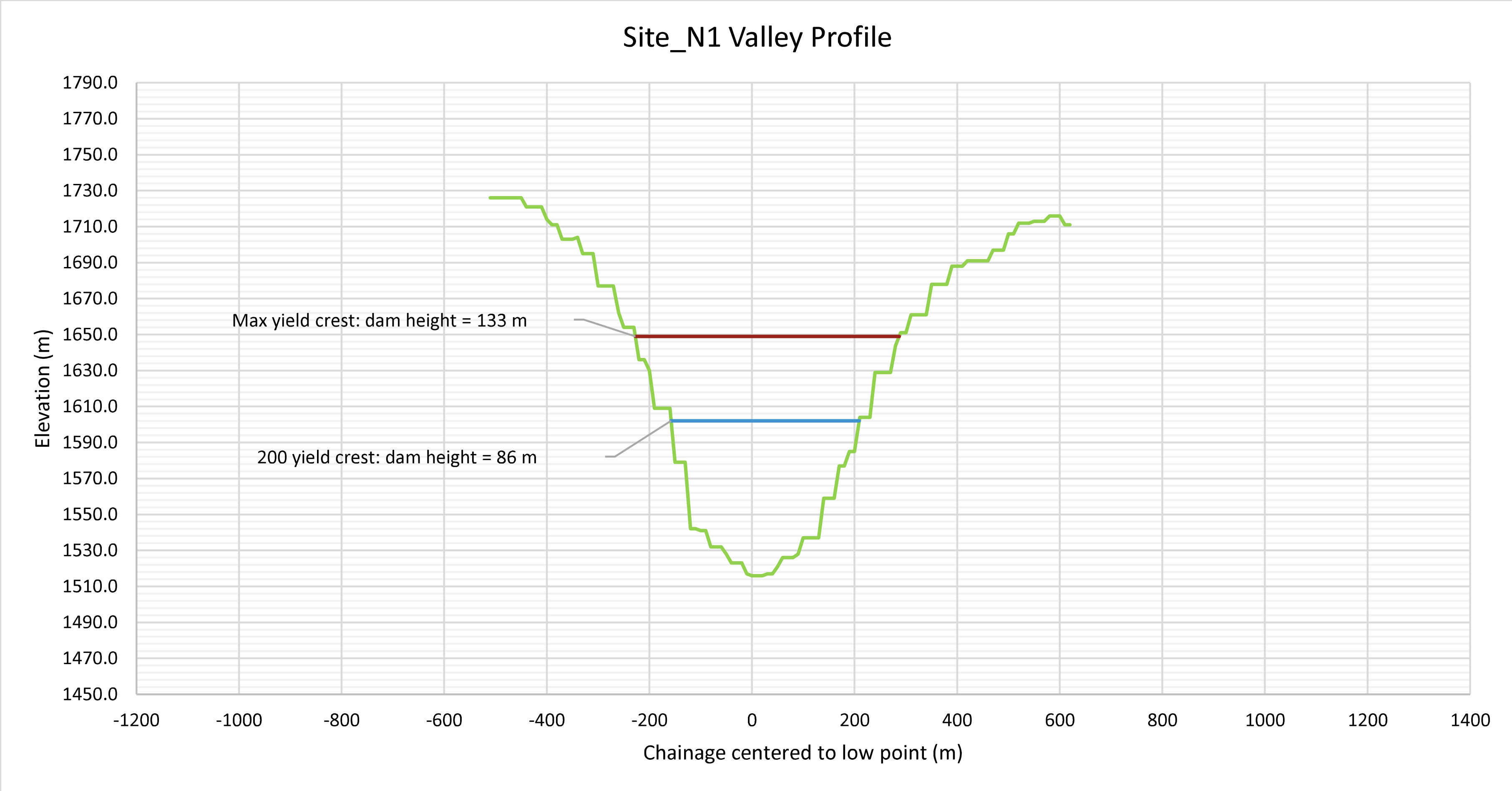


Figure 5: Dam valley profile with dam heights for a dam with 200 MCM/a yield and for a maximum a yield that equates to a capacity of 3 MAR

1.3 DAM HEIGHT OPTIONS

Scenarios	Dam Height to meet 200MCM/a Yield (Scenario 1)	Dam Height for 3 MAR Capacity (Scenario 2)
Height (m)	86	133
Capacity (MCM)	271	1 137
Yield (MCM/a)	200	335
Impact on the yield of Gariep Dam (MCM/a)	-165	-74
Aspect Ratio	4.3	3.9
Likely Dam Type	RCC Gravity Dam	RCC Gravity Dam
River Diversion	Coffer dam, with twin diversion tunnels	Coffer dam, with twin diversion tunnels
Spillway type	Free ogee over crest	Free ogee over crest
Outlet arrangement	Multi-level outlet, with tower against upstream face	Multi-level outlet, with tower against upstream face
Dam material volumes (m^3)	714 539	1 972 415
Hydropower potential - continuous flow (MW)	4.85	13.50
Hydropower potential - peak power (MW)	32.60	90.73
Turbine type - continuous flow	Horizontal Francis	Horizontal Francis
Turbine type - peak power	Vertical Francis	Vertical Francis
Dam Capital Cost Estimate (million R)	R 2 144	R 5 917
URV of yield assured (i = 8%)	1.3	2.1

N2

1.1 LOCATION

The N2 dam site is located at 29°50'45.77"S and 27°37'25.50"E in the West of Lesotho.

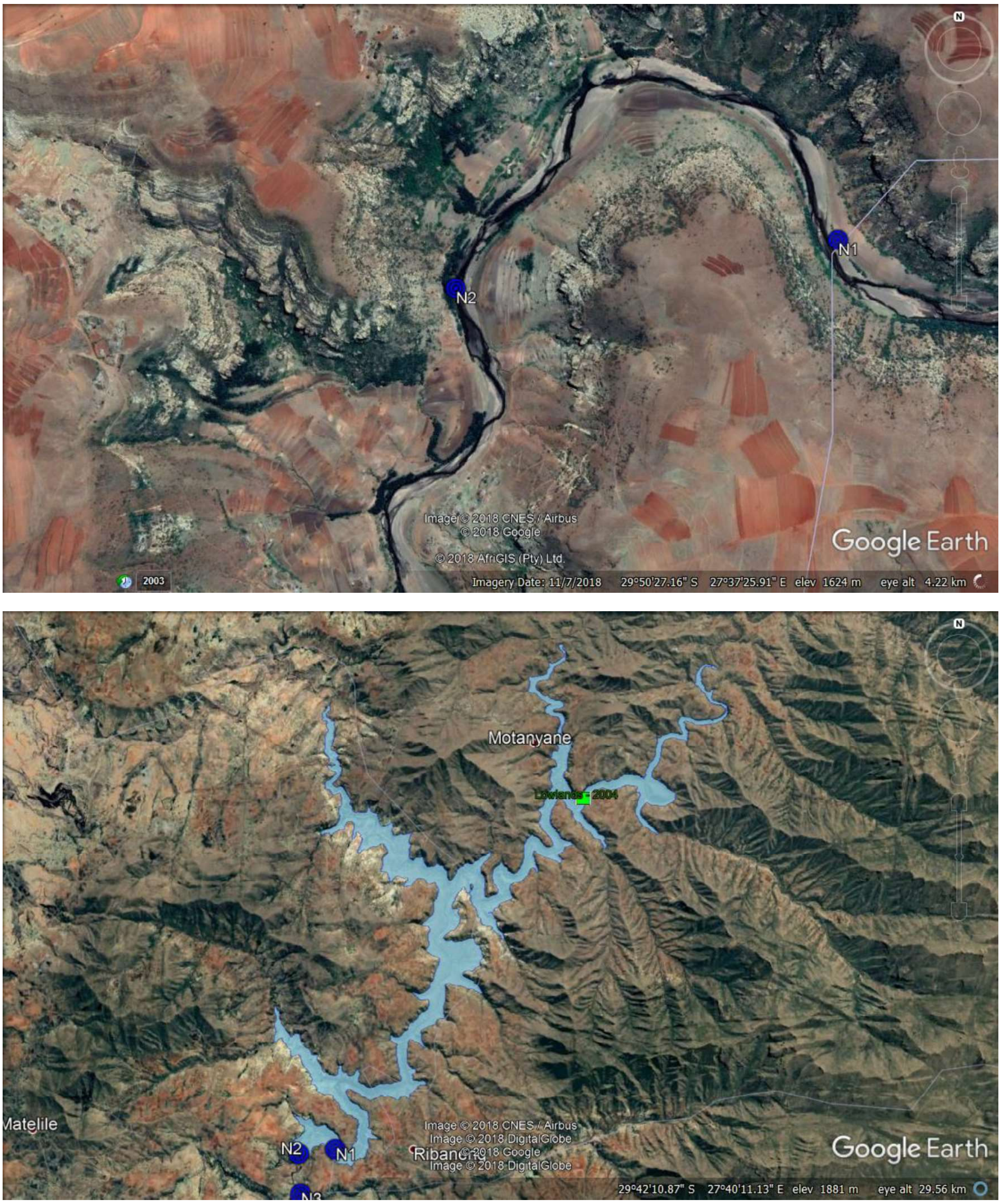


Figure 1: Map of Dam Site Location

1.2 GENERAL

• Catchment Size (km^2):	1 412
• MAR (MCM/a):	380
• Design Floods (m^3/s):	
• 1:10 year (River diversion):	1 035
• 1:200 (Design Flood):	2 515
• RMF + ∆ (Safety Evaluation):	4 700
• Distance to Construction material	+ 5 km
• Expected 50-year Sediment Volumes (million m^3)	28.93

Figure 2: Photograph of Dam Site

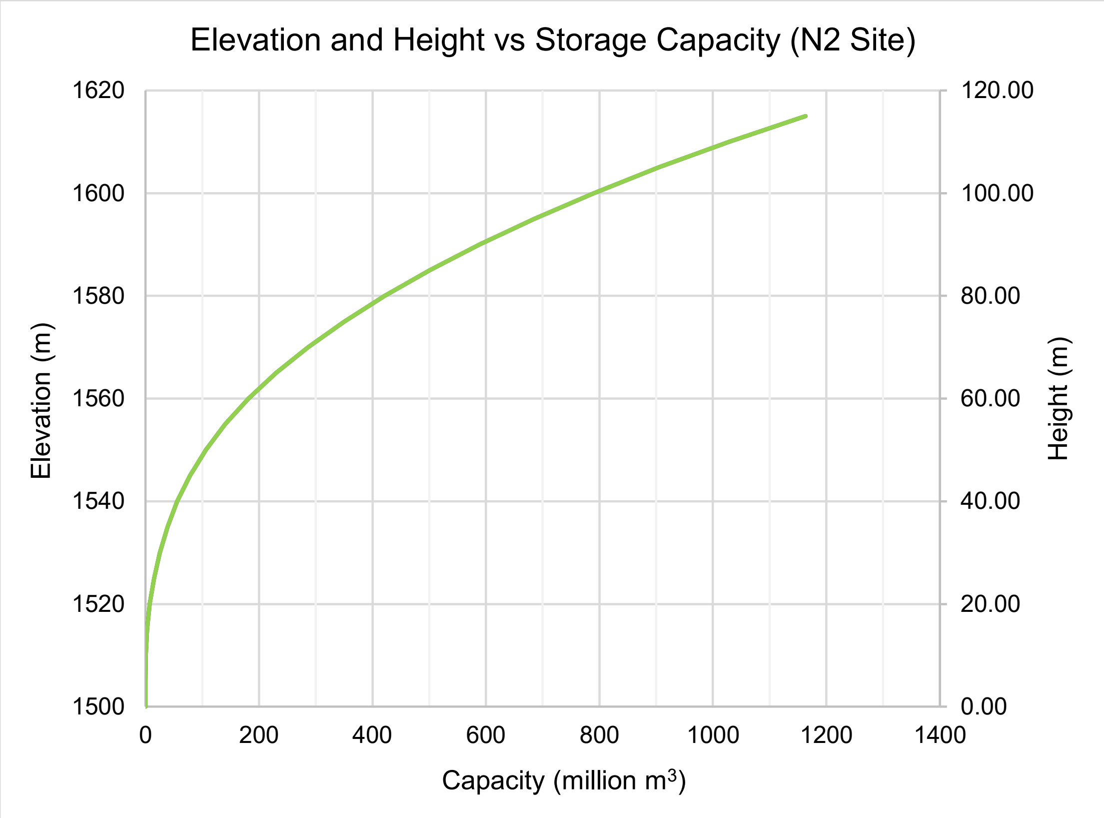


Figure 3: Elevation and Height vs Storage Capacity Graph

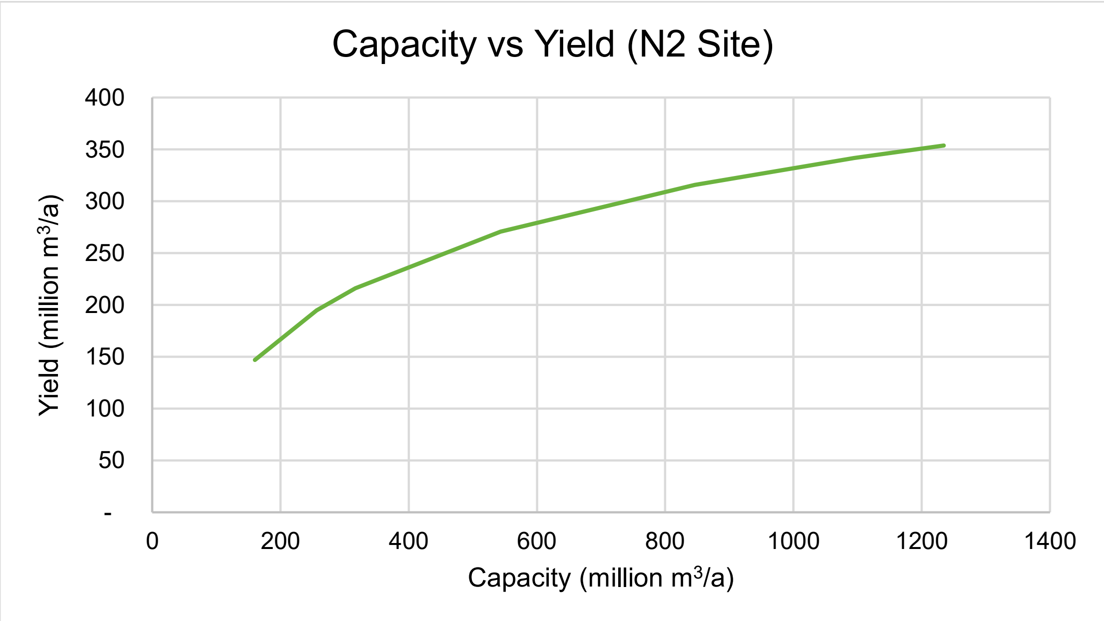


Figure 4: Capacity vs Yield Graph

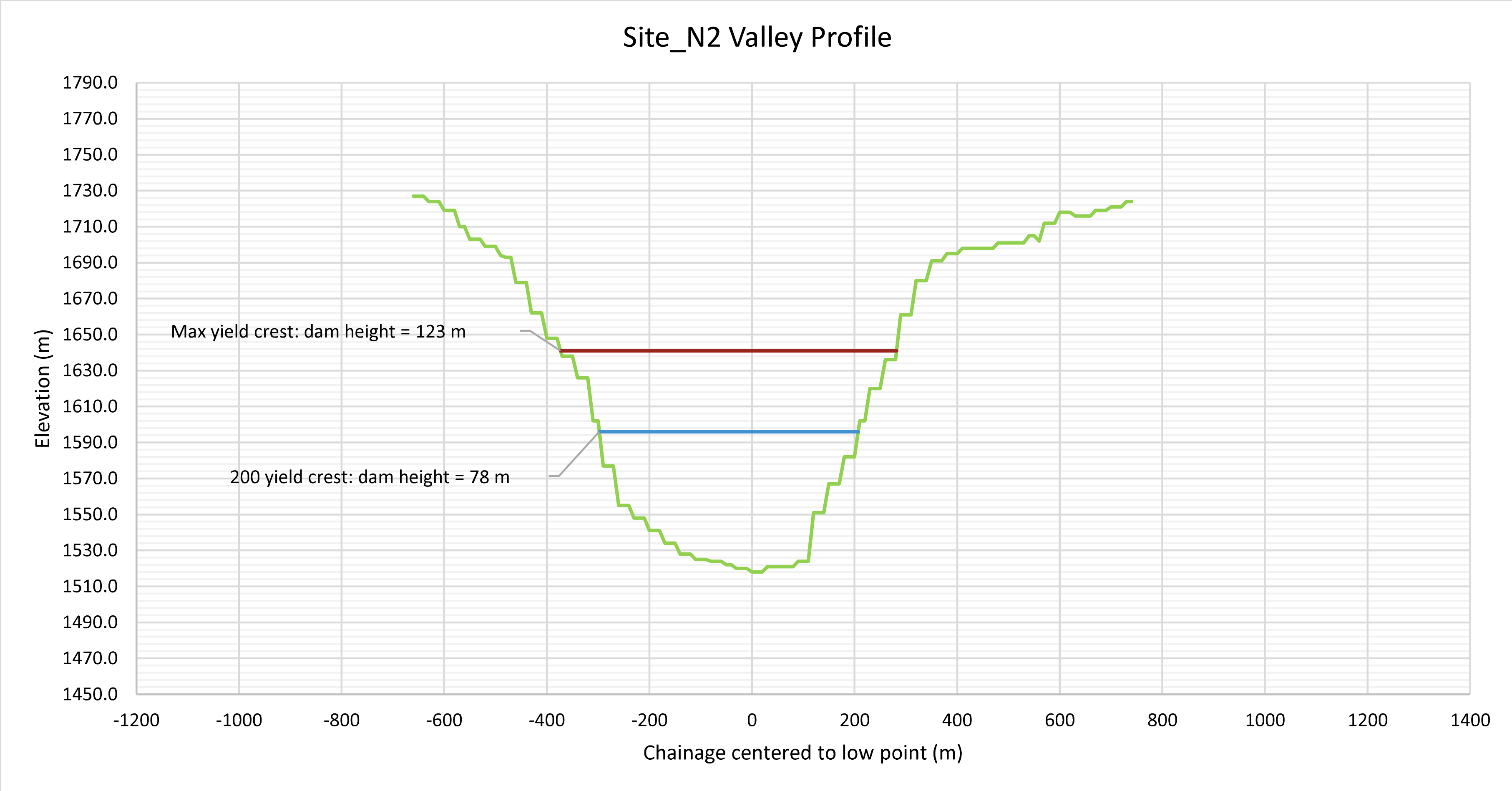


Figure 5: Dam valley profile with dam heights for a dam with 200 MCM/a yield and for a maximum a yield that equates to a capacity of 3 MAR

1.3 DAM HEIGHT OPTIONS

Scenarios	Dam Height to meet 200MCM/a Yield (Scenario 1)	Dam Height for 3 MAR Capacity (Scenario 2)
Height (m)	78	123
Capacity (MCM)	270	1 143
Yield (MCM/a)	200	346
Impact on the yield of Gariep Dam (MCM/a)	-165	-66
Aspect Ratio	6.5	5.3
Likely Dam Type	RCC Gravity Dam	RCC Gravity Dam
River Diversion	Coffer dam, with twin diversion tunnels	Coffer dam, with twin diversion tunnels
Spillway type	Free ogee over crest	Free ogee over crest
Outlet arrangement	Multi-level outlet, with tower against upstream face	Multi-level outlet, with tower against upstream face
Dam material volumes (m^3)	872 493	2 397 463
Hydropower potential - continuous flow (MW)	4.33	12.63
Hydropower potential - peak power (MW)	29.10	84.87
Turbine type - continuous flow	Horizontal Francis	Horizontal Francis
Turbine type - peak power	Vertical Francis	Vertical Francis
Dam Capital Cost Estimate (million R)	R 2 617	R 7 192
URV of yield assured (i = 8%)	1.6	2.5

N3

1.1 LOCATION

The N3 dam site is located at 29°51'27.89"S and 27°37'27.70"E in the West of Lesotho.

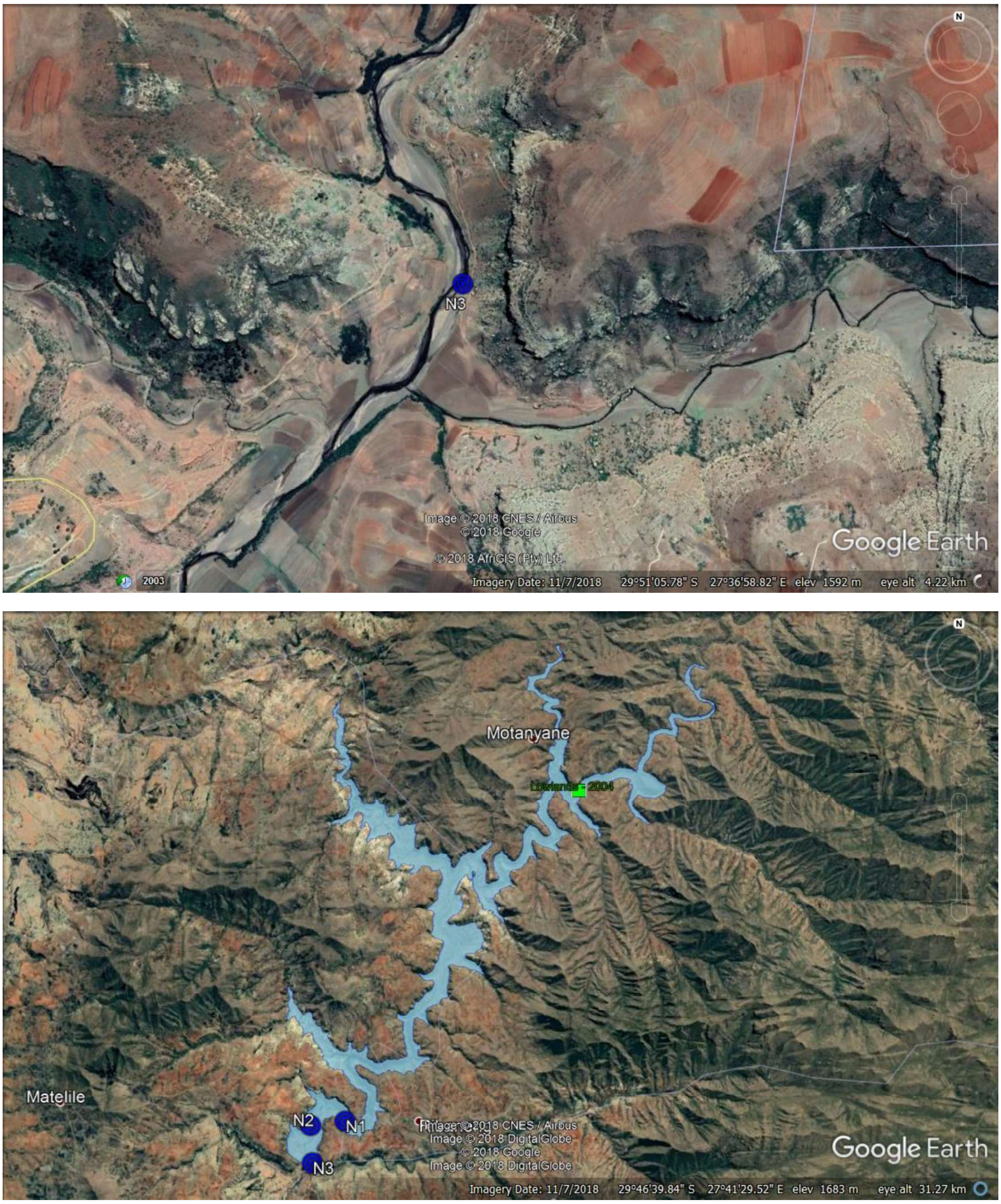


Figure 1: Map of Dam Site Location

1.2 GENERAL

• Catchment Size (km^2):	1 416
• MAR (MCM/a):	380
• Design Floods (m^3/s):	
• 1:10 year (River diversion):	1 035
• 1:200 (Design Flood):	2 515
• RMF + ∆ (Safety Evaluation):	4 705
• Distance to Construction material	+ 5 km
• Expected 50-year Sediment Volumes (million m^3)	29.09

Figure 2: Photograph of Dam Site

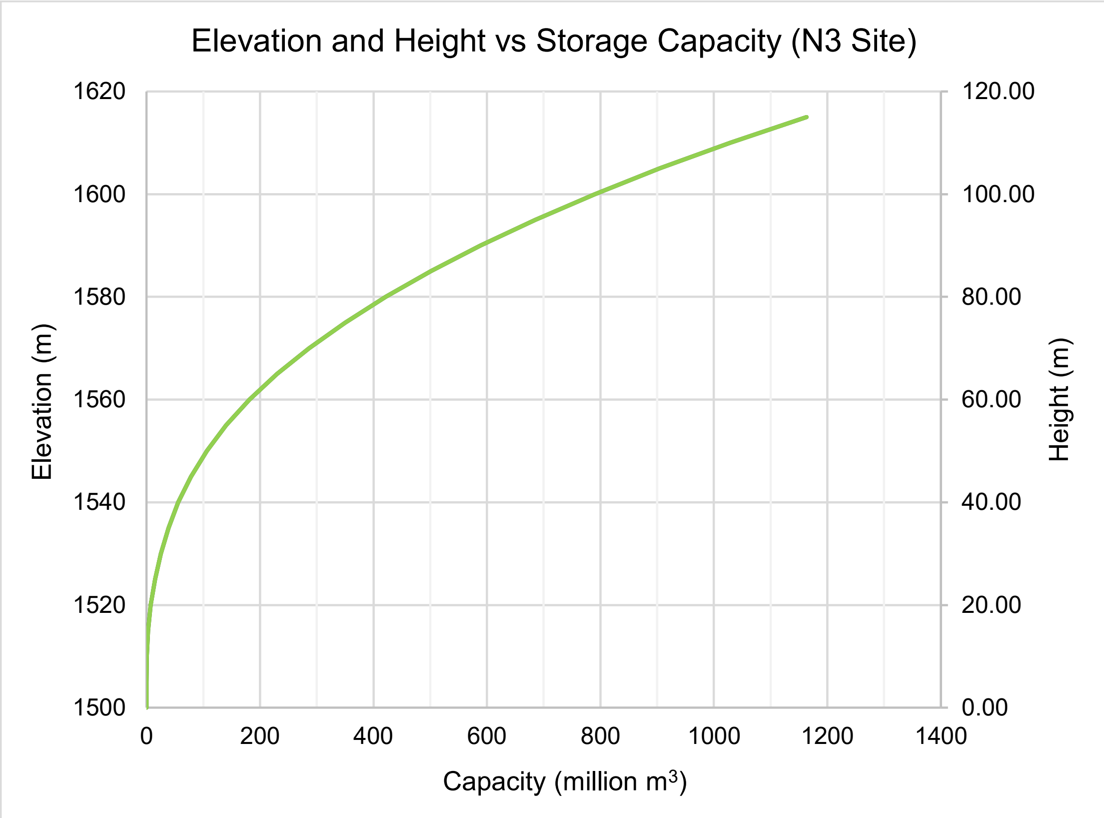


Figure 3: Elevation and Height vs Storage Capacity Graph

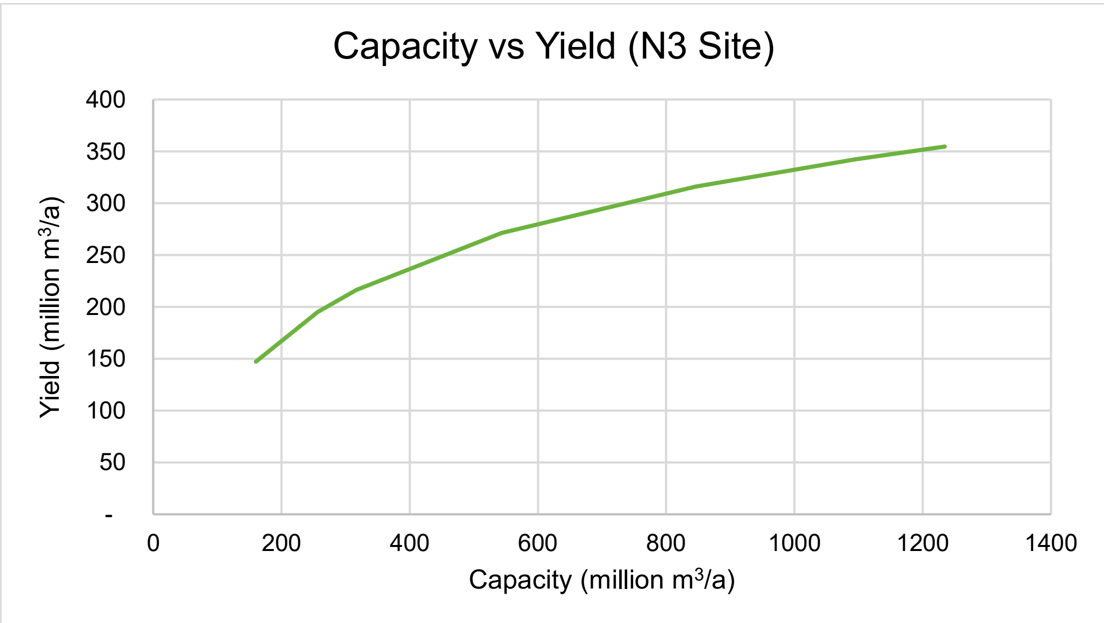


Figure 4: Capacity vs Yield Graph

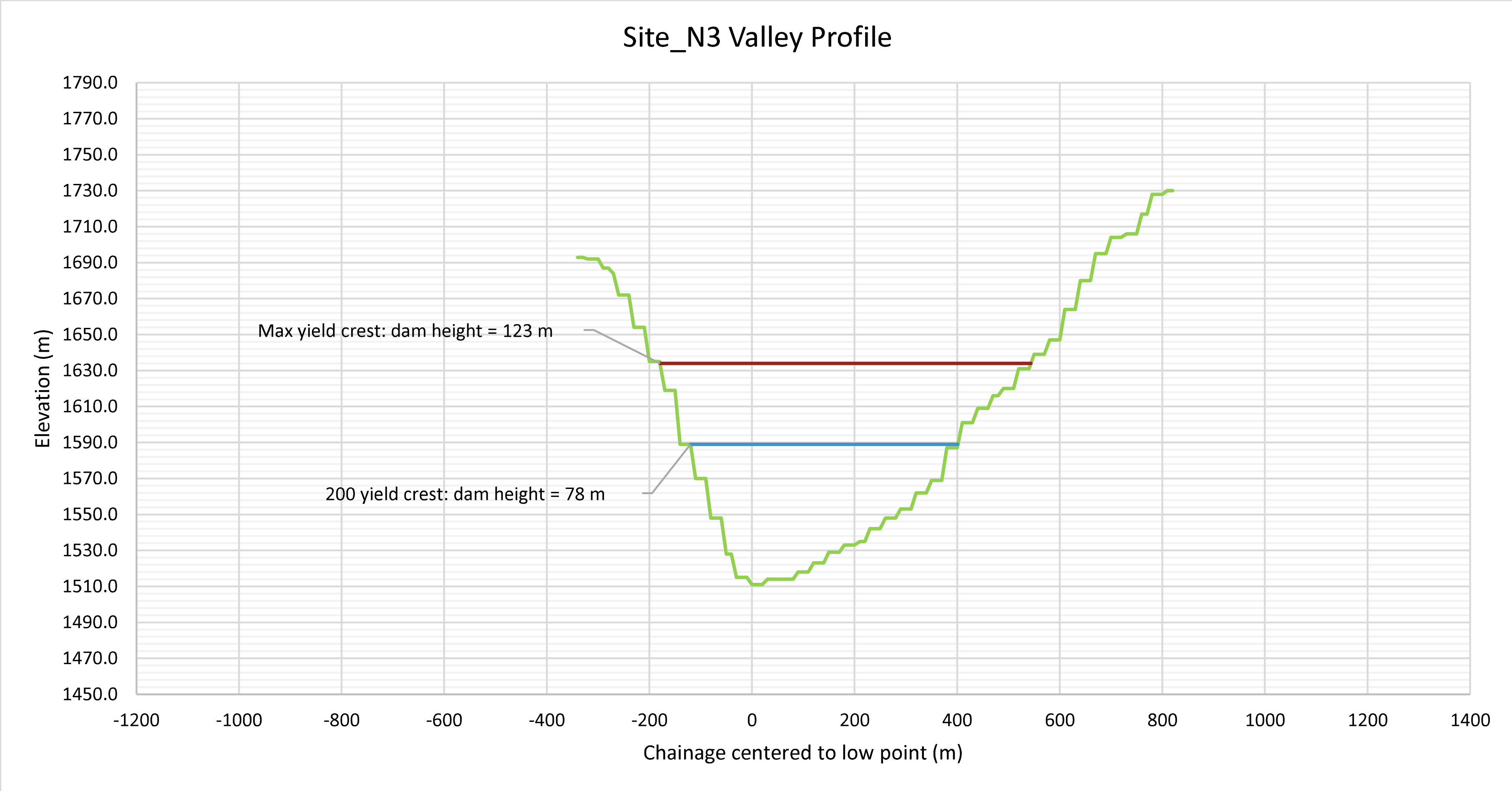


Figure 5: Dam valley profile with dam heights for a dam with 200 MCM/a yield and for a maximum a yield that equates to a capacity of 3 MAR

1.3 DAM HEIGHT OPTIONS

Scenarios	Dam Height to meet 200MCM/a Yield (Scenario 1)	Dam Height for 3 MAR Capacity (Scenario 2)
Height (m)	78	123
Capacity (MCM)	269	1 147
Yield (MCM/a)	200	347
Impact on the yield of Gariep Dam (MCM/a)	-165	-66
Aspect Ratio	6.7	5.9
Likely Dam Type	RCC Gravity Dam	RCC Gravity Dam
River Diversion	Coffer dam, with twin diversion tunnels	Coffer dam, with twin diversion tunnels
Spillway type	Free ogee over crest	Free ogee over crest
Outlet arrangement	Multi-level outlet, with tower against upstream face	Multi-level outlet, with tower against upstream face
Dam material volumes (m^3)	753 928	2 242 203
Hydropower potential - continuous flow (MW)	4.33	12.67
Hydropower potential - peak power (MW)	29.08	85.13
Turbine type - continuous flow	Horizontal Francis	Horizontal Francis
Turbine type - peak power	Vertical Francis	Vertical Francis
Dam Capital Cost Estimate (million R)	R 2 262	R 6 727
URV of yield assured (i = 8%)	1.4	2.3

N4

1.1 LOCATION

The N4 dam site is located at 29°52'25.33"S and 27°36'49.60"E in the West of Lesotho.

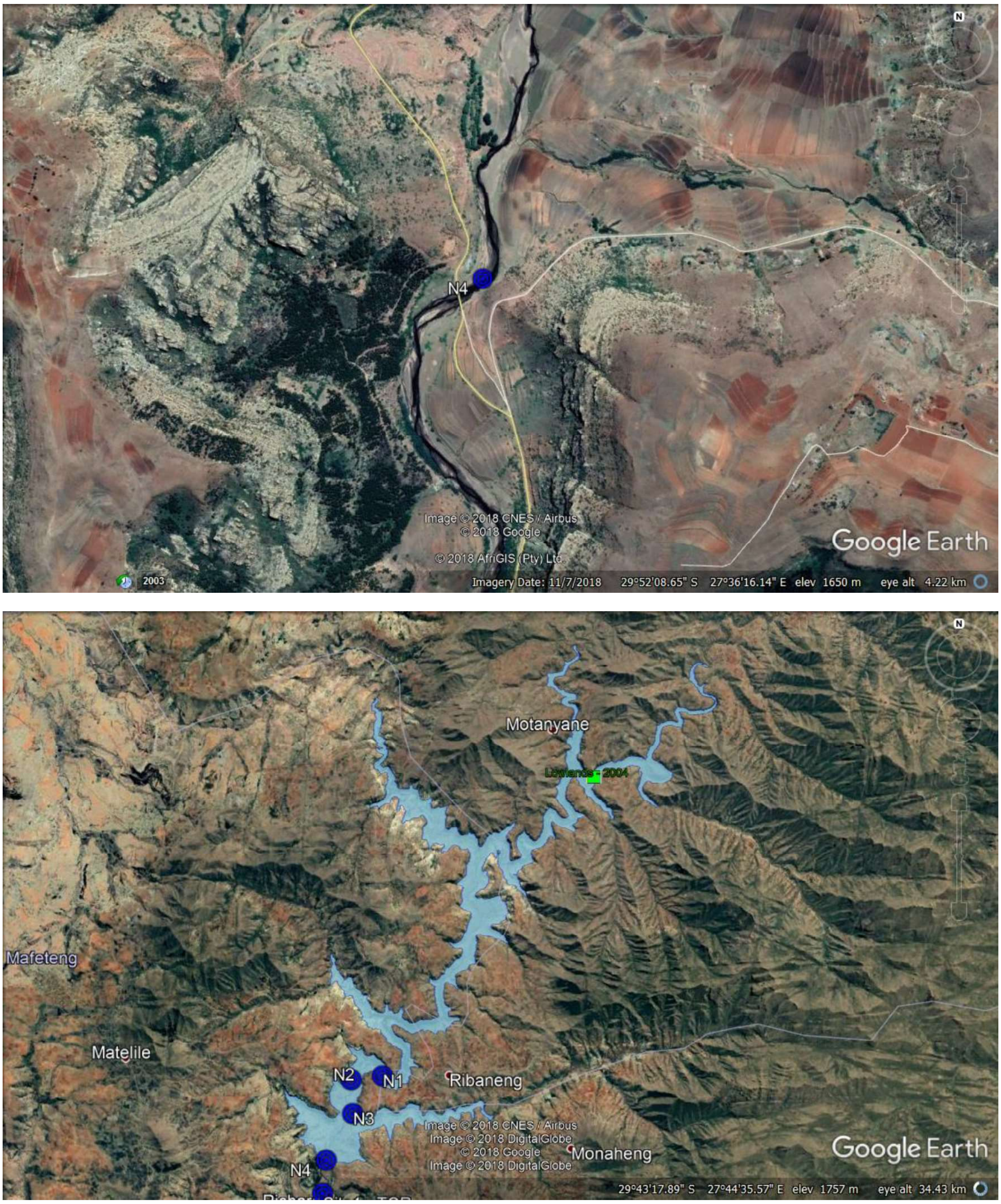


Figure 1: Map of Dam Site Location

1.2 GENERAL

• Catchment Size (km^2):	1 570
• MAR (MCM/a):	420
• Design Floods (m^3/s):	
• 1:10 year (River diversion):	1 090
• 1:200 (Design Flood):	2 660
• RMF + ∆ (Safety Evaluation):	4 945
• Distance to Construction material	+ 5 km
• Expected 50-year Sediment Volumes (million m^3)	34.88

Figure 2: Photograph of Dam Site

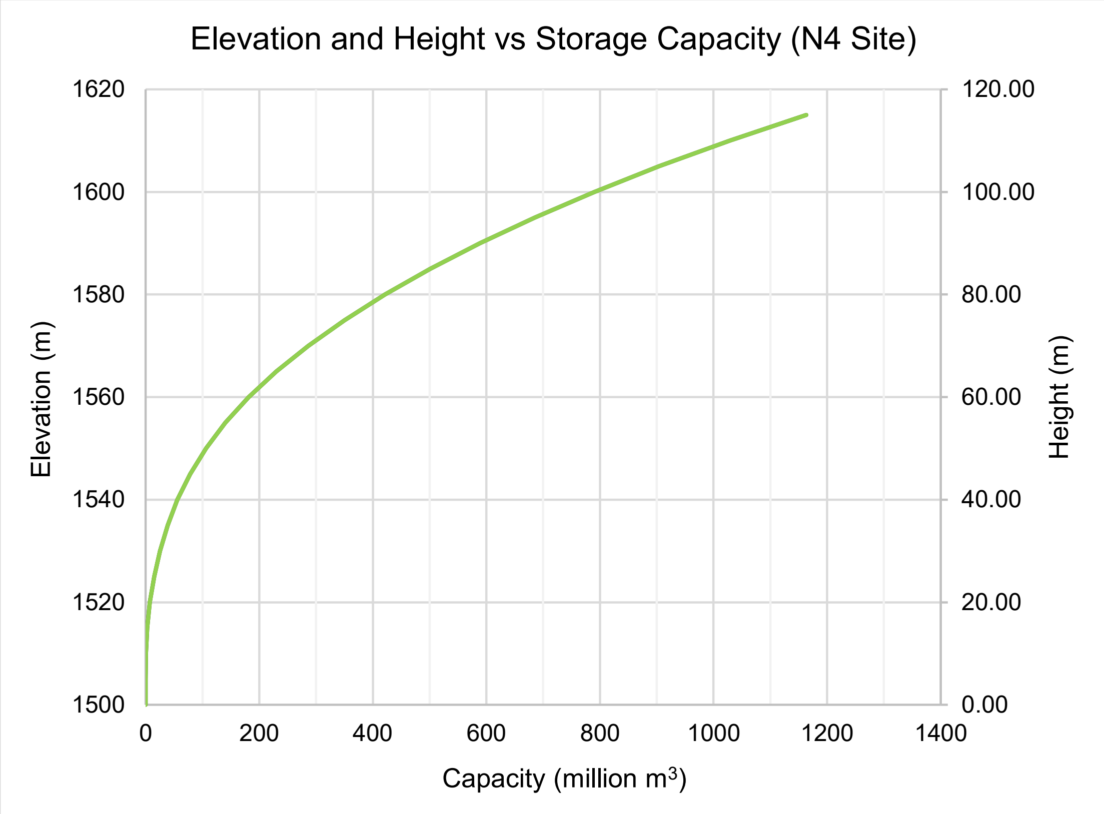


Figure 3: Elevation and Height vs Storage Capacity Graph

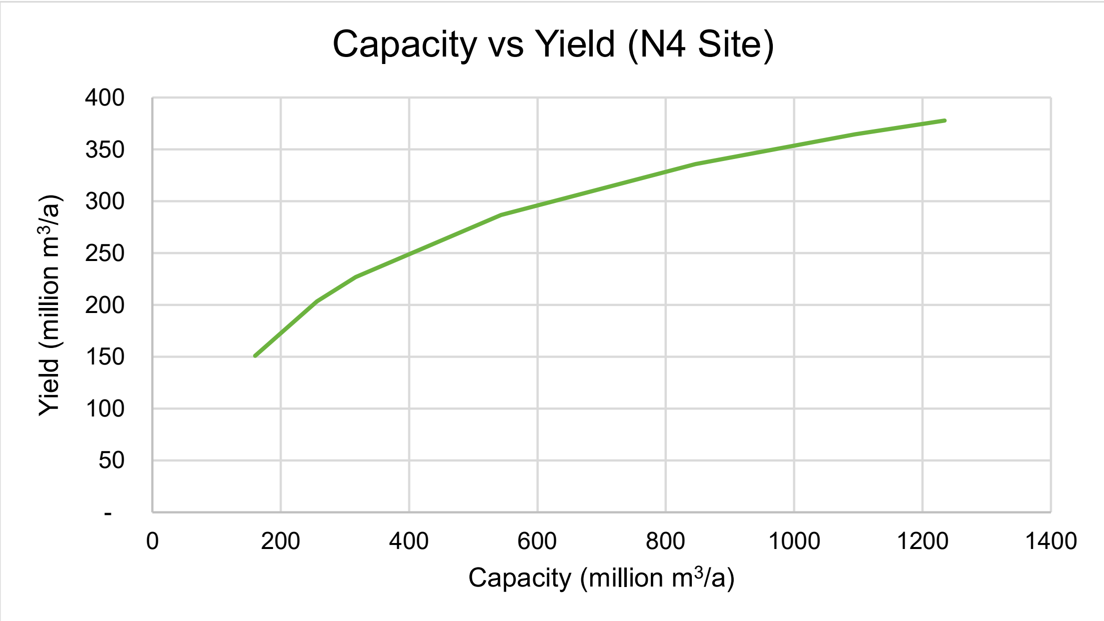


Figure 4: Capacity vs Yield Graph

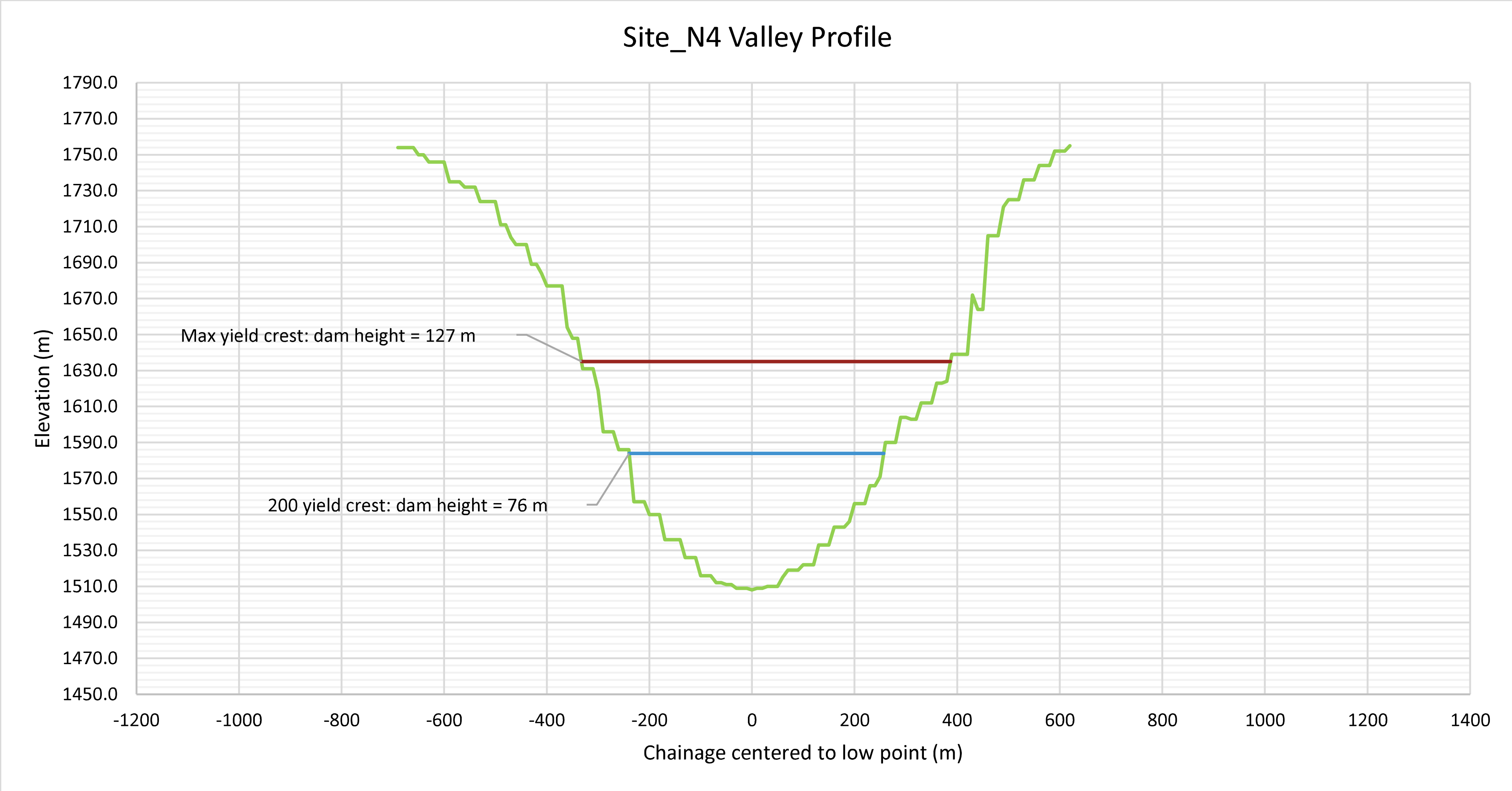


Figure 5: Dam valley profile with dam heights for a dam with 200 MCM/a yield and for a maximum a yield that equates to a capacity of 3 MAR

1.3 DAM HEIGHT OPTIONS

Scenarios	Dam Height to meet 200MCM/a Yield (Scenario 1)	Dam Height for 3 MAR Capacity (Scenario 2)
Height (m)	76	127
Capacity (MCM)	248	1 254
Yield (MCM/a)	200	380
Impact on the yield of Gariep Dam (MCM/a)	-165	-44
Aspect Ratio	6.5	5.7
Likely Dam Type	RCC Gravity Dam	RCC Gravity Dam
River Diversion	Coffer dam, with twin diversion tunnels	Coffer dam, with twin diversion tunnels
Spillway type	Free ogee over crest	Free ogee over crest
Outlet arrangement	Multi-level outlet, with tower against upstream face	Multi-level outlet, with tower against upstream face
Dam material volumes (m^3)	758 815	2 518 354
Hydropower potential - continuous flow (MW)	4.26	13.95
Hydropower potential - peak power (MW)	28.60	93.71
Turbine type - continuous flow	Horizontal Francis	Horizontal Francis
Turbine type - peak power	Vertical Francis	Vertical Francis
Dam Capital Cost Estimate (million R)	R 2 276	R 7 555
URV of yield assured (i = 8%)	1.4	2.4

TOR

1.1 LOCATION

The TOR dam site is located at 29°53'05.80"S and 27°36'44.86"E in the West of Lesotho.

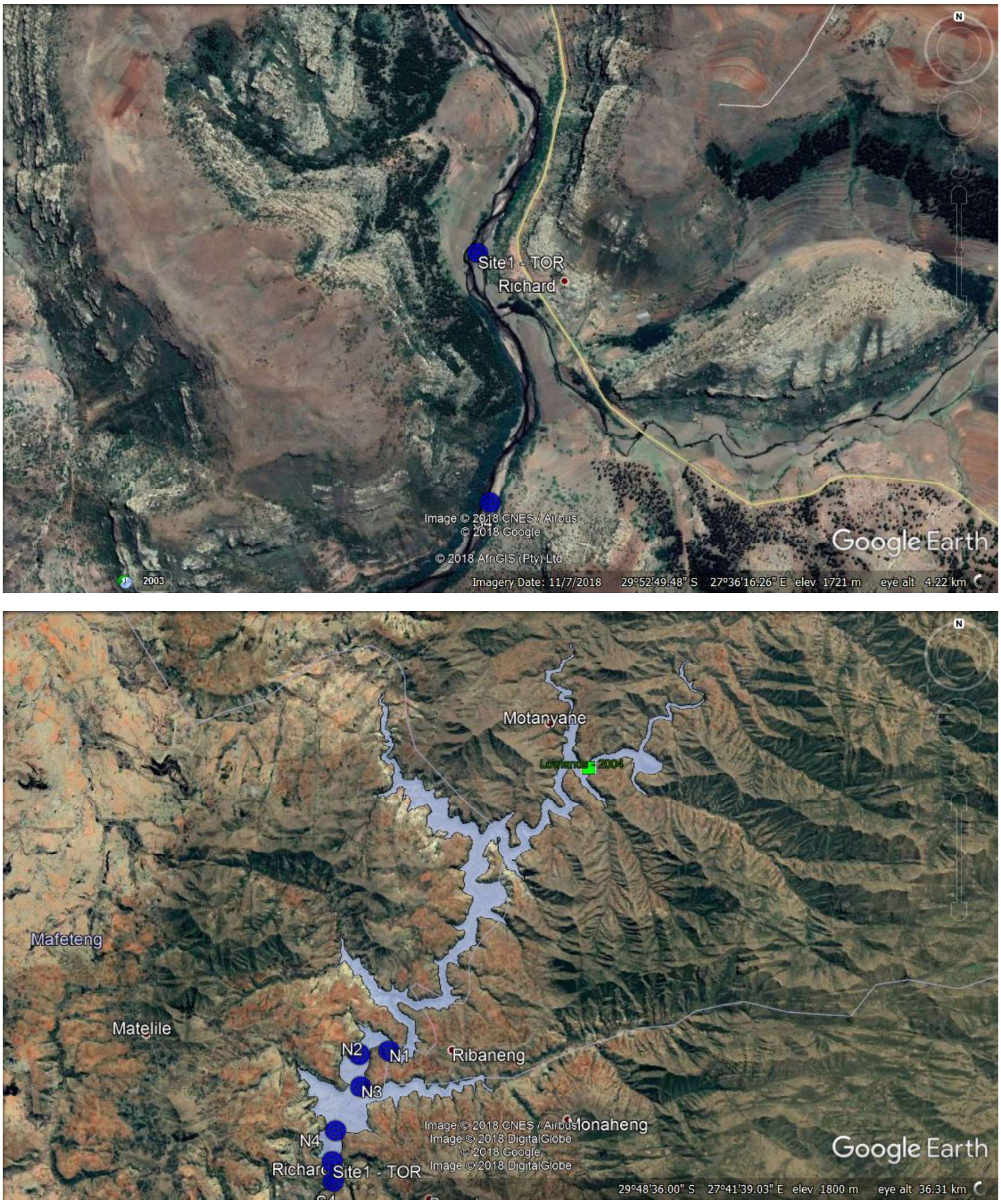


Figure 1: Map of Dam Site Location

1.2 GENERAL

• Catchment Size (km^2):	1 572
• MAR (MCM/a):	420
• Design Floods (m^3/s):	
• 1:10 year (River diversion):	1 090
• 1:200 (Design Flood):	2 665
• RMF + ∆ (Safety Evaluation):	4 945
• Distance to Construction material	12 km E or 22 km SE
• Expected 50-year Sediment Volumes (million m^3)	35.06

Figure 2: Photograph of Dam Site

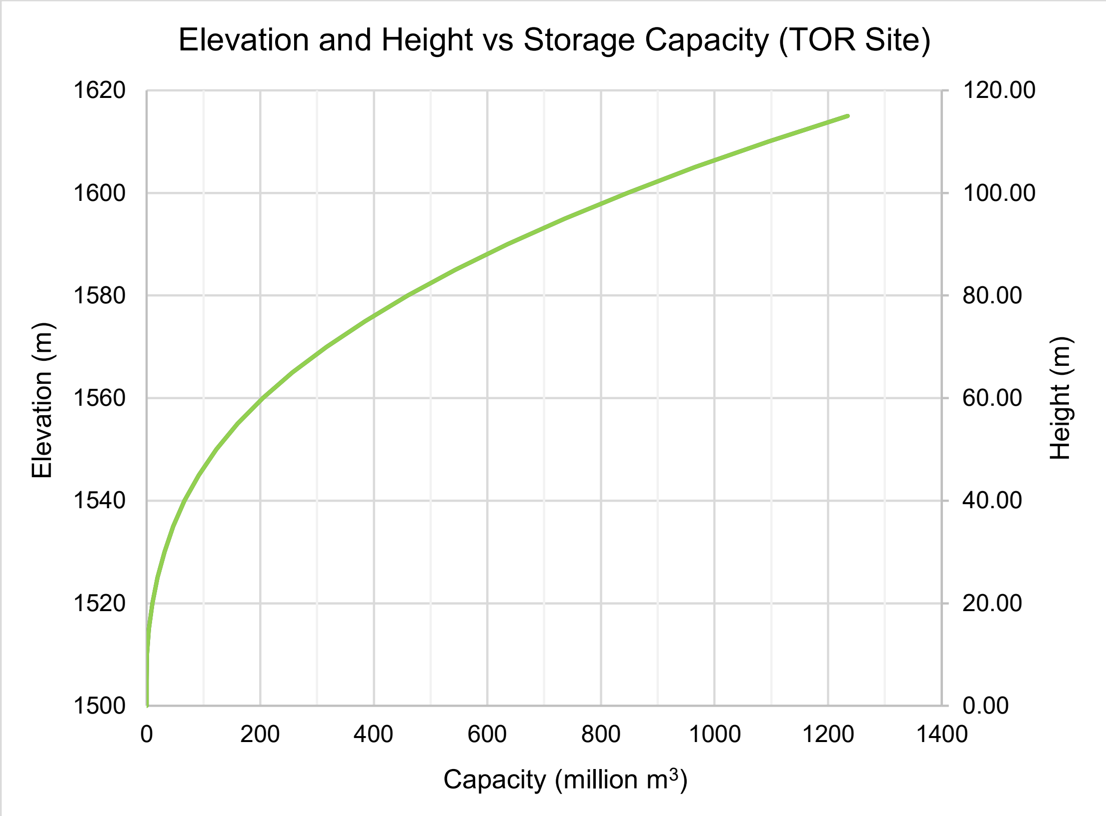


Figure 3: Elevation and Height vs Storage Capacity Graph

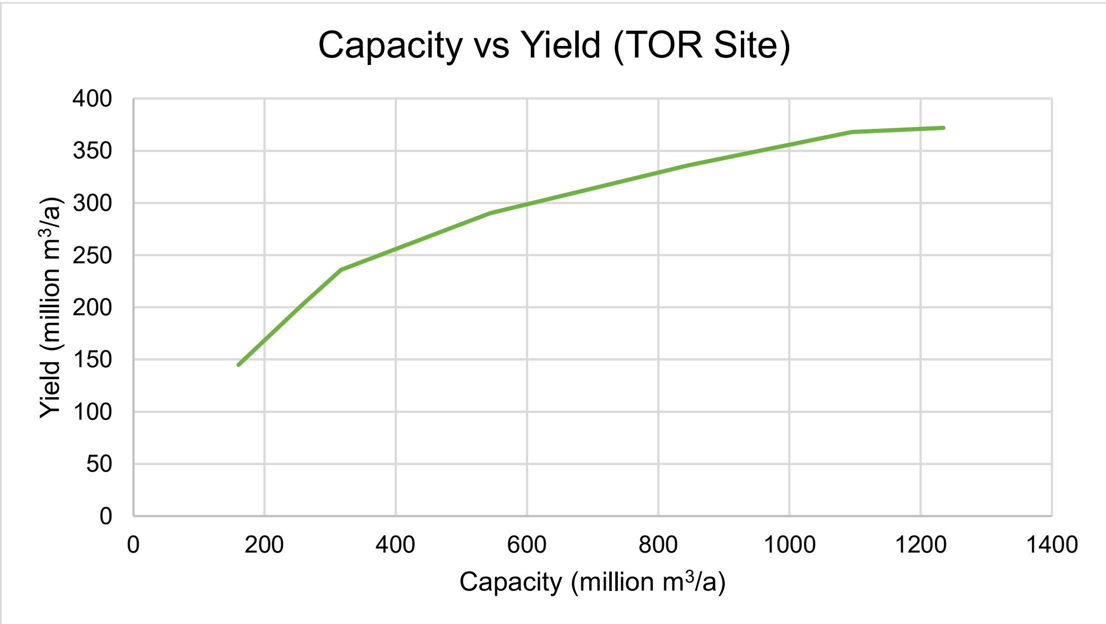


Figure 4: Capacity vs Yield Graph

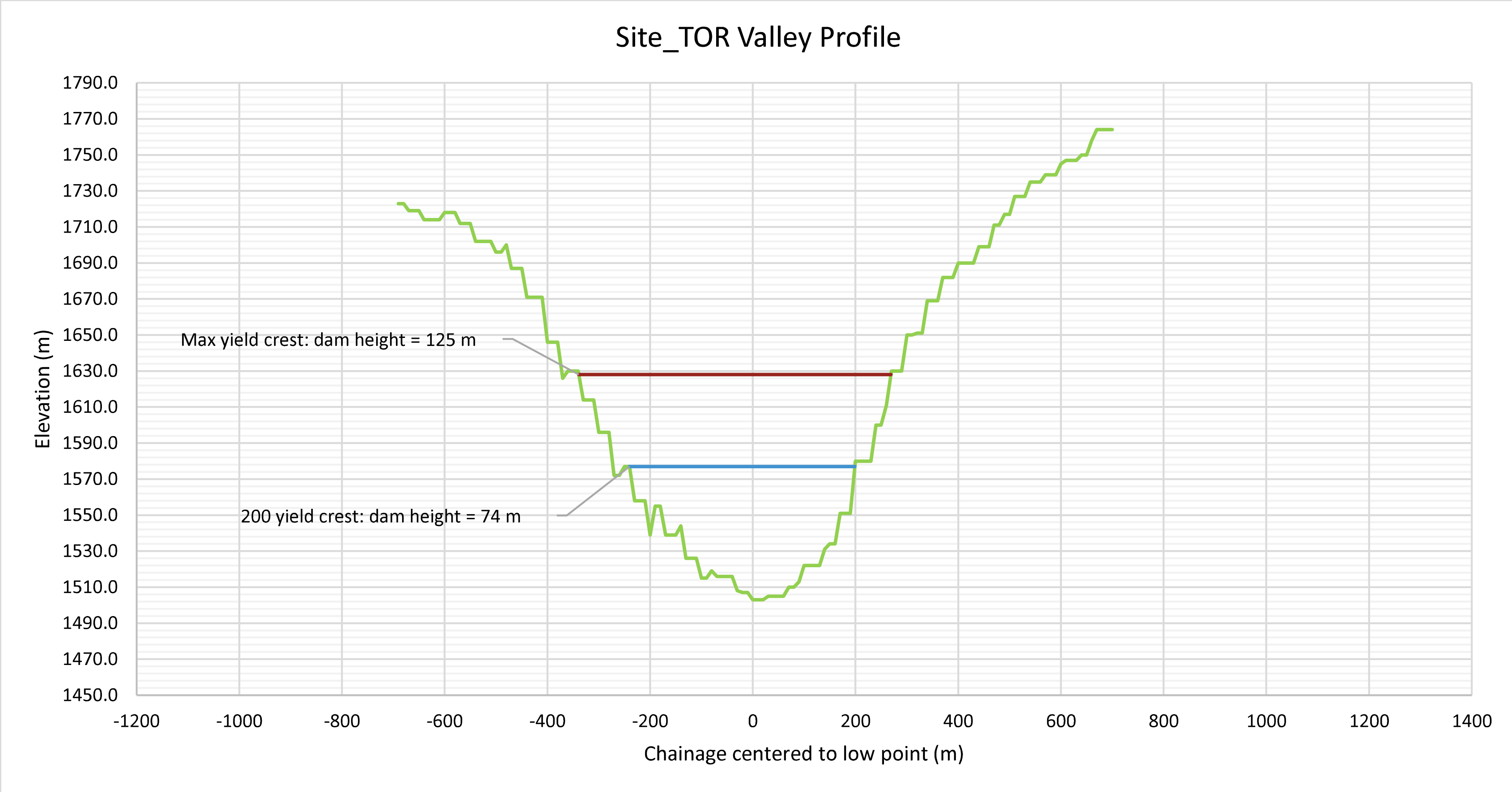


Figure 5: Dam valley profile with dam heights for a dam with 200 MCM/a yield and for a maximum a yield that equates to a capacity of 3 MAR

1.3 DAM HEIGHT OPTIONS

Scenarios	Dam Height to meet 200MCM/a Yield (Scenario 1)	Dam Height for 3 MAR Capacity (Scenario 2)
Height (m)	74	125
Capacity (MCM)	248	1 258
Yield (MCM/a)	200	381
Impact on the yield of Gariep Dam (MCM/a)	-165	-43
Aspect Ratio	5.9	4.9
Likely Dam Type	RCC Gravity Dam	RCC Gravity Dam
River Diversion	Coffer dam, with twin diversion tunnels	Coffer dam, with twin diversion tunnels
Spillway type	Free ogee over crest	Free ogee over crest
Outlet arrangement	Multi-level outlet, with tower against upstream face	Multi-level outlet, with tower against upstream face
Dam material volumes (m^3)	623 576	2 156 303
Hydropower potential - continuous flow (MW)	4.13	13.75
Hydropower potential - peak power (MW)	27.76	92.39
Turbine type - continuous flow	Horizontal Francis	Horizontal Francis
Turbine type - peak power	Vertical Francis	Vertical Francis
Dam Capital Cost Estimate (million R)	R 1 871	R 6 469
URV of yield assured (i = 8%)	1.1	2.0

S4

1.1 LOCATION

The S4 dam site is located at 29°53'31.17"S and 27°36'46.27"E in the West of Lesotho.

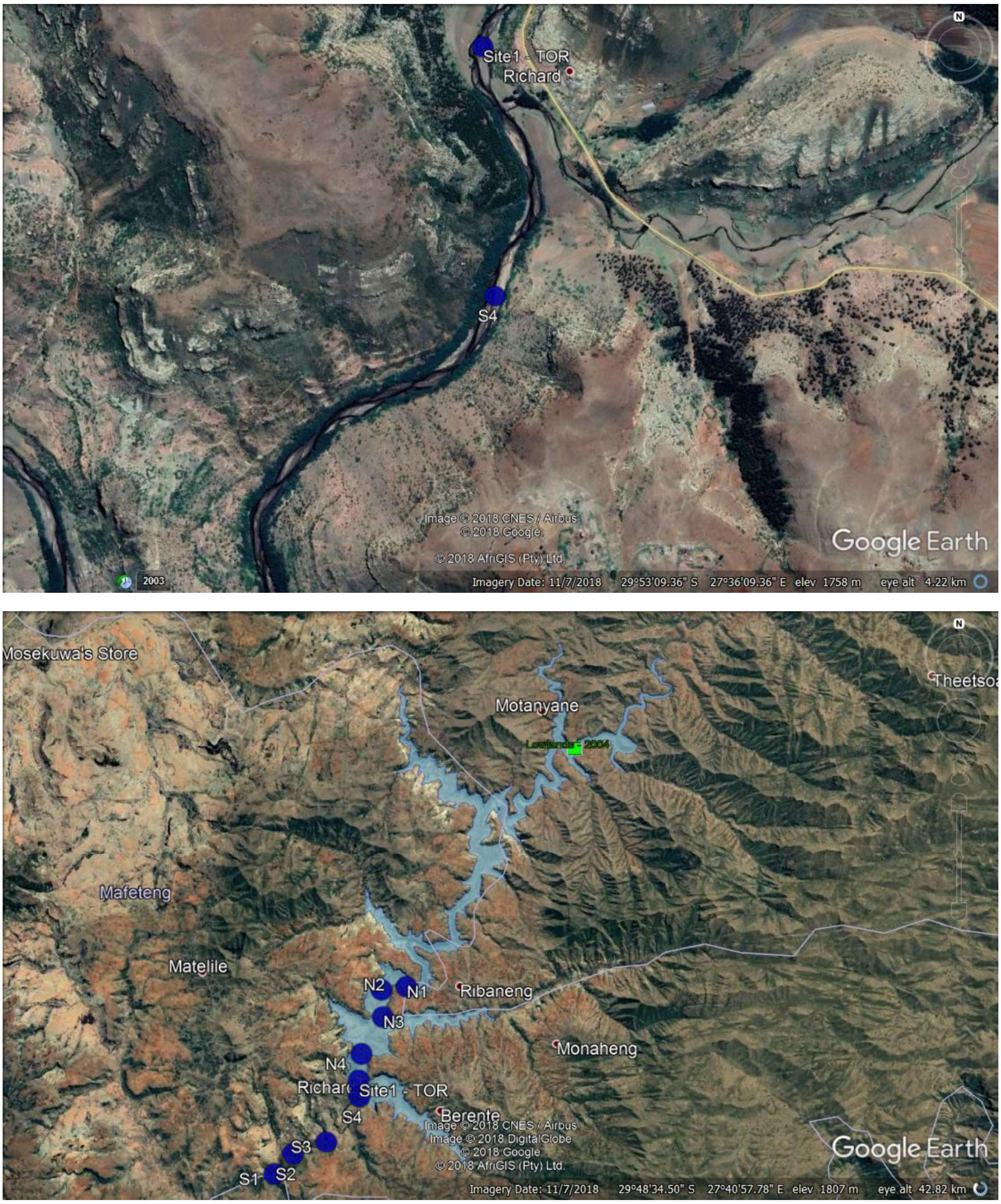


Figure 1: Map of Dam Site Location

1.2 GENERAL

• Catchment Size (km^2):	1 653
• MAR (MCM/a):	435
• Design Floods (m^3/s):	
• 1:10 year (River diversion):	1 120
• 1:200 (Design Flood):	2 735
• RMF + ∆ (Safety Evaluation):	5 065
• Distance to Construction material	12 km E or 22 km SE
• Expected 50-year Sediment Volumes (million m^3)	41.14

Figure 2: Photograph of Dam Site

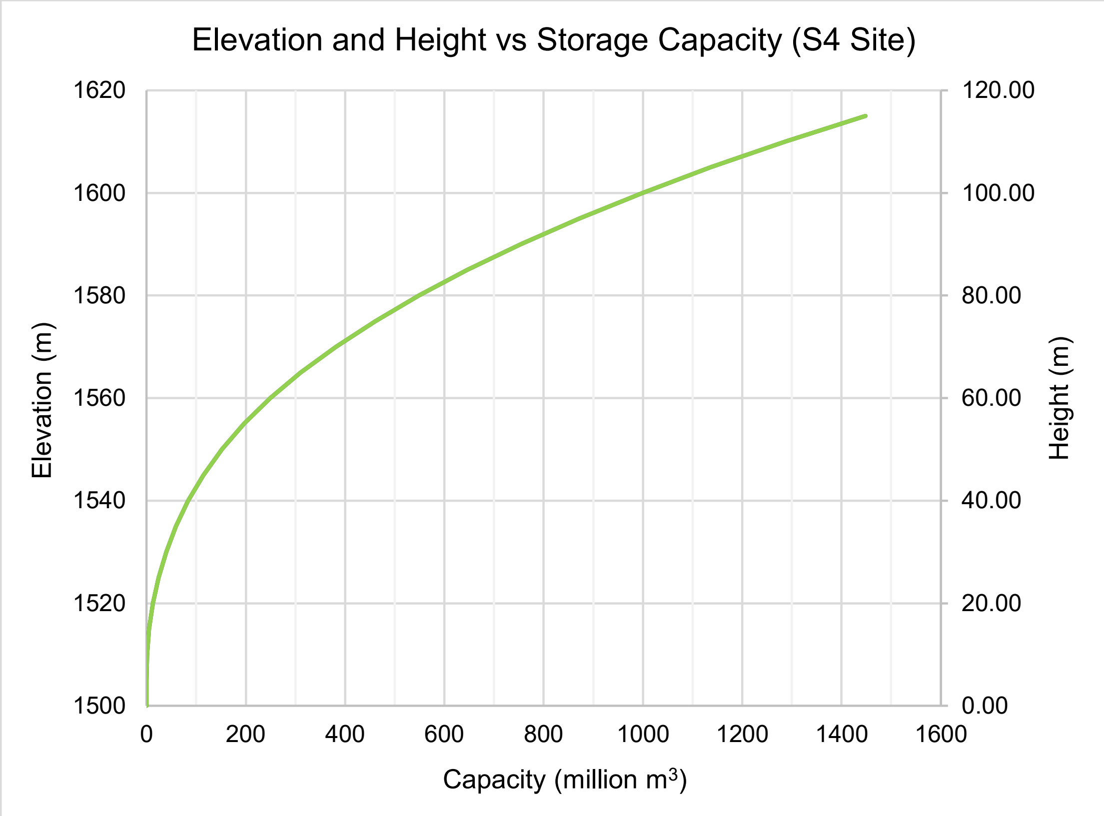


Figure 3: Elevation and Height vs Storage Capacity Graph

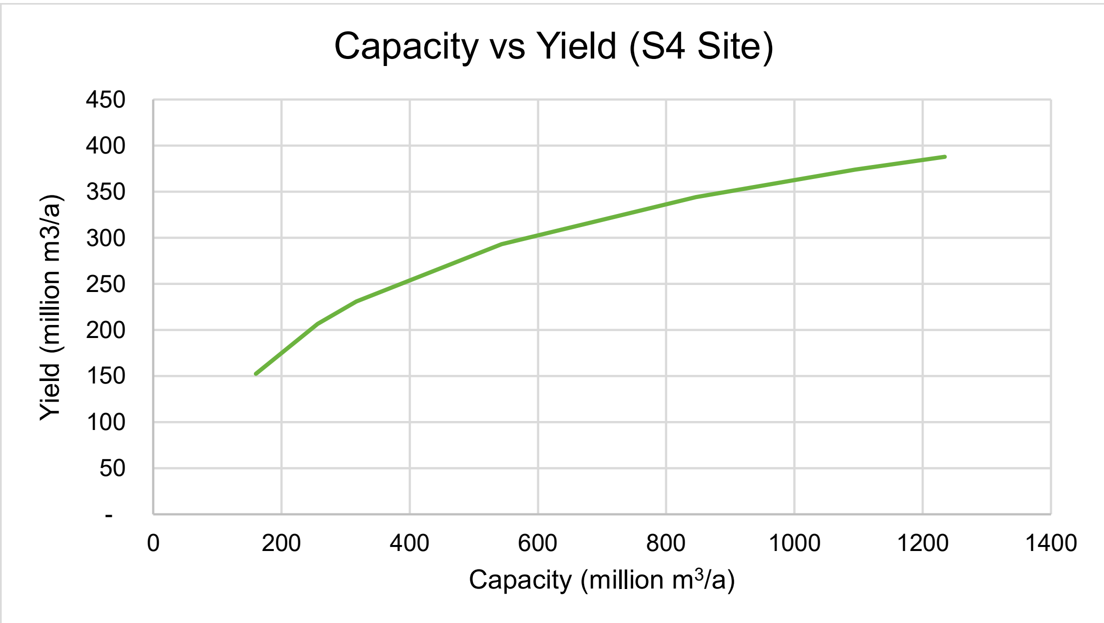


Figure 4: Capacity vs Yield Graph

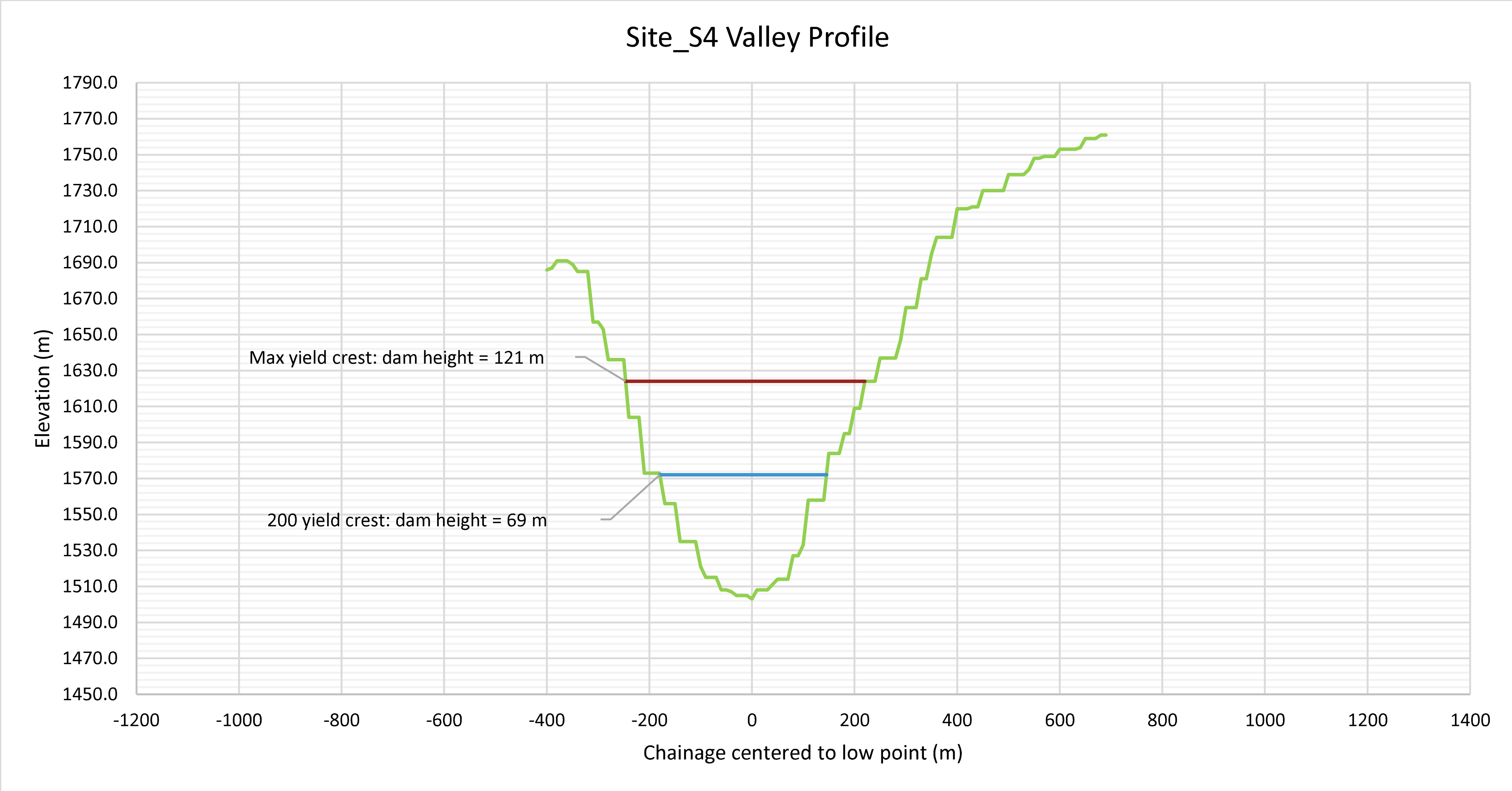


Figure 5: Dam valley profile with dam heights for a dam with 200 MCM/a yield and for a maximum a yield that equates to a capacity of 3 MAR

1.3 DAM HEIGHT OPTIONS

Scenarios	**Dam Height to meet 200MCM/a Yield (Scenario 1)**	**Dam Height for 3 MAR Capacity (Scenario 2)**
Height (m)	69	121
Capacity (MCM)	242	1 301
Yield (MCM/a)	200	394
Impact on the yield of Gariep Dam (MCM/a)	-165	-34
Aspect Ratio	4.7	3.9
Likely Dam Type	RCC Gravity Dam	RCC Gravity Dam
River Diversion	Coffer dam, with twin diversion tunnels	Coffer dam, with twin diversion tunnels
Spillway type	Free ogee over crest	Free ogee over crest
Outlet arrangement	Multi-level outlet, with tower against upstream face	Multi-level outlet, with tower against upstream face
Dam material volumes (m^3)	406 076	1 511 229
Hydropower potential - continuous flow (MW)	3.82	13.66
Hydropower potential - peak power (MW)	25.66	91.82
Turbine type - continuous flow	Horizontal Francis	Horizontal Francis
Turbine type - peak power	Vertical Francis	Vertical Francis
Dam Capital Cost Estimate (million R)	R 1 218	R 4 534
URV of yield assured (i = 8%)	0.7	1.4

S3

1.1 LOCATION

The S3 dam site is located at 29°54'41.63"S and 27°35'46.90"E in the West of Lesotho.

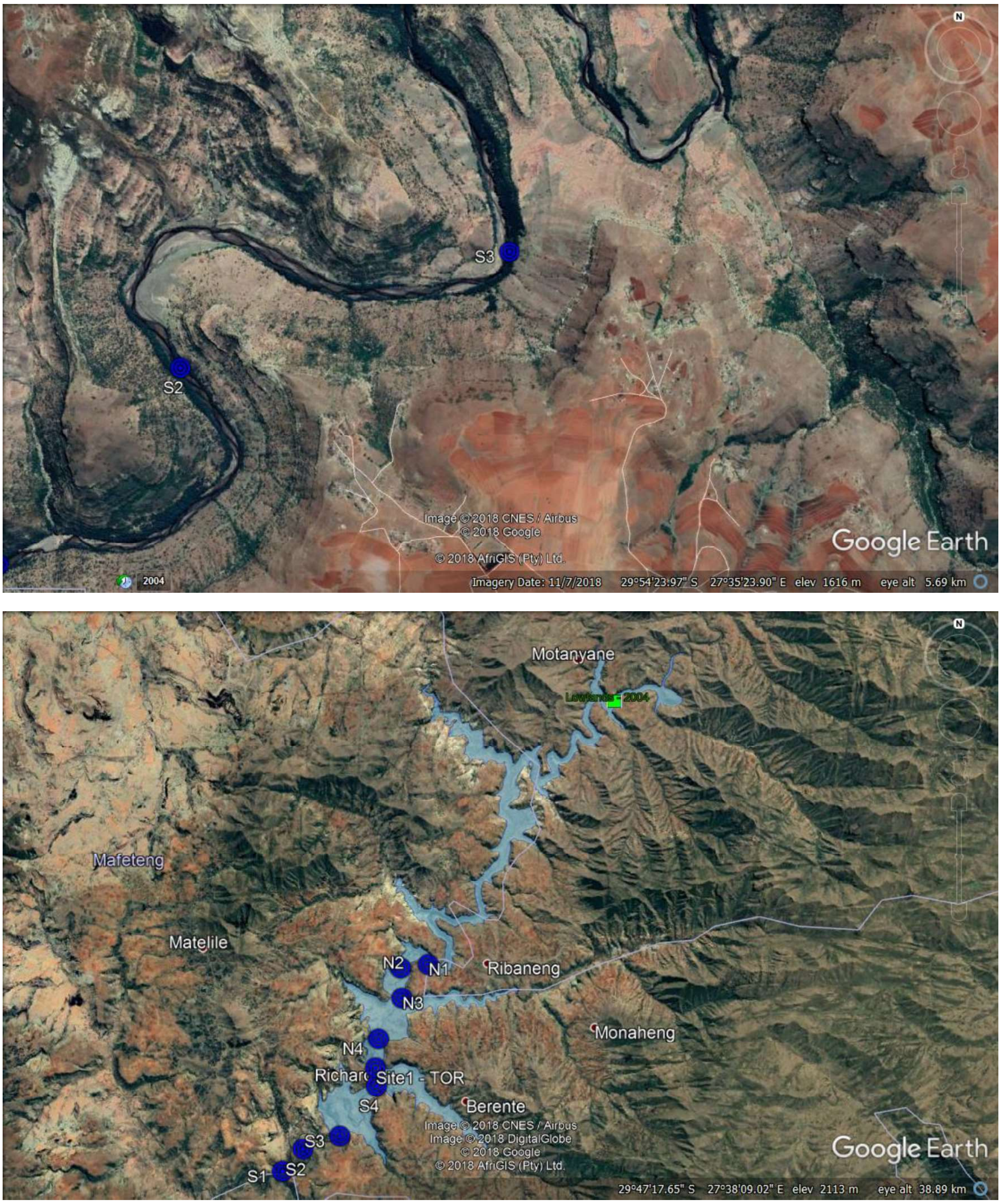


Figure 1: Map of Dam Site Location

1.2 GENERAL

• Catchment Size (km^2):	1 684
• MAR (MCM/a):	440
• Design Floods (m^3/s):	
• 1:10 year (River diversion):	1 130
• 1:200 (Design Flood):	2 760
• RMF + Δ (Safety Evaluation):	5 110
• Distance to Construction material	12 km E or 22 km SE
• Expected 50-year Sediment Volumes (million m^3)	43.45

Figure 2: Photograph of Dam Site

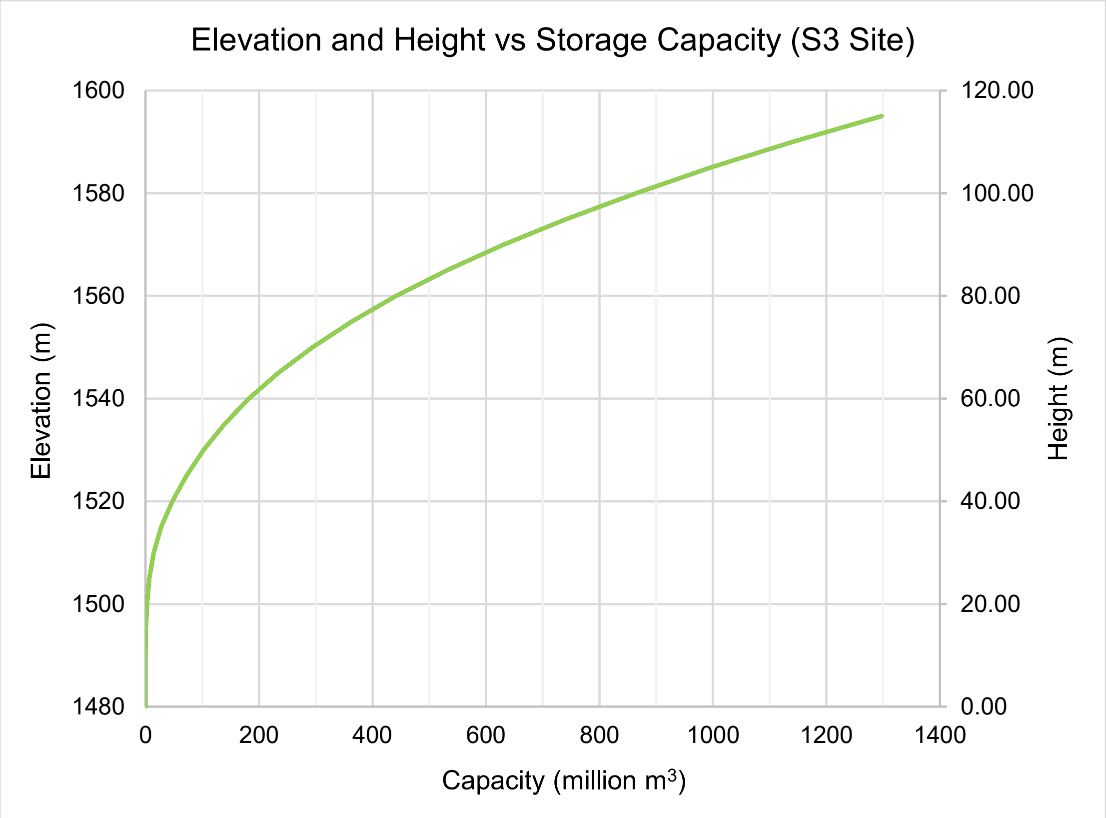


Figure 3: Elevation and Height vs Storage Capacity Graph

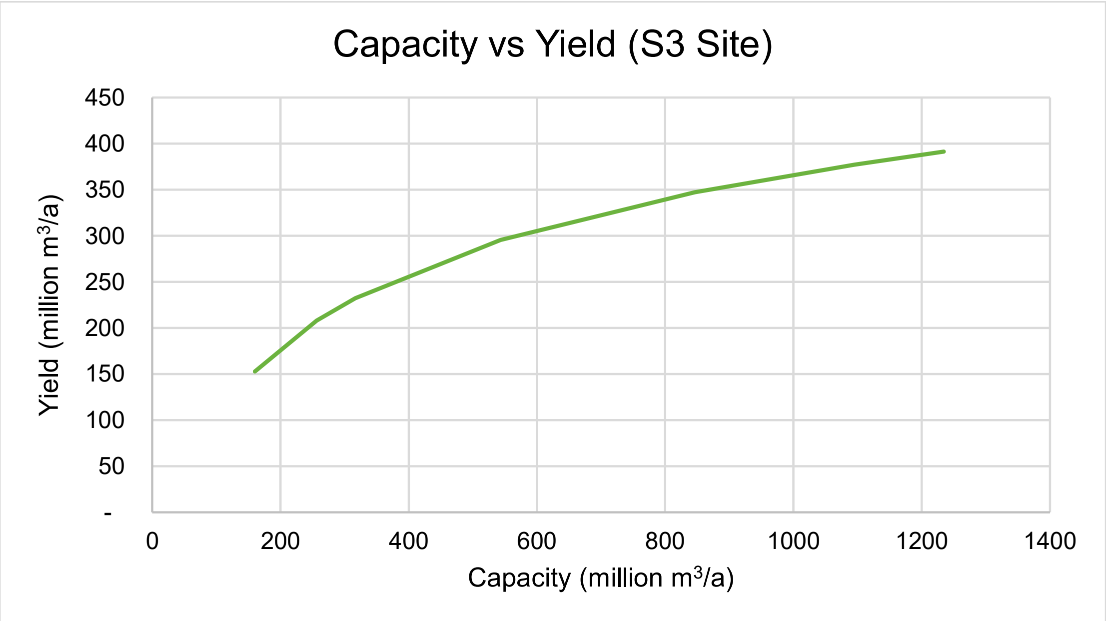


Figure 4: Capacity vs Yield Graph

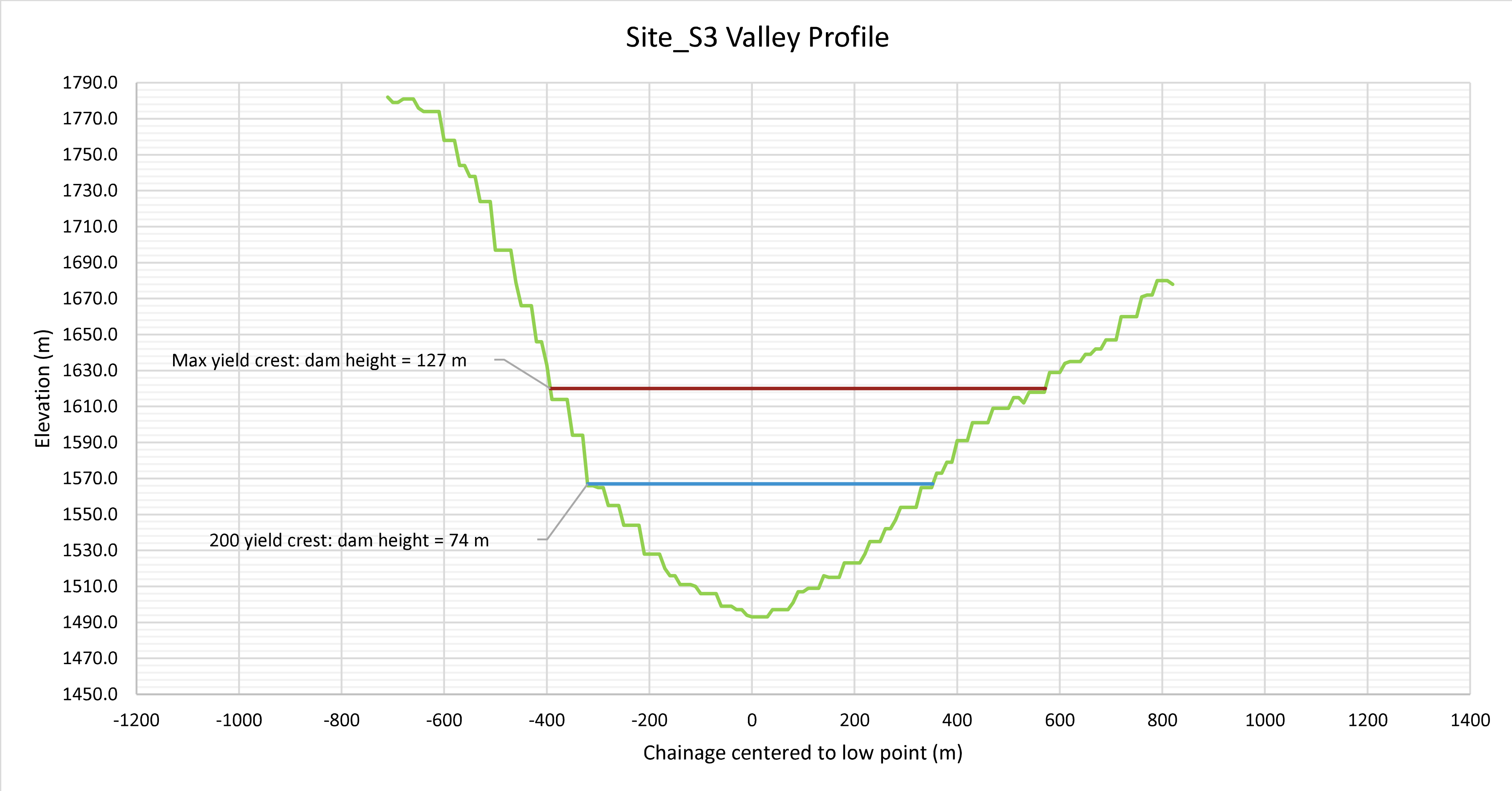


Figure 5: Dam valley profile with dam heights for a dam with 200 MCM/a yield and for a maximum a yield that equates to a capacity of 3 MAR

1.3 DAM HEIGHT OPTIONS

Scenarios	Dam Height to meet 200MCM/a Yield (Scenario 1)	Dam Height for 3 MAR Capacity (Scenario 2)
Height (m)	74	127
Capacity (MCM)	239	1 318
Yield (MCM/a)	200	399
Impact on the yield of Gariep Dam (MCM/a)	-165	-31
Aspect Ratio	9.1	7.6
Likely Dam Type	RCC Gravity Dam	RCC Gravity Dam
River Diversion	Coffer dam, with twin diversion tunnels	Coffer dam, with twin diversion tunnels
Spillway type	Free ogee over crest	Free ogee over crest
Outlet arrangement	Multi-level outlet, with tower against upstream face	Multi-level outlet, with tower against upstream face
Dam material volumes (m^3)	801 511	2 977 179
Hydropower potential - continuous flow (MW)	4.13	14.47
Hydropower potential - peak power (MW)	27.75	97.21
Turbine type - continuous flow	Horizontal Francis	Horizontal Francis
Turbine type - peak power	Vertical Francis	Vertical Francis
Dam Capital Cost Estimate (million R)	R 2 405	R 8 932
URV of yield assured (i = 8%)	1.4	2.7

S2

1.1 LOCATION

The S2 dam site is located at 29°54'59.79"S and 27°34'47.34"E in the West of Lesotho.

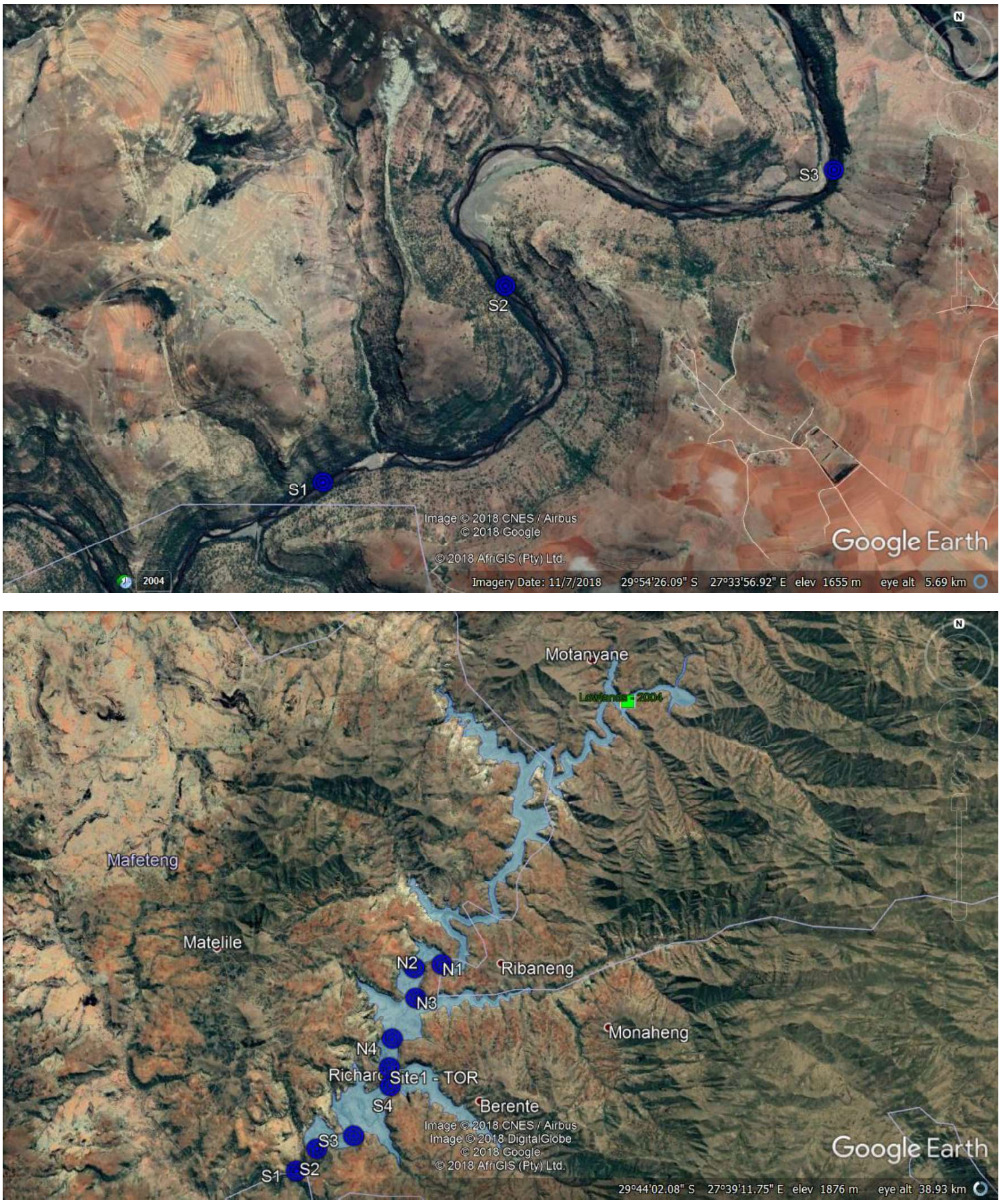


Figure 1: Map of Dam Site Location

1.2 GENERAL

• Catchment Size (km²):	1 688
• MAR (MCM/a):	440
• Design Floods (m³/s):	
• 1:10 year (River diversion):	1 130
• 1:200 (Design Flood):	2 765
• RMF + ∆ (Safety Evaluation):	5 120
• Distance to Construction material	12 km E or 22 km SE
• Expected 50-year Sediment Volumes (million m³)	43.76

Figure 2: Photograph of Dam Site

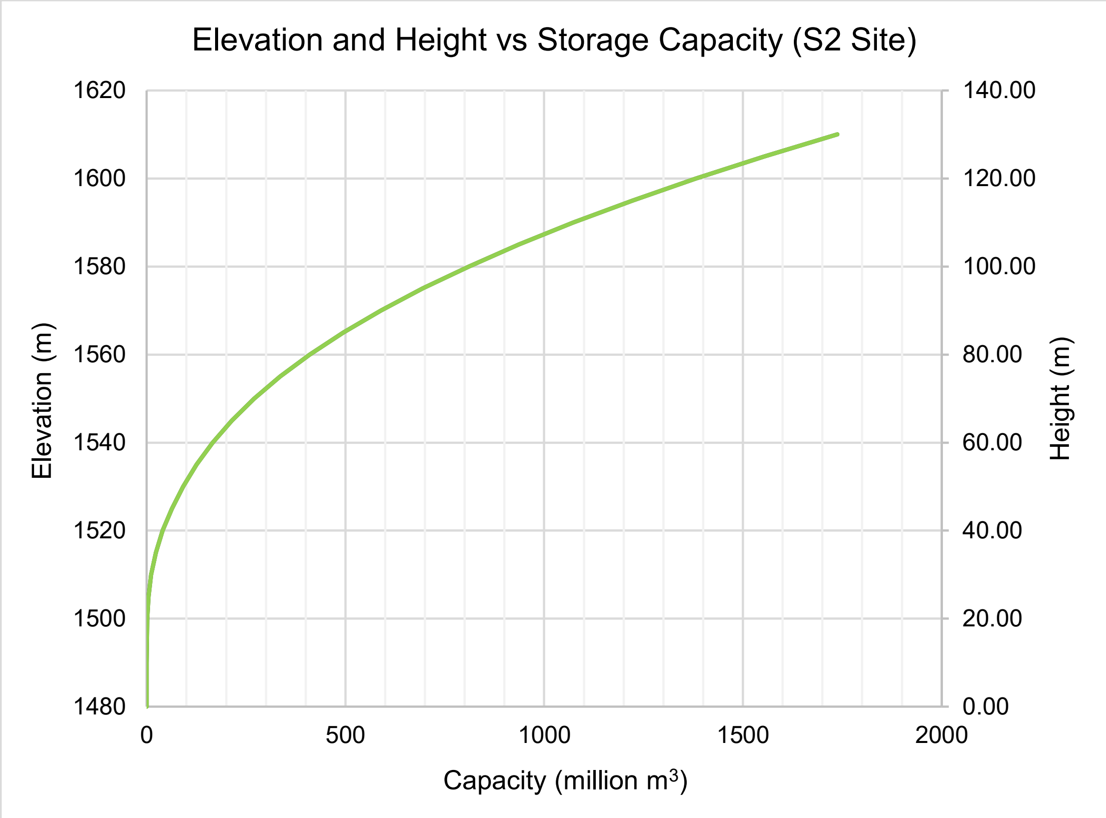


Figure 3: Elevation and Height vs Storage Capacity Graph

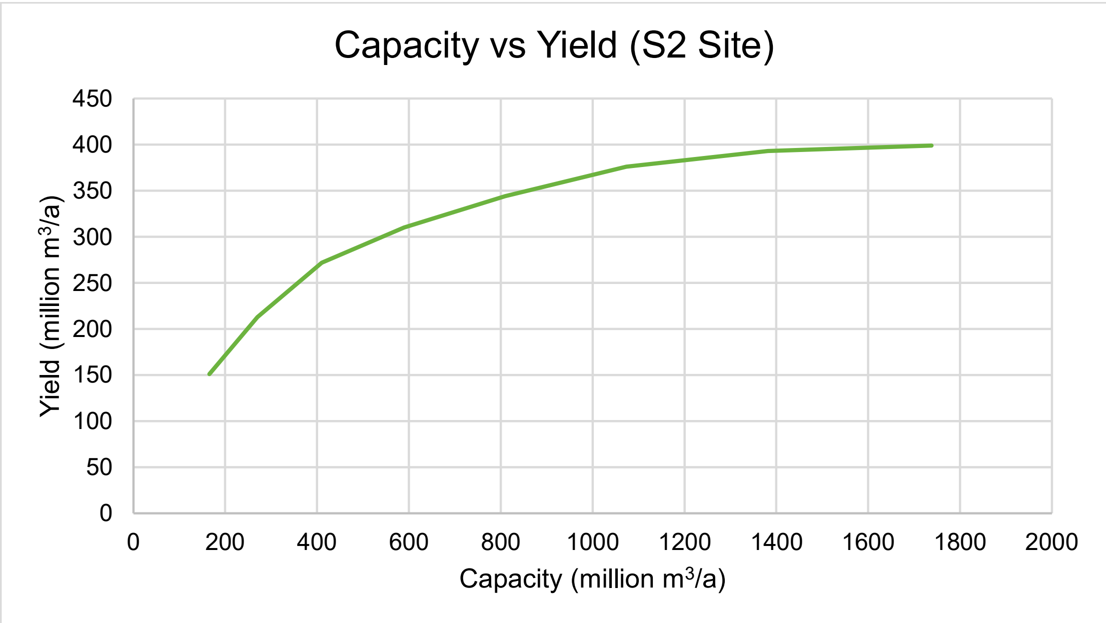


Figure 4: Capacity vs Yield Graph

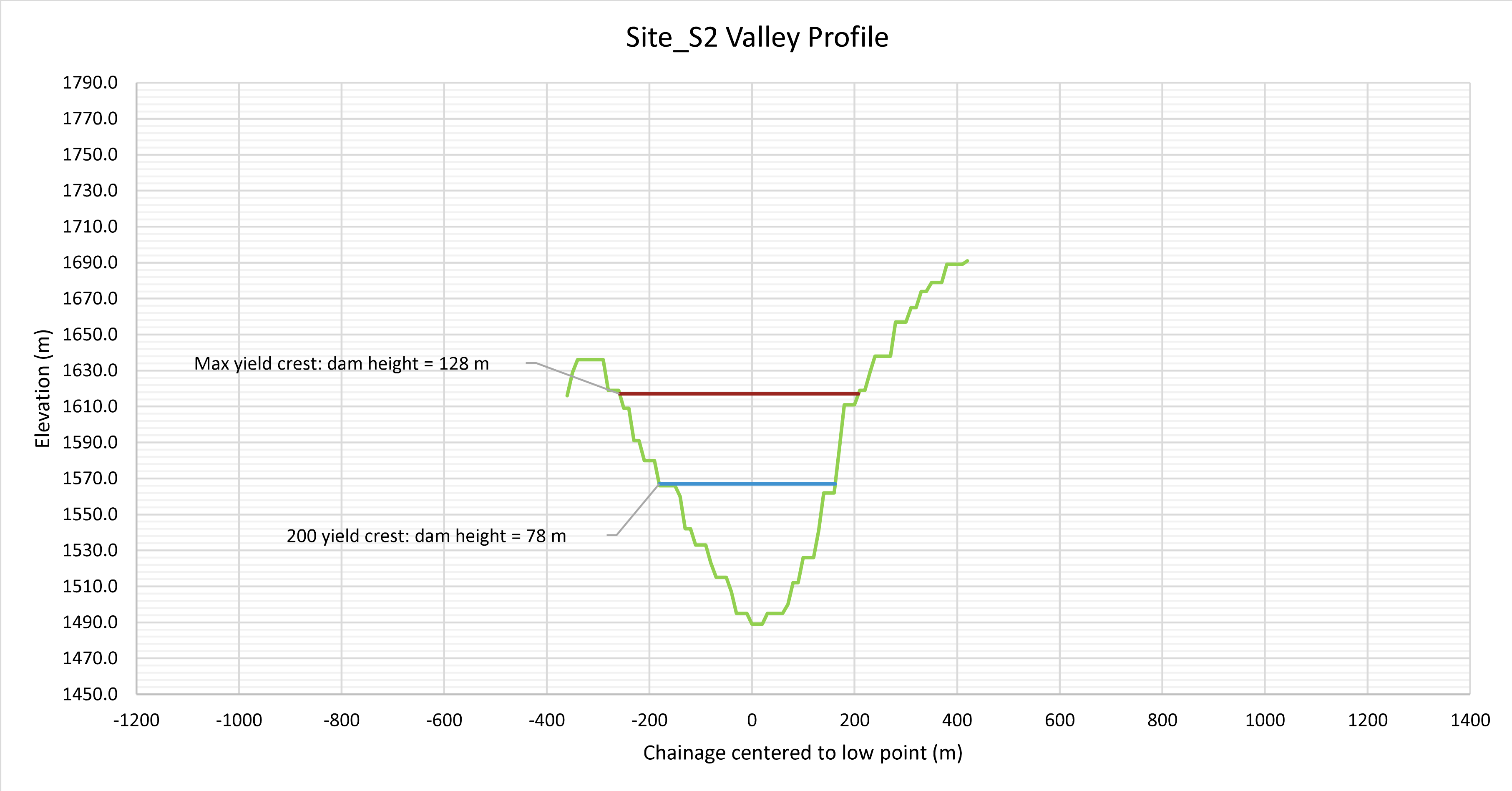


Figure 5: Dam valley profile with dam heights for a dam with 200 MCM/a yield and for a maximum a yield that equates to a capacity of 3 MAR

1.3 DAM HEIGHT OPTIONS

Scenarios	**Dam Height to meet 200MCM/a Yield** **(Scenario 1)**	**Dam Height for 3 MAR Capacity** **(Scenario 2)**
Height (m)	78	128
Capacity (MCM)	236	1 319
Yield (MCM/a)	200	389
Impact on the yield of Gariep Dam (MCM/a)	-165	-38
Aspect Ratio	4.4	3.6
Likely Dam Type	RCC Gravity Dam	CFRD
River Diversion	Coffer dam, with twin diversion tunnels	Coffer dam, with twin diversion tunnels
Spillway type	Free ogee over crest	Side Channel
Outlet arrangement	Multi-level outlet, with tower against upstream face	Multi-level outlet, with free standing tower
Dam material volumes (m^3)	436 976	5 856 101
Hydropower potential - continuous flow (MW)	4.35	14.84
Hydropower potential - peak power (MW)	29.26	99.73
Turbine type - continuous flow	Horizontal Francis	Horizontal Francis
Turbine type - peak power	Vertical Francis	Vertical Francis
Dam Capital Cost Estimate (million R)	R 1 311	R 2 928
URV of yield assured (i = 8%)	0.8	0.9

S1

1.1 LOCATION

The S1 dam site is located at 29°55'30.64"S and 27°34'14.27"E in the West of Lesotho.

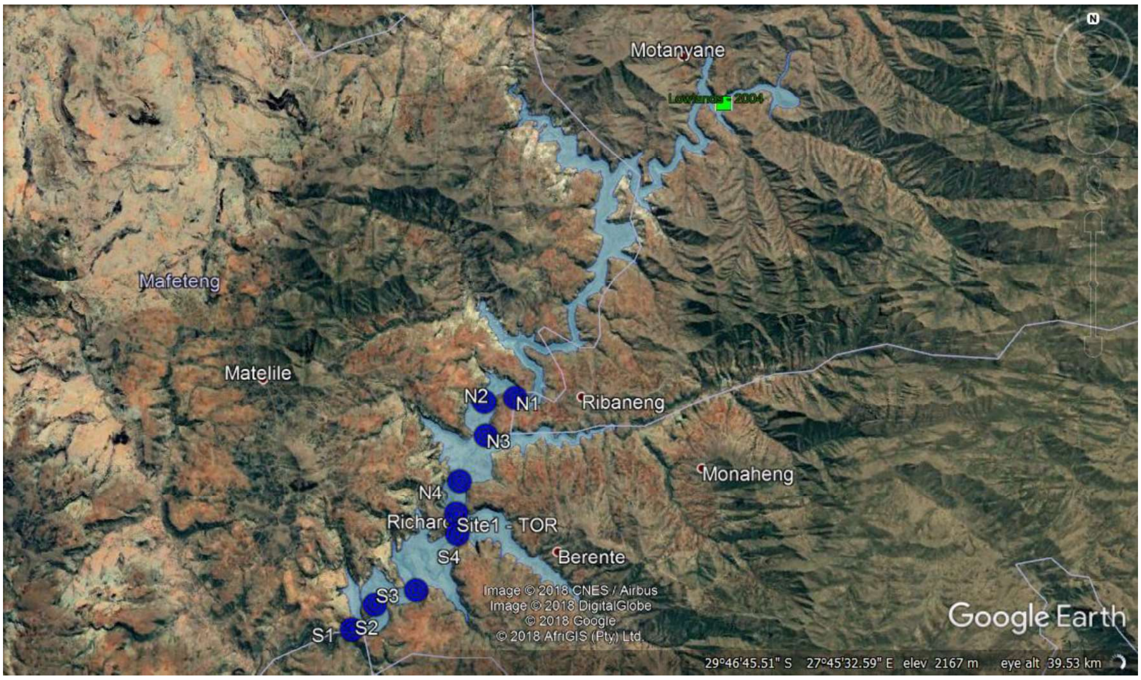


Figure 1: Map of Dam Site Location

1.2 GENERAL

• Catchment Size (km^2):	1 703
• MAR (MCM/a):	445
• Design Floods (m^3/s):	
• 1:10 year (River diversion):	1 135
• 1:200 (Design Flood):	2 780
• RMF + ∆ (Safety Evaluation):	5 140
• Distance to Construction material	12 km E or 22 km SE
• Expected 50-year Sediment Volumes (million m^3)	44.86

Figure 2: Photograph of Dam Site

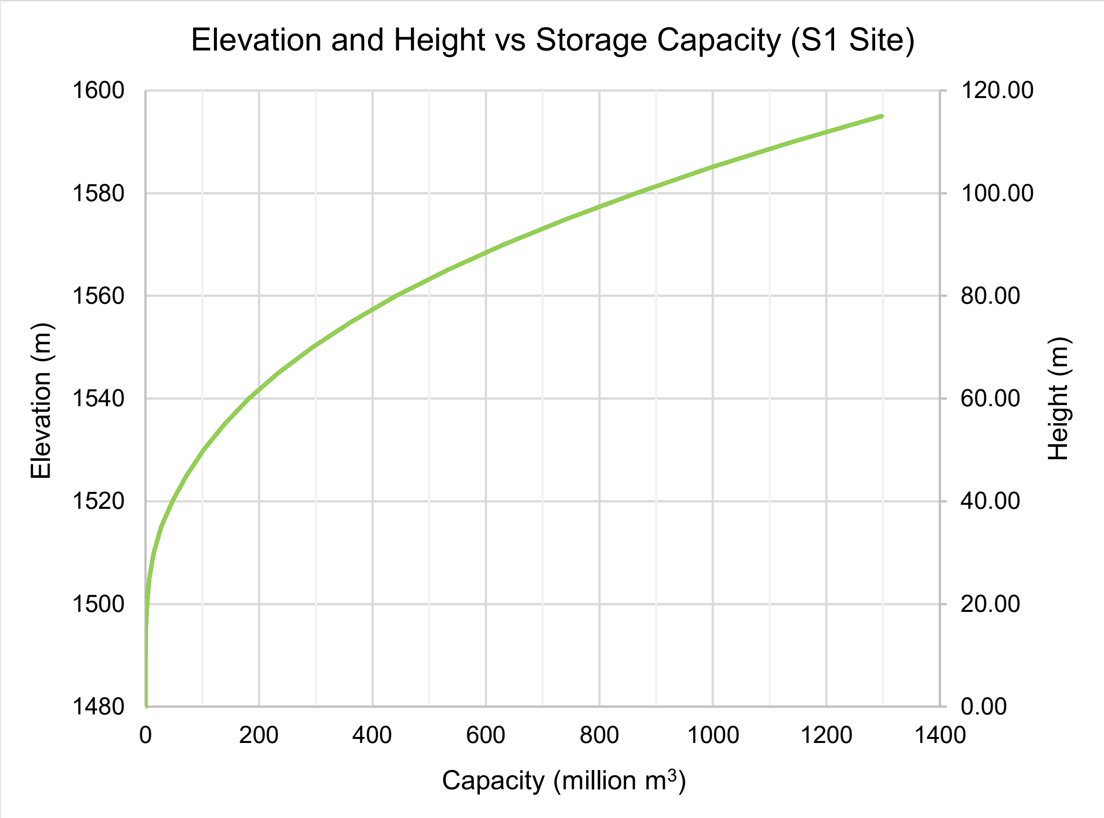


Figure 3: Elevation and Height vs Storage Capacity Graph

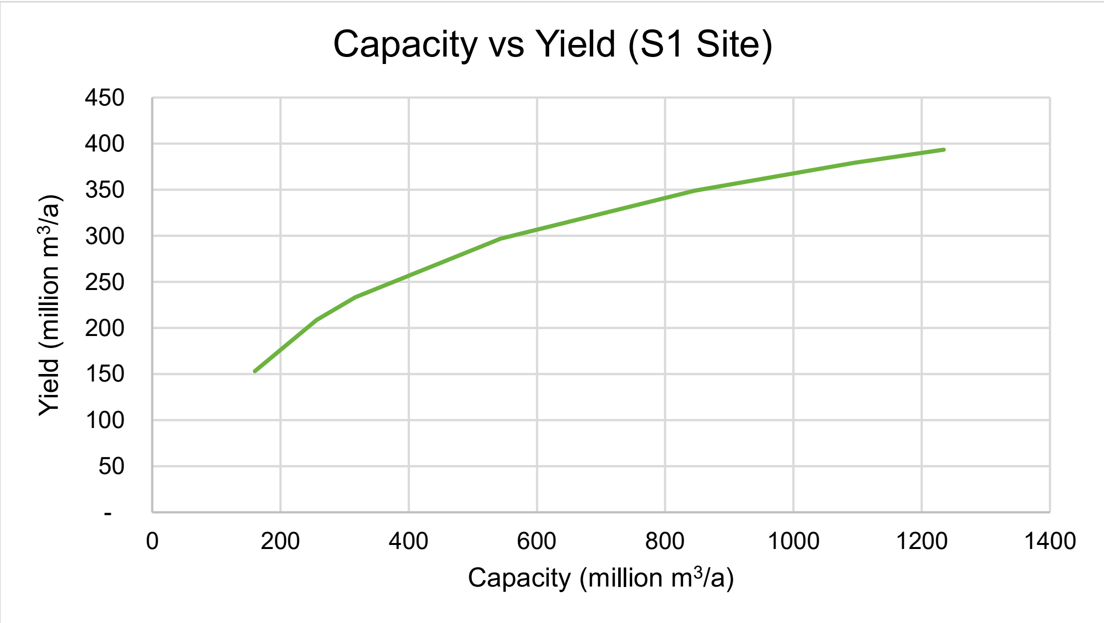


Figure 4: Capacity vs Yield Graph

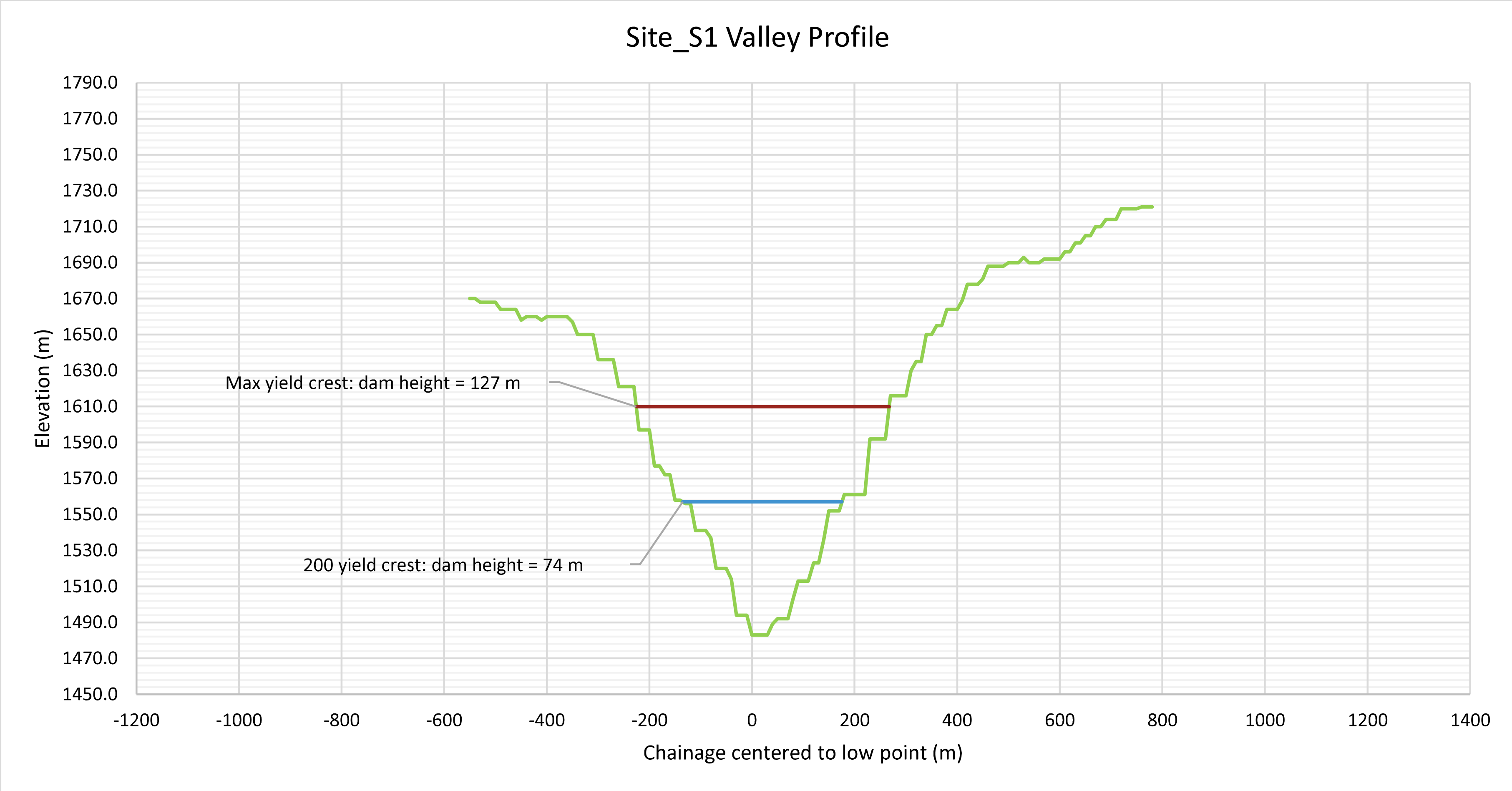


Figure 5: Dam valley profile with dam heights for a dam with 200 MCM/a yield and for a maximum a yield that equates to a capacity of 3 MAR

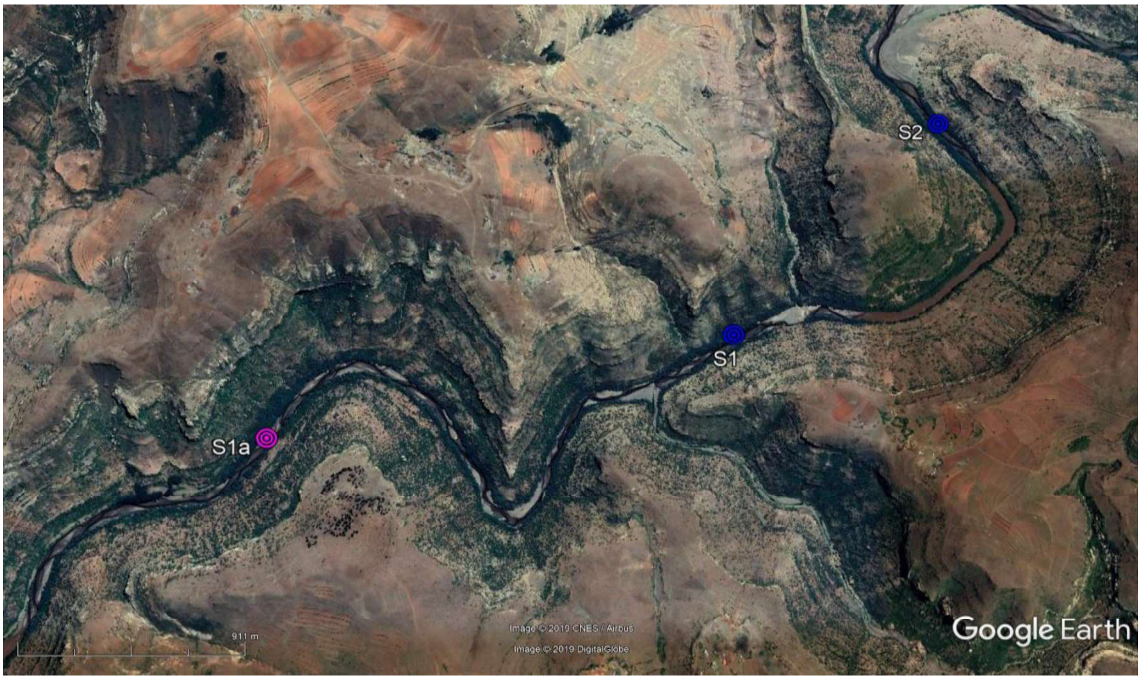
1.3 DAM HEIGHT OPTIONS

Scenarios	Dam Height to meet 200MCM/a Yield (Scenario 1)	Dam Height for 3 MAR Capacity (Scenario 2)
Height (m)	74	127
Capacity (MCM)	238	1 328
Yield (MCM/a)	200	402
Impact on the yield of Gariep Dam (MCM/a)	-165	-29
Aspect Ratio	4.2	3.9
Likely Dam Type	RCC Gravity Dam	RCC Gravity Dam
River Diversion	Coffer dam, with twin diversion tunnels	Coffer dam, with twin diversion tunnels
Spillway type	Free ogee over crest	Free ogee over crest
Outlet arrangement	Multi-level outlet, with tower against upstream face	Multi-level outlet, with tower against upstream face
Dam material volumes (m^3)	348 110	1 403 860
Hydropower potential - continuous flow (MW)	4.13	14.59
Hydropower potential - peak power (MW)	27.76	98.02
Turbine type - continuous flow	Horizontal Francis	Horizontal Francis
Turbine type - peak power	Vertical Francis	Vertical Francis
Dam Capital Cost Estimate (million R)	R 1 044	R 4 212
URV of yield assured (i = 8%)	0.6	1.3

S1A

1.1 LOCATION

The S1a dam site is located at 29°55'44.80"S and 27°33'05.02"E in the West of Lesotho.



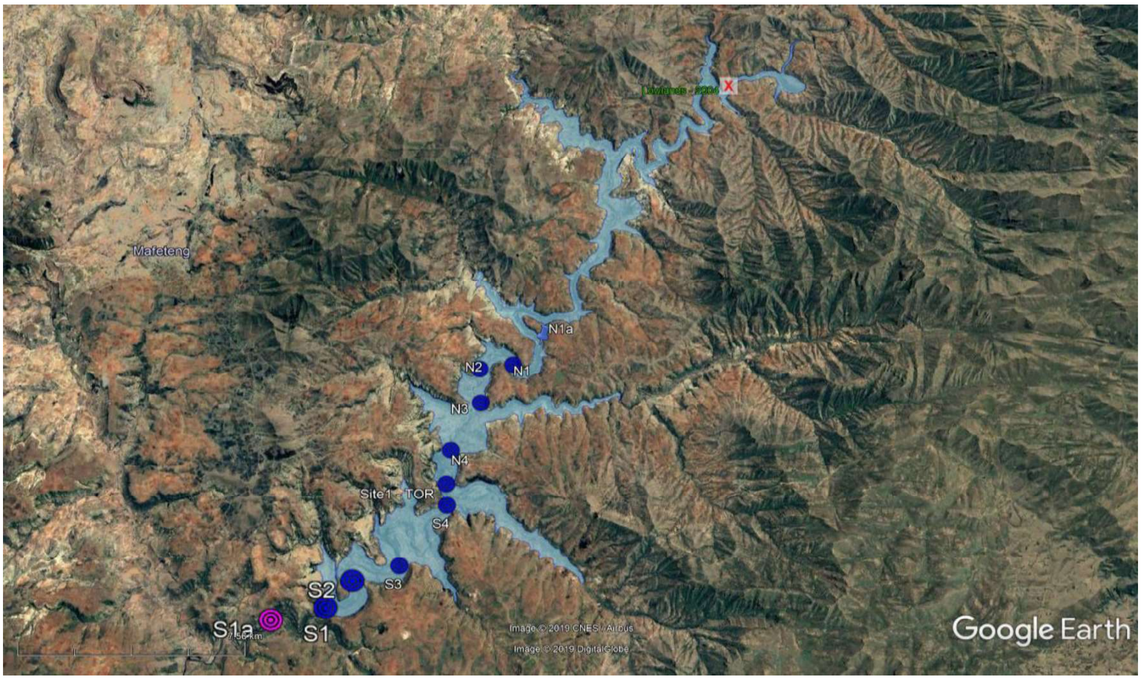


Figure 1: Map of Dam Site Location

1.2 GENERAL

• Catchment Size (km^2):	1 803
• MAR (MCM/a):	460
• Design Floods (m^3/s):	
• 1:10 year (River diversion):	1 168
• 1:200 (Design Flood):	2 865
• RMF + ∆ (Safety Evaluation):	5 285
• Distance to Construction material	12 km E or 22 km SE
• Expected 50-year Sediment Volumes (million m^3)	52.43

Figure 2: Photograph of Dam Site

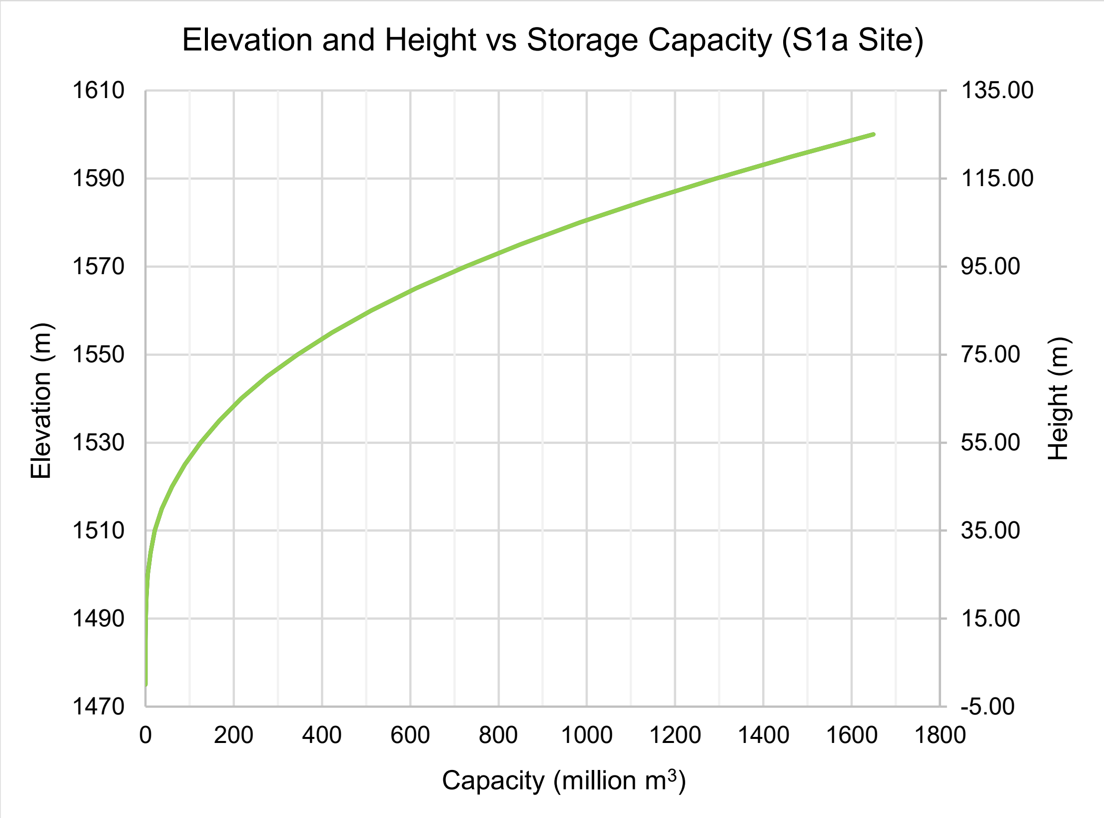


Figure 3: Elevation and Height vs Storage Capacity Graph

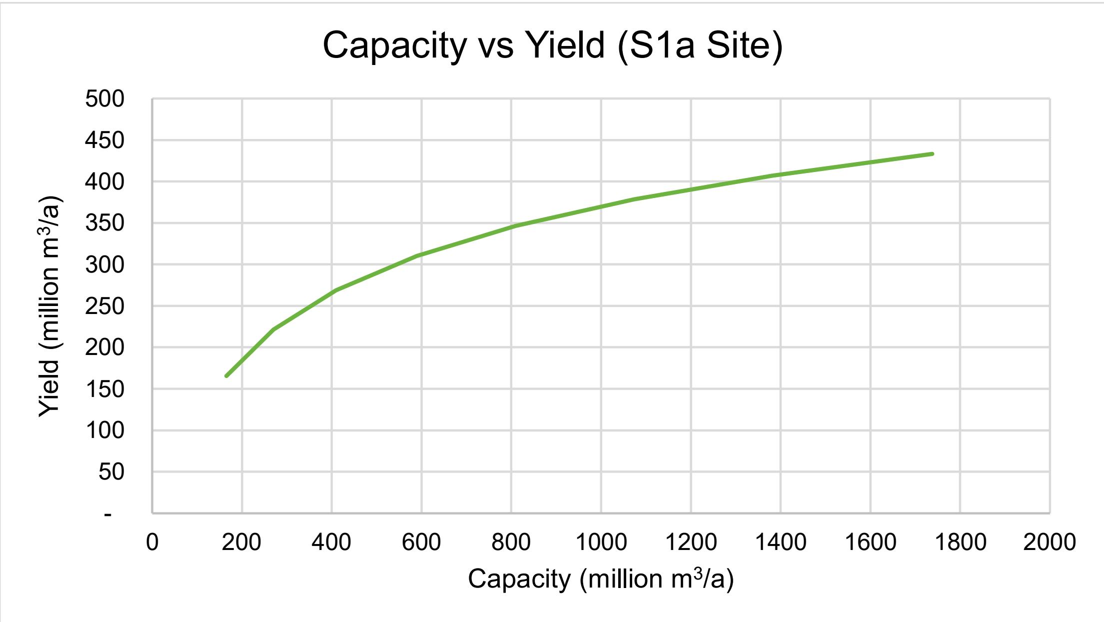


Figure 4: Capacity vs Yield Graph

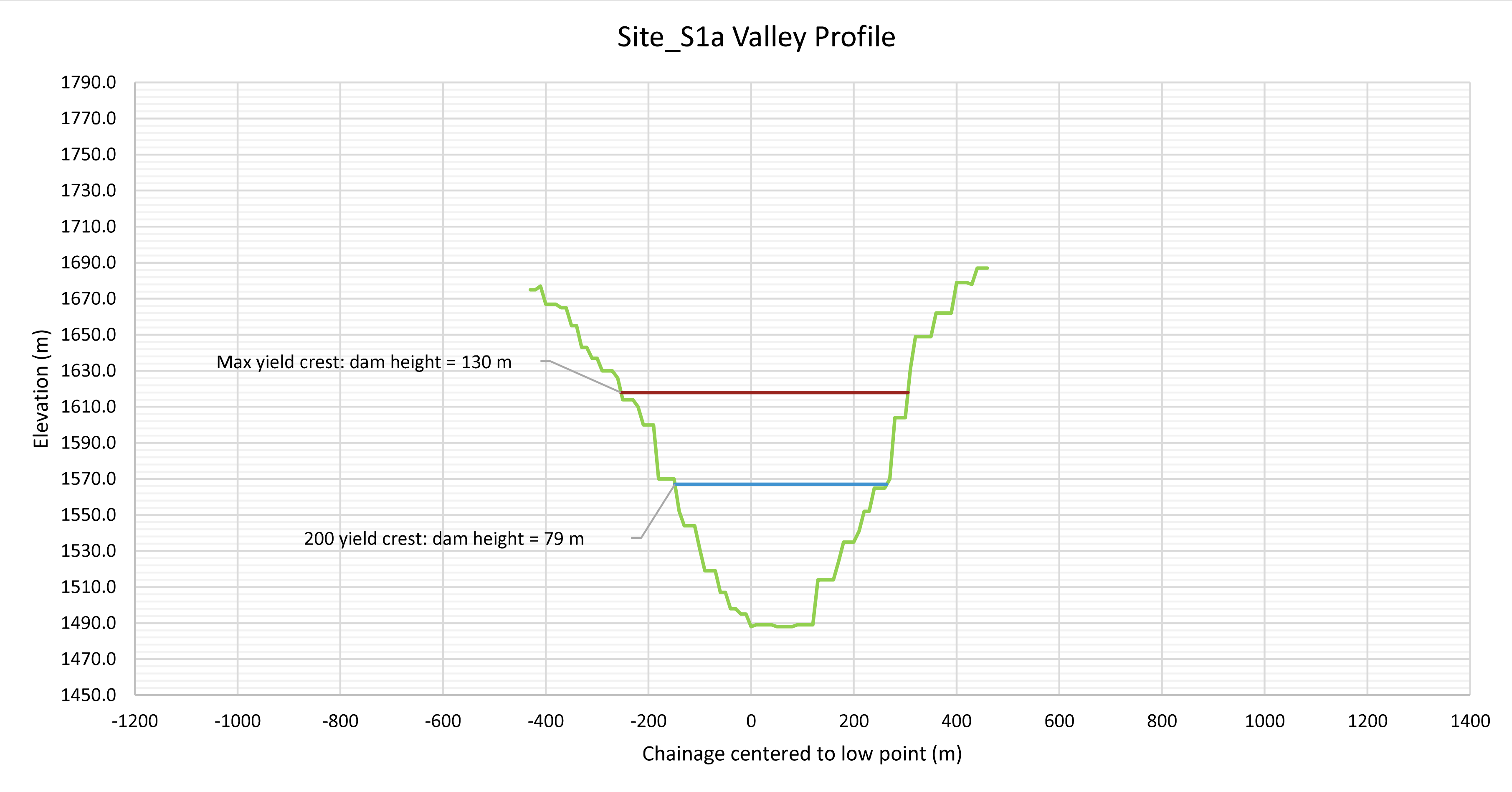


Figure 5: Dam valley profile with dam heights for a dam with 200 MCM/a yield and for a maximum a yield that equates to a capacity of 3 MAR

1.3 DAM HEIGHT OPTIONS

Scenarios	Dam Height to meet 200MCM/a Yield (Scenario 1)	Dam Height for 3 MAR Capacity (Scenario 2)
Height (m)	78	130
Capacity (MCM)	224	1 381
Yield (MCM/a)	200	402
Impact on the yield of Gariep Dam (MCM/a)	-165	-25
Aspect Ratio	5.2	4.3
Likely Dam Type	RCC Gravity Dam	RCC Gravity Dam
River Diversion	Coffer dam, with twin diversion tunnels	Coffer dam, with twin diversion tunnels
Spillway type	Free ogee over crest	Free ogee over crest
Outlet arrangement	Multi-level outlet, with tower against upstream face	Multi-level outlet, with tower against upstream face
Dam material volumes (m^3)	642 246	2 041 314
Hydropower potential - continuous flow (MW)	4.34	15.40
Hydropower potential - peak power (MW)	29.17	103.50
Turbine type - continuous flow	Horizontal Francis	Horizontal Francis
Turbine type - peak power	Vertical Francis	Vertical Francis
Dam Capital Cost Estimate (million R)	R 1 927	R 6 124
URV of yield assured (i = 8%)	1.2	1.9

D4

1.1 LOCATION

The D4 dam site is located at 29°59'07.10"S and 27°30'24.84"E in the West of Lesotho.

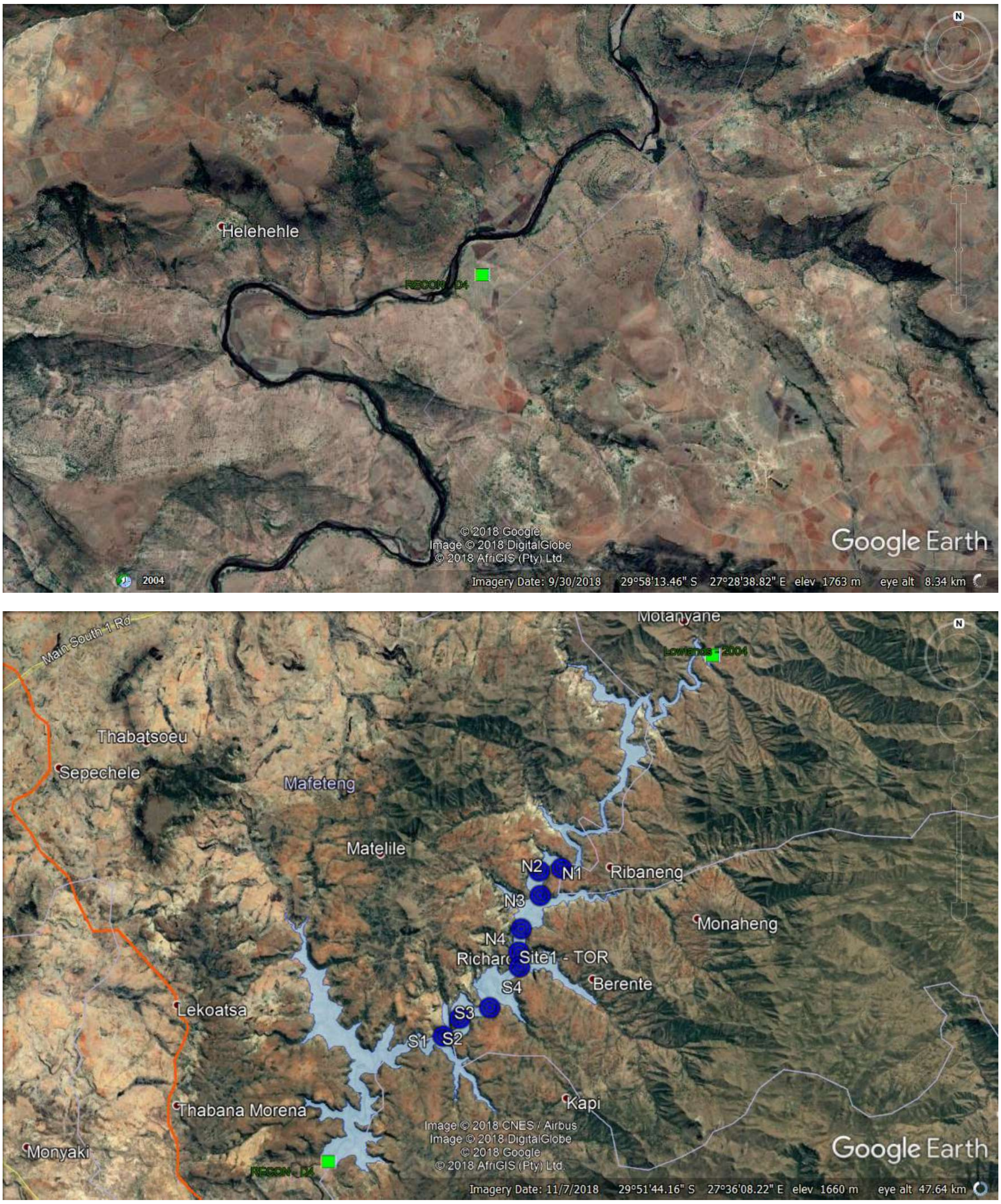


Figure 1: Map of Dam Site Location

1.2 GENERAL

• Catchment Size (km^2):	2 021
• MAR (MCM/a):	500
• Design Floods (m^3/s):	
• 1:10 year (River diversion):	1 235
• 1:200 (Design Flood):	3 045
• RMF + Δ (Safety Evaluation):	5 580
• Distance to Construction material	22 km SE or 13 km NW of site
• Expected 50-year Sediment Volumes (million m^3)	80.80

Figure 2: Photograph of Dam Site

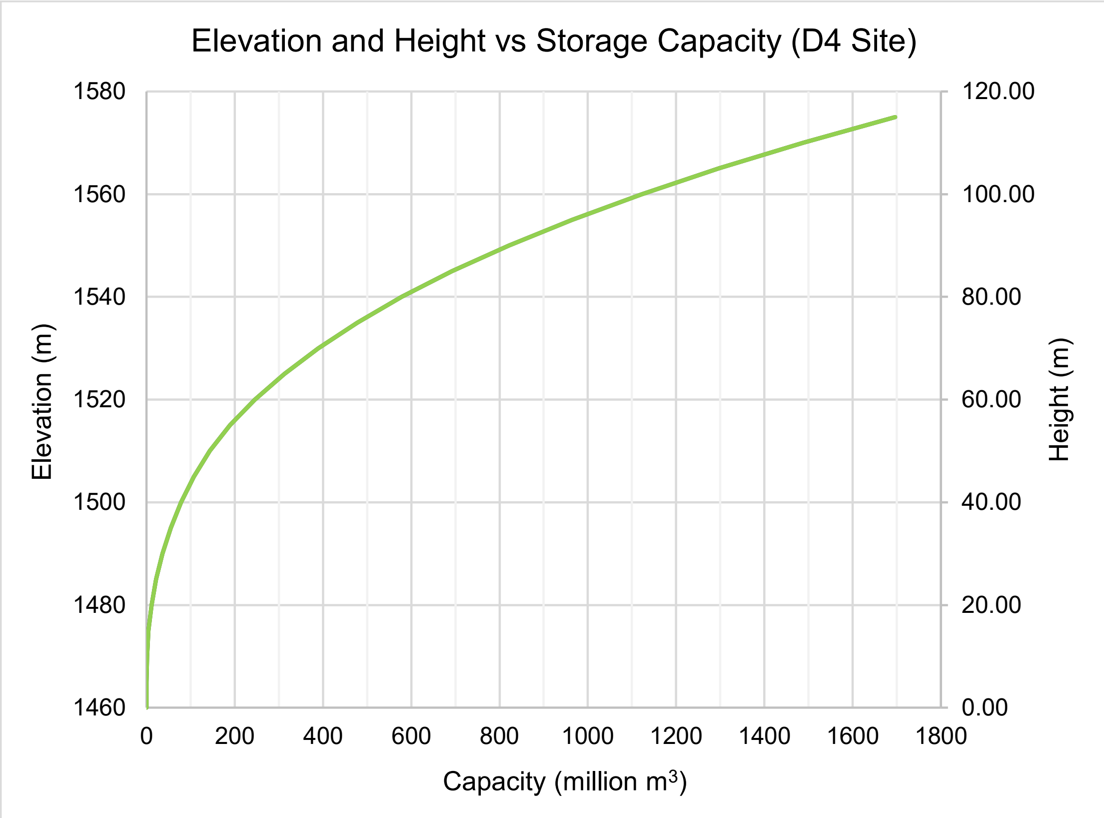


Figure 3: Elevation and Height vs Storage Capacity Graph

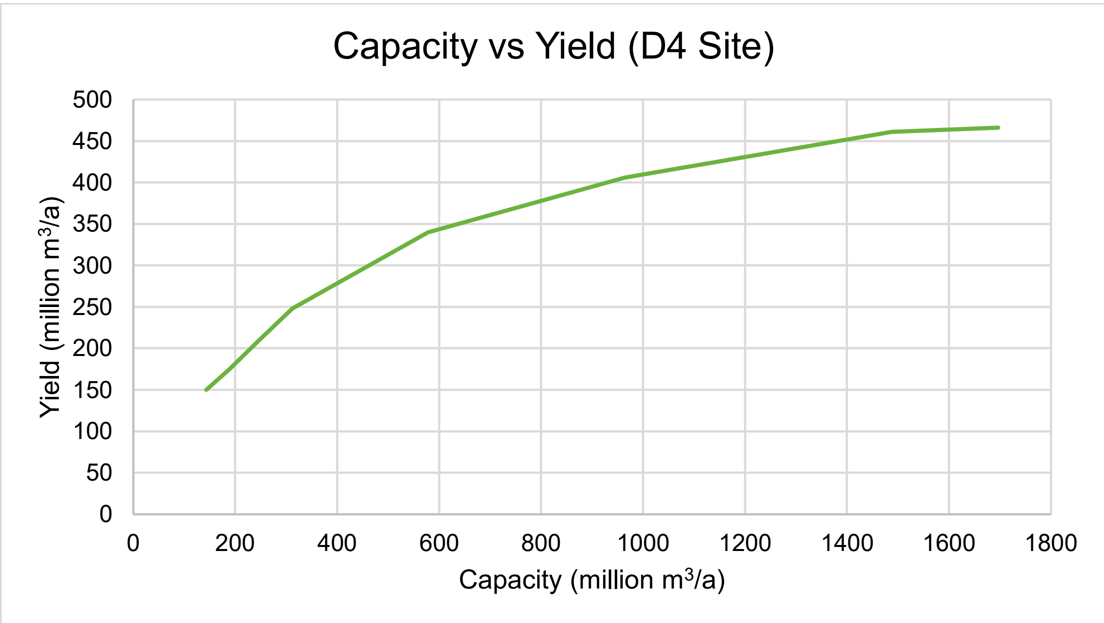


Figure 4: Capacity vs Yield Graph

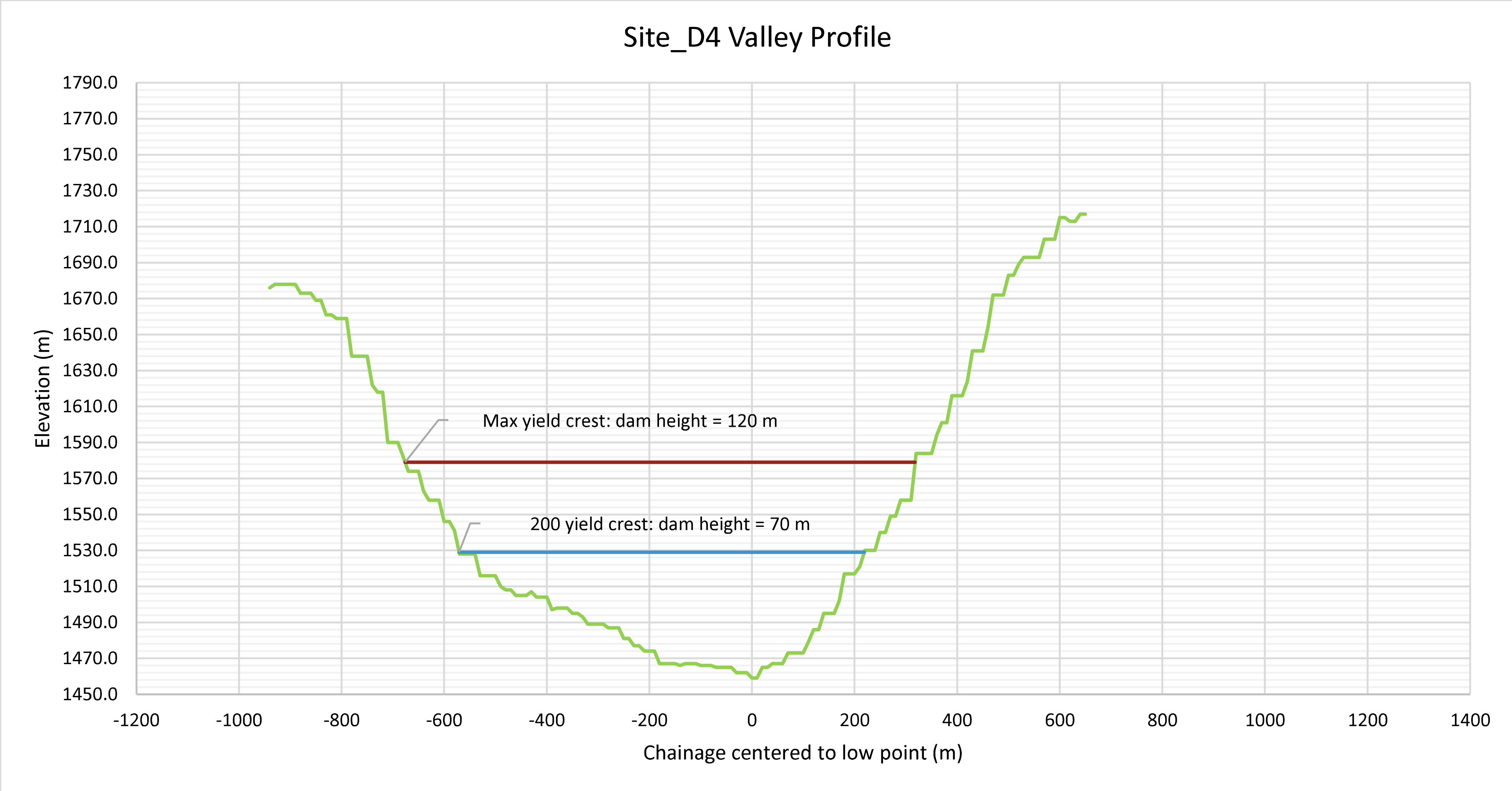


Figure 5: Dam valley profile with dam heights for a dam with 200 MCM/a yield and for a maximum a yield that equates to a capacity of 3 MAR

1.3 DAM HEIGHT OPTIONS

Scenarios	Dam Height to meet 200MCM/a Yield (Scenario 1)	Dam Height for 3 MAR Capacity (Scenario 2)
Height (m)	70	120
Capacity (MCM)	217	1 494
Yield (MCM/a)	200	1 494
Impact on the yield of Gariep Dam (MCM/a)	-165	0
Aspect Ratio	11.3	8.3
Likely Dam Type	RCC Gravity Dam	RCC Gravity Dam
River Diversion	Coffer dam, with twin diversion tunnels	Coffer dam, with twin diversion tunnels
Spillway type	Free ogee over crest	Free ogee over crest
Outlet arrangement	Multi-level outlet, with tower against upstream face	Multi-level outlet, with tower against upstream face
Dam material volumes (m^3)	1 016 033	3 505 171
Hydropower potential - continuous flow (MW)	3.89	16.58
Hydropower potential - peak power (MW)	26.12	111.44
Turbine type - continuous flow	Horizontal Francis	Horizontal Francis
Turbine type - peak power	Vertical Francis	Vertical Francis
Dam Capital Cost Estimate (million R)	R 3 048	R 10 516
URV of yield assured (i = 8%)	1.8	2.7

D3

1.1 LOCATION

The D3 dam site is located at 30°01'07.63"S and 27°29'00.68"E in the West of Lesotho.

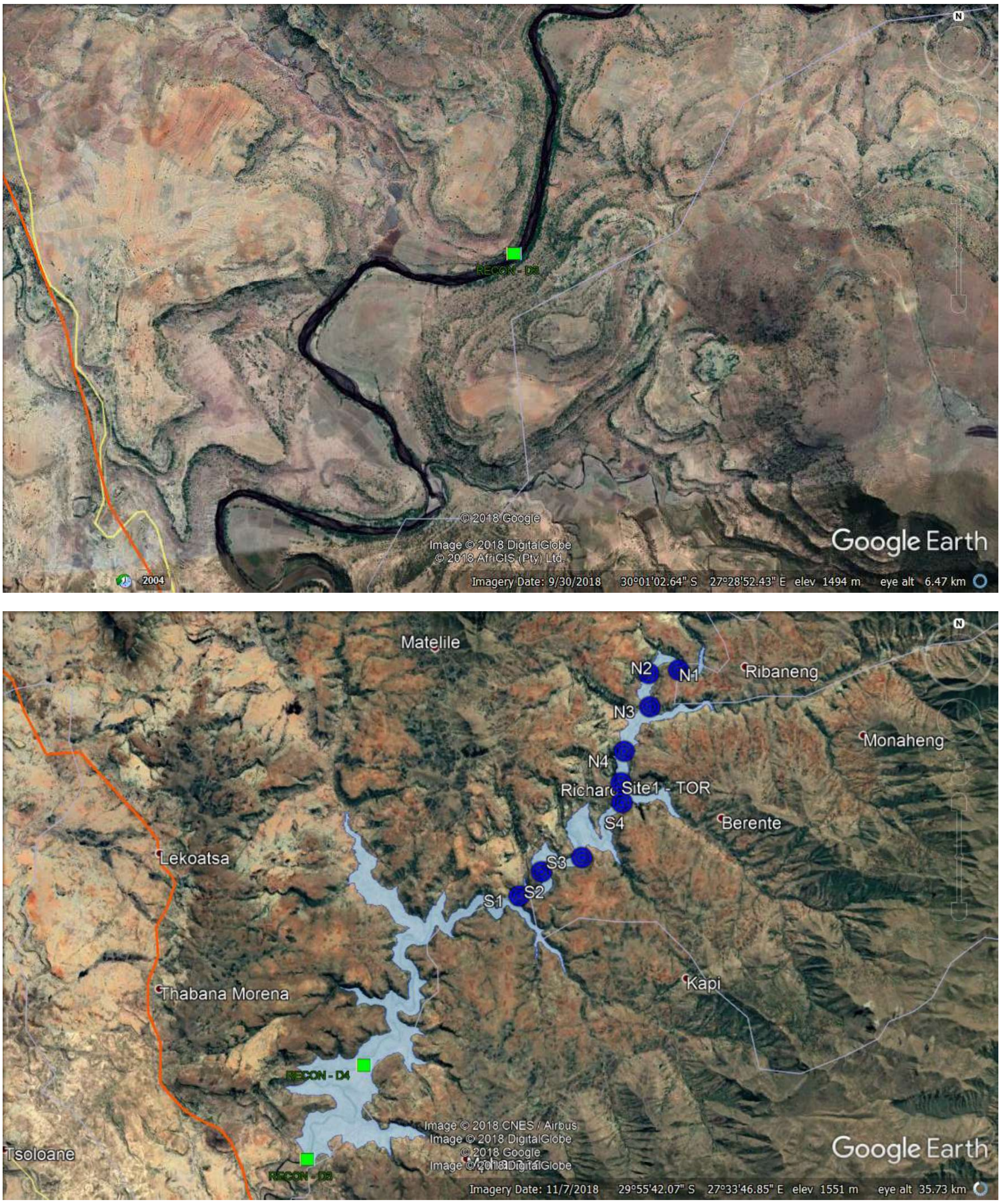


Figure 1: Map of Dam Site Location

1.2 GENERAL

• Catchment Size (km^2):	2 069
• MAR (MCM/a):	505
• Design Floods (m^3/s):	
• 1:10 year (River diversion):	1 250
• 1:200 (Design Flood):	3 085
• RMF + ∆ (Safety Evaluation):	5 645
• Distance to Construction material	22 km SE or 13 km NW of site
• Expected 50-year Sediment Volumes (million m^3)	86.23

Figure 2: Photograph of Dam Site

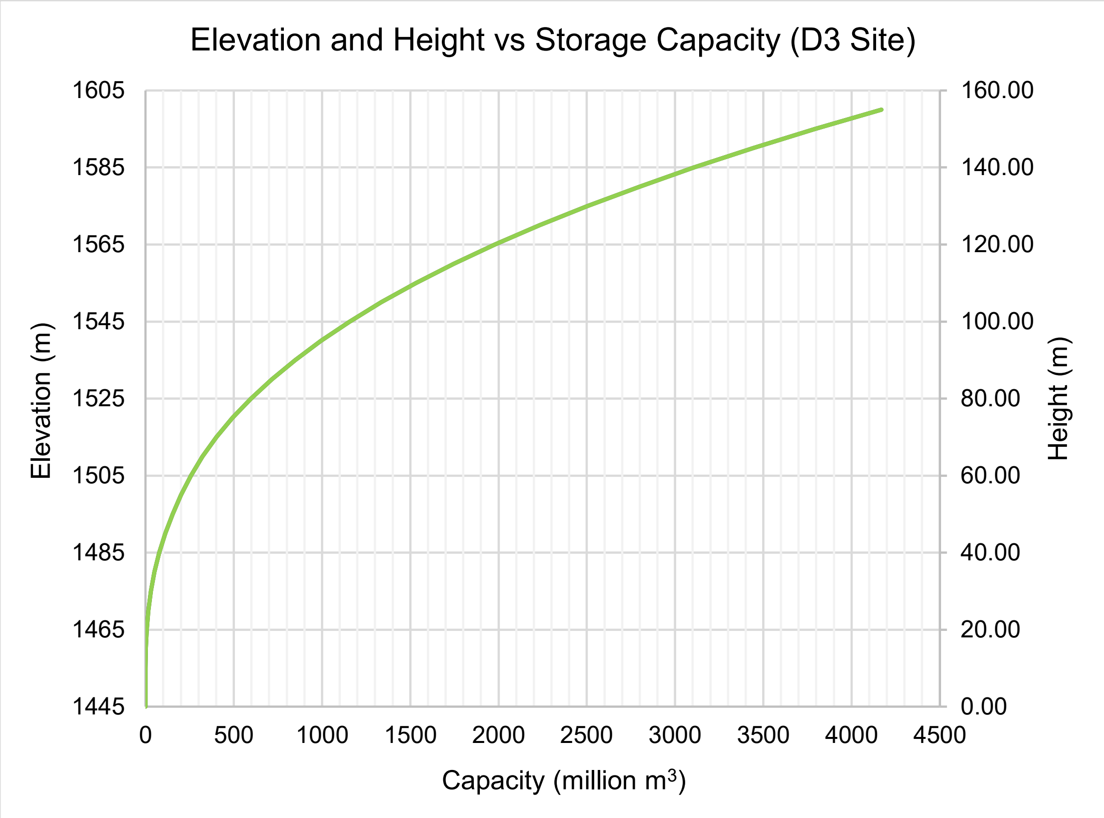


Figure 3: Elevation and Height vs Storage Capacity Graph

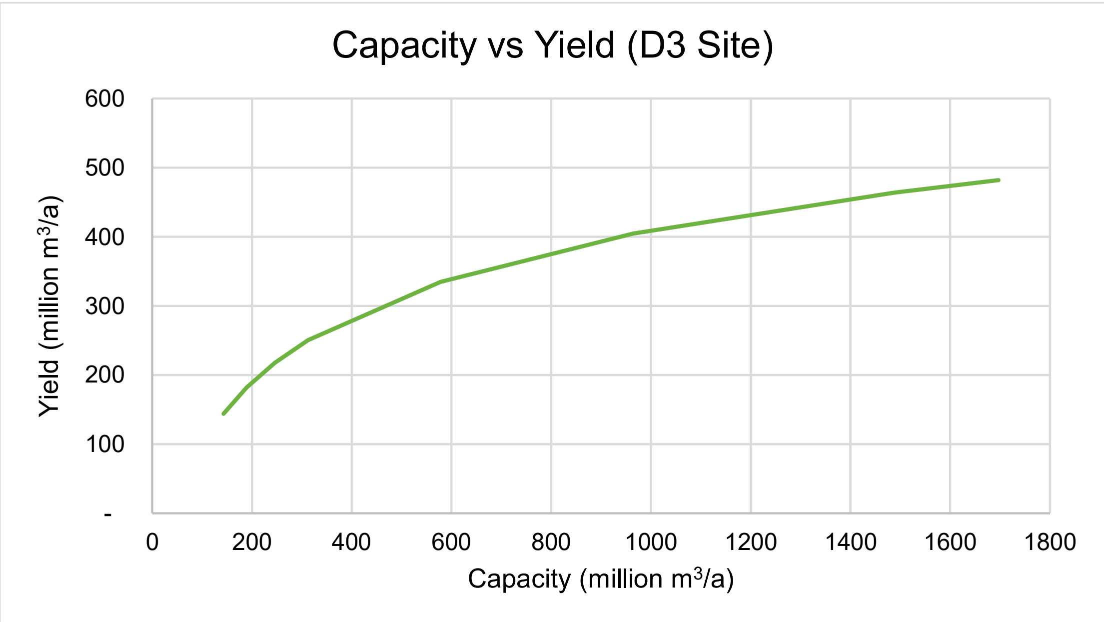


Figure 4: Capacity vs Yield Graph

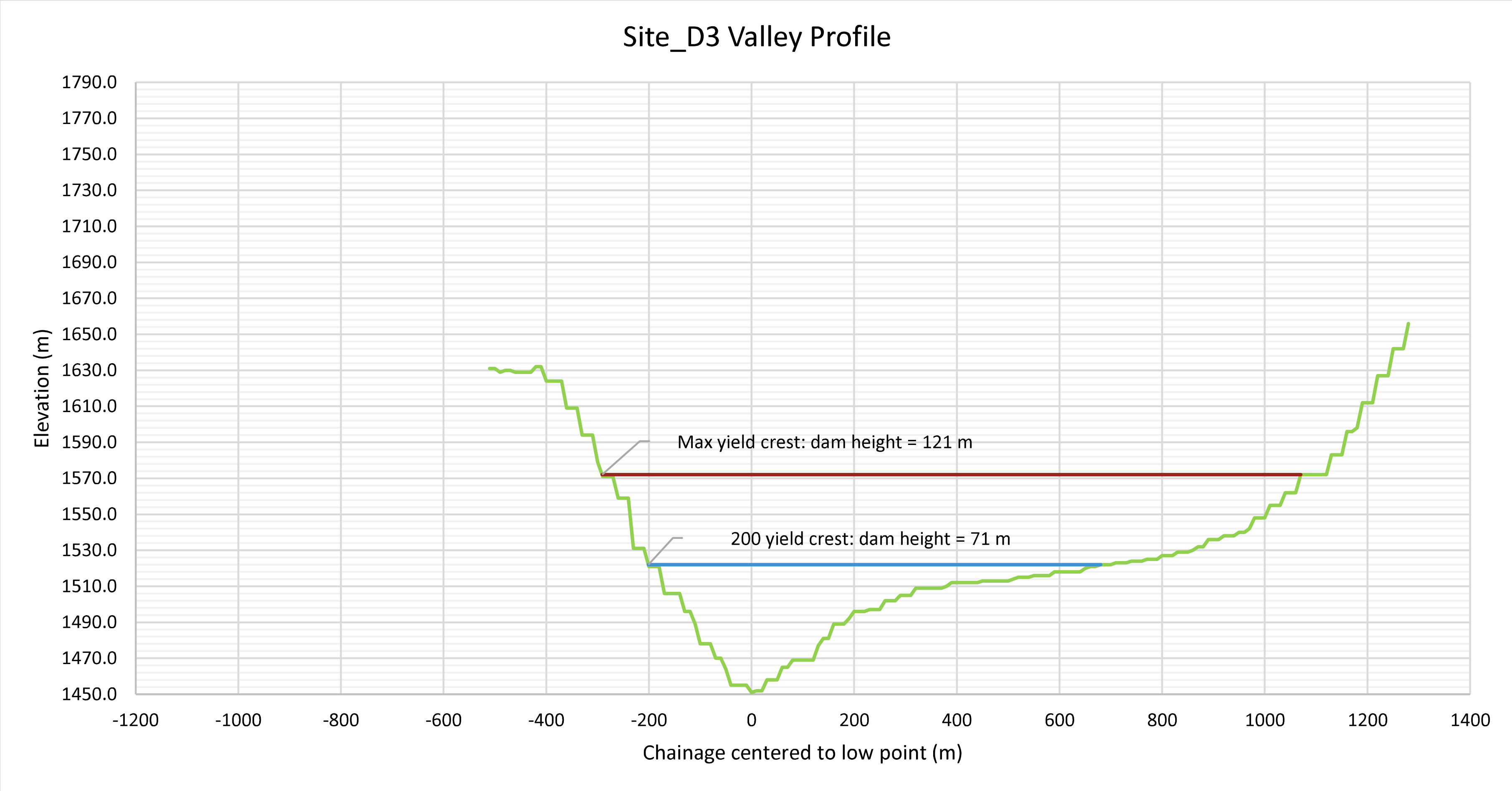


Figure 5: Dam valley profile with dam heights for a dam with 200 MCM/a yield and for a maximum a yield that equates to a capacity of 3 MAR

1.3 DAM HEIGHT OPTIONS

Scenarios	Dam Height to meet 200MCM/a Yield (Scenario 1)	Dam Height for 3 MAR Capacity (Scenario 2)
Height (m)	71	121
Capacity (MCM)	215	1 520
Yield (MCM/a)	200	467
Impact on the yield of Gariep Dam (MCM/a)	-165	0
Aspect Ratio	12.4	11 3
Likely Dam Type	RCC Gravity Dam	RCC Gravity Dam
River Diversion	Coffer dam, with twin diversion tunnels	Coffer dam, with twin diversion tunnels
Spillway type	Free ogee over crest	Free ogee over crest
Outlet arrangement	Multi-level outlet, with tower against upstream face	Multi-level outlet, with tower against upstream face
Dam material volumes (m^3)	676 659	3 207 938
Hydropower potential - continuous flow (MW)	3.90	16.90
Hydropower potential - peak power (MW)	26.22	113.60
Turbine type - continuous flow	Horizontal Francis	Horizontal Francis
Turbine type - peak power	Vertical Francis	Vertical Francis
Dam Capital Cost Estimate (million R)	R 2 030	R 9 624
URV of yield assured (i = 8%)	1.2	2.5

D2

1.1 LOCATION

The D2 dam site is located at 30°03'52.37"S and 27°26'45.99"E in the West of Lesotho.

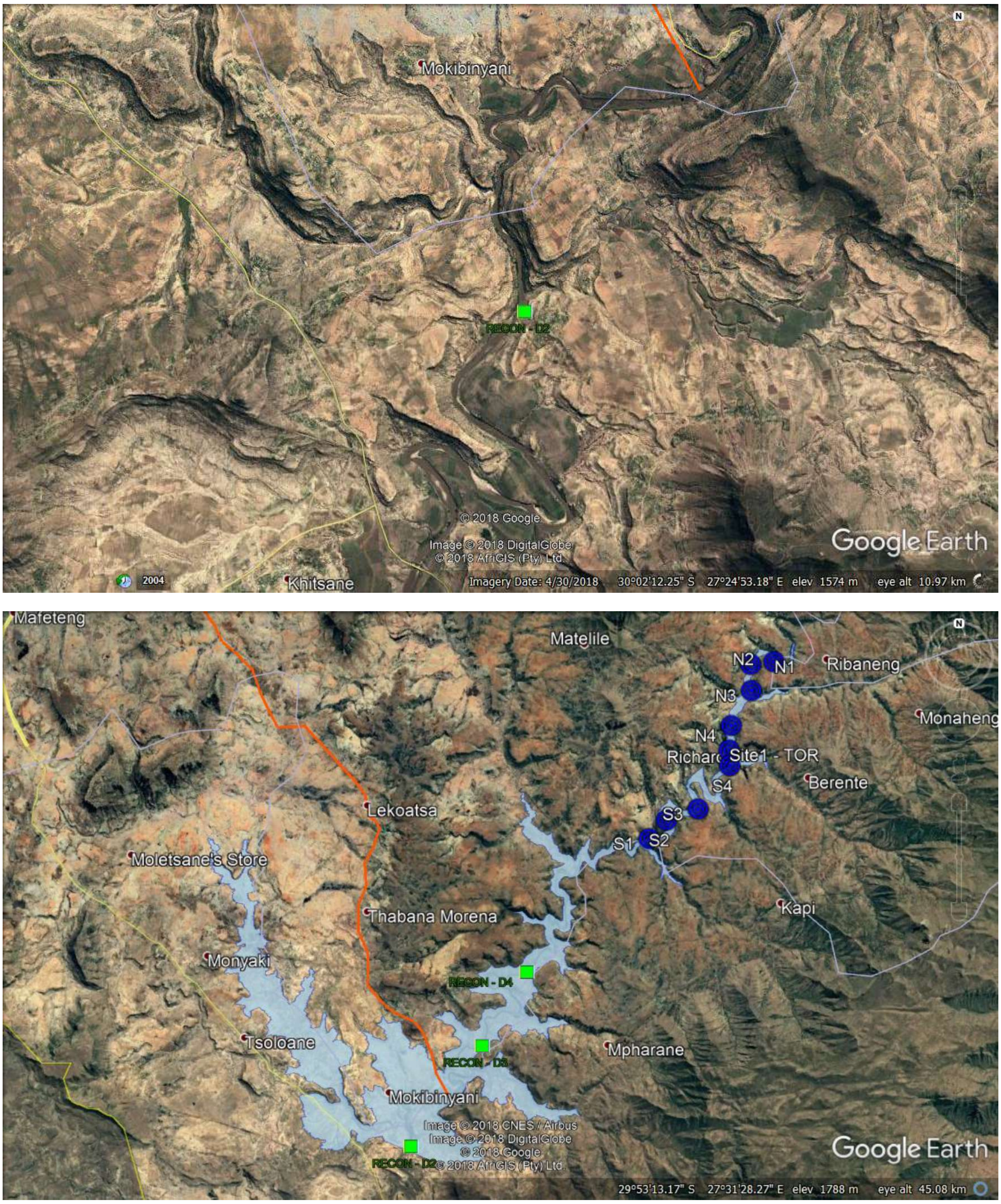


Figure 1: Map of Dam Site Location

1.2 GENERAL

• Catchment Size (km^2):	2 554
• MAR (MCM/a):	645
• Design Floods (m^3/s):	
• 1:10 year (River diversion):	1 390
• 1:200 (Design Flood):	3 455
• RMF + Δ (Safety Evaluation):	6 245
• Distance to Construction material	22 km SE or 13 km NW of site
• Expected 50-year Sediment Volumes (million m^3)	140.85

Figure 2: Photograph of Dam Site

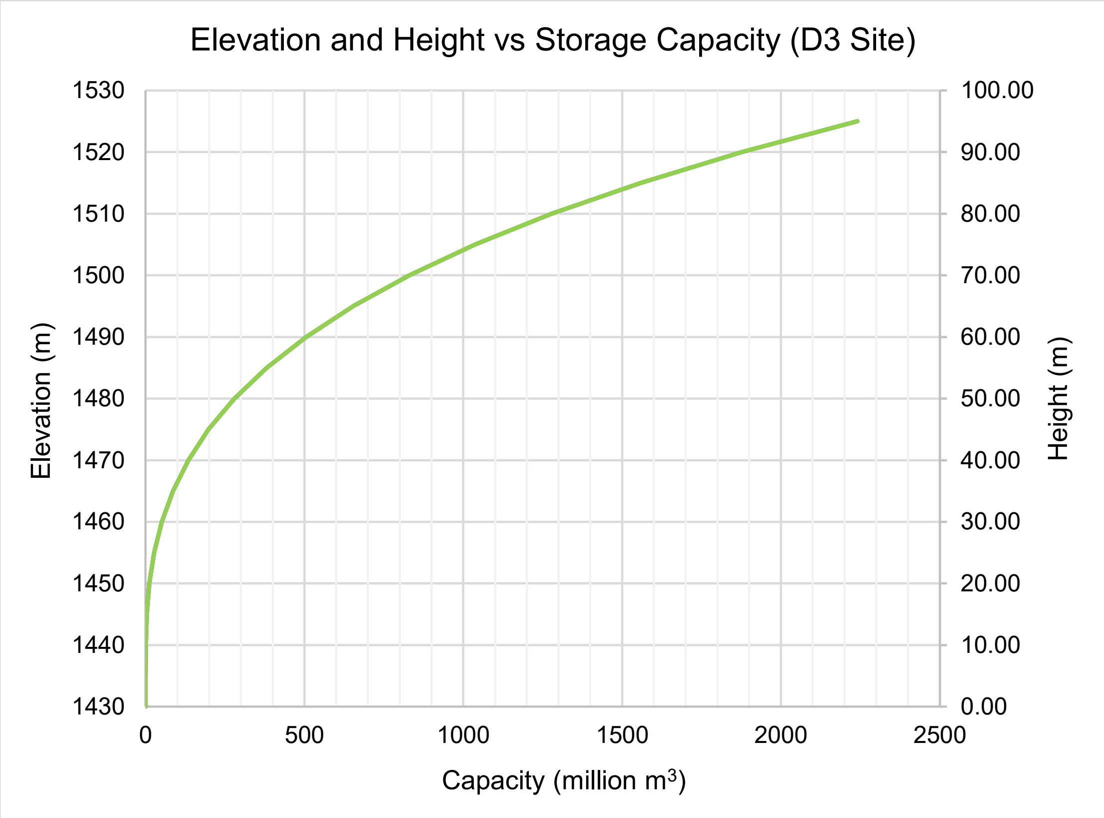


Figure 3: Elevation and Height vs Storage Capacity Graph

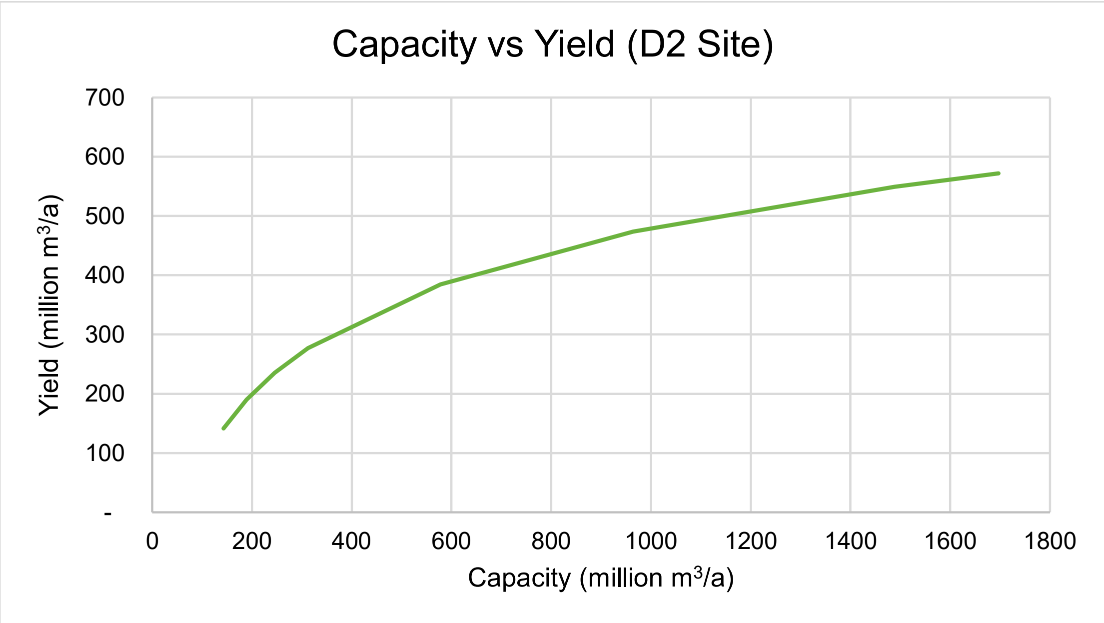


Figure 4: Capacity vs Yield Graph

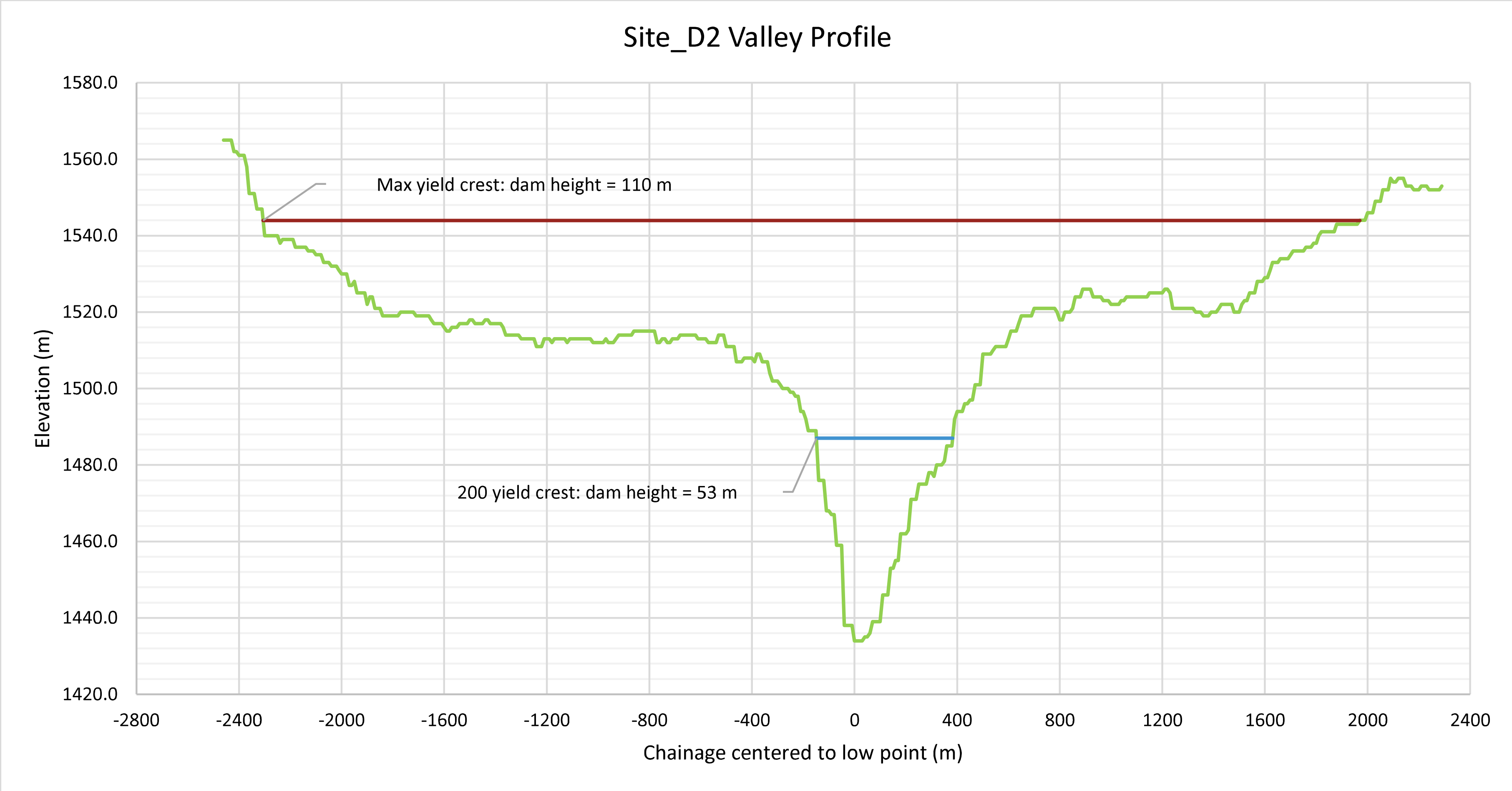
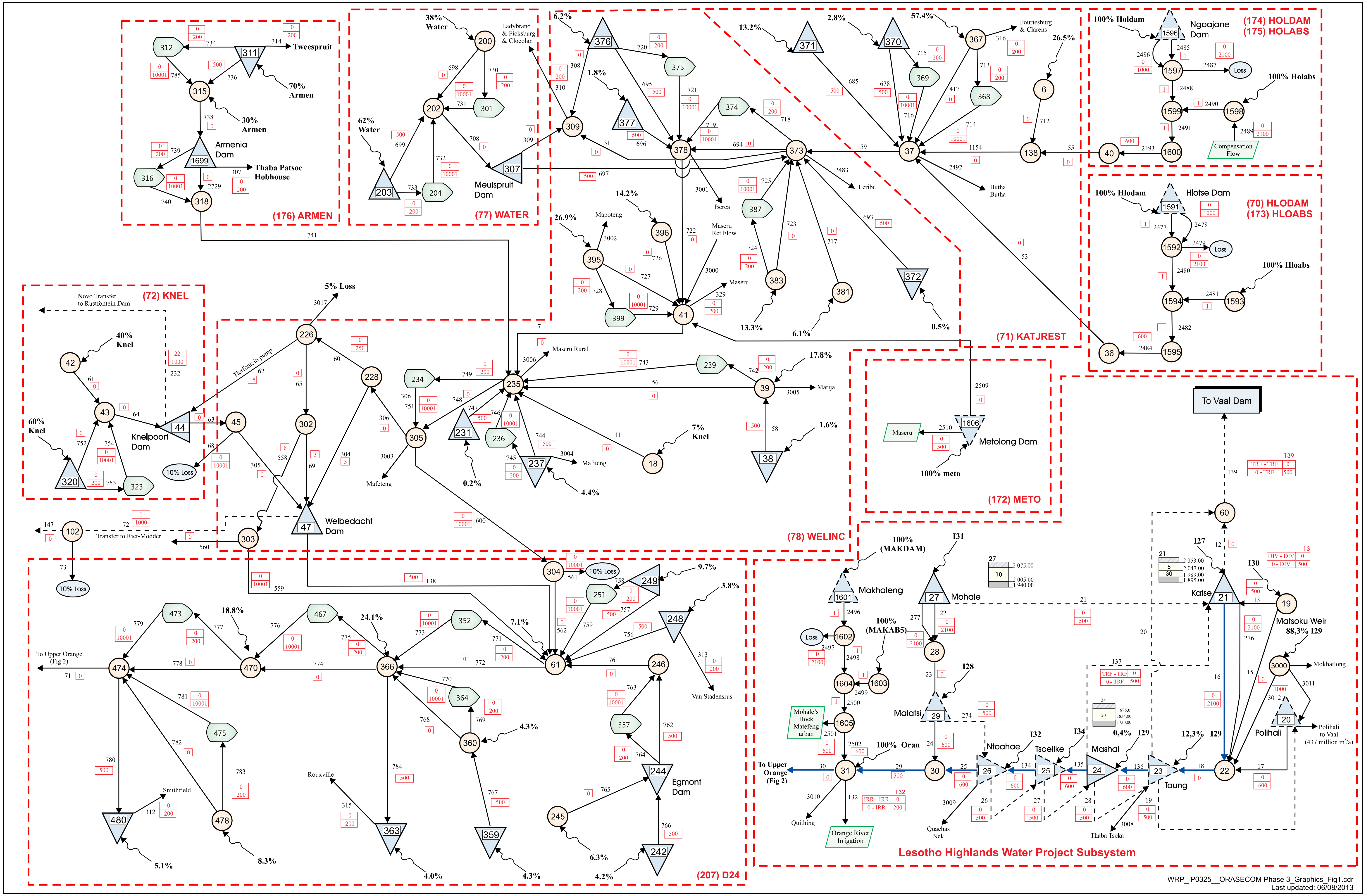


Figure 5: Dam valley profile with dam heights for a dam with 200 MCM/a yield and for a maximum a yield that equates to a capacity of 3 MAR

1.3 DAM HEIGHT OPTIONS

Scenarios	Dam Height to meet 200MCM/a Yield (Scenario 1)	Dam Height for 3 MAR Capacity (Scenario 2)
Height (m)	53	110
Capacity (MCM)	200	1 940
Yield (MCM/a)	200	596
Impact on the yield of Gariep Dam (MCM/a)	-165	0
Aspect Ratio	10.0	38.9
Likely Dam Type	RCC Gravity Dam	RCC Gravity Dam
River Diversion	Coffer dam, with twin diversion tunnels	Coffer dam, with twin diversion tunnels
Spillway type	Free ogee over crest	Free ogee over crest
Outlet arrangement	Multi-level outlet, with tower against upstream face	Multi-level outlet, with tower against upstream face
Dam material volumes (m^3)	393 123	4 166 319
Hydropower potential - continuous flow (MW)	2.81	18.25
Hydropower potential - peak power (MW)	18.89	122.62
Turbine type - continuous flow	Horizontal Francis	Horizontal Francis
Turbine type - peak power	Vertical Francis	Vertical Francis
Dam Capital Cost Estimate (million R)	R 1 179	R 12 499
URV of yield assured (i = 8%)	0.7	2.5

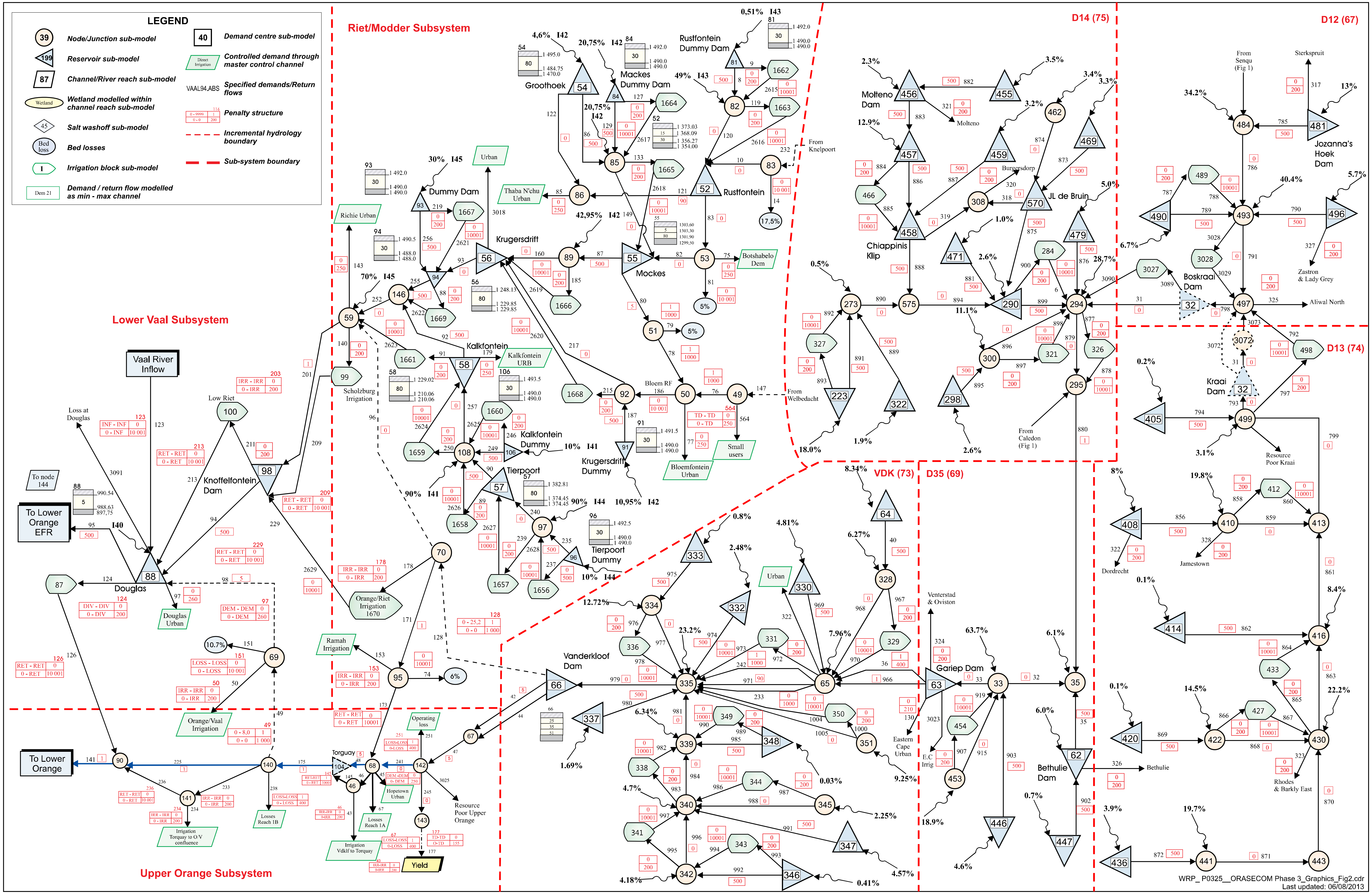
APPENDIX F: System Diagrams



INTEGRATED WATER RESOURCES MANAGEMENT PLAN FOR THE ORANGE-SENQU RIVER CATCHMENT

Orange River Subsystem Schematic - with penalty structures (1 of 5) Senqu & Caledon

Fig-1



INTEGRATED WATER RESOURCES MANAGEMENT PLAN FOR THE ORANGE-SENQU RIVER CATCHMENT

Orange River Subsystem Schematic - with penalty structures (2 of 5) Upper Orange and Riet Modder

Fig-2

APPENDIX G: Conveyance Routes for Dam Options

LOWLANDS

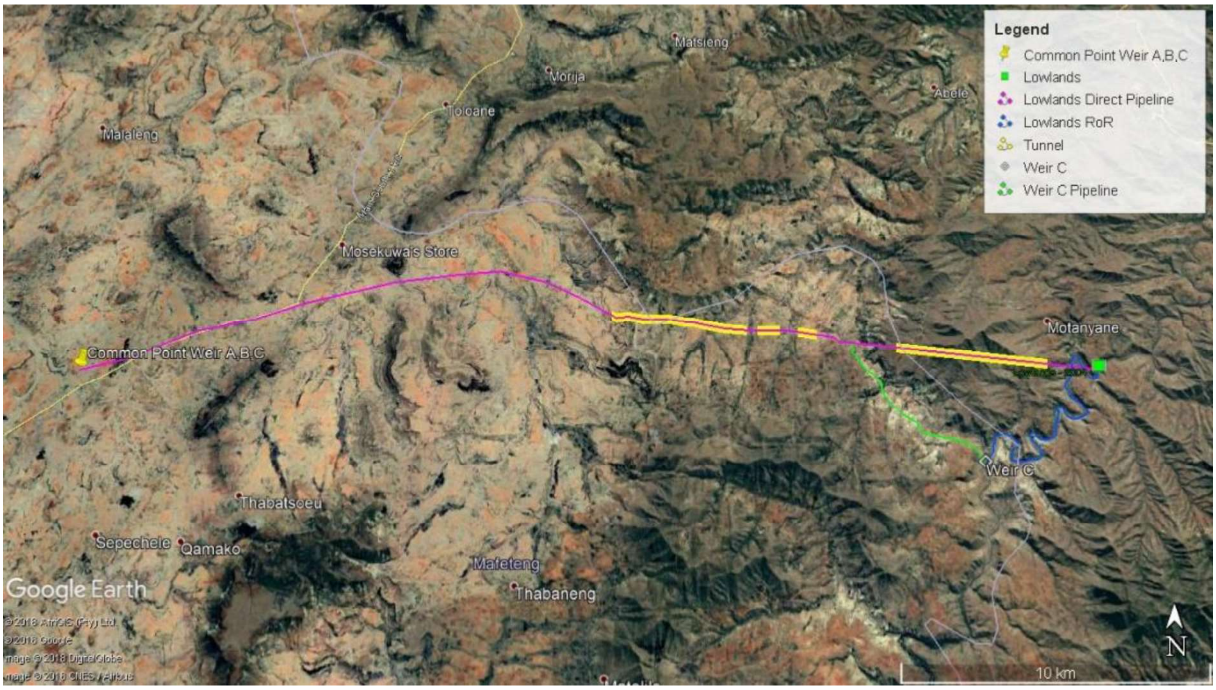


Figure 1: Plan – Conveyance Lowlands 2004

Table 1: Dam site Lowlands

SITE DATA:	**Direct supply from dam:**		**Run-of-river supply:**	
Length of pipeline (km):	24.9		26.6	
Length of tunnel (km):	13.10		9.2	
Scenario:	**Low:**	**High**	**Low:**	**High:**
Capital cost (R millions):	R2 787	R3 150	R2 619	R3 007
NPV (R):	R2 169	R2 589	R2 597	R3 380
URV (R/m^3):	R3.17	R2.23	R3.79	R2.92

Figure 2: Profile - Direct Supply_Lowlands 2004

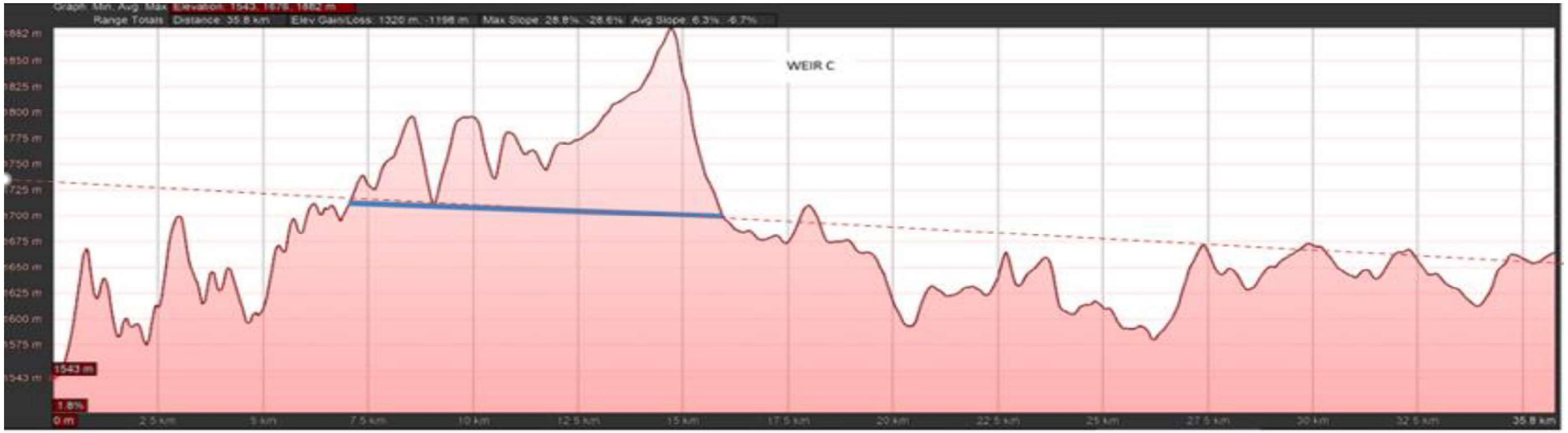


Figure 3: Profile - Run-of-river Supply_Lowlands 2004

N1/ N1A

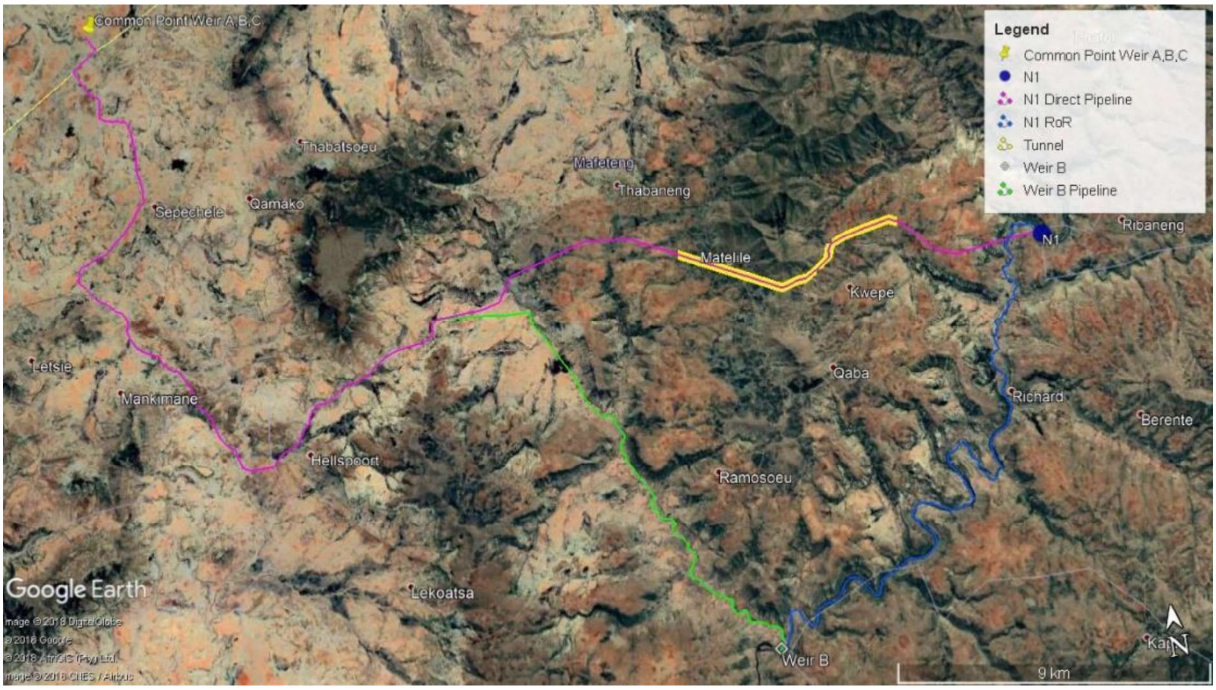


Figure 4: Plan - Conveyance_N1/N1A

Table 2: Dam site N1/N1A

SITE DATA:	**Direct supply from dam:**		**Run-of-river supply:**	
Length of pipeline (km):	29.2		30.3	
Length of tunnel (km):	18.40		13.6	
Scenario:	**Low:**	**High**	**Low:**	**High:**
Capital cost (R millions):	R3 701	R4 126	R3 301	R3 743
NPV (R):	R3 585	R4 582	R3 332	R4 286
URV (R/m^3):	R5.23	R3.96	R4.86	R3.70

Figure 5: Profile - Direct Supply_N1/N1A

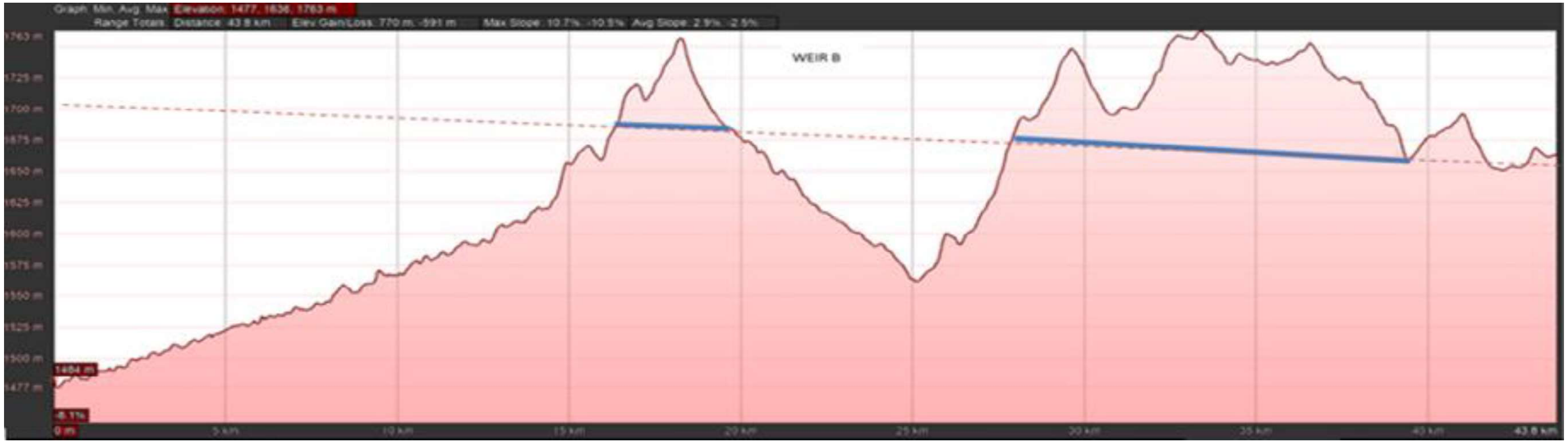


Figure 6: Profile - Run-of-river Supply_N1/N1A

N2

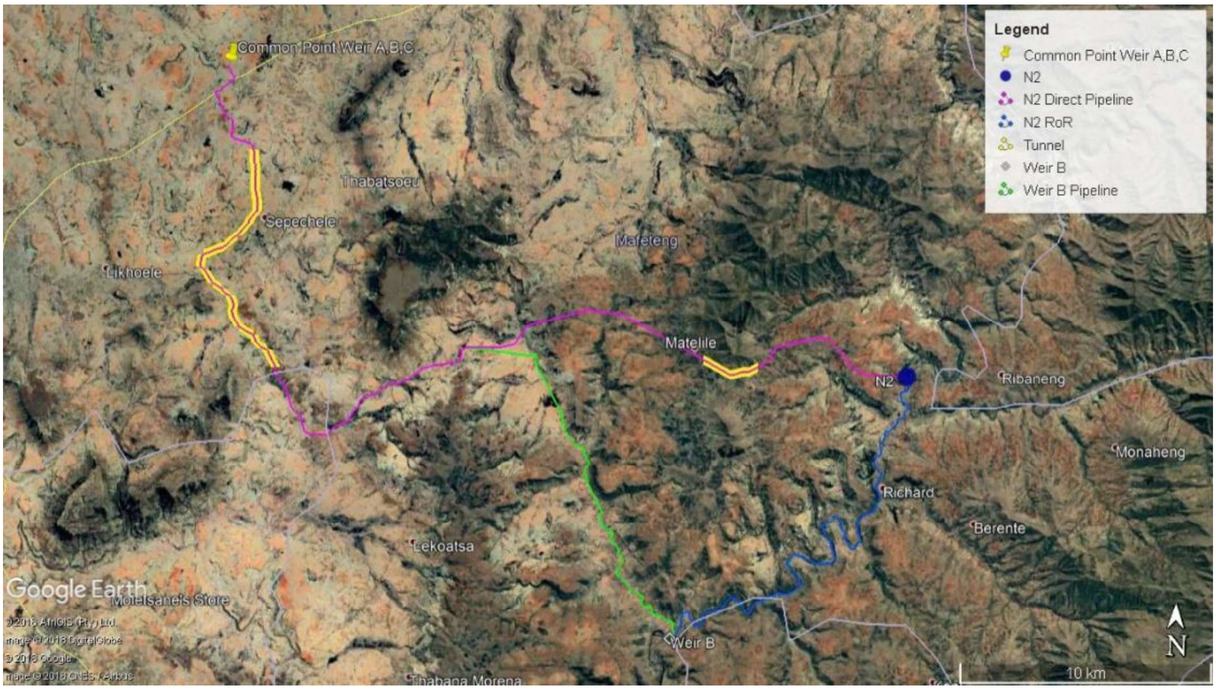


Figure 7: Plan – Conveyance_N2

Table 3: Dam site N2

SITE DATA:	**Direct supply from dam:**		**Run-of-river supply:**	
Length of pipeline (km):	28.3		30.3	
Length of tunnel (km):	18.10		13.6	
Scenario:	**Low:**	**High**	**Low:**	**High:**
Capital cost (R millions):	R3 623	R4 036	R3 301	R3 743
NPV (R):	R3 531	R4 523	R3 332	R4 286
URV (R/m^3):	R5.15	R3.90	R4.86	R3.70

Figure 8: Profile - Direct Supply_N2

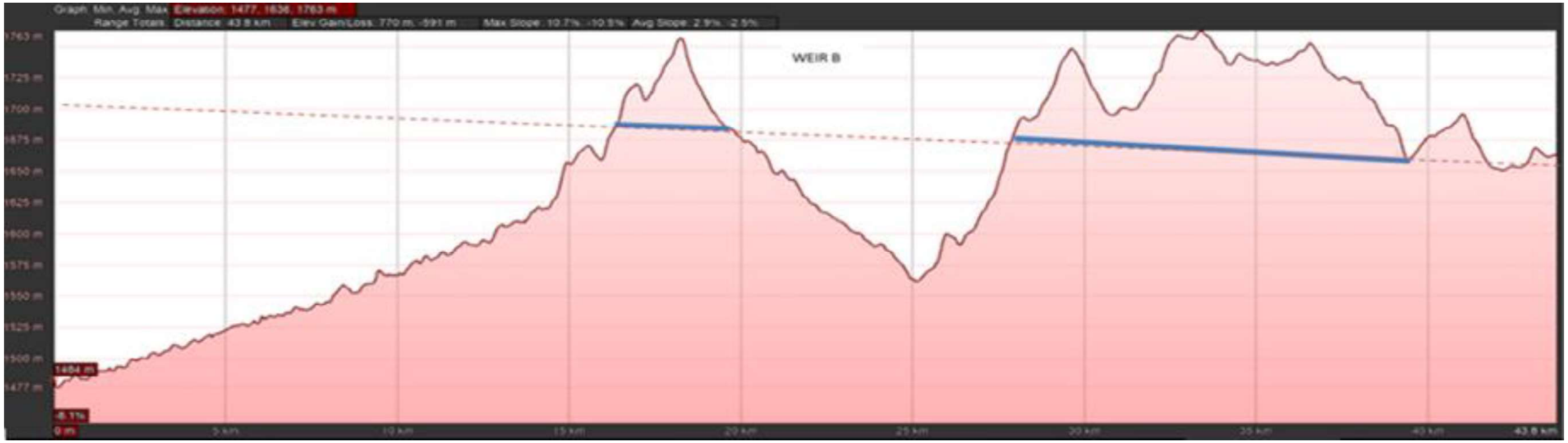


Figure 9: Profile - Run-of-river Supply_N2

N3

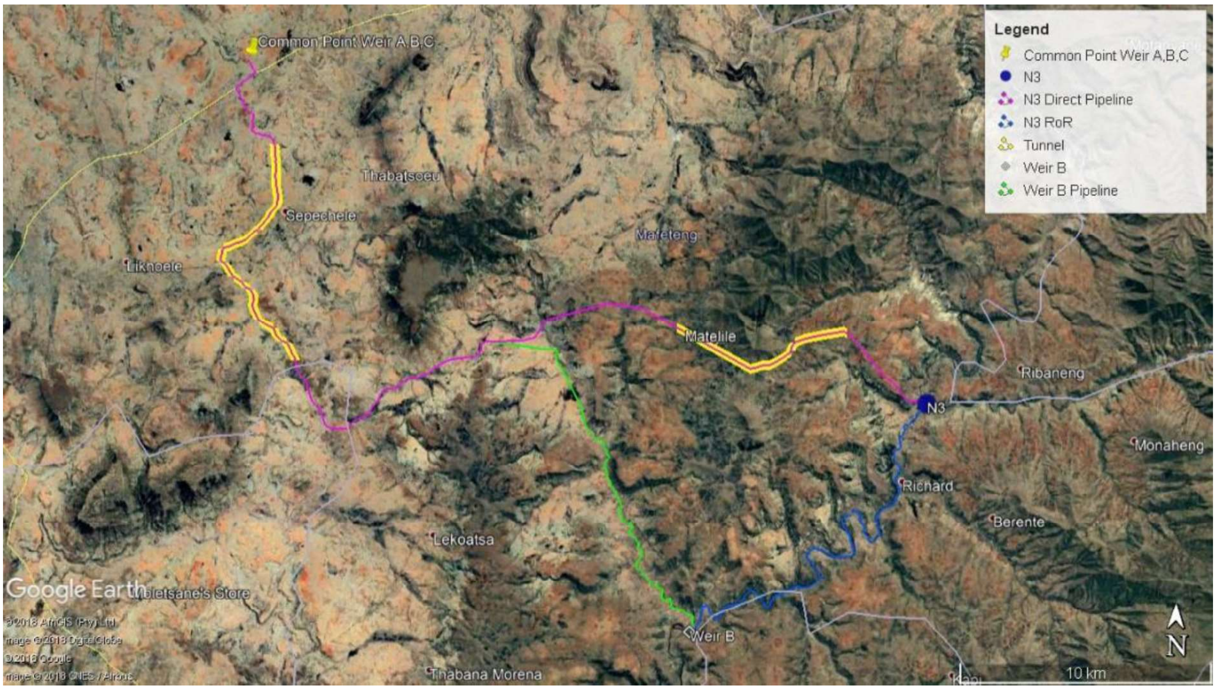


Figure 10: Plan – Conveyance_N3

Table 4: Dam site N3

SITE DATA:	**Direct supply from dam:**		**Run-of-river supply:**	
Length of pipeline (km):	28.9		30.3	
Length of tunnel (km):	18.10		13.6	
Scenario:	**Low:**	**High**	**Low:**	**High:**
Capital cost (R millions):	R3 652	R4 073	R3 301	R3 743
NPV (R):	R3 661	R4 632	R3 332	R4 286
URV (R/m³):	R5.34	R4.00	R4.86	R3.70

Figure 11: Profile - Direct Supply_N3

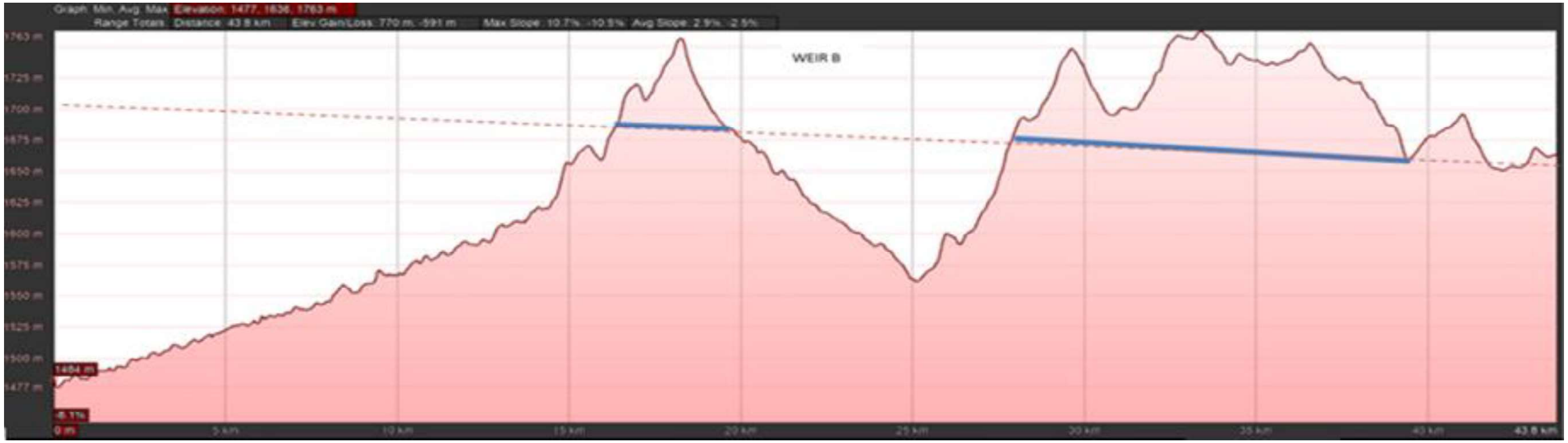


Figure 12: Profile - Run-of-river Supply_N3

N4

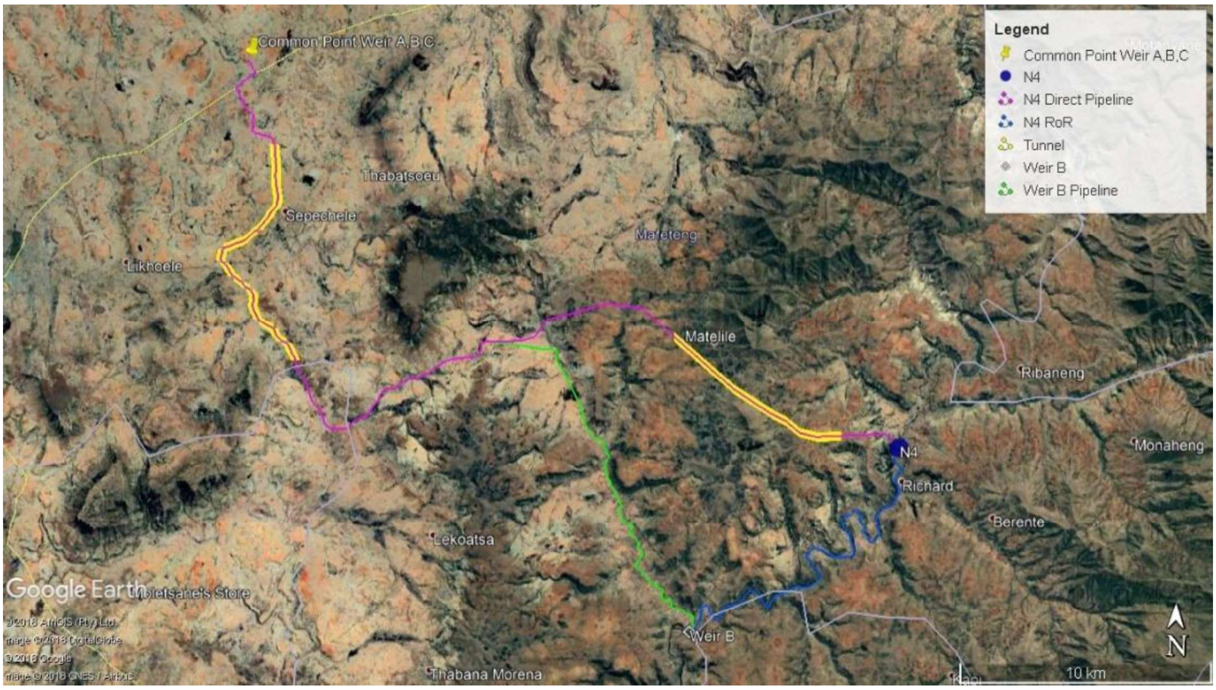


Figure 13: Plan - Conveyance_N4

Table 5: Dam site N4

SITE DATA:	**Direct supply from dam:**		**Run-of-river supply:**	
Length of pipeline (km):	27		30.3	
Length of tunnel (km):	18.60		13.6	
Scenario:	**Low:**	**High**	**Low:**	**High:**
Capital cost (R millions):	R3 619	R4 013	R3 301	R3 743
NPV (R):	R3 541	R4 533	R3 332	R4 286
URV (R/m^3):	R5.17	R3.91	R4.86	R3.70

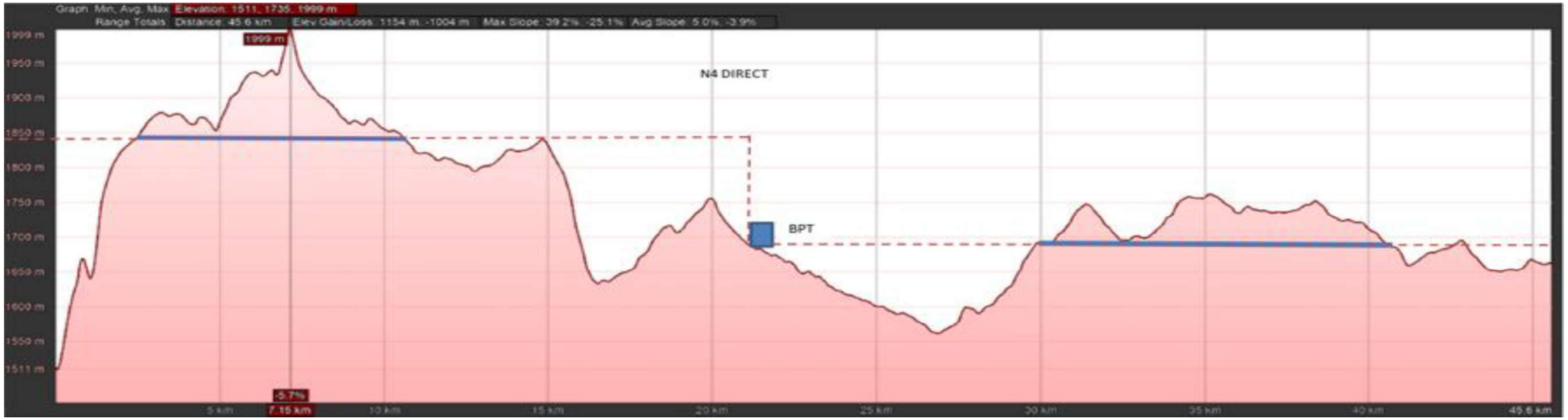


Figure 14: Profile - Direct Supply_N4

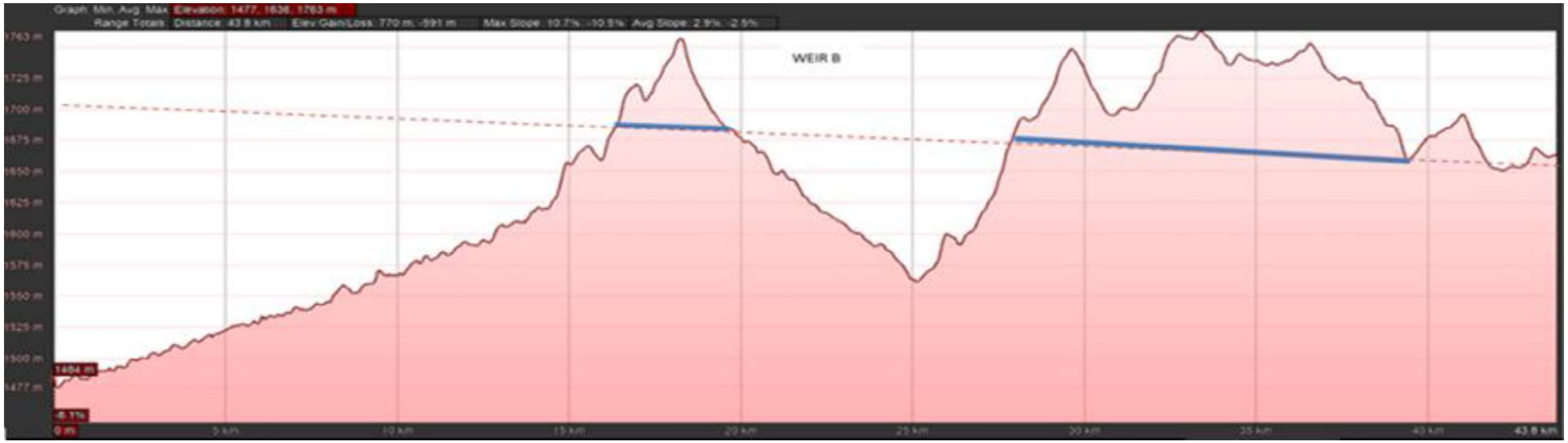


Figure 15: Profile - Run-of-river Supply_N4

TOR

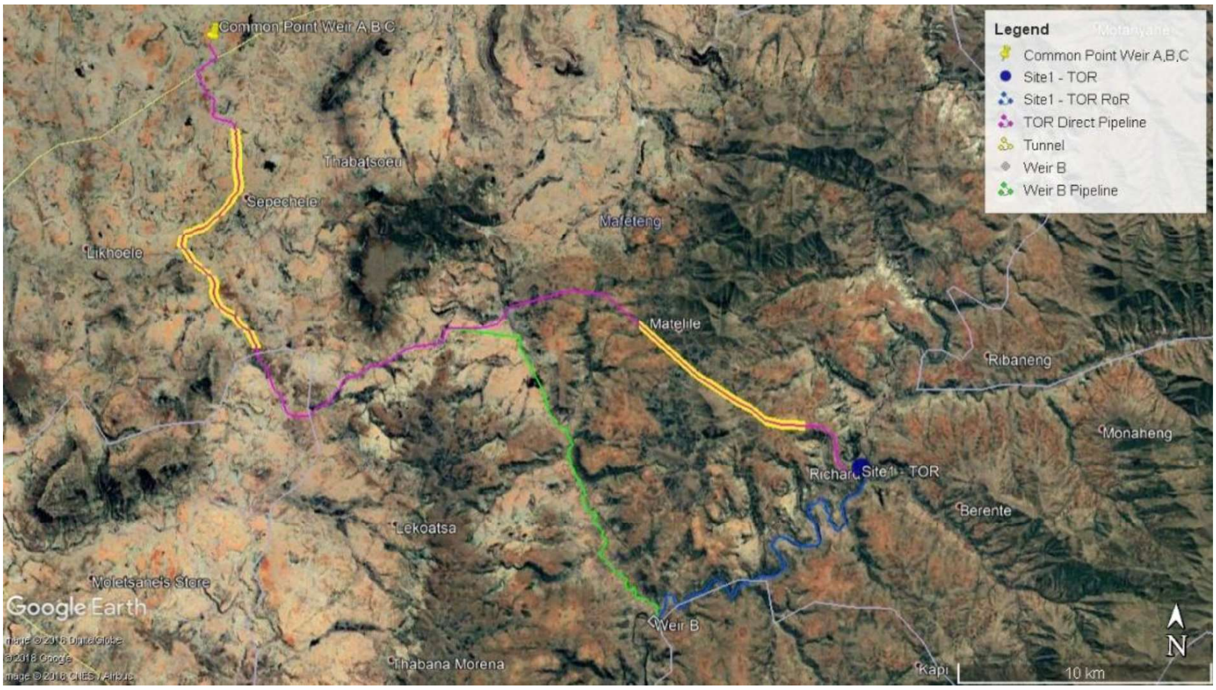


Figure 16: Plan - Conveyance_TOR

Table 6: Dam site TOR

SITE DATA:	**Direct supply from dam:**		**Run-of-river supply:**	
Length of pipeline (km):	27.8		30.3	
Length of tunnel (km):	18.60		13.6	
Scenario:	**Low:**	**High**	**Low:**	**High:**
Capital cost (R millions):	R3 657	R4 063	R3 301	R3 743
NPV (R):	R3 596	R4 611	R3 332	R4 286
URV (R/m^3):	R5.25	R3.98	R4.86	R3.70

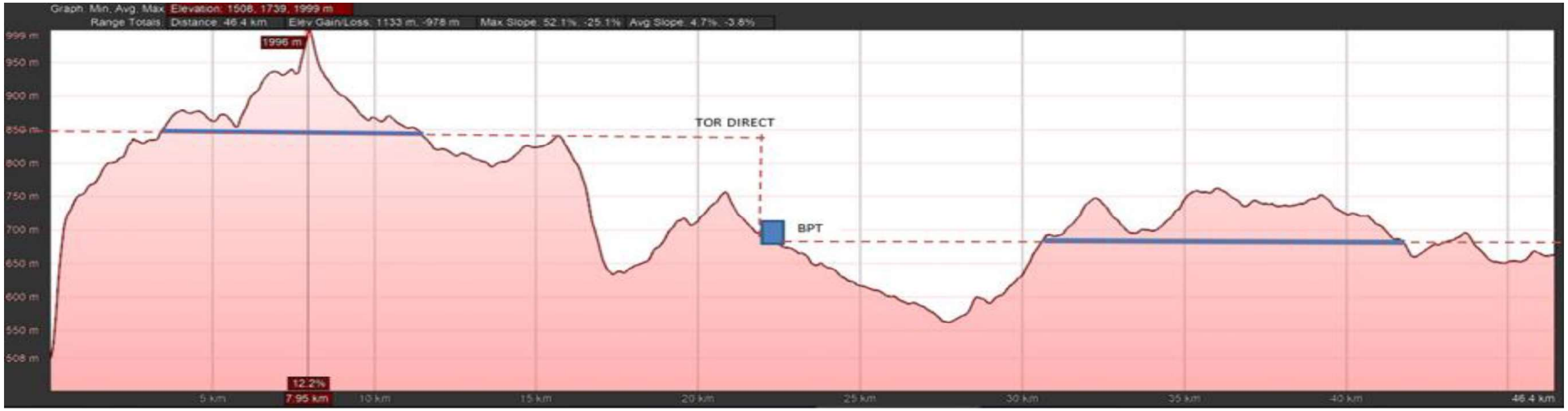


Figure 17: Profile - Direct Supply_TOR

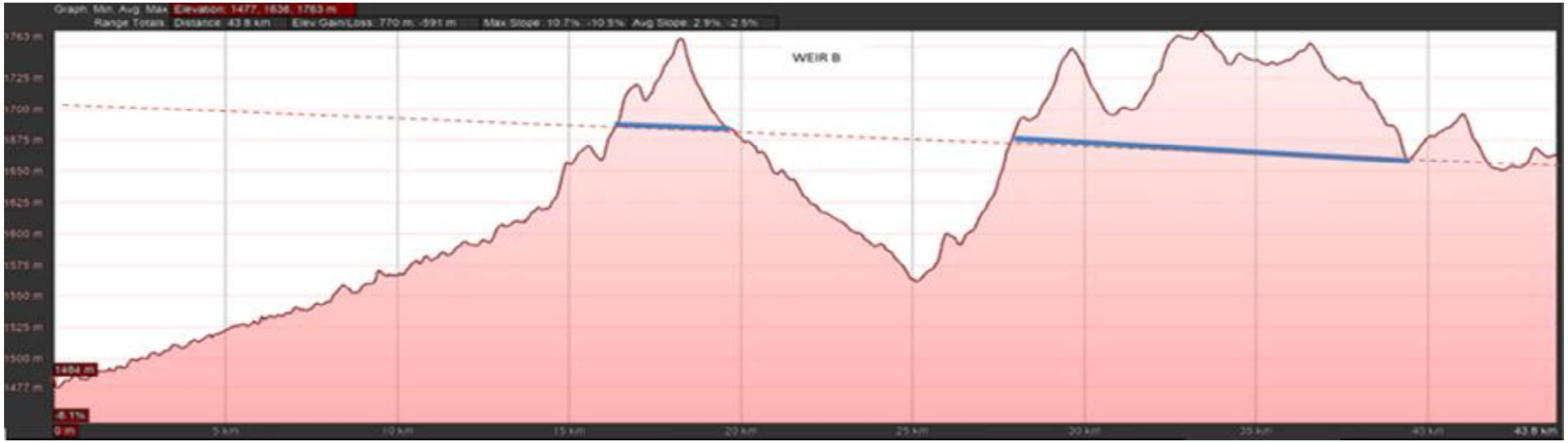


Figure 18: Profile - Run-of-river Supply_TOR

S4

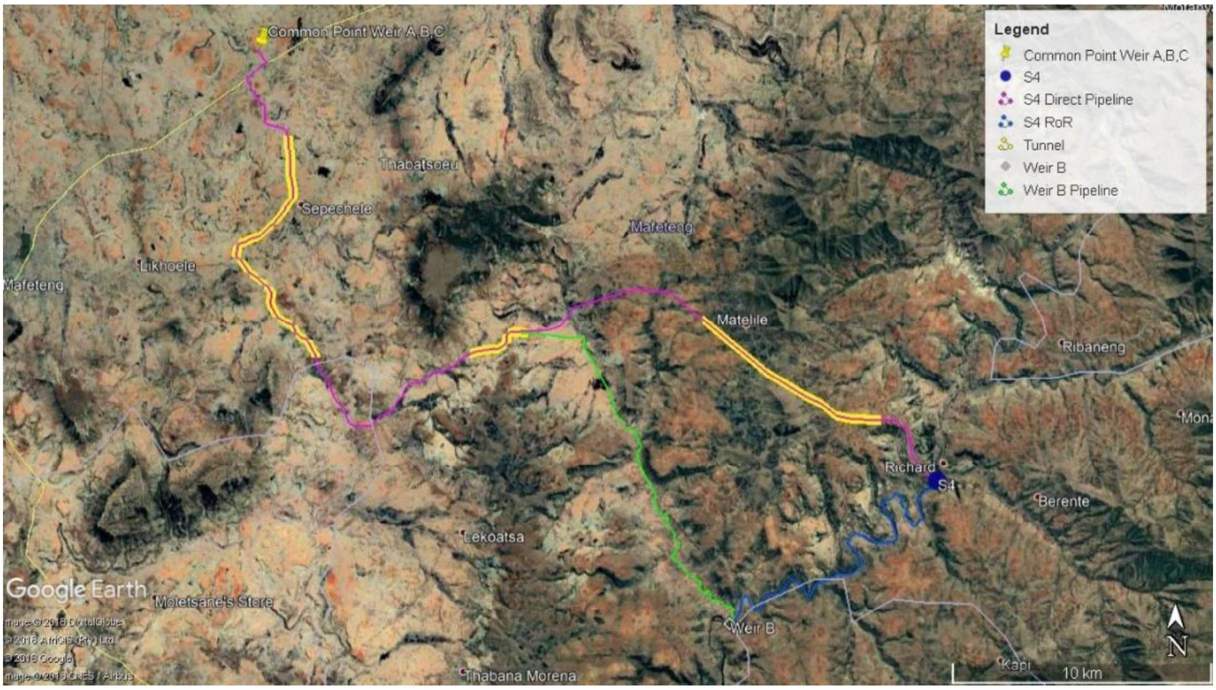


Figure 19: Plan – Conveyance_S4

Table 7: Dam site S4

SITE DATA:	**Direct supply from dam:**		**Run-of-river supply:**	
Length of pipeline (km):	24.9		30.3	
Length of tunnel (km):	21.70		13.6	
Scenario:	**Low:**	**High**	**Low:**	**High:**
Capital cost (R millions):	R3 876	R4 239	R3 301	R3 743
NPV (R):	R3 713	R4 677	R3 332	R4 286
URV (R/m^3):	R5.42	R4.04	R4.86	R3.70

Figure 20: Profile - Direct Supply_S4

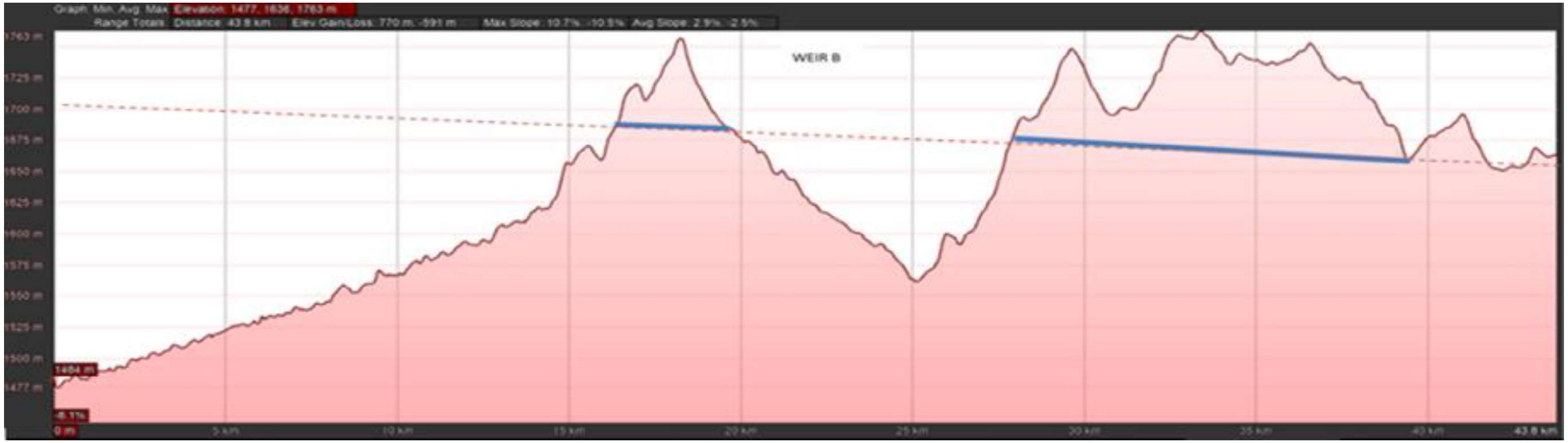


Figure 21: Profile - Run-of-river Supply_S4

S3

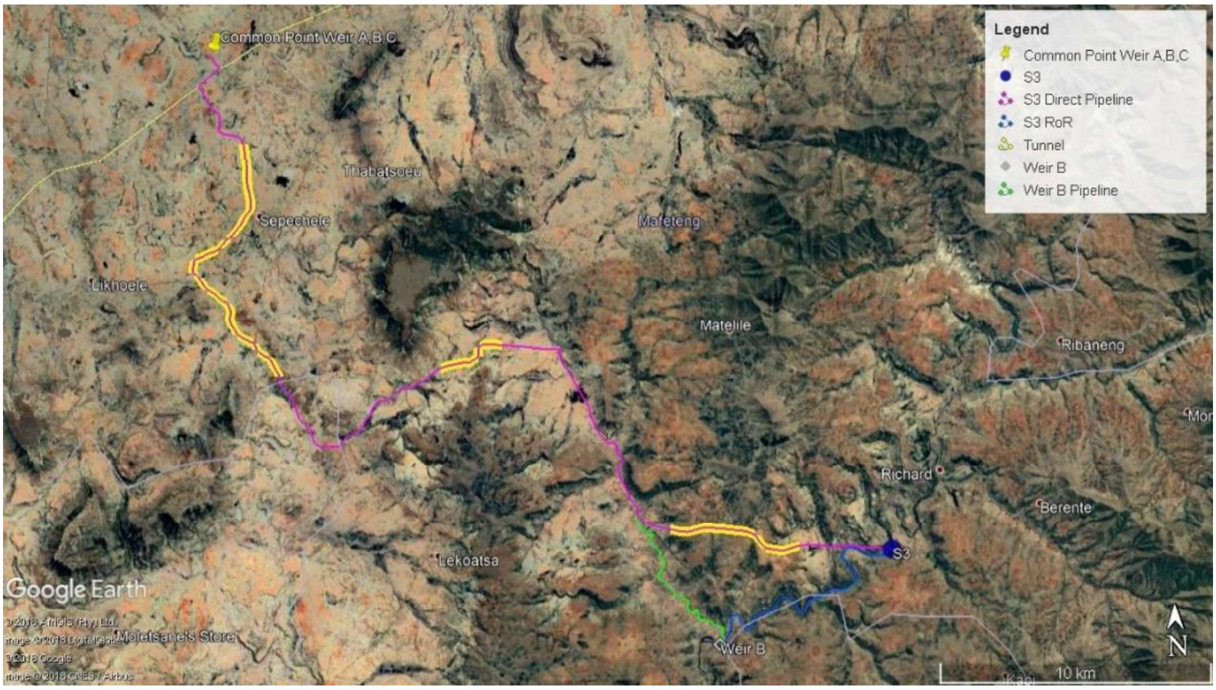


Figure 22: Plan - Conveyance_S3

Table 8: Dam site S3

SITE DATA:	**Direct supply from dam:**		**Run-of-river supply:**	
Length of pipeline (km):	27.9		30.3	
Length of tunnel (km):	18.60		13.6	
Scenario:	**Low:**	**High**	**Low:**	**High:**
Capital cost (R millions):	R3 562	R3 969	R3 301	R3 743
NPV (R):	R3 016	R3 678	R3 332	R4 286
URV (R/m^3):	R4.40	R3.17	R4.86	R3.70

Figure 23: Profile - Direct Supply_S3

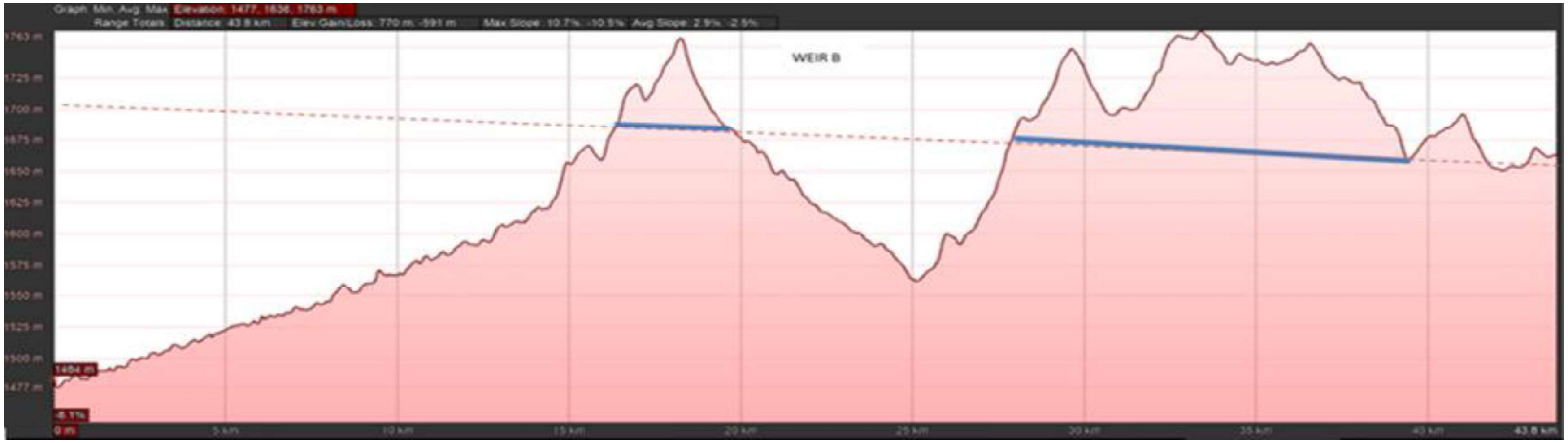


Figure 24: Profile - Run-of-river Supply_S3

S2

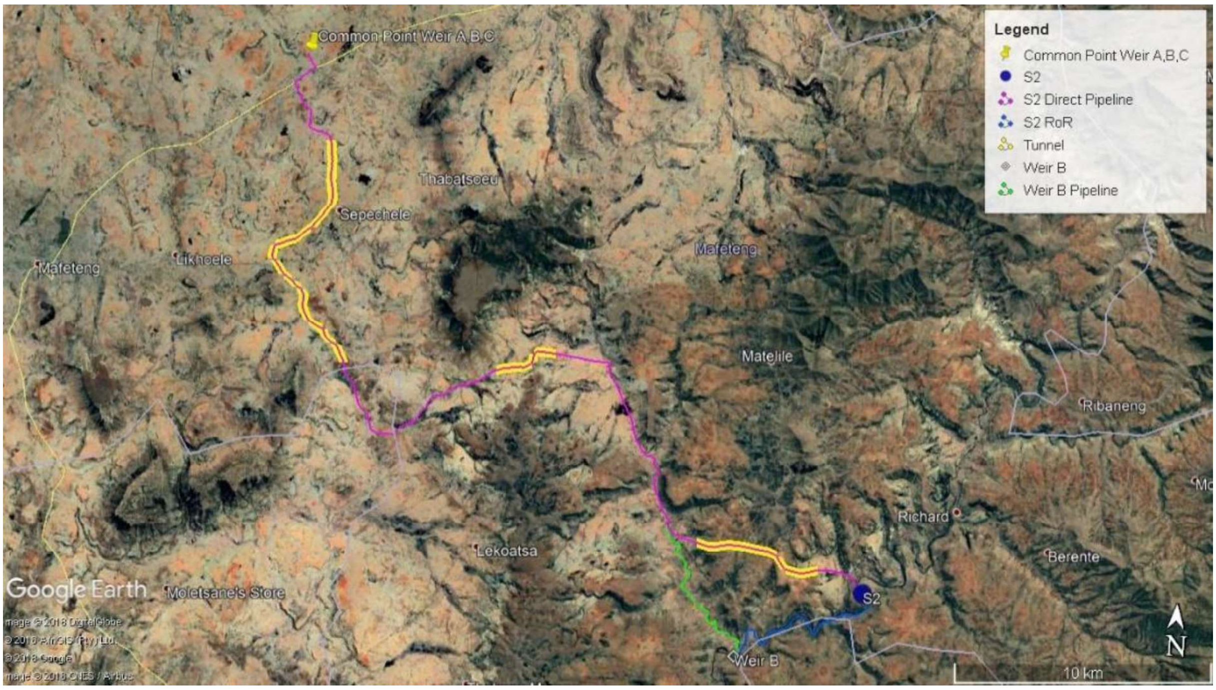


Figure 25: Plan – Conveyance_S2

Table 9: Dam site S2

SITE DATA:	**Direct supply from dam:**		**Run-of-river supply:**	
Length of pipeline (km):	26.6		30.3	
Length of tunnel (km):	18.60		13.6	
Scenario:	**Low:**	**High**	**Low:**	**High:**
Capital cost (R millions):	R3 500	R3 888	R3 301	R3 743
NPV (R):	R2 944	R3 580	R3 332	R4 286
URV (R/m³):	R4.30	R3.09	R4.86	R3.70

Figure 26: Profile - Direct Supply_S2

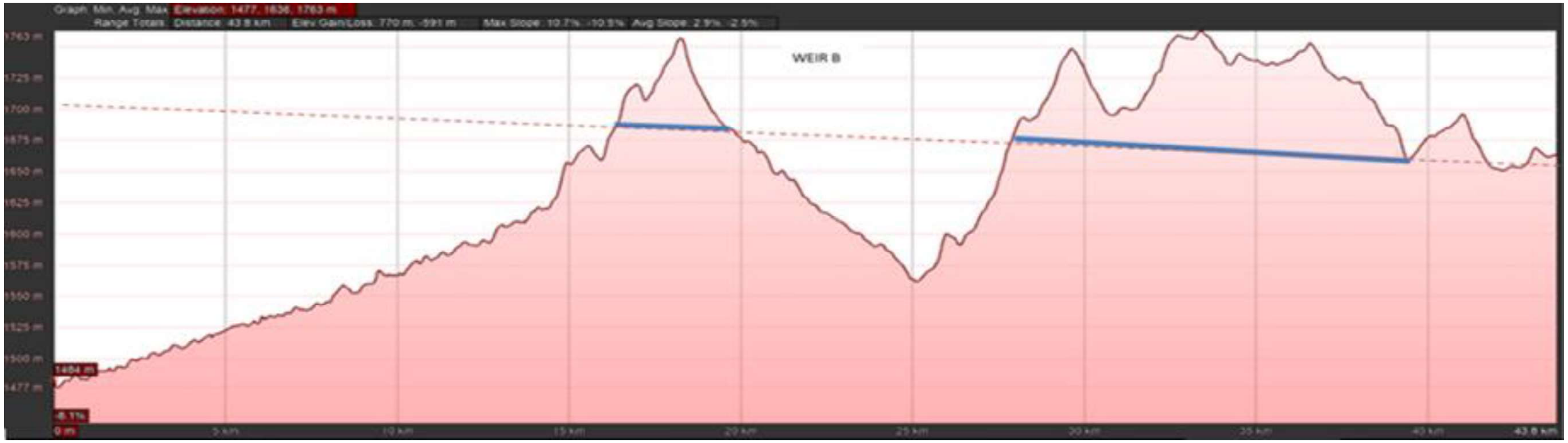


Figure 27: Profile - Run-of-river Supply_S2

S1

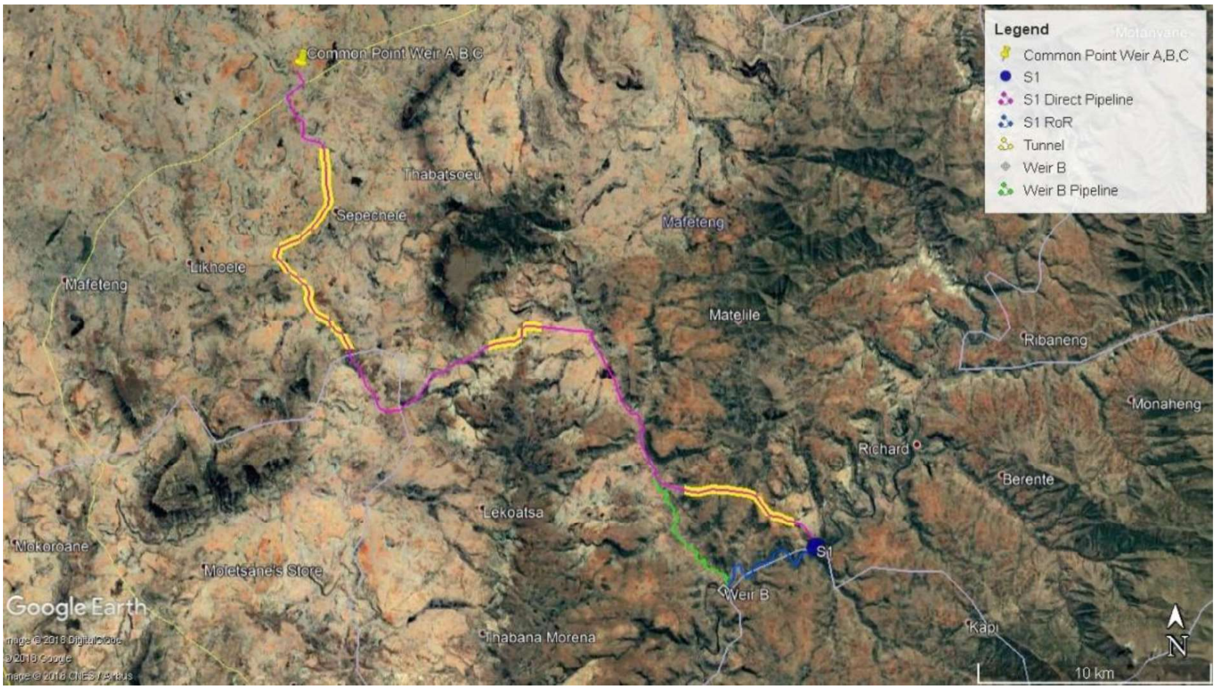


Figure 28: Plan – Conveyance_S1

Table 10: Dam site S1

SITE DATA:	**Direct supply from dam:**		**Run-of-river supply:**	
Length of pipeline (km):	26.2		30.3	
Length of tunnel (km):	18.60		13.6	
Scenario:	**Low:**	**High**	**Low:**	**High:**
Capital cost (R millions):	R3 481	R3 863	R3 301	R3 743
NPV (R):	R2 887	R3 489	R3 332	R4 286
URV (R/m^3):	R4.21	R3.01	R4.86	R3.70

Figure 29: Profile - Direct Supply_S1

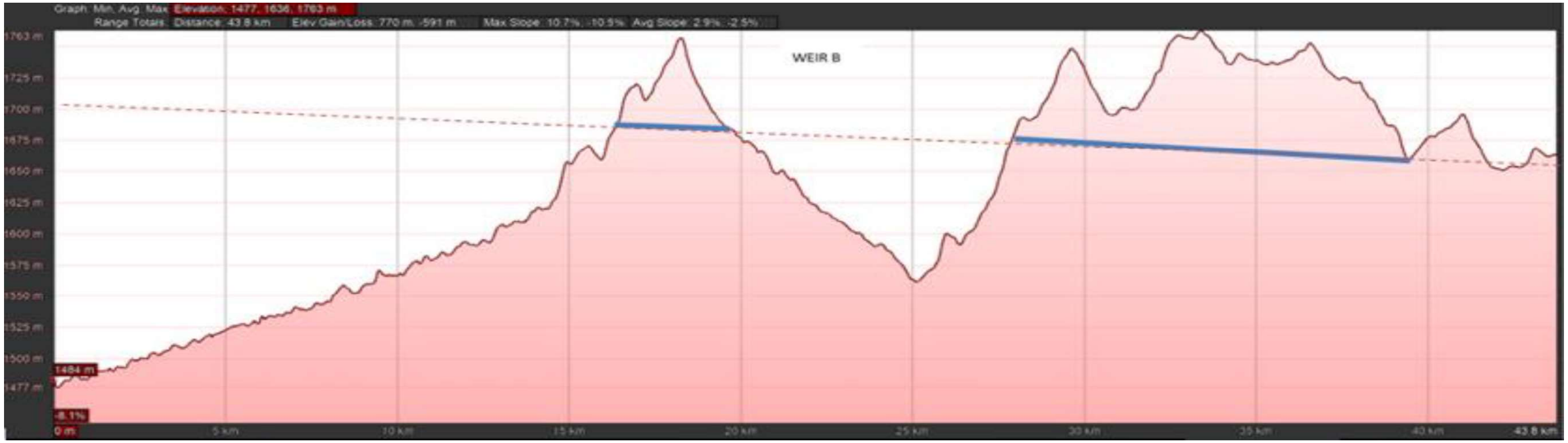


Figure 30: Profile - Run-of-river Supply_S1

S1A

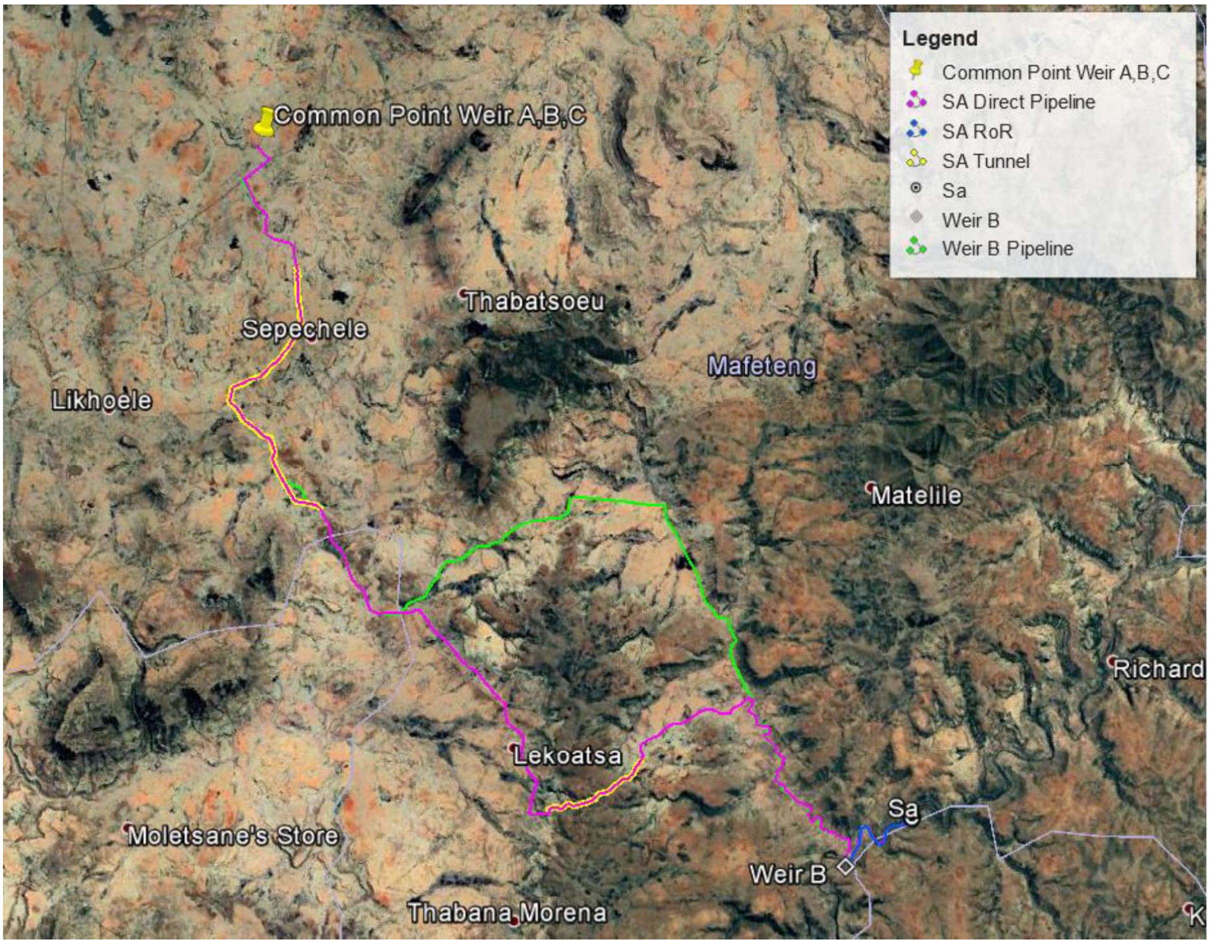


Figure 31: Plan – Conveyance_S1A

Table 11: Dam site Sa

SITE DATA:	**Direct supply from dam:**		**Run-of-river supply:**	
Length of pipeline (km):	34.93		30.3	
Length of tunnel (km):	13.47		13.6	
Scenario:	**Low:**	**High**	**Low:**	**High:**
Capital cost (R millions):	R3 405	R3 915	R3 301	R3 743
NPV (R):	R3 418	R4 418	R3 332	R4 286
URV (R/m^3):	R4.99	R3.81	R4.86	R3.70

Figure 32: Profile – Direct Supply_SA

Figure 33: Profile - Run-of-river Supply_SA (Weir B)

D4

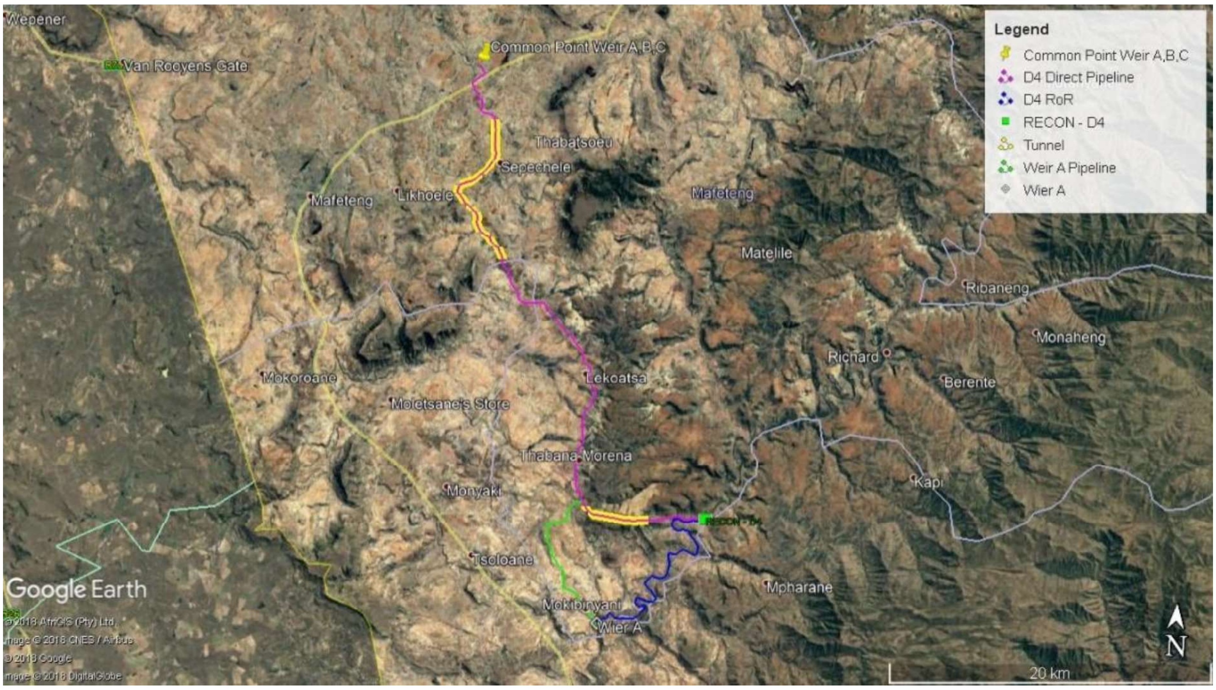


Figure 34: Plan – Conveyance_D4

Table 12: Dam site D4

SITE DATA:	**Direct supply from dam:**		**Run-of-river supply:**	
Length of pipeline (km):	27.7		34.1	
Length of tunnel (km):	14.80		10.6	
Scenario:	**Low:**	**High**	**Low:**	**High:**
Capital cost (R millions):	R3 215	R3 619	R3 236	R3 733
NPV (R):	R2 963	R3 747	R3 530	R4 690
URV (R/m^3):	R4.32	R3.23	R5.15	R4.05

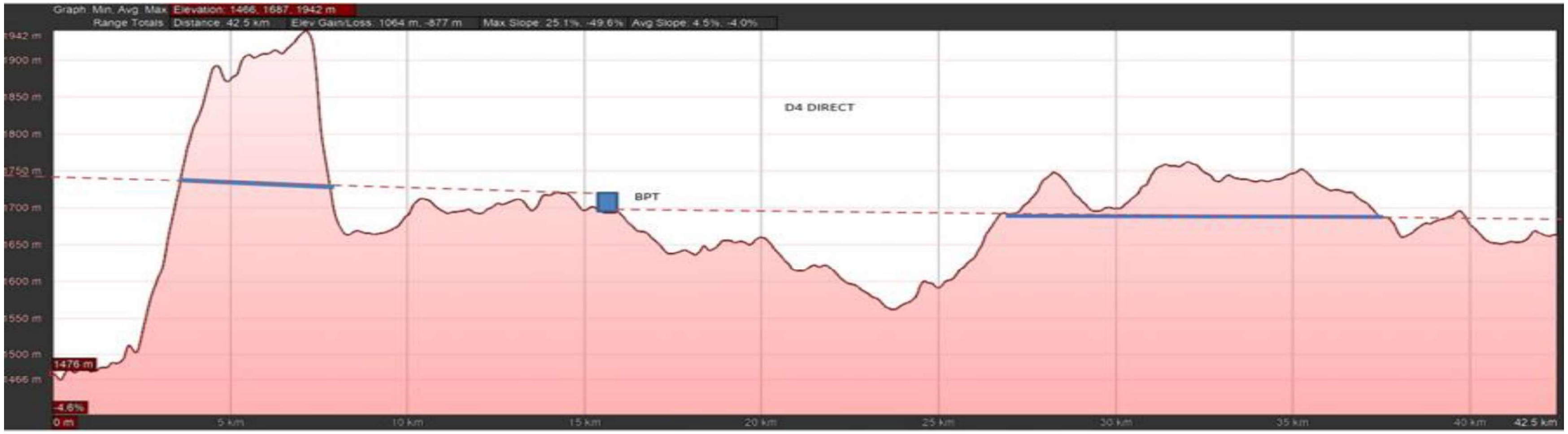


Figure 35: Profile - Direct Supply_D4

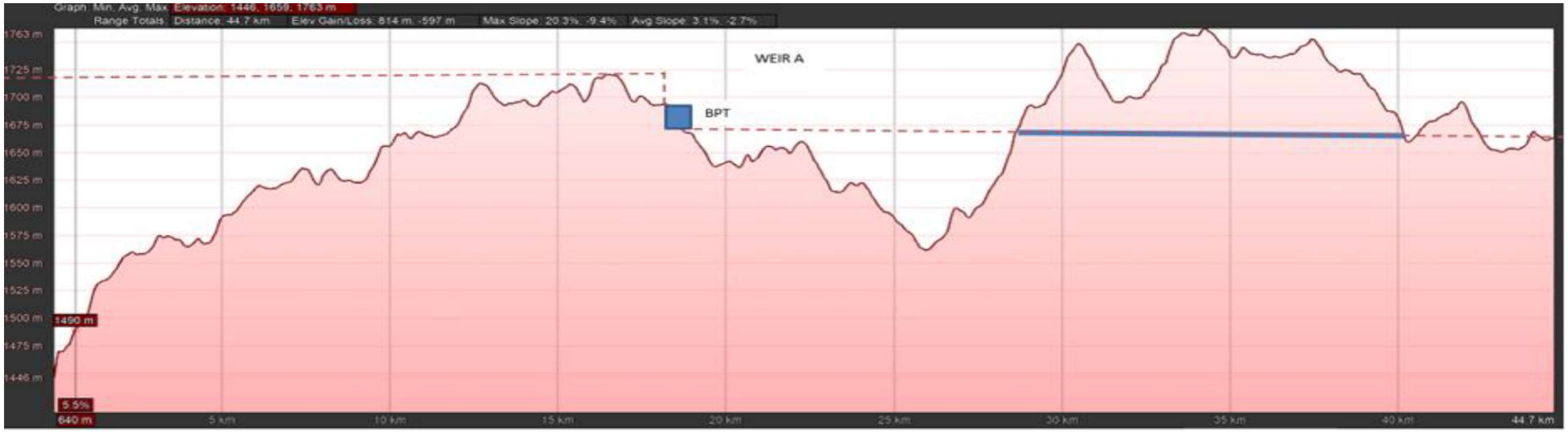


Figure 36: Profile - Run-of-river Supply_D4

D3

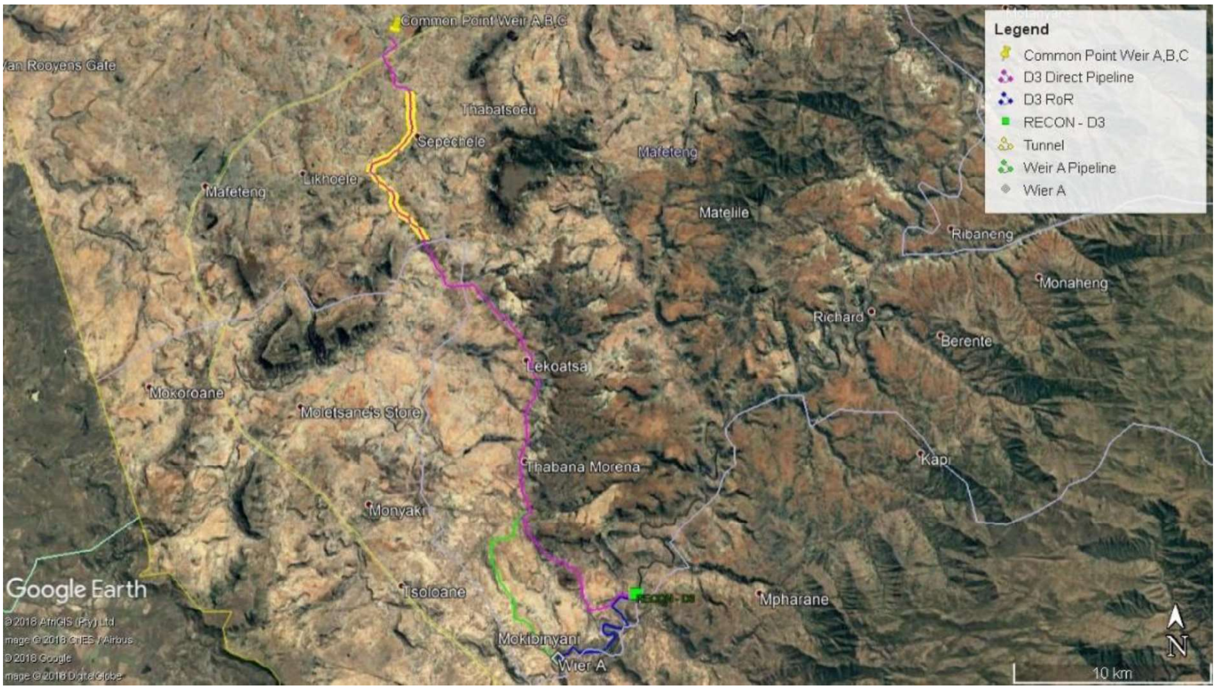


Figure 37: Plan – Conveyance_D3

Table 13: Dam site D3

SITE DATA:	Direct supply from dam:		Run-of-river supply:	
Length of pipeline (km):	33.4		44.7	
Length of tunnel (km):	10.60		10.6	
Scenario:	**Low:**	**High**	**Low:**	**High:**
Capital cost (R millions):	R3 003	R3 490	R3 236	R3 733
NPV (R):	R2 985	R3 885	R3 530	R4 690
URV (R/m³):	R4.36	R3.35	R5.15	R4.05

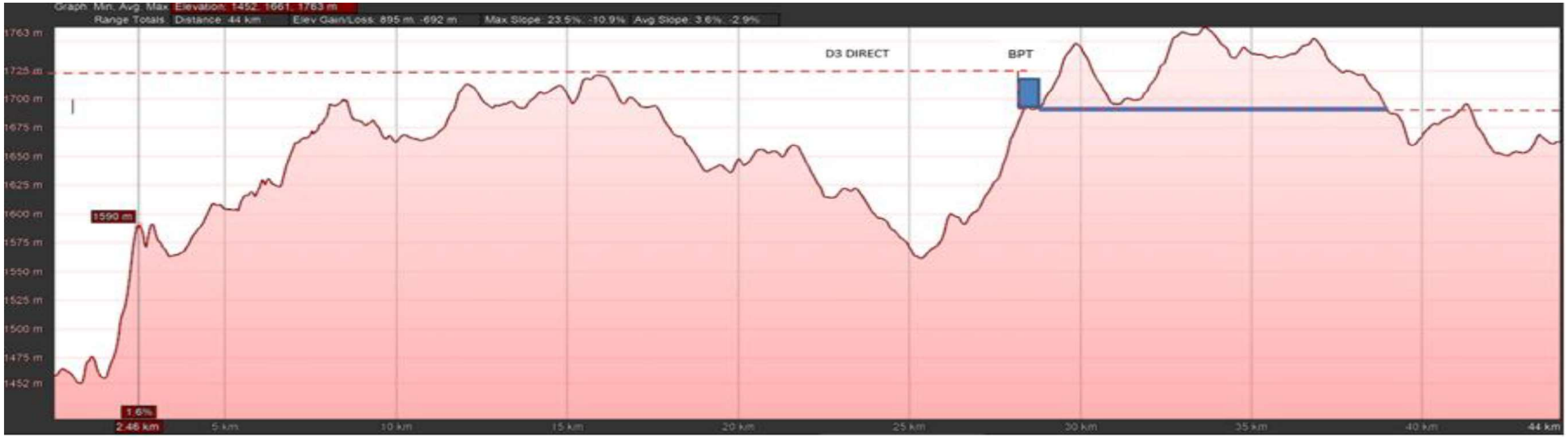


Figure 38: Profile - Direct Supply_D3

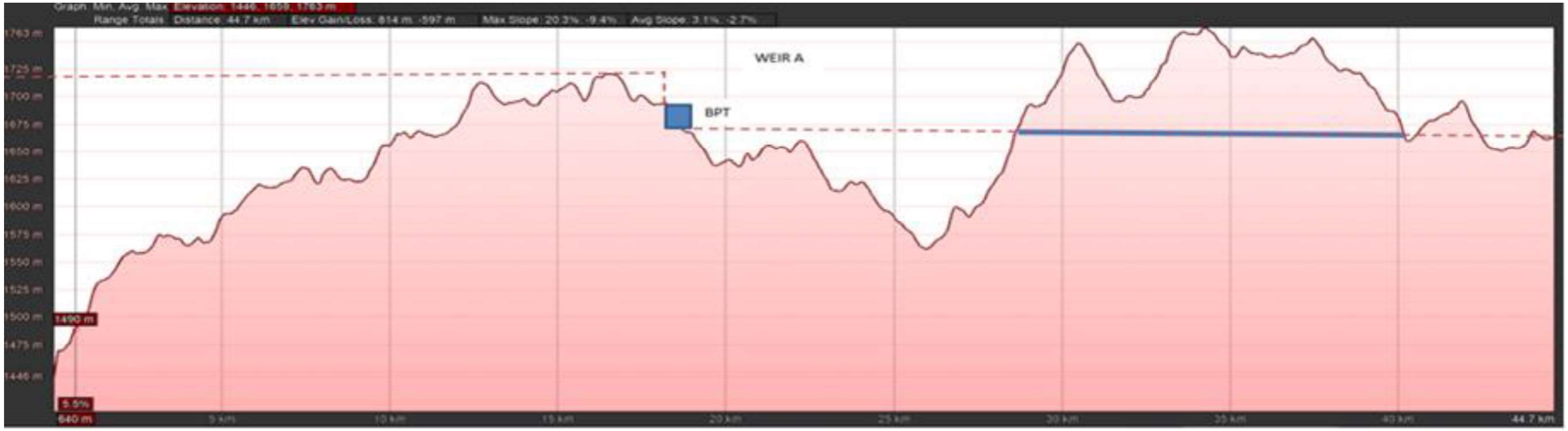


Figure 39: Profile - Run-of-river Supply_D3

D2

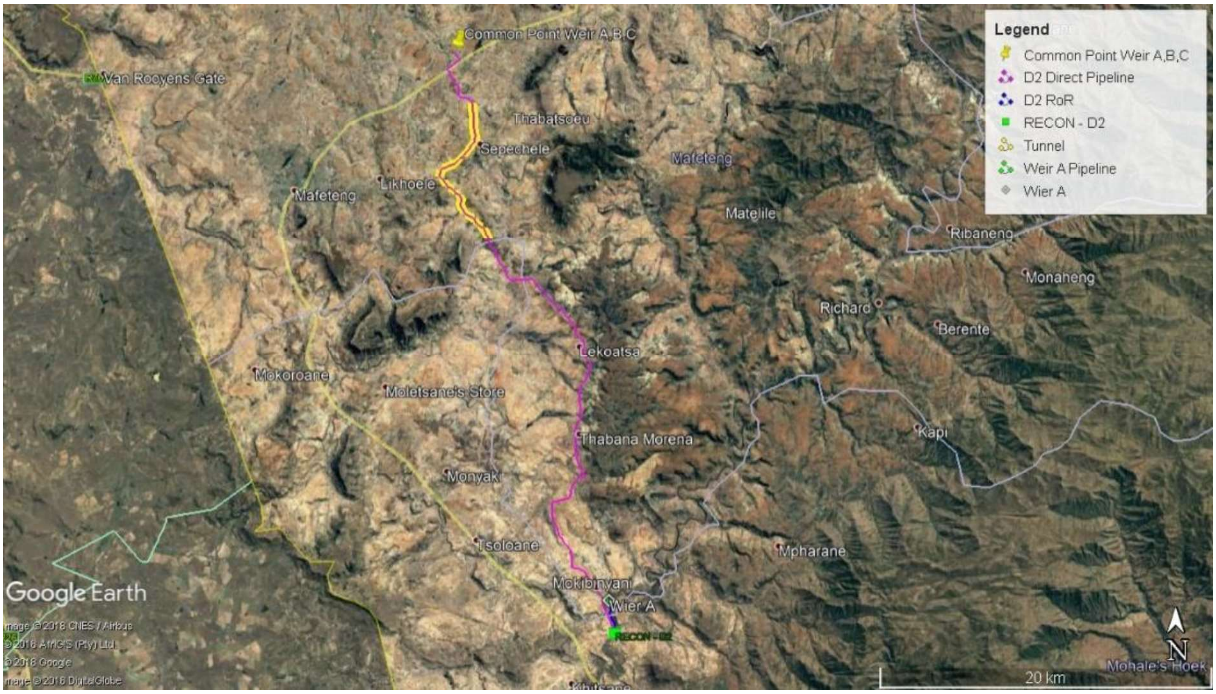


Figure 40: Plan - Conveyance_D2

Table 14: Dam site D2

SITE DATA:	**Direct supply from dam:**		**Run-of-river supply:**	
Length of pipeline (km):	35.8		44.7	
Length of tunnel (km):	10.60		10.6	
Scenario:	**Low:**	**High**	**Low:**	**High:**
Capital cost (R millions):	R3 117	R3 638	R3 236	R3 733
NPV (R):	R3 222	R4 233	R3 530	R4 690
URV (R/m^3):	R4.70	R3.65	R5.15	R4.05

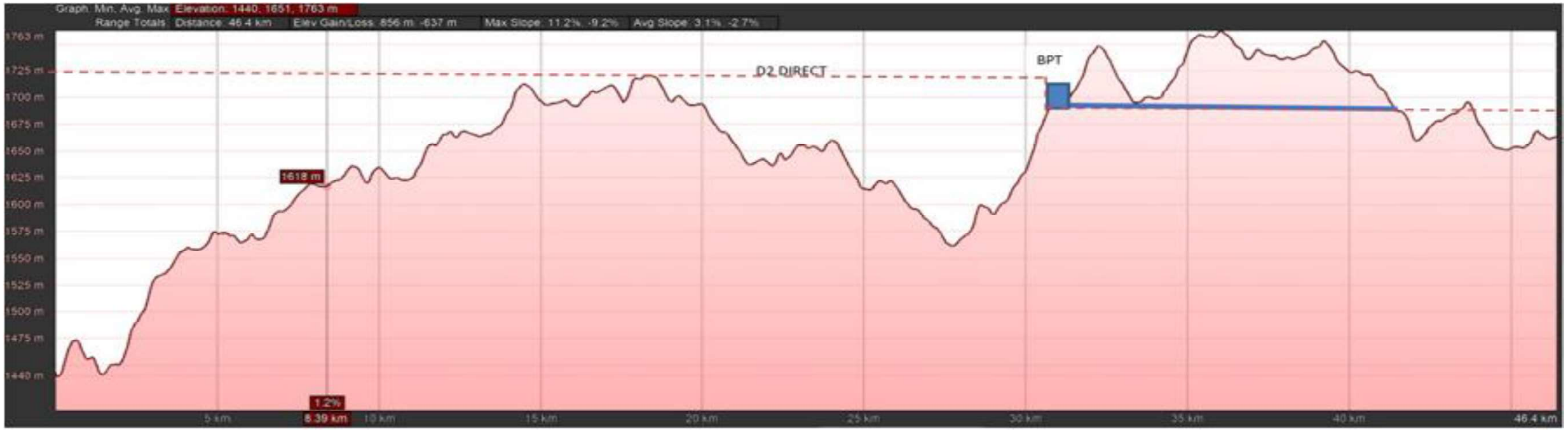


Figure 41: Profile - Direct Supply_D2

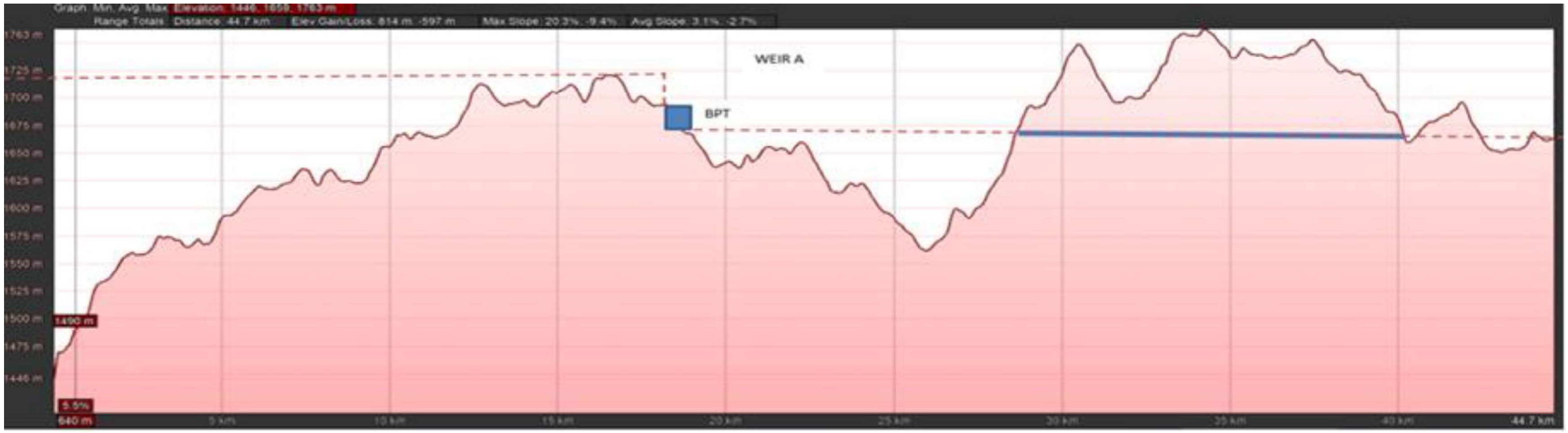
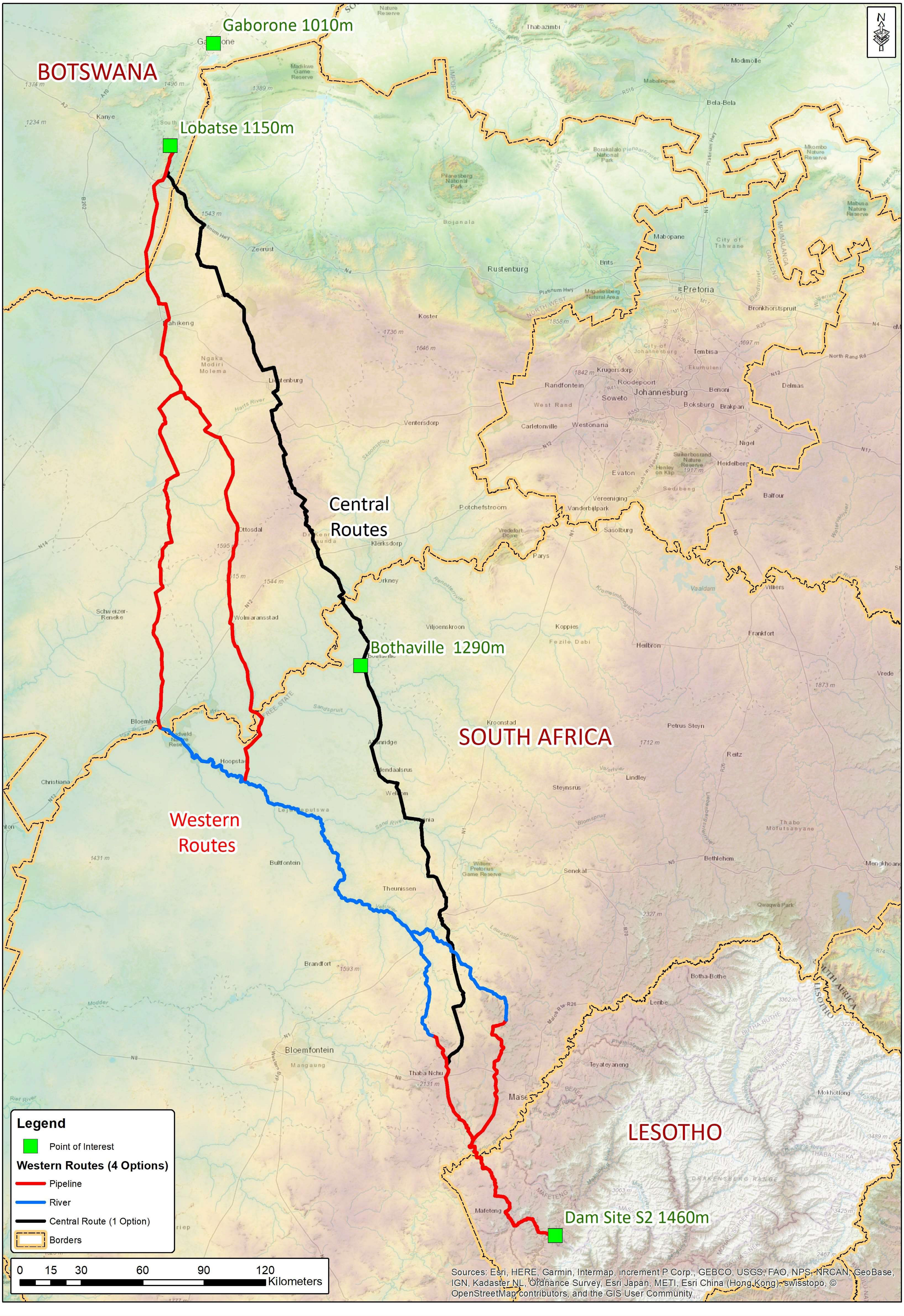
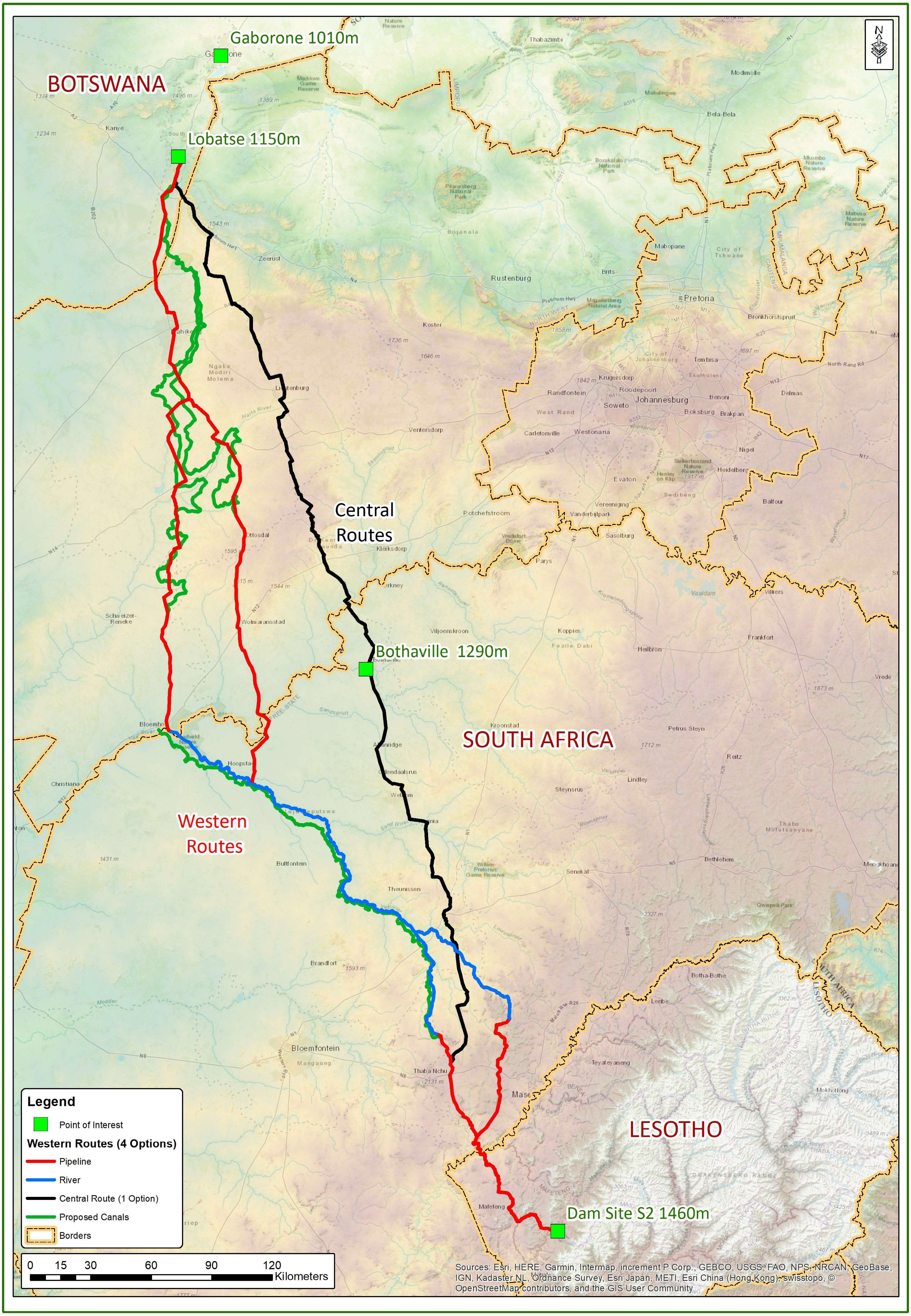


Figure 42: Profile - Run-of-river Supply_D2

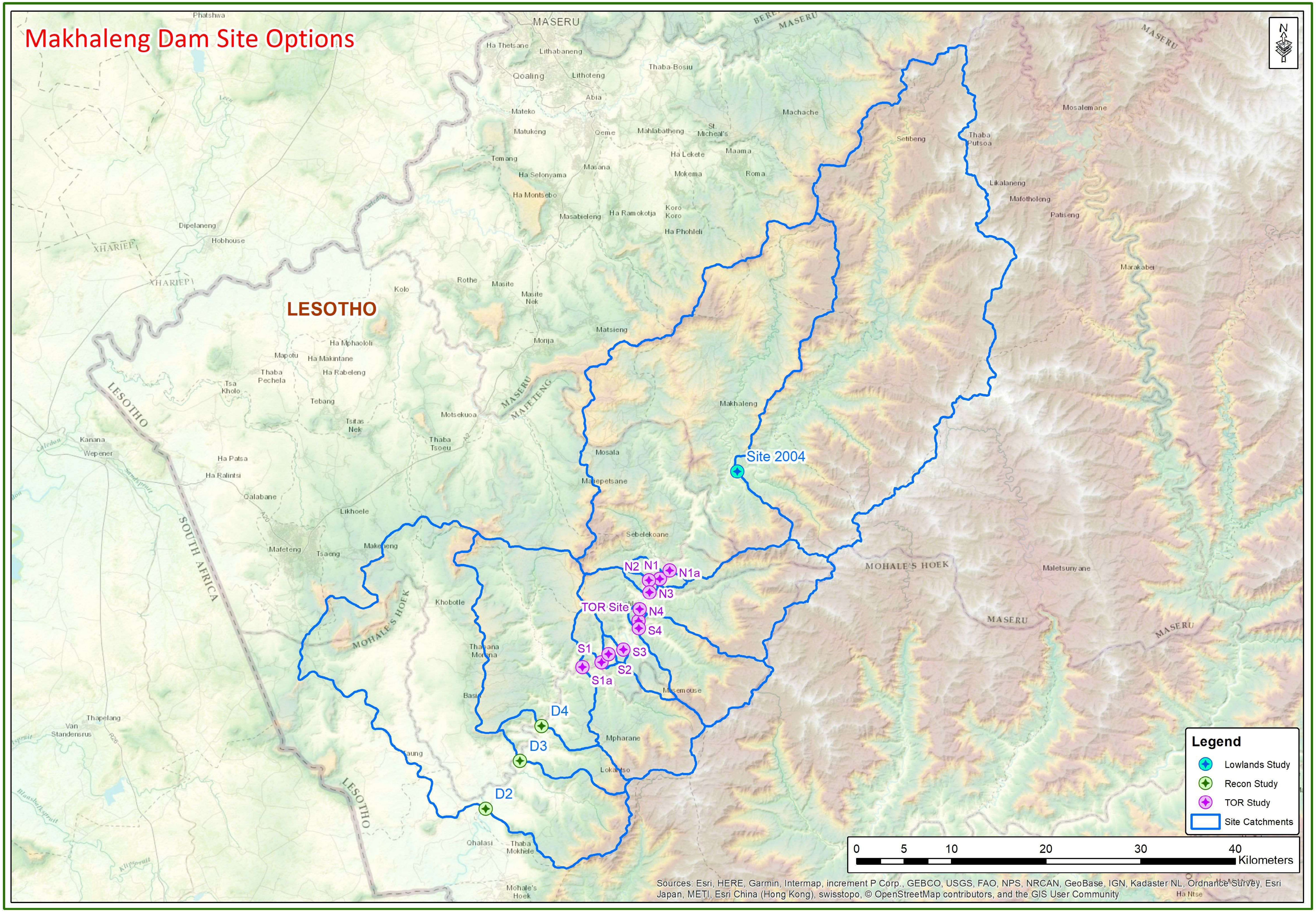
APPENDIX H: Figures

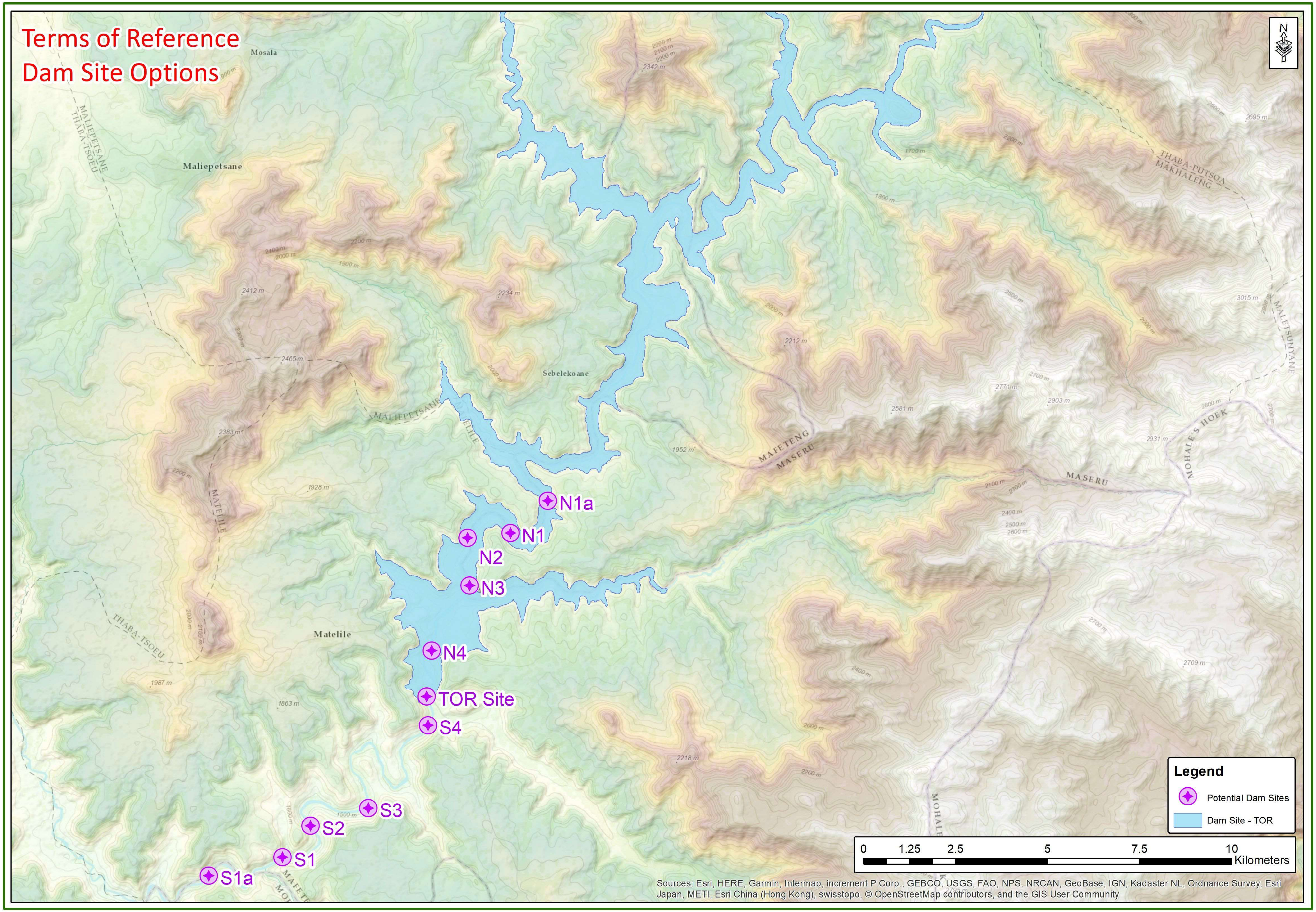


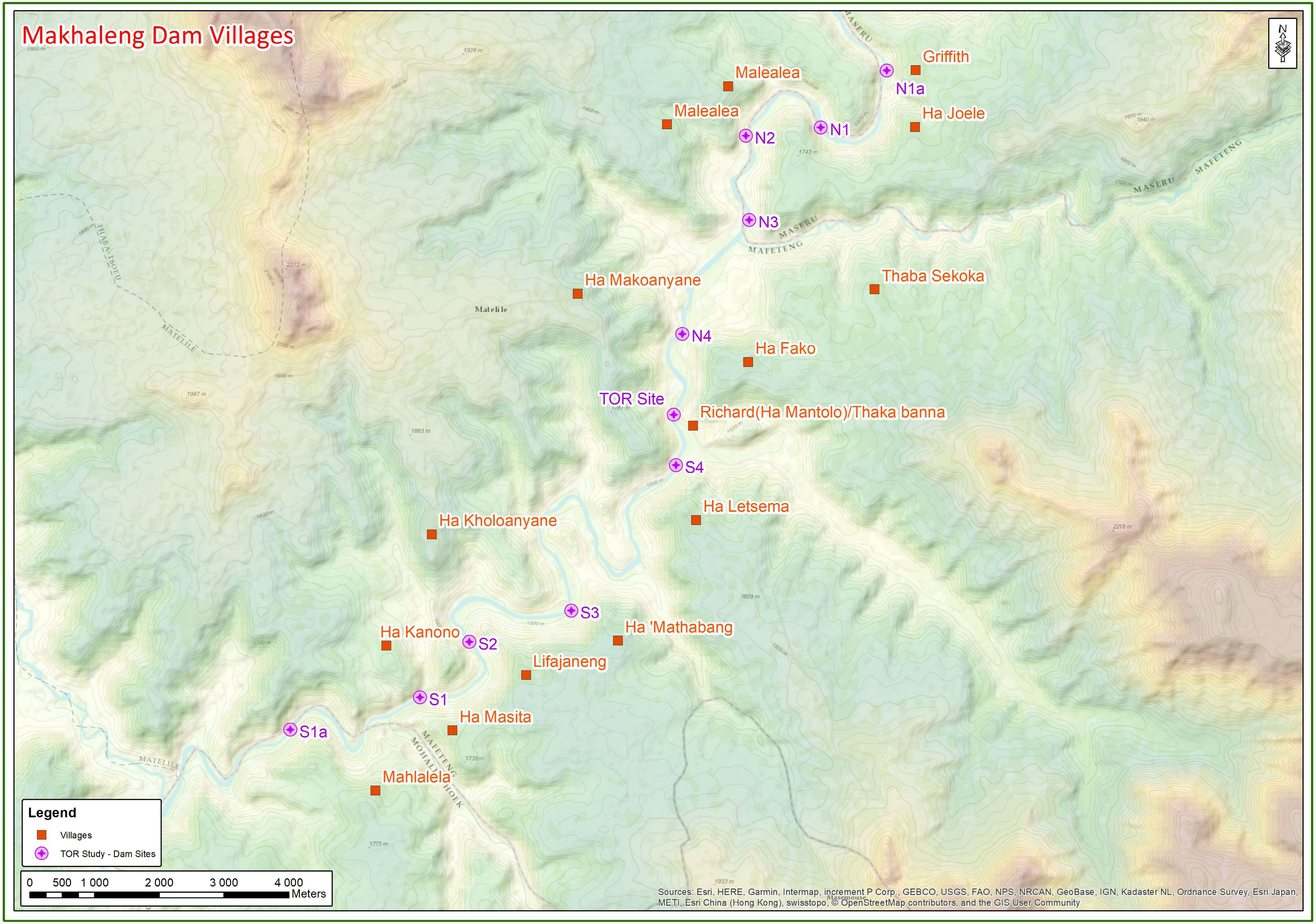
Gaborone 1010m
BOTSWANA
Lobatse 1150m
Central Routes
Bothaville 1290m
SOUTH AFRICA
Western Routes
LESOTHO
Dam Site S2 1460m
Legend
Point of Interest
Western Routes (4 Options)
Pipeline
River
Central Route (1 Option)
Borders
0 15 30 60 90 120
Kilometers
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community



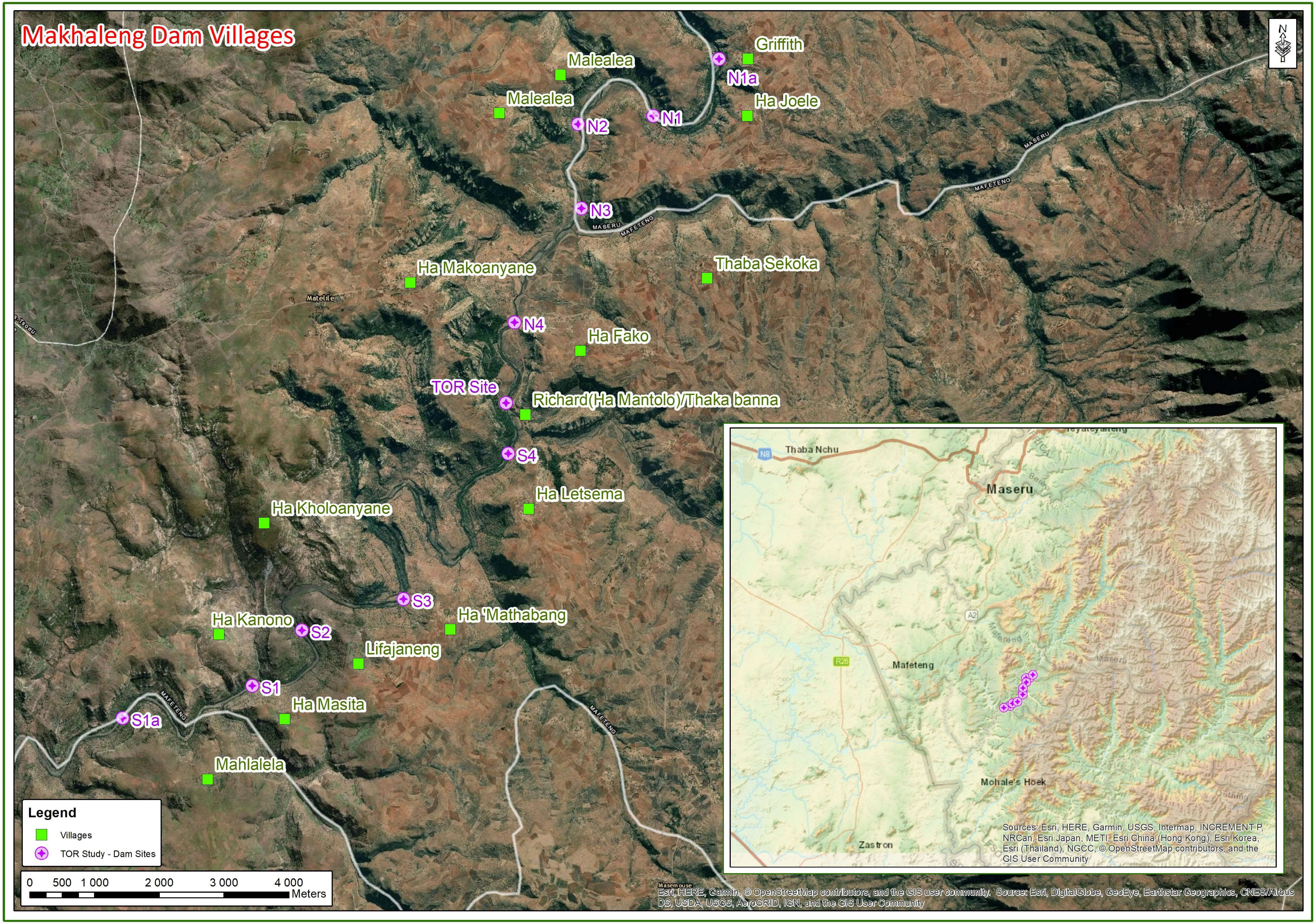
Gaborone 1010m
BOTSWANA
Lobatse 1150m
Central Routes
Bothaville 1290m
SOUTH AFRICA
Western Routes
LESOTHO
Dam Site S2 1460m
Legend
Point of Interest
Western Routes (4 Options)
Pipeline
River
Central Route (1 Option)
Proposed Canals
Borders
0 15 30 60 90 120
Kilometers
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

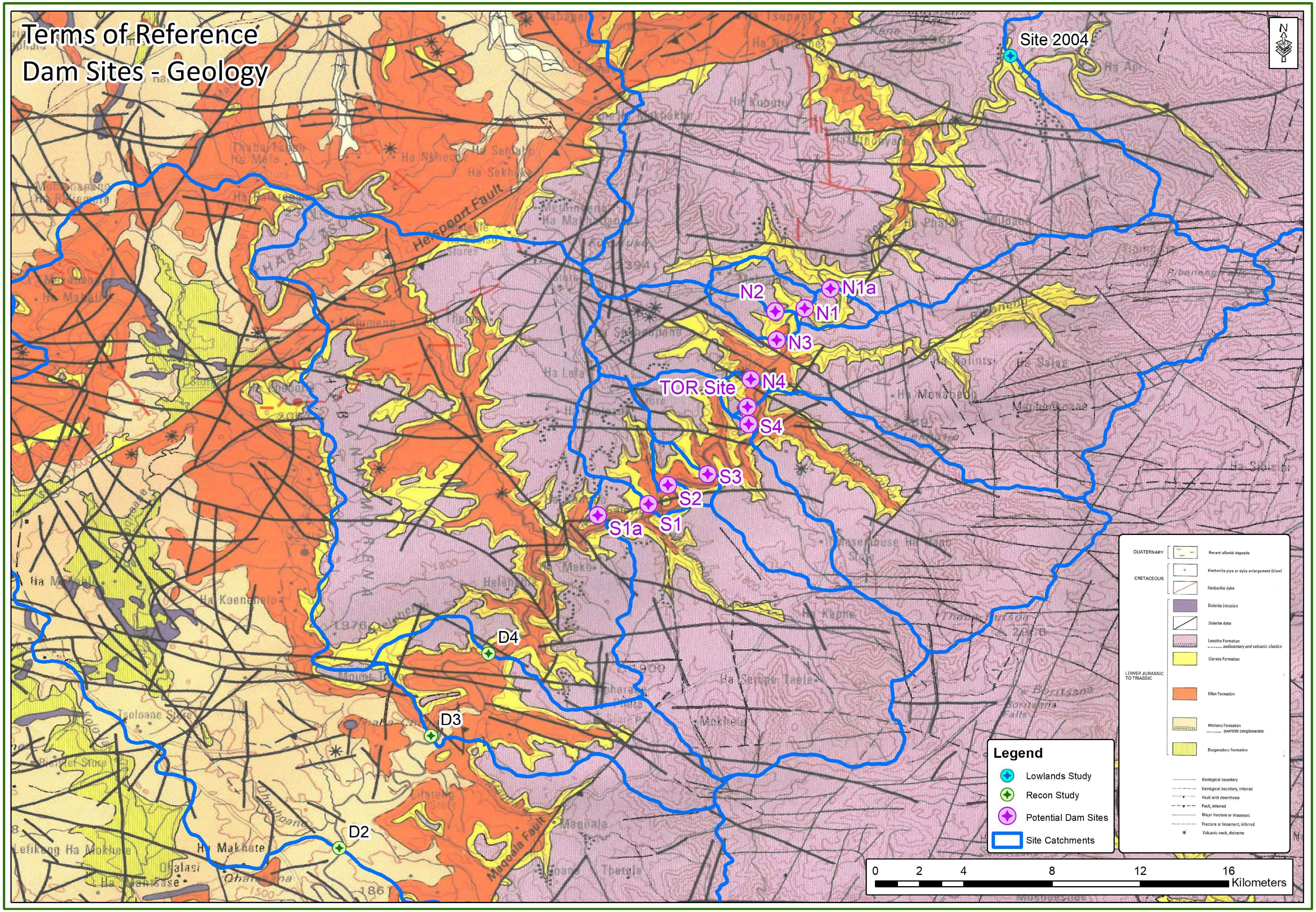

Makhaleng Dam Site Options
LESOTHO
SOUTH AFRICA
MASERU
MAFETENG
MOHALE'S HOEK
XHARIEP
Site 2004
N1
N1a
N2
N3
N4
TOR Site
S1
S1a
S2
S3
S4
D2
D3
D4
Makhaleng
Mosala
Matsieng
Morija
Roma
Maseru
Mafeteng
Legend
Lowlands Study
Recon Study
TOR Study
Site Catchments
0 5 10 20 30 40
Kilometers
N
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community


Terms of Reference
Dam Site Options
Mosala
Maliepetsane
Sebelekoane
Matelile
N1a
N1
N2
N3
N4
TOR Site
S4
S3
S2
S1
S1a
MALIEPETSANE
THABA-TSOEU
MATELILE
MAFETENG
MASERU
MOHALE'S HOEK
MALETSUNYANE
THABA-PUTSOA
MAKHALENG
2342 m
2412 m
2234 m
2465 m
2383 m
1928 m
1987 m
1863 m
1952 m
2212 m
2581 m
2903 m
2931 m
3015 m
2695 m
2709 m
2218 m
Legend
Potential Dam Sites
Dam Site - TOR
0
1.25
2.5
5
7.5
10
Kilometers
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community



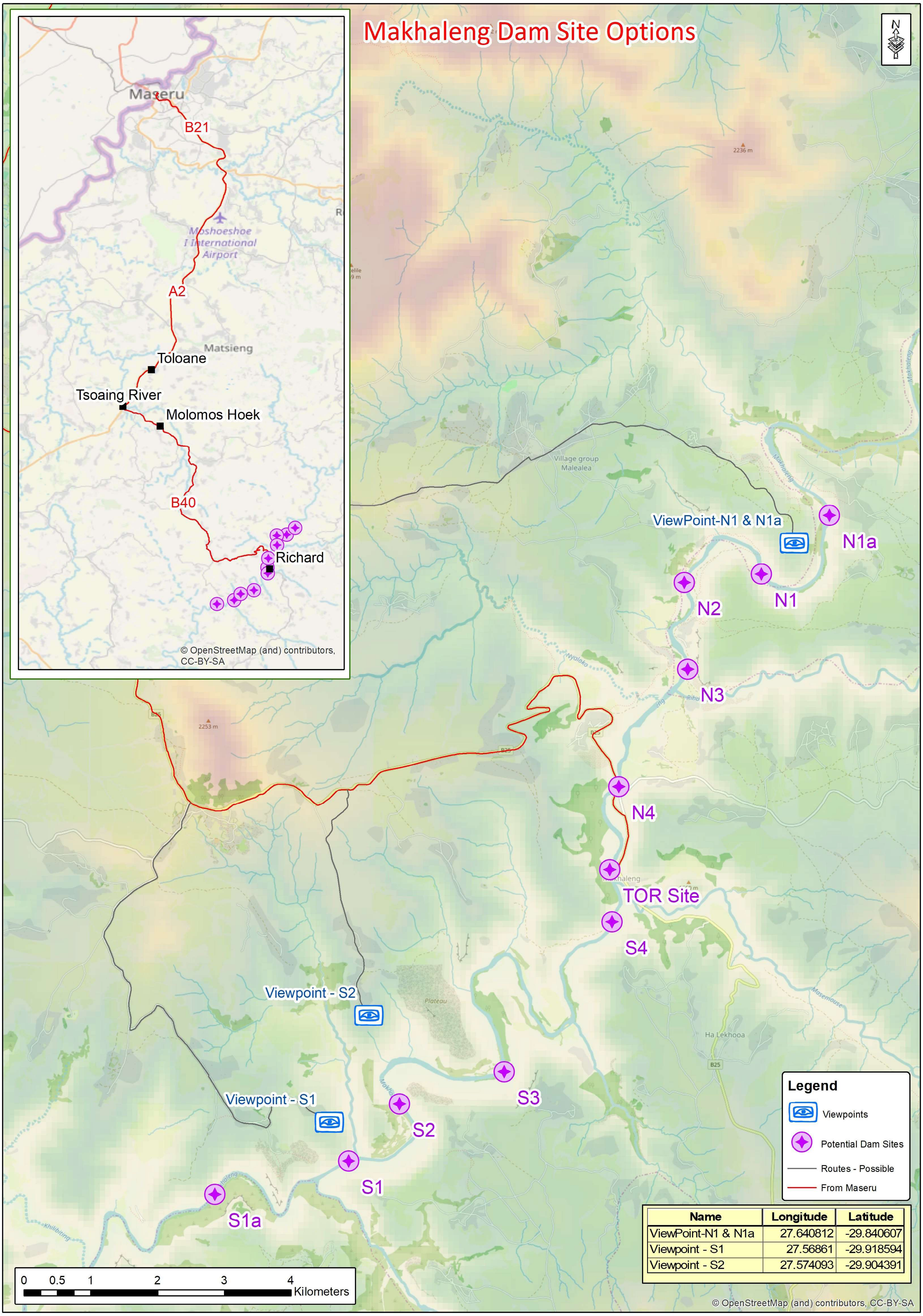
Makhaleng Dam Villages
N
Griffith
Malealea
N1a
Malealea
Ha Joele
N1
N2
N3
MASERU
MAFETENG
Thaba Sekoka
Ha Makoanyane
Matelile
N4
Ha Fako
TOR Site
Richard(Ha Mantolo)/Thaka banna
S4
Ha Letsema
Ha Kholoanyane
S3
Ha 'Mathabang
Ha Kanono
S2
Lifajaneng
S1
Ha Masita
S1a
MATELILE
MAFETENG
MOHALE'S HOEK
Mahlalela
Legend
Villages
TOR Study - Dam Sites
0 500 1 000 2 000 3 000 4 000
Meters
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community


Makhaleng Dam Villages
Griffith
Malealea
N1a
Malealea
Ha Joele
N2
N1
N3
MASERU
MAFETENG
Ha Makoanyane
Thaba Sekoka
Matelile
N4
Ha Fako
TOR Site
Richard(Ha Mantolo)/Thaka banna
S4
Ha Letsema
Ha Kholoanyane
S3
Ha Kanono
S2
Ha 'Mathabang
Lifajaneng
S1
Ha Masita
S1a
Mahlalela
MAFETENG
Legend
Villages
TOR Study - Dam Sites
0 500 1 000 2 000 3 000 4 000
Meters
Thaba Nchu
N8
Maseru
A2
Mafeteng
R26
Mohale's Hoek
Zastron
Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, © OpenStreetMap contributors, and the GIS User Community
Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community. Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

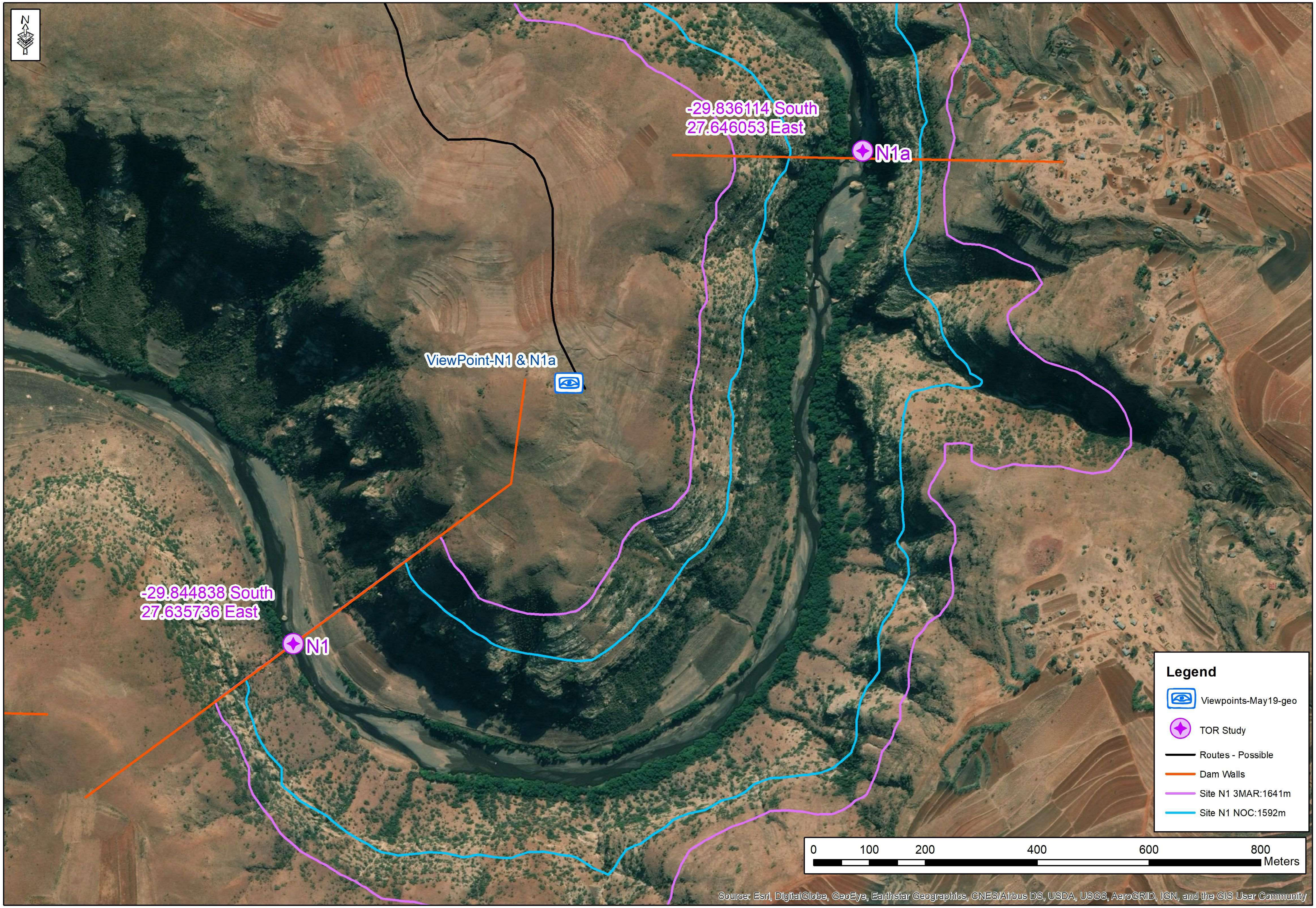


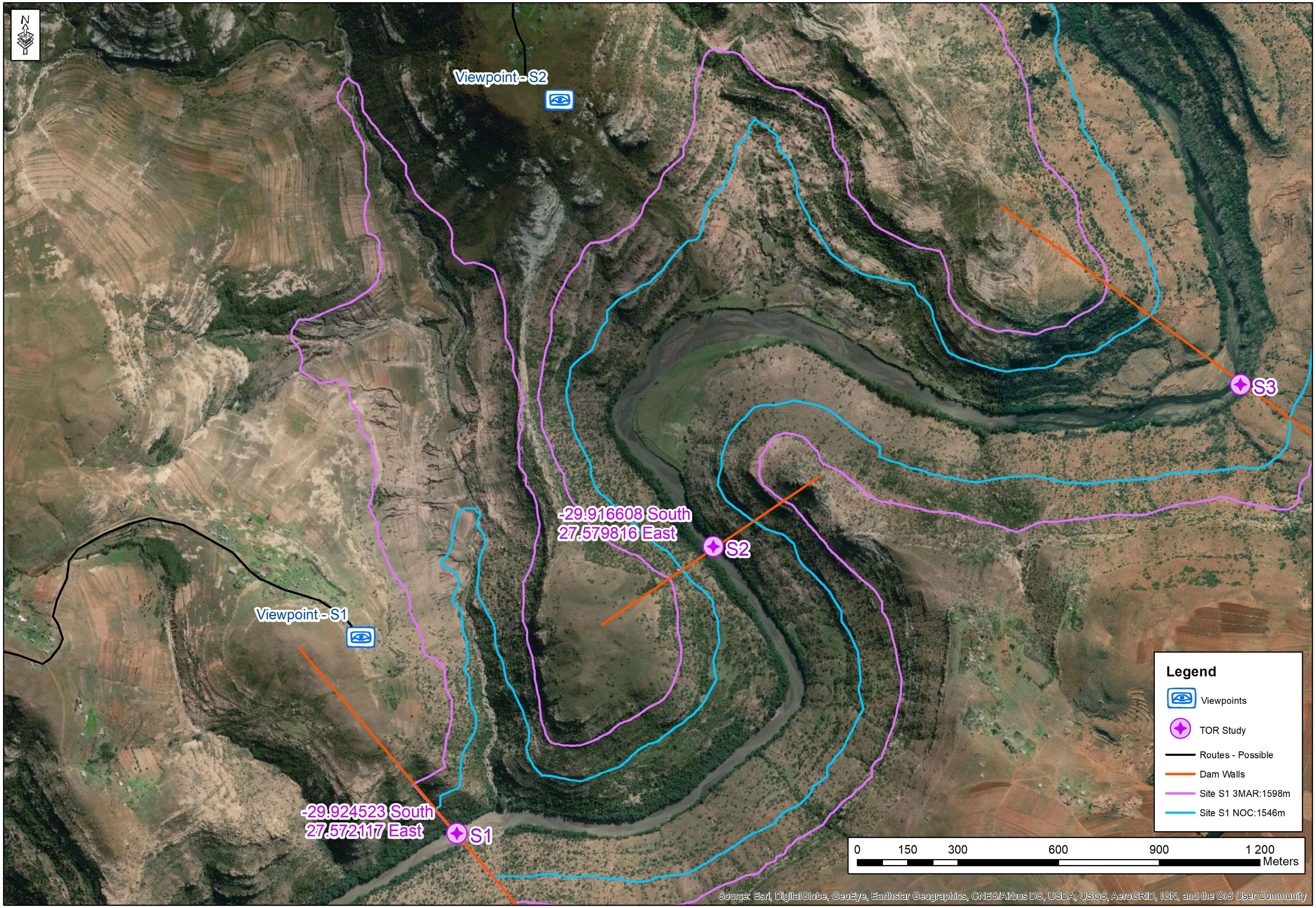
Terms of Reference
Dam Sites - Geology
N
Site 2004
Hellspoort Fault
Maqoala Fault
N1a
N1
N2
N3
N4
TOR Site
S4
S3
S2
S1
S1a
D4
D3
D2
QUATERNARY
Recent alluvial deposits
CRETACEOUS
Kimberlite pipe or dyke enlargement (blow)
Kimberlite dyke
Dolerite intrusion
Dolerite dyke
Lesotho Formation
sedimentary and volcanic clastics
Clarens Formation
LOWER JURASSIC TO TRIASSIC
Elliot Formation
Molteno Formation
quartzite conglomerate
Burgersdorp Formation
Geological boundary
Geological boundary, inferred
Fault with downthrow
Fault, inferred
Major fracture or lineament
Fracture or lineament, inferred
Volcanic neck, diatreme
Legend
Lowlands Study
Recon Study
Potential Dam Sites
Site Catchments
0 2 4 8 12 16
Kilometers

Makhaleng Dam Site Options



Name	Longitude	Latitude
ViewPoint-N1 & N1a	27.640812	-29.840607
Viewpoint - S1	27.56861	-29.918594
Viewpoint - S2	27.574093	-29.904391


N
-29.836114 South
27.646053 East
N1a
ViewPoint-N1 & N1a
-29.844838 South
27.635736 East
N1
Legend
Viewpoints-May19-geo
TOR Study
Routes - Possible
Dam Walls
Site N1 3MAR:1641m
Site N1 NOC:1592m
0
100
200
400
600
800
Meters
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community


N
Viewpoint - S2
Viewpoint - S1
-29.916608 South
27.579816 East
S2
S3
-29.924523 South
27.572117 East
S1
Legend
Viewpoints
TOR Study
Routes - Possible
Dam Walls
Site S1 3MAR:1598m
Site S1 NOC:1546m
0 150 300 600 900 1 200
Meters
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

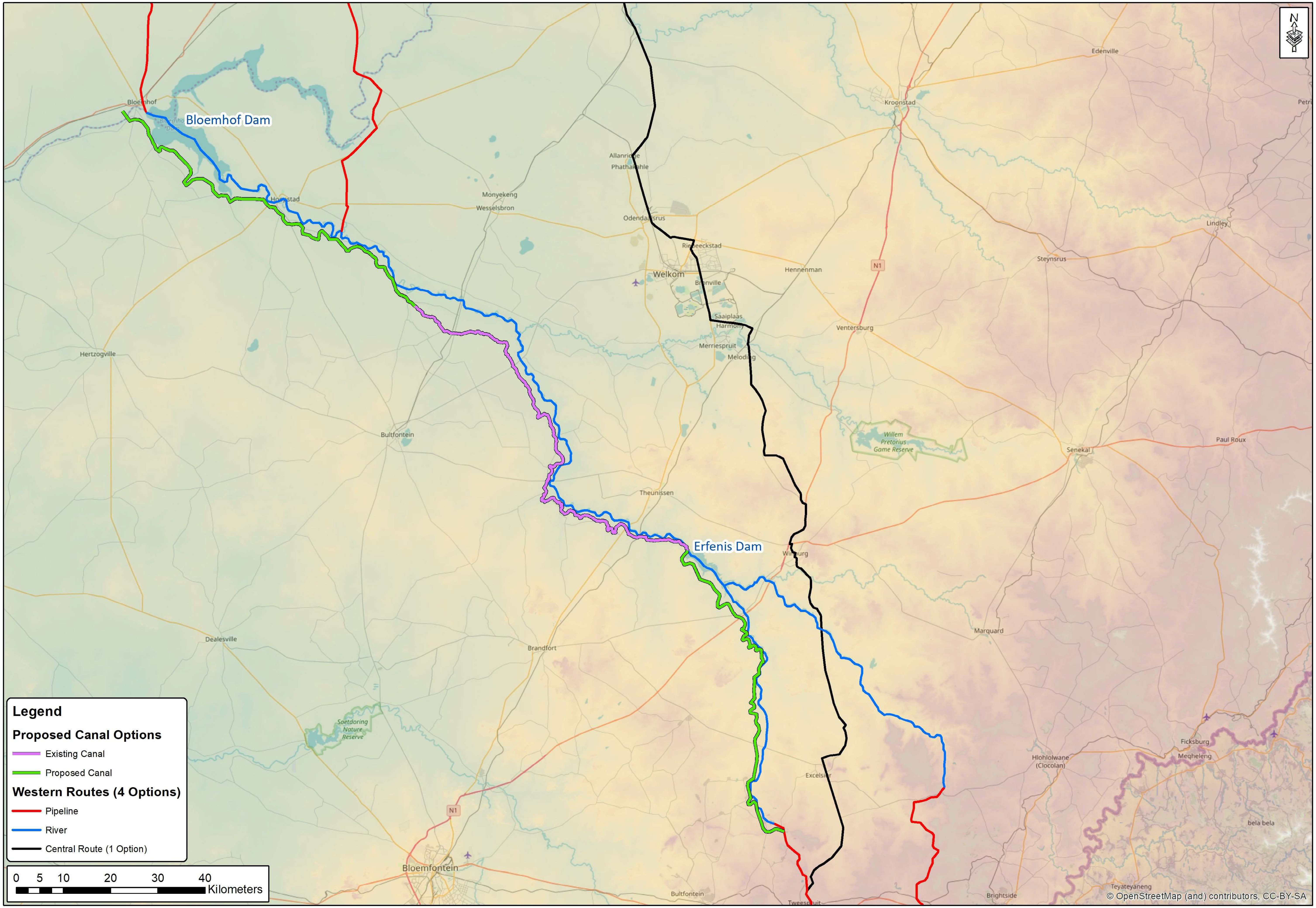

Gaborone 1010m
BOTSWANA
Lobatse 1150m
3EF Merge Point 1406m
Bothaville 1290m
Bloemhof Dam 1215m
3F Abstract Point 1246m
SOUTH AFRICA
River Confluence 1332m
3H
Central Split 1598m
Route Change Point 1555m
LESOTHO
Common Point 1730m
Dam Site S2 1490m
Legend
Point of Interest
Route 3H-4E
Pipeline
River
Borders
0 15 30 60 90 120
Kilometers
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community


Gaborone 1010m
BOTSWANA
Lobatse 1150m
3EF Merge Point 1406m
3F
Bothaville 1290m
Bloemhof Dam 1215m
SOUTH AFRICA
3F Abstract Point 1246m
3C
River Confluence 1332m
Central Split 1598m
3A
Route Change Point 1555m
LESOTHO
Common Point 1730m
Dam Site S2 1490m
Legend
Point of Interest
Route 3A-3C-3F
Pipeline
River
Borders
0 15 30 60 90 120
Kilometers
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Gaborone 1010m
BOTSWANA
Lobatse 1150m
3EF Merge Point 1406m
3E
Bothaville 1290m
Bloemhof Dam 1215m
SOUTH AFRICA
3F Abstract Point 1246m
3C
River Confluence 1332m
Central Split 1598m
3A
LESOTHO
Route Change Point 1555m
Common Point 1730m
Dam Site S2 1490m
Legend
Point of Interest
Route 3A-3C-3E
Pipeline
River
Borders
0 15 30 60 90 120
Kilometers
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Gaborone 1010m
BOTSWANA
Lobatse 1150m
3EF Merge Point 1406m
3E
Bothaville 1290m
Bloemhof Dam 1215m
SOUTH AFRICA
3F Abstract Point 1246m
3D
River Confluence 1332m
Central Split 1598m
3B
Route Change Point 1555m
LESOTHO
Common Point 1730m
Dam Site S2 1490m
Legend
Point of Interest
Route 3B-3D-3E
Pipeline
River
Borders
0 15 30 60 90 120
Kilometers
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Gaborone 1010m
BOTSWANA
Lobatse 1150m
3EF Merge Point 1406m
3F
Bothaville 1290m
Bloemhof Dam 1215m
SOUTH AFRICA
3F Abstract Point 1246m
3D
River Confluence 1332m
Central Split 1598m
3B
Route Change Point 1555m
LESOTHO
Common Point 1730m
Dam Site S2 1490m
Legend
Point of Interest
Route 3B-3D-3F
Pipeline
River
Borders
0 15 30 60 90 120
Kilometers
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community



Bloemhof Dam
Erfenis Dam
Bloemhof
Hoopstad
Monyekeng
Wesselsbron
Allanridge
Phathakahle
Odendaalsrus
Riebeeckstad
Welkom
Bronville
Saaiplaas
Harmony
Merriespruit
Meloding
Hennenman
Ventersburg
Kroonstad
Edenville
Steynsrus
Lindley
Senekal
Paul Roux
Willem Pretorius Game Reserve
Hertzogville
Bultfontein
Theunissen
Winburg
Marquard
Dealesville
Brandfort
Soetdoring Nature Reserve
Excelsior
Ficksburg
Meqheleng
Hlohlolwane (Clocolan)
Bloemfontein
Tweespruit
Teyateyaneng
Brightside
N1
Legend
Proposed Canal Options
Existing Canal
Proposed Canal
Western Routes (4 Options)
Pipeline
River
Central Route (1 Option)
0 5 10 20 30 40
Kilometers
N
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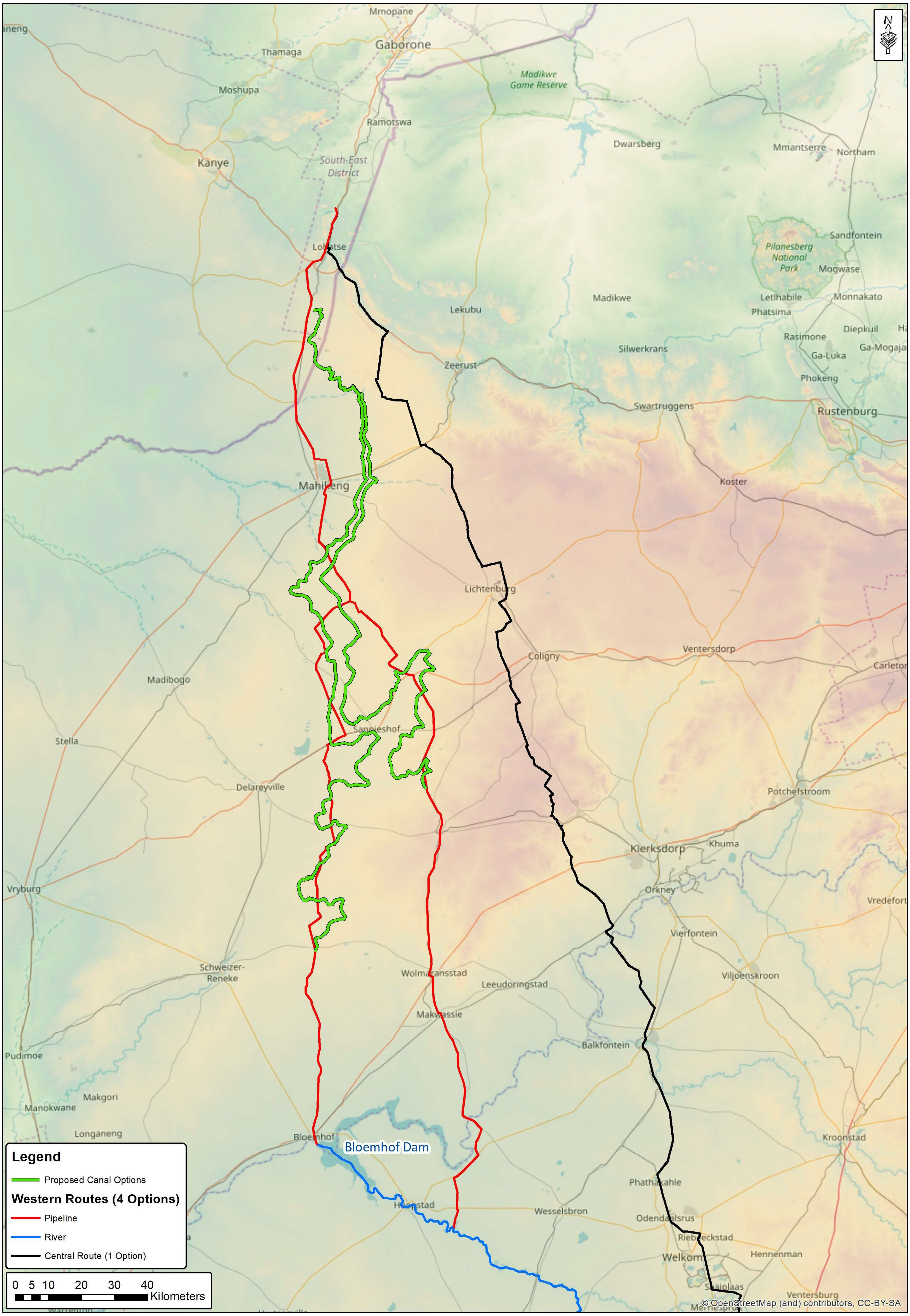

Mmopane
Gaborone
Thamaga
Moshupa
Madikwe Game Reserve
Ramotswa
Dwarsberg
Mmantserre
Northam
Kanye
South-East District
Lobatse
Sandfontein
Pilanesberg National Park
Mogwase
Madikwe
Letlhabile
Monnakato
Lekubu
Phatsima
Diepkuil
Rasimone
Silwerkrans
Ga-Mogaja
Ga-Luka
Zeerust
Phokeng
Swartruggens
Rustenburg
Koster
Mahikeng
Lichtenburg
Coligny
Ventersdorp
Carleton
Madibogo
Sannieshof
Stella
Delareyville
Potchefstroom
Klerksdorp
Khuma
Vryburg
Orkney
Vredefort
Vierfontein
Schweizer-Reneke
Wolmaransstad
Viljoenskroon
Leeudoringstad
Makwassie
Balkfontein
Pudimoe
Makgori
Manokwane
Longaneng
Bloemhof
Bloemhof Dam
Kroonstad
Phathakahle
Hoopstad
Wesselsbron
Odendaalsrus
Riebeeckstad
Welkom
Hennenman
Ventersburg
N
Legend
Proposed Canal Options
Western Routes (4 Options)
Pipeline
River
Central Route (1 Option)
0 5 10 20 30 40
Kilometers
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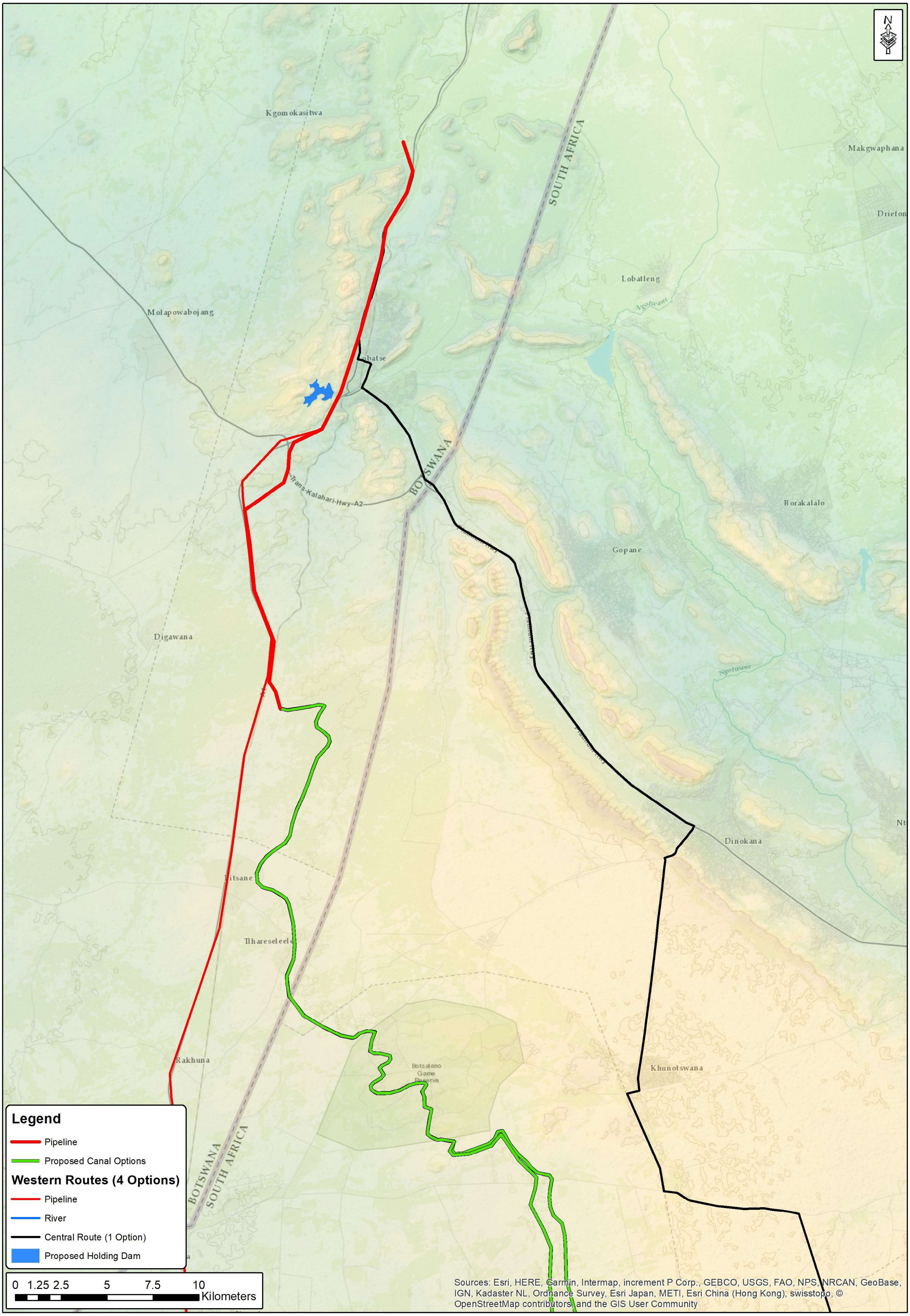
Kgomokasitwa
Makgwaphana
Drieton
SOUTH AFRICA
Lobatleng
Ngotwane
Molapowabojang
obatse
BOTSWANA
Trans-Kalahari-Hwy-A2
Borakalalo
Gopane
Digawana
Ngotwane
Dinokana
Bitsane
Tlhareseleele
Rakhuna
Botsalano Game Reserve
Khunotswana
BOTSWANA
SOUTH AFRICA
Legend
Pipeline
Proposed Canal Options
Western Routes (4 Options)
Pipeline
River
Central Route (1 Option)
Proposed Holding Dam
0 1.25 2.5 5 7.5 10
Kilometers
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community