P WMA 12/T30/00/5212/18

water & sanitation

Department:
Water and Sanitation
REPUBLIC OF SOUTH AFRICA

DIRECTORATE: OPTIONS ANALYSIS

FEASIBILITY STUDY FOR THE MZIMVUBU WATER PROJECT

HYDROPOWER ANALYSIS: LALINI DAM

OCTOBER 2014

FEASIBILITY STUDY FOR THE MZIMVUBU WATER PROJECT
APPROVAL

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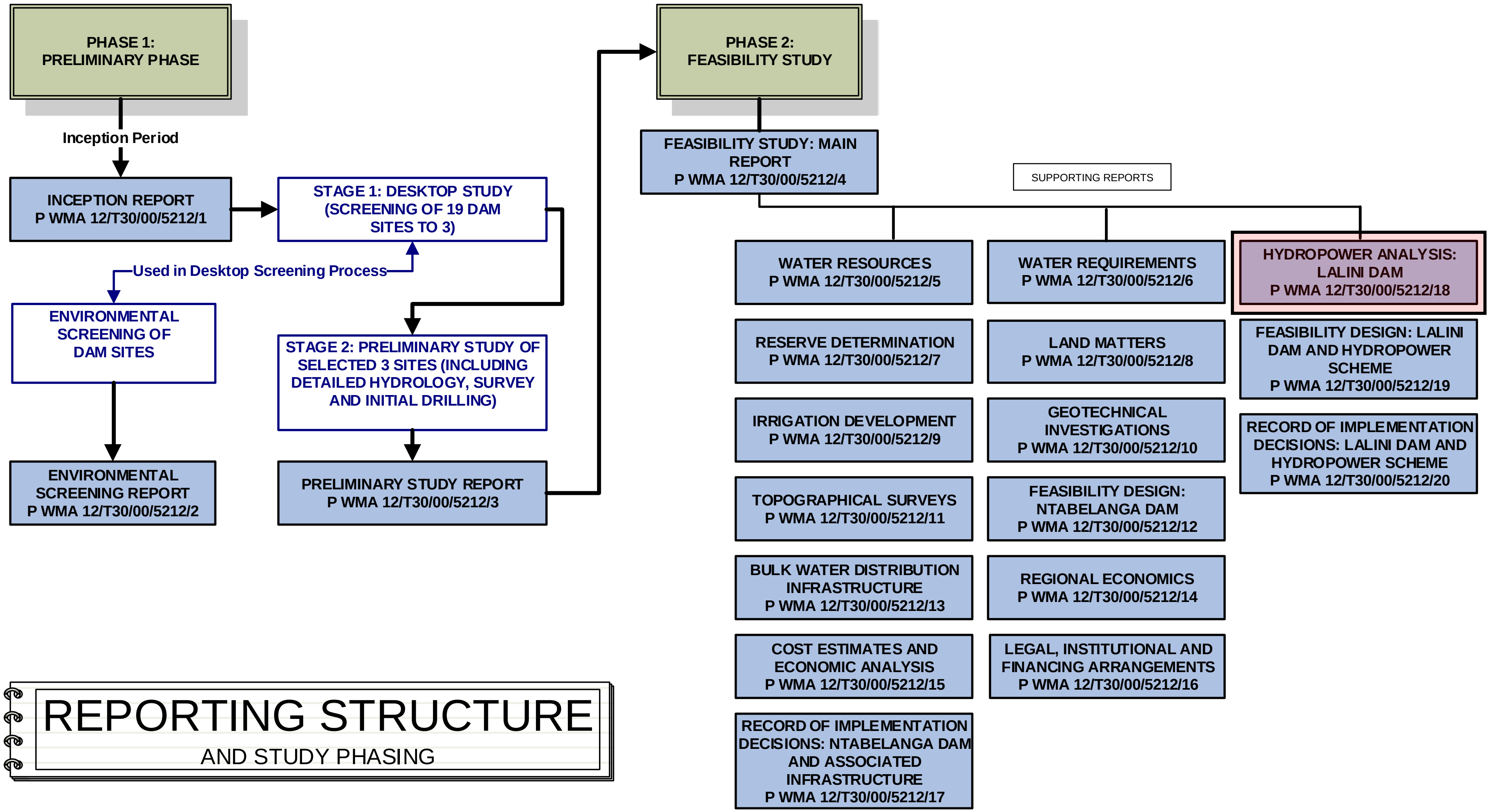
LIST OF REPORTS

REPORT TITLE	DWS REPORT NUMBER
Inception Report	P WMA 12/T30/00/5212/1
Environmental Screening	P WMA 12/T30/00/5212/2
Preliminary Study	P WMA 12/T30/00/5212/3
Feasibility Study: Main Report	P WMA 12/T30/00/5212/4
Volume 1: Report	
Volume 2: Book of Drawings	
FEASIBILITY STUDY: SUPPORTING REPORTS:	
Water Resources	P WMA 12/T30/00/5212/5
Water Requirements	P WMA 12/T30/00/5212/6
Reserve Determination	P WMA 12/T30/00/5212/7
Volume 1: River	
Volume 2: Estuary: Report	
Volume 3 :Estuary: Appendices	
Land Matters	P WMA 12/T30/00/5212/8
Irrigation Development	P WMA 12/T30/00/5212/9
Geotechnical Investigations	P WMA 12/T30/00/5212/10
Volume 1: Ntabelanga, Somabadi and Thabeng Dam Sites: Report	
Volume 2: Ntabelanga, Somabadi and Thabeng Dam Sites: Appendices	
Volume 3: Lalini Dam and Hydropower Scheme: Report	
Volume 4: Lalini Dam and Hydropower Scheme: Appendices	
Topographical Surveys	P WMA 12/T30/00/5212/11
Feasibility Design: Ntabelanga Dam	P WMA 12/T30/00/5212/12
Bulk Water Distribution Infrastructure	P WMA 12/T30/00/5212/13
Regional Economics	P WMA 12/T30/00/5212/14
Cost Estimates and Economic Analysis	P WMA 12/T30/00/5212/15
Legal, Institutional and Financing Arrangements	P WMA 12/T30/00/5212/16
Record of Implementation Decisions: Ntabelanga Dam and Associated Infrastructure	P WMA 12/T30/00/5212/17
Hydropower Analysis: Lalini Dam	**P WMA 12/T30/00/5212/18**
Feasibility Design: Lalini Dam and Hydropower Scheme	P WMA 12/T30/00/5212/19
Record of Implementation Decisions: Lalini Dam and Hydropower Scheme	P WMA 12/T30/00/5212/20


PHASE 1:
PRELIMINARY PHASE
Inception Period
INCEPTION REPORT
P WMA 12/T30/00/5212/1
STAGE 1: DESKTOP STUDY (SCREENING OF 19 DAM SITES TO 3)
Used in Desktop Screening Process
ENVIRONMENTAL SCREENING OF DAM SITES
STAGE 2: PRELIMINARY STUDY OF SELECTED 3 SITES (INCLUDING DETAILED HYDROLOGY, SURVEY AND INITIAL DRILLING)
ENVIRONMENTAL SCREENING REPORT
P WMA 12/T30/00/5212/2
PRELIMINARY STUDY REPORT
P WMA 12/T30/00/5212/3
PHASE 2:
FEASIBILITY STUDY
FEASIBILITY STUDY: MAIN REPORT
P WMA 12/T30/00/5212/4
SUPPORTING REPORTS
WATER RESOURCES
P WMA 12/T30/00/5212/5
WATER REQUIREMENTS
P WMA 12/T30/00/5212/6
HYDROPOWER ANALYSIS: LALINI DAM
P WMA 12/T30/00/5212/18
RESERVE DETERMINATION
P WMA 12/T30/00/5212/7
LAND MATTERS
P WMA 12/T30/00/5212/8
FEASIBILITY DESIGN: LALINI DAM AND HYDROPOWER SCHEME
P WMA 12/T30/00/5212/19
IRRIGATION DEVELOPMENT
P WMA 12/T30/00/5212/9
GEOTECHNICAL INVESTIGATIONS
P WMA 12/T30/00/5212/10
RECORD OF IMPLEMENTATION DECISIONS: LALINI DAM AND HYDROPOWER SCHEME
P WMA 12/T30/00/5212/20
TOPOGRAPHICAL SURVEYS
P WMA 12/T30/00/5212/11
FEASIBILITY DESIGN: NTABELANGA DAM
P WMA 12/T30/00/5212/12
BULK WATER DISTRIBUTION INFRASTRUCTURE
P WMA 12/T30/00/5212/13
REGIONAL ECONOMICS
P WMA 12/T30/00/5212/14
COST ESTIMATES AND ECONOMIC ANALYSIS
P WMA 12/T30/00/5212/15
LEGAL, INSTITUTIONAL AND FINANCING ARRANGEMENTS
P WMA 12/T30/00/5212/16
RECORD OF IMPLEMENTATION DECISIONS: NTABELANGA DAM AND ASSOCIATED INFRASTRUCTURE
P WMA 12/T30/00/5212/17
REPORTING STRUCTURE
AND STUDY PHASING

REFERENCE

This report is to be referred to in bibliographies as:

Department of Water and Sanitation (2014). ***Feasibility Study for the Mzimvubu Water Project: Hydropower Analysis: Lalini Dam***

DWS Report No: P WMA 12/T30/00/5212/18

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Note on Departmental Name Change:

In 2014, the Department of Water Affairs changed its name to the Department of Water and Sanitation, which happened during the course of this study. In some cases this was after some of the study reports had been finalized. The reader should therefore kindly note that references to the Department of Water Affairs and the Department of Water and Sanitation herein should be considered to be one and the same.

Note on Spelling of Laleni:

The settlement named Laleni on maps issued by the Surveyor General is locally known as Lalini and both names therefore refer to the same settlement.

EXECUTIVE SUMMARY

BACKGROUND AND INFORMATION

The Mzimvubu River catchment in the Eastern Cape Province of South Africa is within one of the poorest and least developed regions of the country. Development of the area to accelerate the social and economic upliftment of the people was therefore identified as one of the priority initiatives of the Eastern Cape Provincial Government.

Harnessing the water resources of the Mzimvubu River, the only major river in the country which is still largely unutilised, is considered by the Eastern Cape Provincial Government as offering one of the best opportunities in the Province to achieve such development. In 2007, a special-purpose vehicle (SPV) called ASGISA-Eastern Cape (Pty) Ltd (ASGISA-EC) was formed in terms of the Companies Act to initiate planning and to facilitate and drive the Mzimvubu River Water Resources Development.

The five pillars on which the Eastern Cape Provincial Government and ASGISA-EC proposed to model the Mzimvubu River Water Resources Development are:

- *Forestry;*
- *Irrigation;*
- *Hydropower;*
- *Water transfer; and*
- *Tourism.*

As a result of this the Department of Water and Sanitation (DWS) commissioned the Feasibility Study for the Mzimvubu Water Project with the overarching aim of developing water resources schemes (dams) that can be multi-purpose reservoirs in order to provide benefits to the surrounding communities and to provide a stimulus for the regional economy, in terms of irrigation, forestry, domestic water supply and the potential for hydropower generation amongst others.

The study commenced in January 2012 and was undertaken in three stages as follows:

- *Inception;*
- *Phase 1 – Preliminary Study; and*
- *Phase 2 – Feasibility Study.*

The purpose of the study was not to repeat or restate the research and analyses undertaken on the several key previous studies described below, but to make use of that information previously collected, to update and add to this information, and to undertake more focussed and detailed investigations and feasibility level analyses for the dam site options identified as being the most promising and cost beneficial.

INCEPTION PHASE

The aim of the inception phase was to finalise the Terms of Reference (TOR) as well as to include, inter alia, the following:

- *A detailed review of all the data and information sources available for the assignment;*
- *A revised study methodology and scope of work;*
- *A detailed review of the proposed project schedule, work plan and work breakdown structure indicating major milestones;*
- *Provision of an updated organogram and human resources schedule; and*
- *Provision of an updated project budget and monthly cash flow projections.*

The inception phase culminated in the production of an inception report (DWA Report Number P WMA 12/T30/00/5212/1) which also constituted the final TOR for the study.

PRELIMINARY STUDY

The preliminary report describes the activities undertaken during the preliminary study phase, summarizes the findings and conclusions, and provides recommendations for the way forward and scope of work to be undertaken during the feasibility study phase.

The Preliminary Study Phase was divided into two stages:

(1) Desktop Study; and
(2) Preliminary Study.

The aim of the desktop study was, through a process of desktop review, analyses of existing reports and data, and screening, to determine the three best development options from the pre-identified 19 development options (from the previous investigation).

The next stage involved the gathering of more information with regard to the three selected development options as well as to involve the Eastern Cape Provincial Government and key stakeholders in the process of selecting the single best development option to be taken forward into Phase 2 of the study.

The main activities undertaken during of the preliminary study were as follows:

- *Stakeholder involvement;*
- *Environmental screening;*
- *Water requirements (including domestic water supply, irrigation and hydropower);*
- *Hydrological investigations;*
- *Geotechnical investigations;*
- *Topographical survey investigations, and*
- *Selection process.*

The preliminary study recommended a preferred dam site at Ntabelanga and scheme development to be taken forward to Feasibility Study level.

FEASIBILITY STUDY

The key activities undertaken during the Feasibility Study are as follows:

- *Detailed hydrology (over and above that undertaken during the Preliminary Study);*
- *Reserve determination;*
- *Water requirements investigation (including agricultural and domestic water supply investigations);*
- *Topographical survey (over and above that undertaken during the Preliminary Study);*
- *Geotechnical investigation (more detailed investigations than during the Preliminary Study);*
- *Dam design;*
- *Land matters;*
- *Public participation;*
- *Regional economics; and*
- *Legal, institutional and financial arrangements.*

Consideration was also given to the potential for inter-basin transfer from the Tsitsa River in general and the Ntabelanga Dam in particular. The closest potential need for such a scheme was the main regional centre of Mthatha, which is a fast-growing town of strategic importance.

Apart from some groundwater sources, the main water supply for Mthatha is the existing Mthatha Dam on the Mthatha River which is the main source for potable water production as well as having an allocation for release downstream to maintain flow to two small hydroelectric plants at First Falls and Second Falls.

Given that Mthatha was experiencing challenges with its water supply, consideration was made as to whether inter-basin transfer of raw water from the Ntabelanga Dam to the Mthatha Dam would be a solution.

A high-level conceptual design was undertaken for a water transfer scheme comprising a 37 km long pipeline with capacity to convey some 1 m^3/sec between these two dams.

As this pipeline would need to cross the watershed dividing the Tsitsa and the Mthatha Rivers, some 240 m pumping head would be required.

In summary, such a scheme would cost an estimated R600 million to construct and R20 million/annum to operate and maintain. Excluding capital redemption, the net cost of raw water transferred would be R0.70/m^3. It must also be noted that there would be significant interception, infiltration and evaporation losses once the water is released from this pipeline into the Mthatha Dam's catchment, before supplementing the inflow into the dam.

The DWS Reconciliation Strategy for Mthatha and surrounding village clusters (June 2011) identified that Mthatha's main problem was very high water losses in the system (up to 60%) and that resolution of this problem would secure Mthatha's water supply needs for at least the medium term. In addition, it was stated that the water allocation from the dam between water supply and downstream release for environmental and hydropower purposes was conservative and did not need to be reviewed at this time.

The conclusion was that there was not currently a case for further investigation of an inter-basin transfer scheme between Ntabelanga Dam and Mthatha Dam, but this could be revisited in the longer term.

The DWS Report No. P RSA 000/00/12610, Assessment of the Ultimate Potential and Future Marginal Cost of Water Resources in South Africa, September 2010, investigated all major water resources in the country and undertook an economic and financial analysis to determine the marginal cost and preferred development timing of resources by region.

Inter-basin transfer options were included in this study, and the transfer of water from the Mzimvubu catchment was included in the following augmentation options:

- *Vaal River,*
- *Orange River, and*
- *Algoa Water Supply Area (WSA).*

The results of the study were a ranking of the various water supply resource options in terms of yield and unit reference value (URV) of raw water supplied, against the projected growth in water requirements for each supply area.

For the Vaal River option, the conclusion was that "the transfer of water from the Mzimvubu River to the Vaal River system will be very expensive and measures such as the re-allocation of water (through trading) may be more advisable".

For the Orange River option, the conclusion was "It is doubtful whether the transfer of water from the Mzimvubu catchment for the express purpose of augmenting supplies along the Orange River will ever be necessary and justifiable".

For the Algoa WSA the Mzimvubu transfer is shown to be the last and most expensive option to be developed and produces a unit reference value (URV) of water supplied even higher than desalination.

The conclusion from all of these options is that there is no case for the development of a long-distance inter-basin transfer scheme from the Mzimvubu River in the medium to long-term.

It is recommended, however, that the situation be regularly reassessed in the future.

RECOMMENDATIONS OF FEASIBILITY STUDY

It was confirmed and agreed that the sizing and modus operandi of the Ntabelanga Dam and its associated works would take into account its multi-purpose role, namely:

i. To supply potable water to a current population of some 502 822 people (rising to 726 616 people in 2050) and other water consumers in the region;
ii. To supply raw water for irrigation of some 2 868 ha of high potential agricultural land;
iii. To generate hydropower locally at the dam wall to reduce the cost of energy consumption when pumping water;
iv. To provide sufficient flow of water downstream of the Ntabelanga Dam to meet environmental water requirements for an ecological Class C; and
v. To provide additional balancing storage volume and consistent downstream flow releases to enable a second dam at Lalini (just above the Tsitsa Falls) to generate significant hydropower for supply into the national grid.

These multi-purpose usages and requirements for the Ntabelanga Dam are described in the Water Requirements Report No. P WMA 12/T30/00/5212/6, and the Irrigation Development Report No. P WMA 12/T30/00/5212/9.

An Environmental Impact Assessment was undertaken in a separate study that ran in parallel to this one.

INVESTIGATIONS FOR LALINI DAM AND HYDROPOWER SCHEME

An extension to the feasibility study involved detailed investigations for a second dam on the Tsitsa River at Lalini (3.5 km above the Tsitsa Falls) which would be operated conjunctively with the Ntabelanga Dam to generate significant hydropower for supply into the national grid.

This report describes the process undertaken to determine the hydropower generation potential of the Ntabelanga and Lalini Dams when operated conjunctively.

The Feasibility Design of the Lalini Dam and hydropower scheme is described in Report No. P WMA 12/T30/00/5212/19.

In considering the power supply situation in the region, consultations were held with ESKOM's regional grid access department in East London. They confirmed that the demands on the existing grid were such that locally generated power such as that which could be generated at Lalini could be evacuated into the regional grid to supply local consumers, and this would reduce the power supplied into the grid from further away, which in turn reduces transmission losses and releases that energy for supply to other areas. The limitations in the case of Lalini are that the existing transmission lines that would receive such evacuated energy are 132 kV and this means that evacuation of power at loads greater than 100 MW would not be possible without major additional transmission systems being constructed.

EXISTING HYDROPOWER IN THE REGION

There are two existing mini-hydropower schemes in the Mthatha area which utilize water released from the Mthatha Dam in the next catchment south of the Tsitsa River. These are the First Falls and Second Falls schemes and are operated by ESKOM. They operate in series and are classified as "run-of-river" schemes in that they do not have dedicated balancing storage dams, instead rely on the water released downstream from the Mthatha Dam, which is the primary source of water supply to Mthatha.

Both of these schemes have experienced problems with flooded infrastructure and studies have been undertaken[1] to resolve these problems and to consider possible increased output capacity upgrades.

First and Second Falls hydroelectric plants (HEPs) have installed capacities of 6 MW and 11 MW respectively but these maximum outputs are only produced at flow rates of 26 m^3/s and 28 m^3/s respectively. Given that the Mthatha Dam is primarily used for water supply and can only sustain a constant release of 4.5 m^3/s at high levels of assurance, it is clear that the actual effective continuous outputs of these two HEPs would be significantly less than their installed capacities. For example, analysis undertaken has shown that First Falls HEP can only produce a firm (95% level of assurance) energy output of 1.225 MW, and a similar situation exists at Second Falls pro rata their installed capacities. Thus, for a total installed capacity of these two schemes of 17 MW, the firm energy outputs is probably of the order of 3.5 to 5 MW.

The conclusion of the study also stated that it was not economically viable to increase the installed generating capacity of these HEPs.

Given this background, the proposition of increasing the generating capacity of renewable energy in the region by up to a factor of 10 was considered to be highly significant. It would also provide alternatives when considering whether additional funds should be spent on upgrading and maintaining the First and Second Falls HEPs or whether the conjunctive Ntabelanga and Lalini HEP schemes should replace the First and Second falls schemes altogether. This latter decision is, however, not part of the terms of reference of this study.

[1] *Knight Piesold (2014), Refurbishment of Eastern Cape Mini Hydro Plants and Investigation of Potential Expansion*

NTABELANGA AND LALINI DAMS CONJUNCTIVE HYDROPOWER SCHEME

The basis of approach was that the generating of hydropower could be used to cross-subsidize the significant energy costs required for pumping water for the irrigation and domestic water supply schemes proposed to be supplied from the Ntabelanga Dam.

The mountainous terrain which constitutes the potable water supply area requires a large amount of high-lift pumping as consequent energy costs.

The agricultural water requirements proposed for the Tsolo area would require lifting the water more than 150 m, which would normally render such a scheme non-viable in terms of the pumping cost component of water supplied, unless hydropower is developed to reduce the net unit cost of water.

The purpose of this second dam and hydropower scheme at Lalini would thus be to generate significant revenue by selling energy into the ESKOM grid, thus generating a net positive income stream which would be used to subsidise the energy and operating costs of the main Ntabelanga water supply and irrigation scheme, thus providing self-sustainability.

A more detailed hydropower analysis and feasibility design study was therefore undertaken to assess the output potential of the Lalini Dam hydropower scheme when used conjunctively with the Ntabelanga Dam. This analysis used the detailed hydrology developed for the catchment and the naturalised and historical flow series that was developed therefrom.

It was confirmed and agreed that the sizing and modus operandi of the Lalini Dam and its associated works would take into account its main role, namely:

i. *to generate hydropower both locally at the dam wall and in the Tsitsa River gorge downstream of the Tsitsa Falls, and*
ii. *to provide sufficient flow of water downstream of the Lalini Dam and these hydroelectric plants (HEPs) to meet environmental water requirements for an ecological Class B/C.*

In order to facilitate this analysis detailed investigations were undertaken of the Lalini Dam components of the scheme, inter alia:

- *detailed topographical survey and positioning of the proposed Lalini Dam,*
- *geotechnical investigations of the dam site, sources of construction materials, and tunnel alignments,*
- *investigation of various Lalini hydropower scheme configuration options, and*
- *hydropower modelling simulations of the Lalini hydropower plant and two mini-hydropower plants at Ntabelanga and Lalini dams for the conjunctive scheme.*

A reserve determination needed to be completed for the Lalini Dam and hydropower plant sites as the hydropower releases can have a significant impact upon the riverine ecology downstream of the proposed dam site and hydropower tunnel exit point.

This included the undertaking of a rapid determination of the EWR of the Tsitsa River downstream of the Tsitsa Falls, which indicated an ecological class of B/C. This EWR value and its recommended rules of operation were included into a new hydropower simulation model to improve the accuracy of estimation the potential hydropower outputs of the scheme.

This was undertaken as a part of the independent EIA contract and results are given in that suite of reports. Based upon these findings, Lalini hydropower scheme operating rules were developed to ensure that environmental water requirement (EWR) recommendations were complied with, and these rules were discussed and agreed with the DWS Resource Directed Measures (RDM) Directorate.

The hydropower assessment of the conjunctive use of the Ntabelanga and Lalini Dams on the Tsitsa River, was undertaken using detailed hydrology produced in the earlier analyses stage of this feasibility study, as well as new and highly accurate topographical survey data for the Lalini dam basin.

The analysis was undertaken using the previously recommended Ntabelanga Dam capacity (1.18 MAR_{PD}), and for a range of Lalini Dam capacities from 0.10 MAR_{PD} (Mean Annual Runoff based upon Present Day flows) to 0.75 MAR_{PD}.

The optimum Lalini Dam size selection was based on several factors, such as unit power cost, funding requirements, as well as social and environmental impacts.

The main objective of the hydropower generation assessment was to determine the amount of energy that can be produced per year from each dam capacity option assuming that the environmental, domestic and agricultural water requirements are met first.

Given that the two dams are to be operated conjunctively, there could be a trade-off on water allocation. If the eventual domestic and irrigation water demands upon the Ntabelanga Dam were to be less than projected, then more water could be made available for release from the dam to increase hydropower generation. However, such releases would still need to follow the water reserve operating rule recommendations for environmental water requirements at both Ntabelanga and Lalini Dams.

RESULTS AND CONCLUSIONS

The hydropower assessment of the conjunctive use of the Ntabelanga and Lalini Dams on the Tsitsa River system, was undertaken using detailed hydrology produced in the earlier analyses stage of this feasibility study, as well as new and highly accurate topographical survey data for the Lalini dam basin.

The analysis was undertaken using the previously recommended Ntabelanga Dam capacity of 489.7 million m^3, or 1.18 MAR_{PD}, and for a range of Lalini Dam capacities from 0.10 MAR_{PD} to 0.75 MAR_{PD}.

The optimum Lalini Dam size selection was based on several factors, such as the cost benefits, as well as social and environmental impacts.

The main objective of the hydropower generation assessment was to determine the average amount of energy that can be produced per year from each dam capacity option assuming that the environmental, domestic and agricultural water requirements are met first.

Three Hydroelectric Plants (HEPs) were modelled:

1. *a 5 MW installed capacity mini-HEP just downstream of the Ntabelanga Dam;*
2. *a 5 MW installed capacity mini-HEP just downstream of the Lalini Dam, and*
3. *the main HEP at Lalini located in the Tsitsa River gorge and supplied by a 7.9 km long conduit and tunnel.*

The two mini-HEPs make use of the water released downstream to meet the EWR, and the head of water available in each dam. This means that they can generate between 0.75 and 5 MW each, depending on the head and flow available at the time.

Two base case options were investigated for the main Lalini HEP, namely:

i) installed capacity 50 MW, and
ii) installed capacity 37.5 MW

The results from the hydropower modelling analyses for the recommended Ntabelanga Dam capacity and the range of Lalini Dam storage volumes given above are presented in Figures 1 and 2, and Tables 1 and 2.

The analysis undertaken produced results which showed that the simulated base load (average) hydropower generation from the Lalini Dam ranged from 12.5 MW to 50 MW, depending on the status of the river in terms of season, drought or flood conditions, and the combination of storage capacity options for the Ntabelanga and Lalini Dams.

Given the physical dam capacity constraints which are limited by topography and environmental and social impacts, and capital cost considerations, the preferred installed capacity solution was determined to be 37.5 MW.

The outcome of the investigations indicated that hydropower generation potential at the Lalini Dam, with Ntabelanga Dam acting as a regulating dam for the production of hydropower at Lalini, is potentially cost-beneficial in such a multi-purpose scheme.

The optimum solution was shown to be one where the Ntabelanga Dam is constructed to a maximum capacity of 1.18 MAR_{PD}, as constrained by topographical limitations, with the Lalini Dam capacity set at 0.28 MAR_{PD}.

The energy figures thus produced were incorporated into the economic and financial models undertaken to determine the best conjunctive use solution.

These analyses are described in the Feasibility Design of the Lalini Dam and Hydropower Scheme Report No. P WMA 12/T30/00/5212/19, and in the Cost Estimates and Economic Analysis Report No. P WMA 12/T30/00/5212/15.

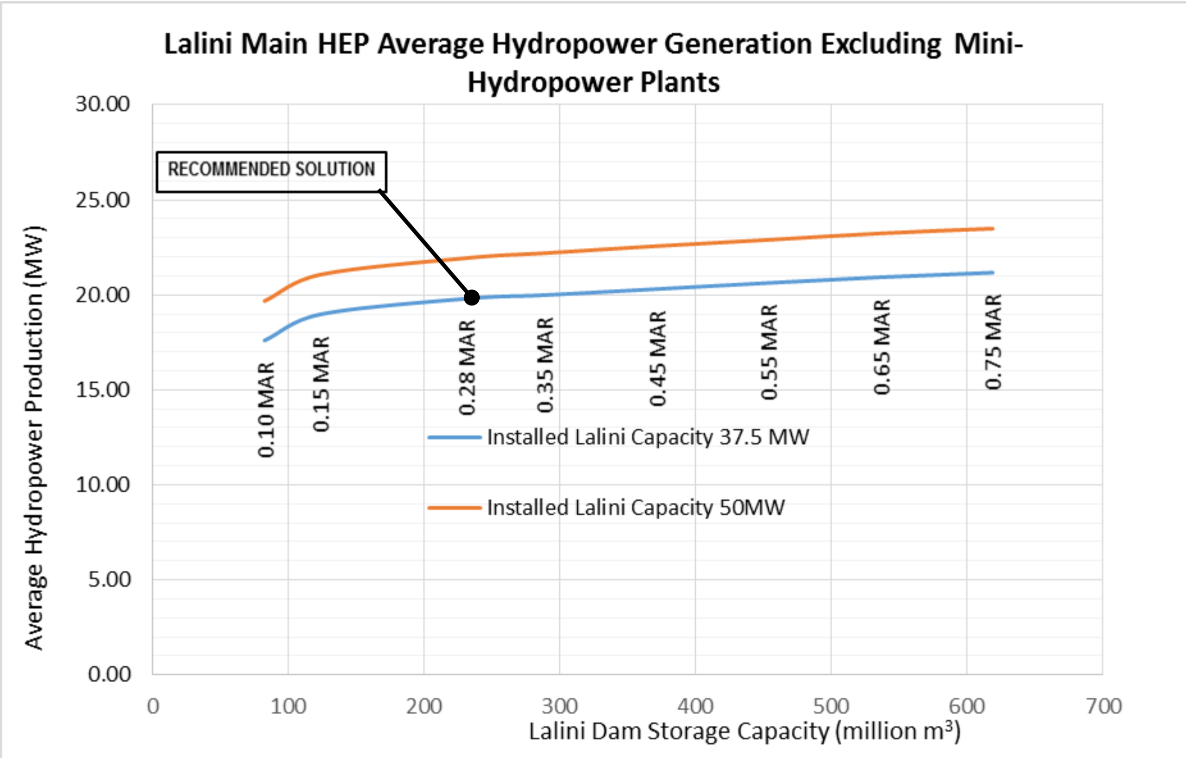


Figure 1: Hydropower Output: Lalini Main HEP

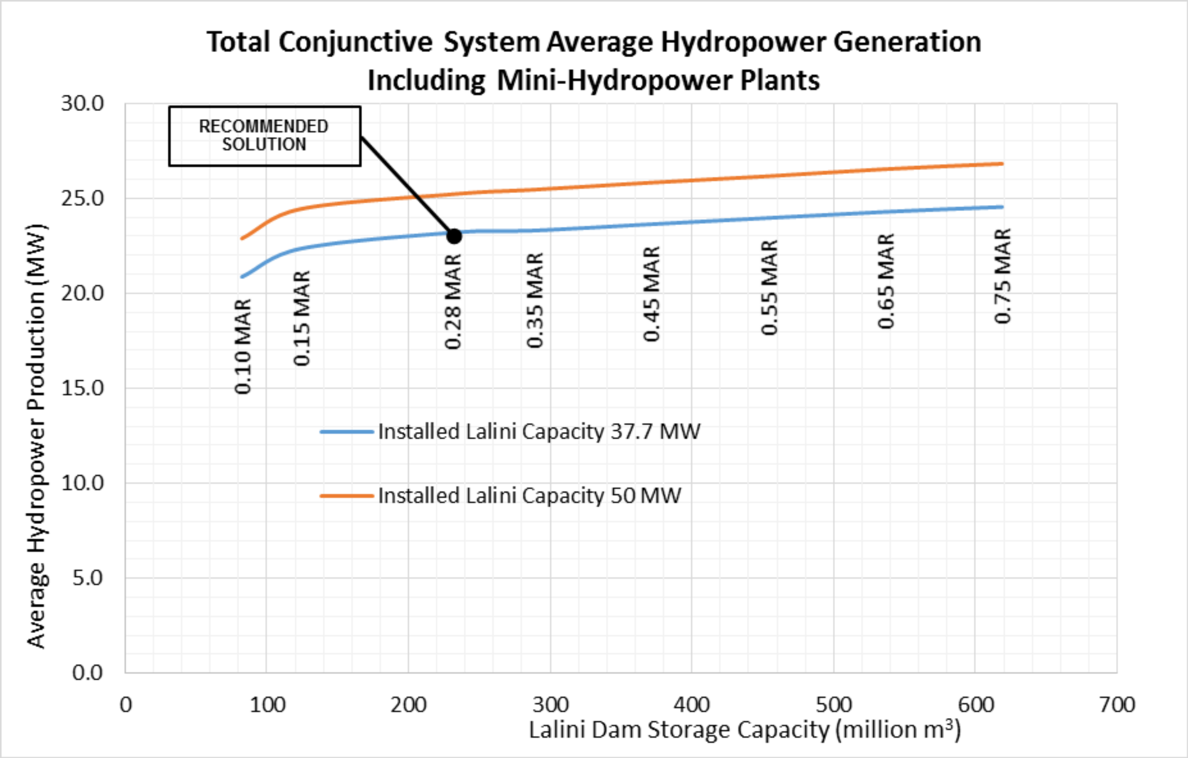


Figure 2: Hydropower Output: Including Mini-HEPs

Note: Recommended solution would produce an average of 23.17 MW.

Table 1: Hydropower Generation Results: 37.5 MW Installed

Scenario		Lalini Dam Statistics					Lalini Dam EWR			Ntabelanga Mini-HEP Maximum Installed Capacity	Ntabelanga Mini-HEP Ave. Annual Power Output	Lalini Main HEP Installed Capacity	Lalini Main HEP Ave. Annual Power Output	Lalini Mini-HEP Maximum Installed Capacity	Lalini Mini-HEP Ave. Annual Power Output
No.	Description	FSL	MOL	Gross storage capacity	Live storage capacity	*Area	Class	Requirements		HydroPower	HydroPower	HydroPower	HydroPower	HydroPower	HydroPower
		m.a.s.l	m.a.s.l	million m^3	million m^3	km^2		million m^3/a	% MAR	MW	MW	MW	MW	MW	MW
01	1.18 MAR Ntabelanga + 0.10 MAR Lalini	751.8	745.2	82.5	40.3	7.61	BC	287.1	33.05	5	1.67	37.5	17.60	5	1.60
02	1.18 MAR Ntabelanga + 0.15 MAR Lalini	756.5	745.2	123.8	81.6	9.85	BC	287.1	33.05	5	1.66	37.5	18.98	5	1.71
03	**1.18 MAR Ntabelanga + 0.28 MAR Lalini**	**765.5**	**745.2**	**231.0**	**188.8**	**14.02**	**BC**	**287.1**	**33.05**	**5**	**1.57**	**37.5**	**19.77**	**5**	**1.83**
04	1.18 MAR Ntabelanga + 0.35 MAR Lalini	769.4	745.2	288.8	246.6	15.80	BC	287.1	33.05	5	1.45	37.5	19.99	5	1.87
05	1.18 MAR Ntabelanga + 0.45MAR Lalini	774.2	745.2	371.3	329.1	18.18	BC	287.1	33.05	5	1.40	37.5	20.31	5	1.93
06	1.18 MAR Ntabelanga + 0.55 MAR Lalini	778.4	745.2	453.8	411.6	20.67	BC	287.1	33.05	5	1.35	37.5	20.63	5	1.99
07	1.18 MAR Ntabelanga + 0.65 MAR Lalini	782.3	745.2	536.3	494.1	22.65	BC	287.1	33.05	5	1.31	37.5	20.93	5	2.05
08	1.18 MAR Ntabelanga + 0.75 MAR Lalini	785.8	745.2	618.75	576.56	24.5	BC	287.1	33.05	5	1.28	37.5	21.17	5	2.10

** Surface area at Full Supply Level*

Recommended Scheme

Table 2: Hydropower Generation Results: 50 MW Installed

Scenario		Lalini Dam Statistics					Lalini Dam EWR			Ntabelanga Mini-HEP Maximum Installed Capacity	Ntabelanga Mini-HEP Ave. Annual Power Output	Lalini Main HEP Installed Capacity	Lalini Main HEP Ave. Annual Power Output	Lalini Mini-HEP Maximum Installed Capacity	Lalini Mini-HEP Ave. Annual Power Output
No.	Description	FSL	MOL	Gross storage capacity	Live storage capacity	*Area	Class	Requirements		HydroPower	HydroPower	HydroPower	HydroPower	HydroPower	HydroPower
		m.a.s.l	m.a.s.l	million m^3	million m^3	km^2		million m^3/a	% MAR	MW	MW	MW	MW	MW	MW
01	1.18 MAR Ntabelanga + 0.10 MAR Lalini	751.8	745.2	82.5	40.3	7.61	BC	287.1	33.05	5	1.65	50	19.68	5	1.56
02	1.18 MAR Ntabelanga + 0.15 MAR Lalini	756.5	745.2	123.8	81.6	9.85	BC	287.1	33.05	5	1.71	50	21.07	5	1.66
03	1.18 MAR Ntabelanga + 0.28 MAR Lalini	765.5	745.2	231.0	188.8	14.02	BC	287.1	33.05	5	1.54	50	21.94	5	1.74
04	1.18 MAR Ntabelanga + 0.35 MAR Lalini	769.4	745.2	288.8	246.6	15.80	BC	287.1	33.05	5	1.47	50	22.20	5	1.79
05	1.18 MAR Ntabelanga + 0.45MAR Lalini	774.2	745.2	371.3	329.1	18.18	BC	287.1	33.05	5	1.41	50	22.57	5	1.85
06	1.18 MAR Ntabelanga + 0.55 MAR Lalini	778.4	745.2	453.8	411.6	20.67	BC	287.1	33.05	5	1.37	50	22.90	5	1.90
07	1.18 MAR Ntabelanga + 0.65 MAR Lalini	782.3	745.2	536.3	494.1	22.65	BC	287.1	33.05	5	1.35	50	23.24	5	1.95
08	1.18 MAR Ntabelanga + 0.75 MAR Lalini	785.8	745.2	618.75	576.56	24.5	BC	287.1	33.05	5	1.34	50	23.49	5	1.99

** Surface area at Full Supply Level*

TABLE OF CONTENTS

FIGURES

TABLES

LIST OF ACRONYMS AND ABBREVIATIONS

ASGISA-EC	Accelerated and Shared Growth Initiative for South Africa – Eastern Cape
CAPEX	Capital Expenditure
CFRD	Concrete-faced rockfill dam
CMA	Catchment Management Agency
CTC	Cost to Company
CV	Coefficient of Variability
DAFF	Department of Agriculture, Forestry and Fisheries
DBSA	Development Bank of Southern Africa
DEA	Department of Environment Affairs
DM	District Municipality
DME	Department of Minerals and Energy
DoE	Department of Energy
DRDAR	Department of Rural Development and Agrarian Reform
DRDLR	Department of Rural Development and Land Reform
DWA	Department of Water Affairs
DWS	Department of Water and Sanitation
EA	Environmental Authorisation
EAP	Environmental Assessment Practitioner
EC	Eastern Cape
ECRD	Earth core rockfill dam
EF	Earthfill (dam)
EIA	Environmental Impact Assessment
EMP	Environmental Management Plan
EPWP	Expanded Public Works Programme
ESIA	Environmental and Social Impact Assessment
EWR	Environmental Water Requirements
FSL	Full Supply Level
GERCC	Grout enriched RCC
GN	Government Notices
GW	Gigawatt
GWh/a	Gigawatt hour per annum
IAPs	Invasive Alien Plants
IB	Irrigation Board
IFC	International Finance Corporation
IPP	Independent Power Producer
IRR	Internal Rate of Return
IVRCC	Internally vibrated RCC
ISO	International Standards Organisation
kW	Kilowatt
LM	Local Municipality
ℓ/s	Litres per second

MAR_{NAT}	Mean Annual Runoff (Naturalised Flows)
MAR_{PD}	Mean Annual Runoff (Present Day Flows)
MEC	Member of the Executive Council
MIG	Municipal Infrastructure Grant
million m^3	Million cubic metres
MW	Megawatt
NEMA	National Environmental Management Act
NERSA	National Energy Regulator of South Africa
NHRA	National Heritage Resources Act
NOCL	Non-overspill crest level
NWA	National Water Act
NWPR	National Water Policy Review
NWRMS	National Water Resources Management Strategy
O&M	Operations and Maintenance
OPEX	Operational Expenditure
PICC	Presidential Infrastructure Co-Ordinating Committee
PPA	Power Purchase Agreement
PPP	Public Private Partnership
PSC	Project Steering Committee
PSP	Professional Services Provider
RBIG	Regional Bulk Infrastructure Grant
RCC	Roller-compacted concrete
REIPPPP	Renewable Energy Independent Power Producer Procurement Programme
RWI	Regional Water Institution
RWU	Regional Water Utilities
SEZ	Special Economic Zone
SIP	Strategic Integrated Project
SMC	Study Management Committee
SPV	Special Purpose Vehicle
TCTA	Trans Caledon Tunnel Authority
ToR	Terms of Reference
UOS	Use of System
URV	Unit Reference Value
WEF	Water Energy Food
WRYM	Water Resources Yield Model
WSA	Water Services Authority
WSP	Water Services Provider
WTE	Water Trade Entity
WUA	Water User Association

LIST OF UNITS

Description	Standard unit
Elevation	m a.s.l.
Height	m
Distance	m, km
Dimension	mm, m
Area	m^2 , ha or km^2
Volume (storage)	m^3
Yield, Mean Annual Runoff	m^3/a
Rotational speed	rpm
Head of Water	m
Pressure	Pa
Diameter	mm or m
Temperature	ºC

Description	Standard unit
Velocity, speed	m/s, km/hr
Discharge	m^3/s
Mass	kg, tonne
Force, weight	N
Gradient (V:H)	%
Slope (H:V) or (V:H)	1:5 (H:V) <u>or</u> 5:1 (V:H)
Volt	V
Power	W
Energy used	kWh
Acceleration	m/s^2
Density	kg/m^3
Frequency	Hz

1. BACKGROUND AND INTRODUCTION

The Mzimvubu River catchment in the Eastern Cape Province of South Africa is within one of the poorest and least developed regions of the country. Development of the area to accelerate the social and economic upliftment of the people was therefore identified as one of the priority initiatives of the Eastern Cape Provincial Government.

Harnessing the water resources of the Mzimvubu River, the only major river in the country which is still largely unutilised, is considered by the Eastern Cape Provincial Government as offering one of the best opportunities in the Province to achieve such development. In 2007, a special-purpose vehicle (SPV) called ASGISA-Eastern Cape (Pty) Ltd (ASGISA-EC) was formed in terms of the Companies Act to initiate planning and to facilitate and drive the Mzimvubu River Water Resources Development.

The five pillars on which the Eastern Cape Provincial Government and ASGISA-EC proposed to model the Mzimvubu River Water Resources Development are:

- Forestry;
- Irrigation;
- Hydropower;
- Water transfer; and
- Tourism.

As a result of this the Department of Water and Sanitation (DWS) commissioned the Feasibility Study for the Mzimvubu Water Project with the overarching aim of developing water resources schemes (dams) that can be multi-purpose reservoirs in order to provide benefits to the surrounding communities and to provide a stimulus for the regional economy, in terms of irrigation, forestry, domestic water supply and the potential for hydropower generation amongst others.

1.1 Feasibility Study Stages

The study commenced in January 2012 and was undertaken in three stages as follows:

- Inception;
- Phase 1 – Preliminary Study; and
- Phase 2 – Feasibility Study.

The purpose of the study was not to repeat or restate the research and analyses undertaken on the several key previous studies described below, but to make use of that information previously collected, to update and add to this information, and to undertake more focussed and detailed investigations and feasibility level analyses for the dam site options identified as being the most promising and cost beneficial.

1.1.1 Inception

The aim of the inception phase was to finalise the Terms of Reference (TOR) as well as to include, *inter alia*, the following:

- A detailed review of all the data and information sources available for the assignment;
- A revised study methodology and scope of work;
- A detailed review of the proposed project schedule, work plan and work breakdown structure indicating major milestones;
- Provision of an updated organogram and human resources schedule; and
- Provision of an updated project budget and monthly cash flow projections.

The inception phase culminated in the production of an inception report (DWA Report Number P WMA 12/T30/00/5212/1) which also constituted the final TOR for the study.

1.1.2 *Preliminary Study*

The preliminary report describes the activities undertaken during the preliminary study phase, summarizes the findings and conclusions, and provides recommendations for the way forward and scope of work to be undertaken during the feasibility study phase.

The Preliminary Study Phase was divided into two stages:

(3) Desktop Study; and
(4) Preliminary Study.

The aim of the desktop study was, through a process of desktop review, analyses of existing reports and data, and screening, to determine the three best development options from the pre-identified 19 development options (from the previous investigation). This process is described in Section 2 of this report.

The aim of the preliminary study was to gather more information with regard to the three selected development options as well as to involve the Eastern Cape Provincial Government and key stakeholders in the process of selecting the single best development option to be taken forward into Phase 2 of the study.

The main activities undertaken during of the preliminary study were as follows:

- Stakeholder involvement;
- Environmental screening;
- Water requirements (including domestic water supply, irrigation and hydropower);
- Hydrological investigations;
- Geotechnical investigations;
- Topographical survey investigations, and
- Selection process.

1.1.3 *Feasibility Study*

The preliminary study recommended a preferred dam site and scheme development to be taken forward to Feasibility Study level.

The key activities undertaken during the Feasibility Study are as follows:

- Detailed hydrology (over and above that undertaken during the Preliminary Study);
- Reserve determination;
- Water requirements investigation (including agricultural and domestic water supply investigations);
- Topographical survey (over and above that undertaken during the Preliminary Study);
- Geotechnical investigation (more detailed investigations than during the Preliminary Study);
- Dam design;
- Land matters;
- Public participation;
- Regional economics; and
- Legal, institutional and financial arrangements.

A separate Environmental Impact Assessment was undertaken by an independent PSP in parallel to this feasibility study.

1.2 Inter-Basin Transfer

Consideration was given to the potential for inter-basin transfer from the Tsitsa River in general and the Ntabelanga Dam in particular. The closest potential need for such a scheme was the main regional centre of Mthatha, which is a fast-growing town of strategic importance.

Apart from some groundwater sources, the main water supply for Mthatha is the existing Mthatha Dam on the Mthatha River which is the main source for potable water production as well as having an allocation for release downstream to maintain flow to two small hydroelectric plants at First Falls and Second Falls.

Given that Mthatha was experiencing challenges with its water supply, consideration was made as to whether inter-basin transfer of raw water from the Ntabelanga Dam to the Mthatha Dam would be a solution.

A high-level conceptual design was undertaken for a water transfer scheme comprising a 37 km long pipeline with capacity to convey some 1 m3/sec between these two dams.

As this pipeline would need to cross the watershed dividing the Tsitsa and the Mthatha Rivers, some 240 m pumping head would be required.

In summary, such a scheme would cost an estimated R600 million to construct and R20 million/annum to operate and maintain. Excluding capital redemption, the net cost of raw water transferred would be R0.70/m3. It must also be noted that there would be significant interception, infiltration and evaporation losses once the water is released from this pipeline into the Mthatha Dam's catchment, before supplementing the inflow into the dam.

The DWS Reconciliation Strategy for Mthatha and surrounding village clusters (June 2011) identified that Mthatha's main problem was very high water losses in the system (up to 60%) and that resolution of this problem would secure Mthatha's water supply needs for at least the medium term. In addition, it was stated that the water allocation from the dam between water supply and downstream release for environmental and hydropower purposes was conservative and did not need to be reviewed at this time.

The conclusion was that there was not currently a case for further investigation of an inter-basin transfer scheme between Ntabelanga Dam and Mthatha Dam, but this could be revisited in the longer term.

The DWS Report No. P RSA 000/00/12610, Assessment of the Ultimate Potential and Future Marginal Cost of Water Resources in South Africa, September 2010, investigated all major water resources in the country and undertook an economic and financial analysis to determine the marginal cost and preferred development timing of resources by region.

Inter-basin transfer options were included in this study, and the transfer of water from the Mzimvubu catchment was included in the following augmentation options:

- Vaal River,
- Orange River, and
- Algoa Water Supply Area (WSA).

The results of the study were a ranking of the various water supply resource options in terms of yield and unit reference value (URV) of raw water supplied, against the projected growth in water requirements for each supply area.

For the Vaal River option, the conclusion was that "the transfer of water from the Mzimvubu River to the Vaal River system will be very expensive and measures such as the re-allocation of water (through trading) may be more advisable".

For the Orange River option, the conclusion was "It is doubtful whether the transfer of water from the Mzimvubu catchment for the express purpose of augmenting supplies along the Orange River will ever be necessary and justifiable".

For the Algoa WSA the Mzimvubu transfer is shown to be the last and most expensive option to be developed and produces a unit reference value (URV) of water supplied even higher than desalination.

The conclusion from all of these options is that there is no case for the development of a long-distance inter-basin transfer scheme from the Mzimvubu River in the medium to long-term.

It is recommended, however, that the situation be regularly reassessed in the future.

1.3 Investigations for Lalini Dam and Hydropower Scheme

An extension to the feasibility study involved detailed investigations for a second dam on the Tsitsa River at Lalini (3.5 km above the Tsitsa Falls) which would be operated conjunctively with the Ntabelanga Dam to generate significant hydropower for supply into the national grid.

This report describes the process undertaken to determine the hydropower generation potential of the Ntabelanga and Lalini Dams when operated conjunctively.

The Feasibility Design of the Lalini Dam and hydropower scheme is described in Report No. P WMA 12/T30/00/5212/19.

In considering the power supply situation in the region, consultations were held with ESKOM's regional grid access department in East London. They confirmed that the demands on the existing grid were such that locally generated power such as that which could be generated at Lalini could be evacuated into the regional grid to supply local consumers, and this would reduce the power supplied into the grid from further away, which in turn reduces transmission losses and releases that energy for supply to other areas. The limitations in the case of Lalini are that the existing transmission lines that would receive such evacuated energy are 132 kV and this means that evacuation of power at loads greater than 100 MW would not be possible without major additional transmission systems being constructed.

1.3.1 Existing Hydropower in the Region

There are two existing mini-hydropower schemes in the Mthatha area which utilize water released from the Mthatha Dam (See Figure 2-2) in the next catchment south of the Tsitsa River. These are the First Falls and Second Falls schemes and are operated by ESKOM. They operate in series and are classified as "run-of-river" schemes in that they do not have dedicated balancing storage dams, instead rely on the water released downstream from the Mthatha Dam, which is the primary source of water supply to Mthatha.

Both of these schemes have experienced problems with flooded infrastructure and studies have been undertaken2 to resolve these problems and to consider possible increased output capacity upgrades.

[2] *Knight Piesold (2014), Refurbishment of Eastern Cape Mini Hydro Plants and Investigation of Potential Expansion*

First and Second Falls hydroelectric plants (HEPs) have installed capacities of 6 MW and 11 MW respectively but these maximum outputs are only produced at flow rates of 26 m^3/s and 28 m^3/s respectively. Given that the Mthatha Dam is primarily used for water supply and can only sustain a constant release of 4.5 m^3/s at high levels of assurance, it is clear that the actual effective continuous outputs of these two HEPs would be significantly less than their installed capacities.

For example, analysis undertaken has shown that First Falls HEP can only produce a firm (95% level of assurance) energy output of 1.225 MW, and a similar situation exists at Second Falls pro rata their installed capacities. Thus, for a total installed capacity of these two schemes of 17 MW, the firm energy outputs is probably of the order of 3.5 to 5 MW.

The conclusion of that study also stated that it was not economically viable to increase the installed generating capacity of these HEPs.

Given this background, the proposition of increasing the generating capacity of renewable energy in the region by up to a factor of 10 was considered to be highly significant. It would also provide alternatives when considering whether additional funds should be spent on upgrading and maintaining the First and Second Falls HEPs or whether the conjunctive Ntabelanga and Lalini HEP schemes should replace the First and Second falls schemes altogether. This latter decision is, however, not part of the terms of reference of this study.

1.3.2 Ntabelanga and Lalini Dams Conjunctive Hydropower Scheme

The basis of approach was that the generating of hydropower could be used to cross-subsidize the significant energy costs required for pumping water for the irrigation and domestic water supply schemes proposed to be supplied from the Ntabelanga Dam.

The mountainous terrain which constitutes the potable water supply area requires a large amount of high-lift pumping as consequent energy costs.

The agricultural water requirements proposed for the Tsolo area would require lifting the water more than 150 m, which would normally render such a scheme non-viable in terms of the pumping cost component of water supplied, unless hydropower is developed to reduce the net unit cost of water.

The purpose of this second dam and hydropower scheme at Lalini would thus be to generate significant revenue by selling energy into the ESKOM grid, thus generating a net positive income stream which would be used to subsidise the energy and operating costs of the main Ntabelanga water supply and irrigation scheme, thus providing self-sustainability.

A more detailed hydropower analysis and feasibility design study was therefore undertaken to assess the output potential of the Lalini Dam hydropower scheme when used conjunctively with the Ntabelanga Dam. This analysis used the detailed hydrology developed for the catchment and the naturalised and historical flow series that was developed therefrom.

It was confirmed and agreed that the sizing and modus operandi of the Lalini Dam and its associated works would take into account its main role, namely:

i) to generate hydropower both locally at the dam wall and in the Tsitsa River gorge downstream of the Tsitsa Falls, and
ii) to provide sufficient flow of water downstream of the Lalini Dam and these hydroelectric plants (HEPs) to meet environmental water requirements for an ecological Class B/C.

In order to facilitate this analysis detailed investigations were undertaken of the Lalini Dam components of the scheme, inter alia:

- detailed topographical survey and positioning of the proposed Lalini Dam,
- geotechnical investigations of the dam site, sources of construction materials, and tunnel alignments,
- investigation of various Lalini hydropower scheme configuration options, and
- hydropower modelling simulations of the Lalini hydropower plant and two mini-hydropower plants at Ntabelanga and Lalini dams for the conjunctive scheme.

A reserve determination needed to be completed for the Lalini Dam and hydropower plant sites as the hydropower releases can have a significant impact upon the riverine ecology downstream of the proposed dam site and hydropower tunnel exit point.

This included the undertaking of a rapid determination of the EWR of the Tsitsa River downstream of the Tsitsa Falls, which indicated an ecological class of B/C. This EWR value and its recommended rules of operation were included into a new hydropower simulation model to improve the accuracy of estimation the potential hydropower outputs of the scheme.

This was undertaken as a part of the independent EIA contract and results are given in that suite of reports. Based upon these findings, Lalini hydropower scheme operating rules were developed to ensure that environmental water requirement (EWR) recommendations were complied with, and these rules were discussed and agreed with the DWS Resource Directed Measures (RDM) Directorate.

The hydropower assessment of the conjunctive use of the Ntabelanga and Lalini Dams on the Tsitsa River, was undertaken using detailed hydrology produced in the earlier analyses stage of this feasibility study, as well as new and highly accurate topographical survey data for the Lalini dam basin.

The analysis was undertaken using the previously recommended Ntabelanga Dam capacity (1.18 MAR_{PD}), and for a range of Lalini Dam capacities from 0.10 MAR_{PD} (Mean Annual Runoff based upon Present Day flows) to 0.75 MAR_{PD}.

The optimum Lalini Dam size selection was based on several factors, such as unit power cost, funding requirements, as well as social and environmental impacts.

The main objective of the hydropower generation assessment was to determine the amount of energy that can be produced per year from each dam capacity option assuming that the environmental, domestic and agricultural water requirements are met first.

Given that the two dams are to be operated conjunctively, there could be a trade-off on water allocation. If the eventual domestic and irrigation water demands upon the Ntabelanga Dam were to be less than projected, then more water could be made available for release from the dam to increase hydropower generation. However, such releases would still need to follow the water reserve operating rule recommendations for environmental water requirements at both Ntabelanga and Lalini Dams.

The findings of this report were used for the Feasibility Design of the Lalini Dam and hydropower scheme, which is described in Report No. P WMA 12/T30/00/5212/19.

2. STUDY AREA

The Mzimvubu River Catchment, which is the study area, is situated in the Eastern Cape (EC) Province of South Africa which consists of six District Municipalities (DM) and two Metropolitan Municipalities (Buffalo City and Nelson Mandela Bay). These include Cacadu DM in the west across to the Alfred Nzo DM in the east with the two Metropolitan Areas being located around the two major centres of the province, East London and Port Elizabeth, both of which border the Indian Ocean.

The Mzimvubu River Catchment traverses three DMs, namely the Joe Gcabi DM in the north west, the OR Tambo DM in the south west and the Alfred Nzo DM in the east and north east.

A locality map of the catchment area and its position in relation to the DMs in the area is provided in Figure 2-1. The two dam sites that were selected for detailed investigation are also shown on this figure, as follows:

- Ntabelanga Dam located on the Tsitsa River within the quaternary catchment T35E; and
- Lalini Dam, which is also located on the Tsitsa River, within the quaternary catchment T33L.

The proposed Ntabelanga Dam is located approximately 55 km north of Mthatha on the Tsitsa River and the proposed Lalini Dam is located approximately 38 km north-east of Mthatha, as illustrated in Figure 2-1.

The catchment areas contributing to the Ntabelanga and Lalini Dams are approximately 1 967 km^2 and 4 422 km^2, respectively (cf. Table 2-1 for the contributing quaternary catchment areas) and are depicted in Figure 2-2.

The catchment area contributing to the Ntabelanga and Lalini Dams in the Tertiary catchment T35 is somewhat developed with approximately 10% of the catchment area under commercial forestry.

Table 2-1: Contributing Catchment Areas for the Study Area

Tsitsa River Catchment	
Quaternary Catchment	**Catchment Area (km^2)**
T35A	476.5
T35B	396.8
T35C	307.0
T35D	348.9
T35E	493.5
T35F	359.6
T35G	576.2
T35H	521.0
T35J	189.0
T35K	627.1
T35L	339.5
TOTAL	**4 635.1**

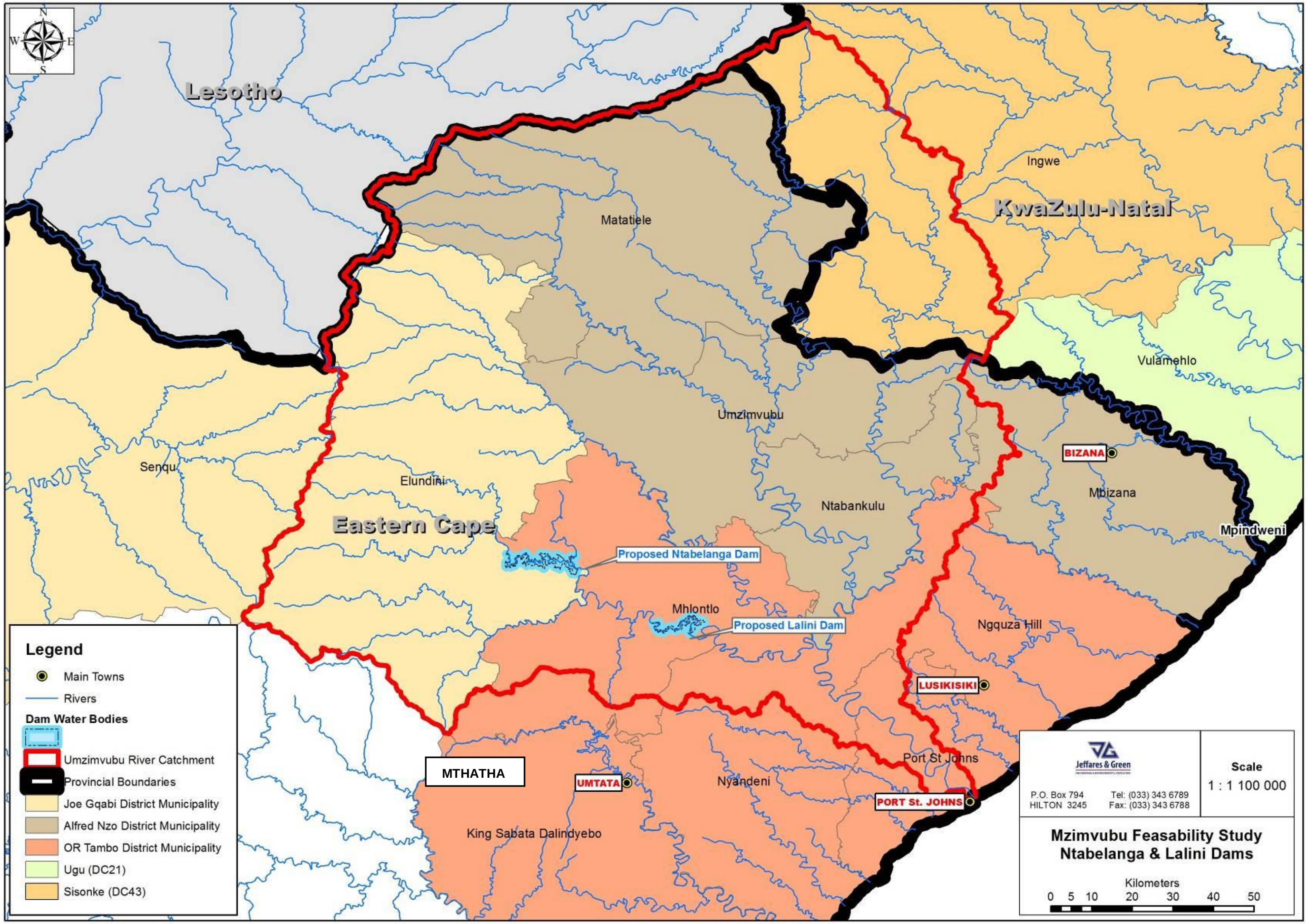


Figure 2-1: Locality Map of the Mzimvubu River Catchment

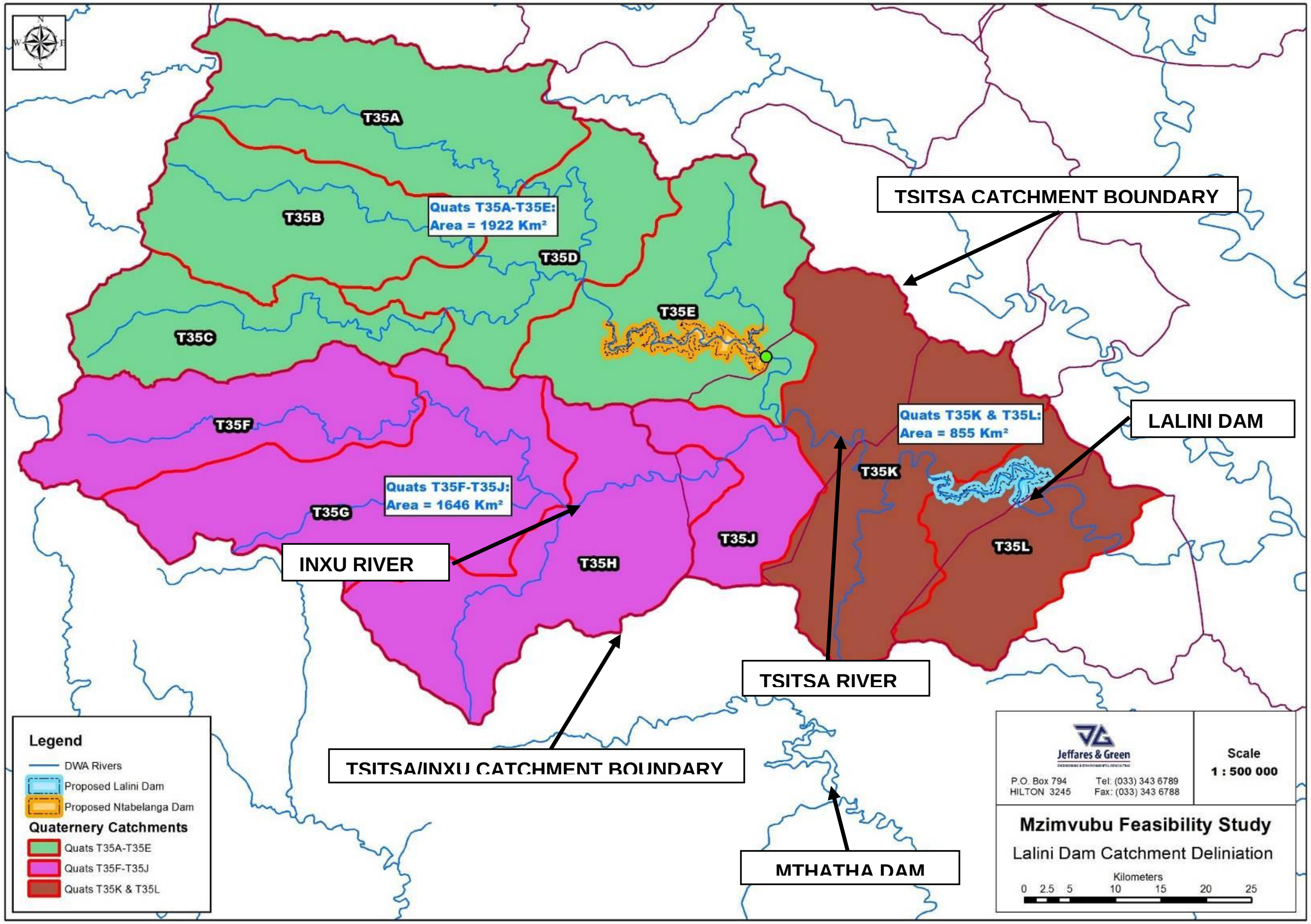


Figure 2-2: Lalini Dam Catchment Deliniation

3. DATA USED IN THE HYDROPOWER GENERATION MODELLING

A detailed report on the detailed hydrology of the Tsitsa River is included in the Water Resources Report No. P WMA 12/T30/00/5212/5, and should be consulted for specifics regarding the methods used and results obtained.

The outputs from the above report form the backbone of the hydropower simulation modelling. In particular, the model uses the following data inputs:

- monthly simulated historical naturalised flow volumes for the Tsitsa River at the Ntabelanga Dam;
- monthly simulated historical present day flow volumes for the Tsitsa River at the Ntabelanga Dam;
- monthly simulated historical naturalised flow volumes for the incremental Tsitsa River catchment area between the Ntabelanga Dam and the Lalini Dam;
- monthly simulated historical present day flow volumes for the incremental Tsitsa River catchment area between the Ntabelanga Dam and the Lalini Dam;
- monthly average rainfall figures in the Ntabelanga and Lalini Dam catchments, and
- monthly average open water evaporation figures in the Ntabelanga and Lalini Dam catchments

Both data and the modelling simulations cover a historical record set of 90 years, or 1 080 months. The historical monthly figures for each dam site were used to generate flow duration curves for each calendar month so that natural variations in flow patterns could be understood and emulated in the modelling.

The simulated naturalised mean annual runoff (MAR_{NAT}) was modelled to be 428.5 million m^3/a at the Ntabelanga Dam site, with the present day mean annual runoff (MAR_{PD}) at the same site being slightly lower at 415.0 million m^3/a. This relatively small difference in MAR between the naturalised and present day flow regimes highlighted the relatively small development level within the catchment.

The naturalised mean annual runoff (MAR_{NAT}) was modelled to be 868.6 million m^3/a at the Lalini Dam site, with the present day mean annual runoff (MAR_{PD}) at the same site being lower at 828.0 million m^3/a. This moderate difference further highlights the limited development level of the Tsitsa River catchment.

The Environmental Water Requirement (EWR) for the Ntabelanga Dam was determined through an Intermediate Reserve Determination (Report No. P WMA 12/T30/00/5212/7), which described the river reach associated with the Ntabelanga Dam to be an ecological Class C, allocating 87.3 million m^3 (20.4% of the MAR_{NAT}) as an annual average EWR.

The EWR for the Lalini Dam was determined through a Rapid Reserve Determination using inputs from the Intermediate Reserve Determination upstream to improve the level of confidence in these results.

The Rapid EWR study of Lalini Dam determined the river reach to be an ecological Class B/C, allocating 287.1 million m^3 (33.1% MAR_{NAT}) as an annual average EWR.

The Reserve Determination studies included recommendations for how and when such EWR are to be released from each dam each month. These take into account the annual and seasonal variations in the historical inflow series. The rules to be applied as to how much water is to be release as EWR relate to the percentage occurrence of the precedent inflows from the above flow duration curves.

The allowance made for trapped sediment accumulation for Ntabelanga Dam was estimated using the updated version of the Rooseboom (1992) method, developed by the WRC (2010). This method was also used to determine the incremental sedimentation allowance taking into consideration the additional catchment area for the proposed Lalini Dam, located on the same river and below Ntabelanga Dam. The values estimated for the Ntabelanga and Lalini dams were the V_{50} values of 35.7 and 32.1 million m^3, respectively.

In addition to the EWR component, the Ntabelanga Dam would supply some 59.86 million m^3/a of raw water for potable and irrigation purposes at a 98% assurance of supply. The seasonal pattern of supply of this water abstracted from the Ntabelanga Dam is allowed for in the hydropower simulation model.

In the earlier part of the feasibility study, hydropower scenarios were investigated at desk top level (using the WRYM hydropower module) to determine the viability of operating the Ntabelanga Dam conjunctively with a second dam on the same river at Lalini, which latter dam and hydropower scheme had been previously identified in a 2004 ESKOM study as having the highest economic viability of potential schemes in this region.

This desk top study indicated that a “maximum” Ntabelanga Dam with a capacity of some 1.18 MAR_{PD}, when operated conjunctively with a “minimum” Lalini Dam with a capacity of some 0.18 MAR_{PD} showed a high potential for hydropower production, and it was decided that this merited a more detailed investigation using more accurate and detailed information.

A study extension was issued to undertake more detailed investigations to improve the reliability of data and information to be used on the Lalini hydropower study. This included a detailed topographical survey to accurately define the dam site geometry, the depth verses capacity and depth verses surface area statistics for the Lalini Dam, as well as geotechnical investigations and options analyses to define and optimise the hydropower system characteristics to be used in the hydropower generation simulation models.

In this detailed hydropower analysis, modelling was undertaken for a range of Lalini Dam storage capacities from 0.10 MAR_{PD} to 0.75 MAR_{PD}, operated conjunctively with the 1.18 MAR_{PD} storage capacity Ntabelanga Dam.

4. HYDROPOWER YIELD MODELLING APPROACH

A previous desk top hydropower assessment of the Tsitsa River system was undertaken using the hydropower module of the WRYM model and based on available data, i.e. the basin characteristics were based on the 20 m contours and the Environmental Water Requirements (EWR) were based on a Desktop Reserve.

Subsequently, more detailed studies and investigations were completed which has improved the overall confidence in the simulated hydropower generation results.

A bespoke spreadsheet-based model was developed to simulate the hydropower generation potential of the system rather than using WRYM. This decision was based on the limited flexibility of the WRYM in terms of hydropower generation simulations for multiple sites. However, the spreadsheet based model was developed using the same principles that the WRYM model is based on and was configured in the same manner (Figure A1 in Annexure A).

The Hydroelectric Plants (HEPs) at each site were configured as follows:

- Ntabelanga Dam had a "mini" HEP with an installed capacity of up to 5 MW (5 x 1 MW sets);
- Lalini Dam had two separated HEPs, namely:
  - A "mini" HEP with an installed capacity of up to 5 MW (5 x 1 MW sets) ; and
  - The "main" HEP with an installed capacity of either 37.5 MW or 50 MW (comprising three or four 12.5 MW units).

These plants and their various turbine combinations were optimised with the aim of generating as much power as possible per year, given the balancing storage provided by the two dams, and taking into consideration the Environmental Water Requirements and consequent operating rules.

The following sub-sections provide detail on the aspects of the modelling that were updated from the previous part of the study.

4.1 Basin Characteristics – Lalini Dam

A LiDAR Survey was undertaken for the Lalini Dam basin. The resultant detailed basin characteristics used for the Lalini Dam site are presented in Table 4-1 and Figure 4-1, respectively.

The detailed survey showed a reduction in stored volume per water depth when compared to the basin characteristics generated from the 20 m contours and used in the previous assessments.

The difference ranged from a 200% reduction in storage at elevation 740 m.a.s.l., to approximately 15% at elevation 770 m.a.s.l.

This change impacts the available live storage for hydropower generation when compared to the previous assessment.

Table 4-1: Detailed Basin Characteristics of the Lalini Dam

Water Level (m.a.s.l.)	Accumulated Volume (MCM)	Area (km2)
787.00	649.72	25.15
780.00	486.58	21.49
775.00	385.79	18.68
770.00	299.10	16.12
765.00	224.36	13.81
760.00	161.10	11.49
755.00	109.58	9.16
750.00	69.78	6.76
745.00	41.40	4.68
740.00	22.24	3.08
735.00	10.22	1.85
730.00	3.67	0.76
725.00	1.08	0.34
720.00	0.07	0.04
717.00	0.00	0.00

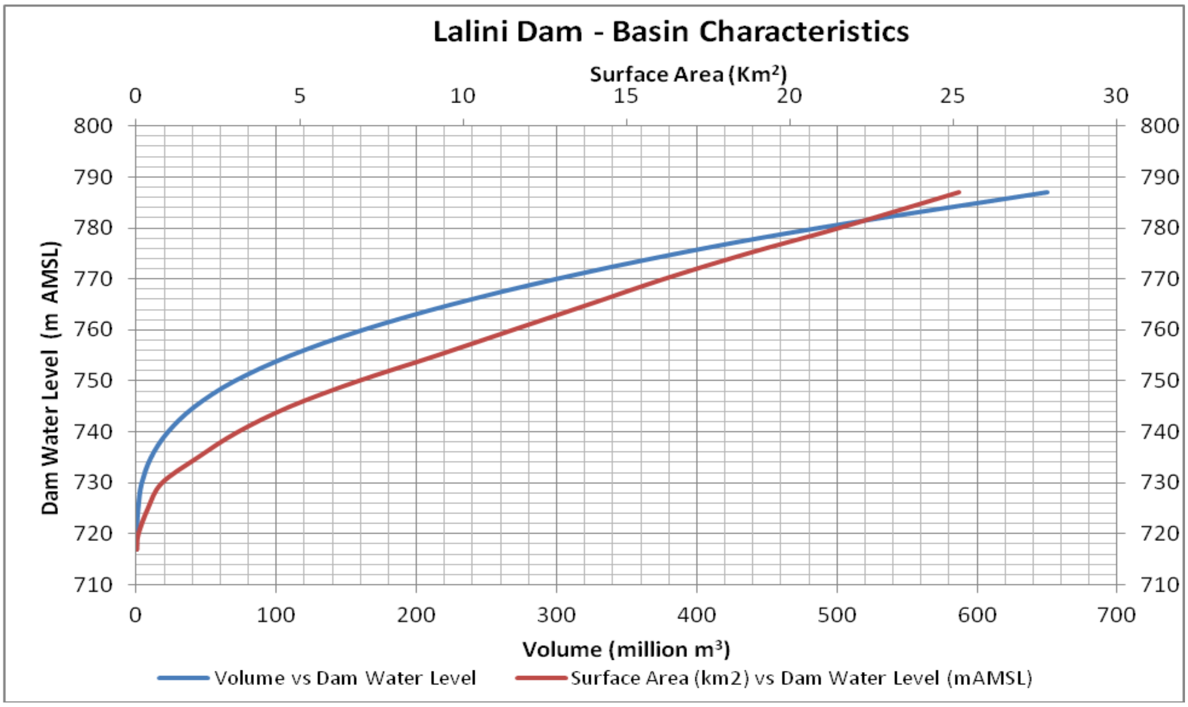


Figure 4-1: Lalini Dam Detailed Basin Characteristics

4.2 Environmental Water Requirements

Following the Intermediate Reserve Determination completed for the Ntabelanga Dam site as a part of this study (Report No. P WMA 12/T30/00/5212/7), a Rapid Reserve Determination was undertaken for the Lalini Dam site. The results from this study are summarised in Table 4-2.

The results show that the Present Ecological State (PES) of the Tsitsa River at this site is an ecological class B/C, which is less than the assumed Desktop Reserve PES. However, the Rapid Reserve study has a better understanding of the ecological flow requirements needed for the biophysical environment and included floods and freshettes required as ecological triggers.

The total recommended release equated to 33.1% of the simulated natural flows at the dam site, i.e. 287.1 million m^3 per year, on average.

Table 4-2 : Rapid Reserve Results for the Lalini Dam Releases

Month	Natural Flows (m^3/s)			Modified Flows (IFR) (m^3/s)			
	Mean	SD	CV	Low Flows	Drought	High Flows	Total Flows
				Maint.		Maint.	Maint.
Oct	17.80	15.57	0.37	3.24	1.17	3.34	6.67
Nov	31.44	29.39	0.36	4.27	1.53	3.55	7.81
Dec	37.62	34.37	0.34	4.85	1.73	4.67	9.52
Jan	45.15	36.88	0.31	5.69	2.01	7.92	13.61
Feb	59.57	44.01	0.31	7.38	2.60	19.48	26.86
Mar	57.99	41.52	0.27	7.48	2.63	15.68	23.16
Apr	32.10	26.84	0.32	6.42	2.27	0.00	6.42
May	12.45	11.68	0.35	4.29	1.54	0.00	4.30
Jun	9.46	11.67	0.48	2.47	1.24	0.00	2.47
Jul	9.28	14.23	0.57	2.16	1.09	0.00	2.16
Aug	8.69	10.17	0.44	2.07	1.02	0.00	2.07
Sep	11.24	16.29	0.56	2.06	1.04	3.46	5.52

A summary of the estimate for the Lalini EWR determination based on the defined BBM table with site specific assurance rules is as follows:

Annual lows (million m^3 or index values):

MAR	=	868.63	
S.Dev	=	373.46	
CV	=	0.43	
Q75	=	15.50	
Q75/MMF	=	0.21	
BFI Index	=	0.36	
CV (JJA+JFM) Index	=	2.07	
ERC = B/C			
Total IFR	=	287.05	(33.1 % MAR)
Maintenance Low flow	=	136.86	(15.8 % MAR)
Drought Low flow	=	52.01	(6.0 % MAR)
Maint. High flow	=	150.18	(17.3 % MAR)
Distribution Type		T Region	

4.3 Hydropower Yield Modelling Assumptions

The majority of the assumptions made in the hydropower yield modelling exercise revolved around the release rules from each dam site in order to limit the impact on the associated ecology and functioning of the river system, whilst still obtaining a reasonable average monthly hydropower generation.

The main assumptions were as follows:

1. The minimum release from the Ntabelanga Dam will conform to the results of the Intermediate Reserve Determination (Class C).

2. The maximum allowable release from Ntabelanga Dam, for the purposes of hydropower generation at Lalini Dam, is equivalent to the greater of the Simulated Naturalised Inflow into Ntabelanga Dam, or seven cubic metres per second. This release is only made when triggered by insufficient water resources at Lalini Dam.

3. The minimum and maximum releases from Lalini Dam not for hydropower generation would conform to the results of the Rapid Reserve Determination (Class B/C).

4. Spillages from either dam can account for the required releases for EWR.

5. The maximum release from Lalini Dam through the HEP will be the flow required to meet the required hydropower generation target for a specific month, assuming that the flow required is available.

6. The practical minimum operating level of the Lalini Dam, including an allowance for the 31.2 million m^3 of storage for the V50 sediment volume, was selected as 745.16 m.a.s.l., or 42.19 million m^3.

7. The HEP elevation is at 450 m.a.s.l., which equates to a maximum static head of 315.47 m and a minimum static head of 295.16 m.

8. Frictional head losses through the two small HEPs (one at each dam to generate hydropower from the required operational releases) were conservatively assumed to be constant at five metres.

9. Frictional head losses in the transfer conduit to the main Lalini Dam HEP vary, depending on the installed maximum turbine generating capacity. These head losses were calculated for the particular conduit diameter required for each installation option, at the flow rate applicable to the number of turbines in operation.

10. Releases from Ntabelanga Dam to Lalini Dam for the purpose of sustaining hydropower generation at Lalini were triggered when the live storage in Lalini Dam dropped below 60 million m^3.

11. The EWR releases from both dams were given first priority in the system.

12. The domestic and agricultural water requirements at Ntabelanga Dam were given priority over releases for hydropower production at Lalini.

13. Spills were not included in the releases to generate hydropower at the two smaller HEPs.

14. Conveyance losses of 10% were assumed on all releases from Ntabelanga for the purpose of hydropower generation at Lalini Dam.

15. All HEP systems were assumed to be 75 % efficient in their production of power. This is a conservative figure.

16. The flow from Ntabelanga was restricted based on outlet works capacity, i.e. the maximum flow through the HEP was limited to 42.85 million m^3/month (16 m^3/s) and the maximum release from Ntabelanga Dam was limited to 160.7 million m^3/m (60 m^3/s).

17. Both dams were started at 100 % Full Supply Capacity for all simulations.

18. All results are based on the historical flow time series, with all hydropower generation results presented in average megawatts per month.

19. The system objective was to generate a monthly target hydropower output at the main Lalini HEP after meeting the EWR, domestic and agricultural water demands. These monthly targets were based upon multiples of installed turbine capacities (e.g. 1, 2, 3 or 4 turbines operating) and took cognisance of the natural monthly flow variations in the river system.

20. The hydropower simulations assumed base load hydropower generation (i.e. 24 hrs per day, 7 days per week operations). Economic analyses were also undertaken for peaking power operations outside of the simulation model.

21. The Ntabelanga Dam's storage capacity remained constant throughout all simulations at 1.18 MAR_{PD}, or 490.5 million m^3. This was as a result of the findings from the preceding part of the study. Simulations were run for Lalini Dam capacities ranging from 0.1 MAR_{PD} to 0.75 MAR_{PD}.

The model works on a "bottom up" principle as regards the water required for targeted Lalini HEP hydropower production, and on a "top down" principle as regards the water available for such hydropower production and other requirements.

A monthly volumetric balance calculation is made, commencing with a starting water level in each dam (normally starts full).

Inflow into Ntabelanga Dam is the historical present day flow for that month and year, plus monthly rainfall falling over the prevailing dam water surface area.

Outflow for that same period is the gross evaporation over the dam water surface, plus the raw water abstracted from the dam for potable and irrigation purposes. The resulting balance in the dam becomes water available for release downstream.

4.3.1 Operating Rules – Ntabelanga Dam

This dam release flows down the Tsitsa River into the Lalini Dam and, together with the incremental inflow from the intervening catchment areas, thus supplementing the volume in Lalini Dam that can be utilized for hydropower generation and EWR purposes. In-steam losses are allowed for between the Ntabelanga and Lalini Dams.

The amount of water released downstream from the Ntabelanga Dam would be determined by operating rules which the dam operators will need to follow on a weekly basis. Based upon the recommendations of the EWR studies, the *minimum* amount released is determined by the monthly EWR requirement with the same percentage occurrence as the measured inflow volume, as is given on the EWR flow duration curve for that particular calendar month. Thus the EWR releases will mimic the prevailing rainfall-runoff conditions in the catchment in any particular month, bearing in mind the historical flow patterns that occurred historically over the 90 year simulation period.

The *maximum* that can be released from the Ntabelanga Dam is generally limited to the simulated naturalized monthly flow with the same percentage of occurrence as the prevailing inflow as determined from the flow duration curves for that same calendar month. The exception to this is where the dam spills, and no constraints are applied.

It was noted that in extreme drought periods, the EWR volumes released did not always satisfy the hydropower generation needs to be sustained by the Lalini Dam balancing storage. In such cases it was agreed that up to 7 m^3/s could be released from Ntabelanga Dam downstream to sustain a minimum hydropower generation output and the EWR requirements at Lalini Dam.

Hydropower generation is achieved at Ntabelanga Dam by using the available head of water in the dam and passing the EWR releases through the mini-HEP located just downstream of the dam wall before returning this flow back to the river. This HEP diversion is limited to 16 m^3/s as EWR flows above this have a low recurrence interval, and it was considered not worth sizing the HEP plant and its conduit for a larger flow rate than this.

4.3.2 Operating Rules – Lalini Dam

The monthly inflow balancing regime as described for Ntabelanga Dam is modelled in the same way at Lalini Dam. In this case however, there is no potable or irrigation water requirement, but water is instead diverted through the 7.8 km long main HEP conduit to the main HEP located in the river gorge downstream of the Tsitsa Falls, and at an elevation of some 300 m below the Lalini Dam site. This arrangement is shown in Figure 4-2. The figure shows two tunnel options of which the deeper, direct option is recommended.

The feasibility design of the Lalini Dam and hydropower scheme is described in detail in Report No. P WMA 12/T30/00/5212/19, and Cost Estimates and Economic Analysis of this project component are included in Report No. P WMA 12/T30/00/5212/15.

The amount of water released downstream from the Lalini Dam would again be determined by operating rules which the dam operators will need to follow on a weekly basis. Based upon the recommendations of the EWR studies, the <u>minimum</u> amount released is determined by the monthly EWR requirement with the same percentage occurrence as the measured inflow volume, as is given on the EWR flow duration curve for that particular calendar month.

In this case the water released from the Ntabelanga Dam would alter the natural Lalini inflow regime, and this will need to be taken into consideration when determining the precedent streamflow conditions in the Lalini catchment when setting the percentage occurrence factor to apply to the monthly flow duration curve, and thus the volume of EWR to be released in any particular month.

Hydropower generation is achieved at the Lalini Dam itself by using the available head of water in the dam and passing the EWR releases through the mini-HEP located just downstream of the dam wall before returning this flow back to the river. This HEP diversion is again limited to 16 m^3/s as EWR flows above this have a low recurrence interval, and it was considered not worth sizing the HEP plant and its conduit for a larger flow rate than this.

The hydropower simulation model always allows for the EWR to be released downstream of the Lalini dam before allowing water to be passed through the main HEP system via the conduit shown in Figure 4-2.

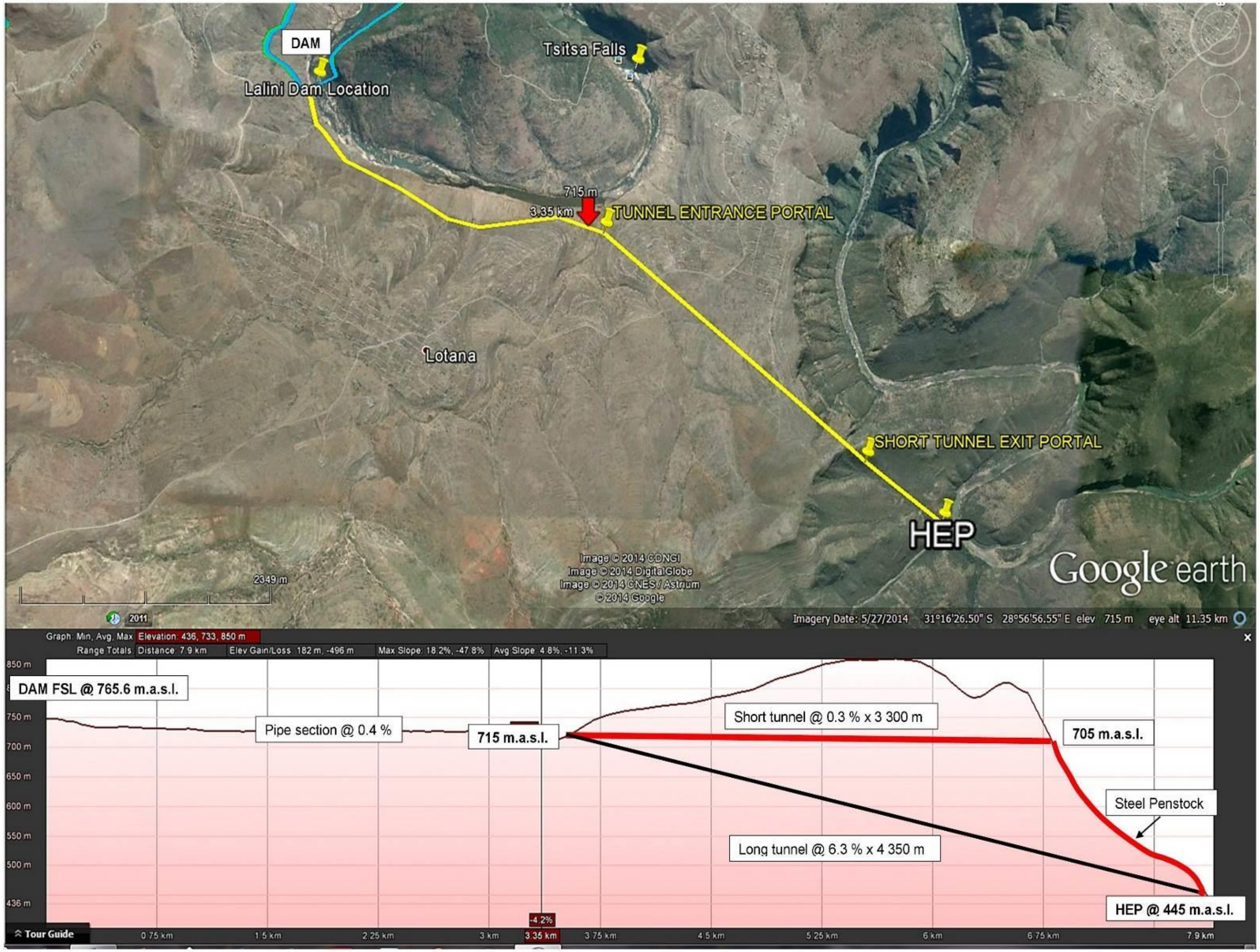


Figure 4-2: Lalini Main HEP System Arrangement

In order to determine how much water is to be passed through the main HEP plant, a target hydropower output was set for each month of the year. The model allows this to be undertaken quickly and iteratively until the maximum average energy output per year is achieved.

From the results that this produced it was noted that for a base load (24/7 operations) main HEP there was no merit in installing plant of capacity greater than 50 MW and, furthermore, this maximum installed capacity was often only fully useable in the one wettest month of the year.

In addition, in the drier months of the year, it was shown that the maximum power output would drop to around 5 to 15 MW, due to the need to limit the flow rate of water returned back into the river when mimicking the naturalized flow regime, as well as times in drought cycles when both Ntabelanga and Lalini Dams would be at their lowest levels.

If the rule of not exceeding the simulated naturalized flow regime for all months and percentage occurrences is strictly adhered to, then the main Lalini HEP scheme would need to be shut down or operated at a very low output level in a significant number of months in the driest years of operation.

This is exemplified in Table 4-3, which shows the percentage occurrences of various naturalised flow rates (expressed in m^3/s) over the 12 calendar months, taken from the monthly flow duration curves.

Table 4-4 shows the recommended minimum EWR releases in each calendar month, based upon the same percentage occurrences as the prevailing inflow conditions in the catchment.

Table 4-3: Simulated Naturalized Flows at Lalini Dam

	%age Occurrence of Naturalized Flow in m^3/s										
MONTH	**0%**	**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**99%**
Oct	89.98	42.94	27.85	18.44	13.98	11.12	9.52	7.63	5.63	3.76	2.87
Nov	133.46	77.20	47.35	38.34	28.40	21.91	16.37	13.21	10.38	6.78	4.04
Dec	171.33	90.62	66.48	46.83	31.95	22.89	19.07	16.32	10.86	7.77	1.91
Jan	178.63	98.97	65.61	56.75	45.03	34.06	25.45	23.41	15.70	10.93	3.27
Feb	177.76	122.79	94.58	75.57	60.22	47.89	39.18	27.38	19.35	16.24	7.11
Mar	218.40	117.67	80.20	70.21	59.99	53.36	37.29	29.55	24.31	15.11	7.95
Apr	157.53	57.10	46.10	39.52	34.55	28.25	18.40	14.51	10.90	8.16	3.05
May	76.51	25.89	18.07	13.07	10.35	8.77	7.06	5.97	4.88	4.05	3.32
Jun	73.12	19.29	12.67	8.43	6.89	5.24	4.88	4.08	3.72	3.14	2.47
Jul	67.65	17.85	10.29	8.16	5.72	4.76	4.33	3.89	3.33	2.99	2.14
Aug	60.82	22.86	10.98	7.44	6.16	5.14	4.20	3.75	3.05	2.65	2.45
Sep	128.80	28.34	14.70	9.36	7.90	6.09	4.78	3.92	3.38	2.65	2.03
AVE	**127.83**	**60.13**	**41.24**	**32.68**	**25.93**	**20.79**	**15.88**	**12.80**	**9.62**	**7.02**	**3.55**

Table 4-4: Desktop Class BC EWR at Lalini Dam

	%age Occurrence of EWR in m³/s										
MONTH	**0%**	**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**99%**
Oct	9.18	9.18	9.07	8.81	8.28	7.37	6.04	4.44	2.96	1.95	1.56
Nov	10.88	10.88	10.76	10.46	9.87	8.81	7.26	5.38	3.60	2.40	1.94
Dec	13.53	13.53	13.42	13.16	12.63	11.66	10.09	7.89	5.39	3.26	1.91
Jan	25.49	25.49	22.81	20.51	18.36	14.54	12.62	9.91	6.80	4.13	2.89
Feb	51.87	51.87	45.40	39.93	35.01	26.30	22.68	17.63	11.86	6.96	4.67
Mar	46.42	46.42	39.95	34.54	29.62	21.66	17.74	13.00	8.53	5.50	4.34
Apr	9.69	9.69	9.58	9.33	8.82	7.93	6.65	5.10	3.66	2.69	2.31
May	6.48	6.48	6.41	6.24	5.90	5.31	4.45	3.43	2.46	1.81	1.57
Jun	3.63	3.63	3.58	3.47	3.25	2.89	2.42	1.93	1.55	1.33	1.26
Jul	3.18	3.18	3.13	3.03	2.83	2.51	2.10	1.68	1.35	1.17	1.10
Aug	2.95	2.95	2.91	2.82	2.64	2.35	1.97	1.57	1.26	1.09	1.03
Sep	7.43	7.43	7.34	7.13	6.72	6.00	4.78	3.70	2.52	1.73	1.43
AVE	**15.90**	**15.90**	**14.53**	**13.28**	**11.99**	**9.78**	**8.23**	**6.30**	**4.33**	**2.83**	**2.17**

Table 4-5 shows the water thus available to be passed through the main Lalini HEP under the same prevailing catchment conditions, being the difference between the naturalised and EWR flow figures.

The cells highlighted in Table 4-5 are those where available average monthly flow would be insufficient to operate the main HEP at its minimum output (one turbine set operating) continuously throughout the month. In the wetter months, this only occurs between 10 and 20% of the years, but in the dry season months this reduced output could occur to a lesser or greater degree up to 60% of the years.

The flow rate required to operate a single 12.5 MW turbine unit continuously is some 6 m^3/s. The operational regime proposed is to therefore make use of the available balancing capacity in the dams to pass a minimum of 6 m^3/s through the main Lalini HEP turbines in the particularly low flow dry season months in order to ensure that a minimum of 12.5 MW can always be produced by the main HEP at all times.

Table 4-6 (based on the 37.5 MW installed capacity option) shows the impact of strictly limiting the main HEP flow throughput to the naturalized flow regime, and it is evident that the power outputs in dry season months could be low for a significant proportion of the years of simulation.

The highlighted cells in Table 4-7 show the quantum of water that would be required to be released through the main HEP extra over the naturalized flow regime values, and the percentage occurrence of when this would be required (e.g. 80% actually means this would only be required 20% of the time).

As can be seen this additional release amount averages less than 3 m^3/s, but in some drought years could be up to the maximum 6 m^3/s, albeit that this would be a rare occurrence.

Table 4-5: Flow Available for Hydropower Generation

	%age Occurrence of Flow Available for Hydropower Generation (m^3/s)										
MONTH	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	80.80	33.76	18.78	9.63	5.70	3.75	3.48	3.19	2.67	1.81	1.30
Nov	122.58	66.32	36.59	27.88	18.53	13.10	9.11	7.84	6.78	4.38	2.10
Dec	157.79	77.09	53.07	33.68	19.32	11.22	8.98	8.43	5.47	4.51	0.00
Jan	153.14	73.48	42.81	36.25	26.67	19.52	12.83	13.50	8.90	6.80	0.38
Feb	125.89	70.92	49.19	35.64	25.20	21.59	16.50	9.76	7.49	9.29	2.44
Mar	171.97	71.25	40.26	35.67	30.37	31.70	19.55	16.55	15.78	9.61	3.61
Apr	147.84	47.41	36.51	30.19	25.73	20.31	11.76	9.40	7.24	5.47	0.73
May	70.03	19.40	11.66	6.83	4.45	3.46	2.61	2.54	2.42	2.24	1.76
Jun	69.49	15.66	9.08	4.96	3.65	2.35	2.46	2.15	2.17	1.81	1.22
Jul	64.47	14.67	7.16	5.13	2.89	2.25	2.23	2.21	1.97	1.82	1.04
Aug	57.87	19.91	8.07	4.63	3.52	2.79	2.23	2.18	1.78	1.57	1.42
Sep	121.37	20.91	7.36	2.22	1.18	0.09	0.00	0.22	0.85	0.92	0.60
AVE	111.94	44.23	26.71	19.39	13.93	11.01	7.65	6.50	5.29	4.18	1.38

Table 4-6: Main HEP Power Output without Supplementary Release through HEP

	%age Occurrence of HEP Output (MW) - No Supplementary Release										
MONTH	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	37.5	37.5	37.5	18.6	11.0	7.2	6.7	6.1	5.1	3.5	2.5
Nov	37.5	37.5	37.5	37.5	35.7	25.2	17.5	15.1	13.1	8.4	4.0
Dec	37.5	37.5	37.5	37.5	37.5	21.6	17.3	16.2	10.5	8.7	0.0
Jan	37.5	37.5	37.5	37.5	37.5	37.5	24.7	26.0	17.1	13.1	0.7
Feb	37.5	37.5	37.5	37.5	37.5	37.5	31.8	18.8	14.4	17.9	4.7
Mar	37.5	37.5	37.5	37.5	37.5	37.5	37.5	31.9	30.4	18.5	7.0
Apr	37.5	37.5	37.5	37.5	37.5	37.5	22.7	18.1	13.9	10.5	1.4
May	37.5	37.5	22.5	13.2	8.6	6.7	5.0	4.9	4.7	4.3	3.4
Jun	37.5	30.2	17.5	9.6	7.0	4.5	4.7	4.1	4.2	3.5	2.3
Jul	37.5	28.3	13.8	9.9	5.6	4.3	4.3	4.3	3.8	3.5	2.0
Aug	37.5	37.5	15.5	8.9	6.8	5.4	4.3	4.2	3.4	3.0	2.7
Sep	37.5	37.5	14.2	4.3	2.3	0.2	0.0	0.4	1.6	1.8	1.2
AVE	37.52	36.14	28.84	24.12	22.04	18.77	14.72	12.51	10.20	8.06	2.67

As shown in Table 4-8, the benefits of this additional release allowance within the EWR rules are obvious, in that on average, some 10% more power can be generated by the same HEP configuration than if the additional release is not allowed.

This situation was presented to the team undertaking the Lalini EWR study and the consensus was that such releases would not significantly change the ecological regime of the river below the HEP outlet, and therefore could be allowed.

Flowing review and discussion of the EWR Report the DWS RDM office has approved the operational regime whereby an additional 6 m^3/s over naturalized flow can be passed through the HEP turbines and released back to the river as and when required in any month.

Table 4-7: Water released through HEP extra over naturalized flow to maintain 12.5 MW

	% age Occurrence of Water Released Over Naturalized Flow (m³/s) to Maintain 12.5 MW Output										
MONTH	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	0.00	0.00	0.00	0.00	0.30	2.25	2.52	2.81	3.33	4.19	4.70
Nov	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.62	3.90
Dec	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.53	1.49	6.00
Jan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.62
Feb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.56
Mar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.39
Apr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.53	5.27
May	0.00	0.00	0.00	0.00	1.55	2.54	3.39	3.46	3.58	3.76	4.24
Jun	0.00	0.00	0.00	1.04	2.35	3.65	3.54	3.85	3.83	4.19	4.78
Jul	0.00	0.00	0.00	0.87	3.11	3.75	3.77	3.79	4.03	4.18	4.96
Aug	0.00	0.00	0.00	1.37	2.48	3.21	3.77	3.82	4.22	4.43	4.58
Sep	0.00	0.00	0.00	3.78	4.82	5.91	6.00	5.78	5.15	5.08	5.40
AVE	0.00	0.00	0.00	0.59	1.22	1.78	1.92	1.96	2.06	2.46	4.62

Table 4-8: Main HEP Power Output with Supplementary Release through HEP (MW)

	%age Occurrence of HEP Output (MW) - With Supplementary Release										
MONTH	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	37.5	37.5	37.5	19.3	12.5	12.5	12.5	12.5	12.5	12.5	12.5
Nov	37.5	37.5	37.5	37.5	37.1	26.2	18.2	15.7	13.6	12.5	12.5
Dec	37.5	37.5	37.5	37.5	37.5	22.4	18.0	16.9	12.5	12.5	12.5
Jan	37.5	37.5	37.5	37.5	37.5	37.5	25.7	27.0	17.8	13.6	12.5
Feb	37.5	37.5	37.5	37.5	37.5	37.5	33.0	19.5	15.0	18.6	12.5
Mar	37.5	37.5	37.5	37.5	37.5	37.5	37.5	33.1	31.6	19.2	12.5
Apr	37.5	37.5	37.5	37.5	37.5	37.5	23.5	18.8	14.5	12.5	12.5
May	37.5	37.5	23.3	13.7	12.5	12.5	12.5	12.5	12.5	12.5	12.5
Jun	37.5	31.3	18.2	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5
Jul	37.5	29.3	14.3	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5
Aug	37.5	37.5	16.1	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5
Sep	37.5	37.5	14.7	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5
AVE	37.52	36.32	29.11	25.67	24.97	22.81	19.24	17.16	14.99	13.66	12.50

4.3.3 Peaking Power Generation Options

As described in detail in Report Nos. P WMA 12/T30/00/5212/19 and P WMA 12/T30/00/5212/15, the operation of the base load Lalini HEP scheme as a peaking station during winter months, or as a full-time peaking station with up to 150 MW of installed power, is not recommended, and was not investigated further in the hydropower modelling process.

4.3.4 Base Load Power Generation Options

Two base case options were investigated, namely

i) installed capacity 50 MW, and
ii) installed capacity 37.5 MW

Option i) has increased capital and operating cost implications in that the HEP plant and larger diameter conduit costs would be higher than that of option ii). Option i), however, does deliver more energy per annum into the grid system, and this is discussed further in the following sections.

The electro-mechanical specialists on the team undertook an optimisation investigation, including consultation with international hydropower turbine manufacturers, and their recommendation was that an arrangement of 3 or 4 identical turbines, each with a net power output (after efficiency and transmission losses) of 12.5 MW, would be the best operational regime. The hydropower model was therefore set up so that 1, 2 3 or 4 generating sets were activated in order to try to meet the target power output for each individual month of the year.

A similar approach was taken for the Ntabelanga and Lalini Dam mini-HEPs where up to 5 x 1 MW turbines can be activated.

It should be noted that, on average, the full monthly power output targets were met in greater than 70% of the simulation months, and that there were very few months in the total 90 year simulation period whereby the HEP plant would have to be taken off-line altogether.

Tables 4-9 to 4-11 and Figures 4-3 to 4-5 summarise the results of the modelling run undertaken for the recommended conjunctive hydropower scheme (37.5 MW installed capacity option).

Table 4-9: Model Results: Ntabelanga Dam HEP

Month	Monthly Target (MW)	Avg HP Output (MW)	Avg Energy Supplied (KWh)
Oct	1.00	0.74	547 860
Nov	3.00	1.71	1 229 237
Dec	3.00	1.55	1 152 316
Jan	4.00	2.00	1 491 215
Feb	5.00	3.77	2 557 827
Mar	5.00	3.14	2 338 611
Apr	5.00	2.07	1 493 446
May	4.00	0.99	734 676
Jun	2.00	0.91	652 112
Jul	1.00	0.62	460 567
Aug	1.00	0.59	436 999
Sep	1.00	0.69	500 319
Total Energy Per Year (kWh)			**13 595 184**
Average Power (MW)		**1.57**	

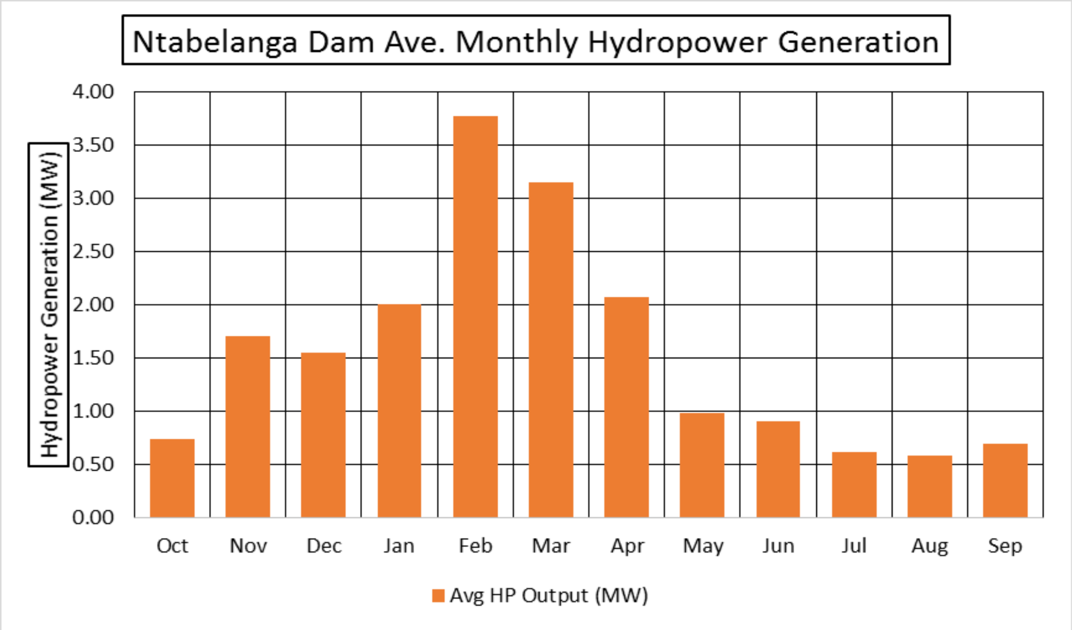


Figure 4-3: Ntabelanga Dam HEP Average Monthly Hydropower Generation

Table 4-10: Model Results: Lalini Main HEP

Month	Monthly Target (MW)	Avg HP Output (MW)	Avg Energy Supplied (KWh)
Oct	12.50	18.76	13 959 044
Nov	12.50	23.67	17 043 420
Dec	25.00	22.99	17 102 324
Jan	25.00	21.89	16 283 250
Feb	25.00	23.54	15 963 055
Mar	37.50	24.55	18 268 136
Apr	25.00	22.27	16 035 946
May	12.50	15.69	11 672 893
Jun	12.50	15.83	11 399 591
Jul	12.50	15.95	11 866 003
Aug	12.50	16.04	11 931 220
Sep	12.50	16.46	11 849 343
Total Energy Per Year (kWh)			**173 374 226**
Average Power (MW)		**19.77**	

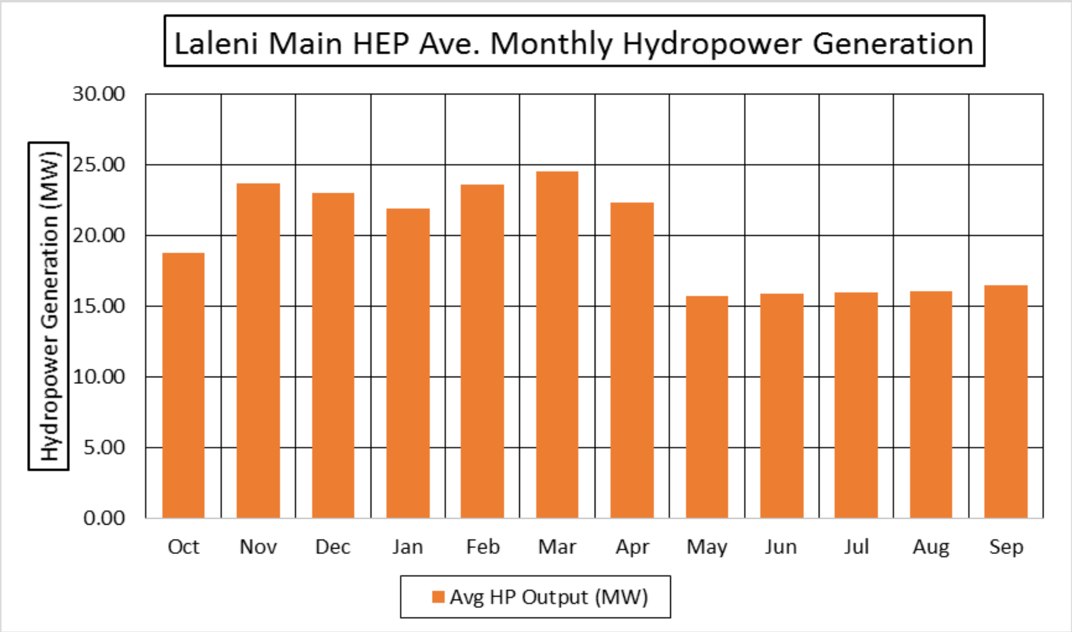


Figure 4-4: Lalini Main HEP Average Monthly Hydropower Generation

Table 4-11: Model Results: Lalini Dam HEP

Month	Monthly Target (MW)	Avg HP Output (MW)	Avg Energy Supplied (KWh)
Oct	2.00	1.41	1 047 895
Nov	3.00	1.74	1 251 338
Dec	3.00	2.34	1 742 819
Jan	4.00	3.10	2 303 120
Feb	5.00	3.90	2 644 895
Mar	5.00	3.91	2 910 565
Apr	5.00	1.74	1 249 716
May	4.00	1.22	905 288
Jun	3.00	0.66	476 106
Jul	1.00	0.59	440 637
Aug	1.00	0.54	401 078
Sep	1.00	0.81	585 678
Total Energy Per Year (kWh)			**15 959 136**
Average Power (MW)		**1.83**	

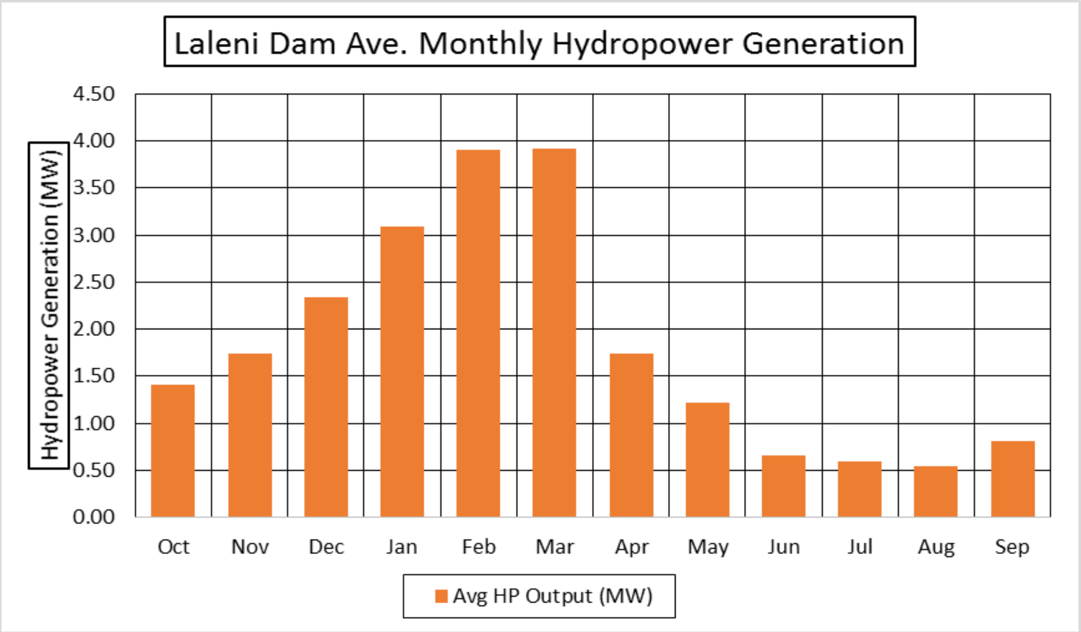


Figure 4-5: Lalini Dam HEP Average Monthly Hydropower Generation

For this same example, Figures 4-6 and 4-7 show the variation in water levels, EWR releases and spills for the Ntabelanga and Lalini Dams throughout the 90 year simulation period, as well as the main Lalini HEP hydropower outputs.

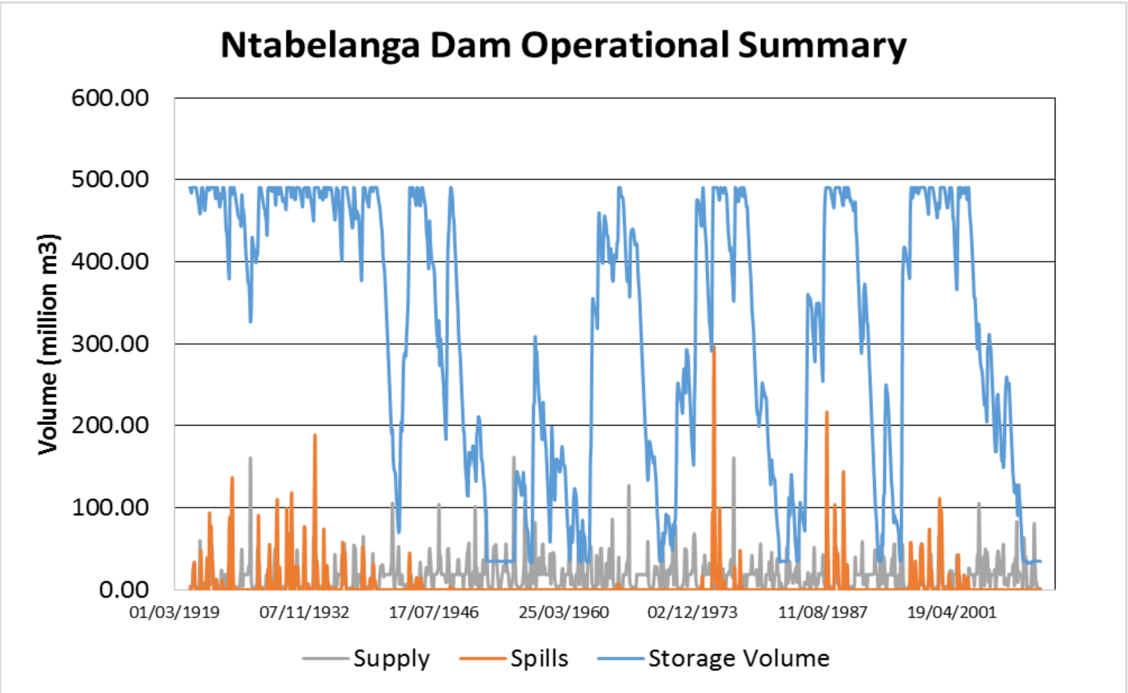


Figure 4-6: Ntabelanga Dam: Water Levels, Releases and Spills

These show that both dams will regularly fill and draw down as required and the full range of available balancing storage is utilized to ensure there is sufficient water to run the hydropower plants on a predominantly continuous basis.

As can be seen, there are at least three extreme drought periods in the 90 years of simulation at which time the dams will have insufficient balancing storage to maintain the full targeted outputs of the hydropower plants. This is a pattern that is experienced regularly in southern Africa.

During these periods, hydropower output would be lower than targeted, and in a few of the months, the scheme would be shut down until dam levels recover.

This is a relatively infrequent occurrence, and other forms of energy production also have periods when installed power output reduces, including wind and solar power.

Even nuclear and coal-fired power stations are occasionally taken off-line for periodical planned maintenance, and such drought periods could be used as an opportunity to undertake similar preventative maintenance or parts replacement on these particular hydropower plants.

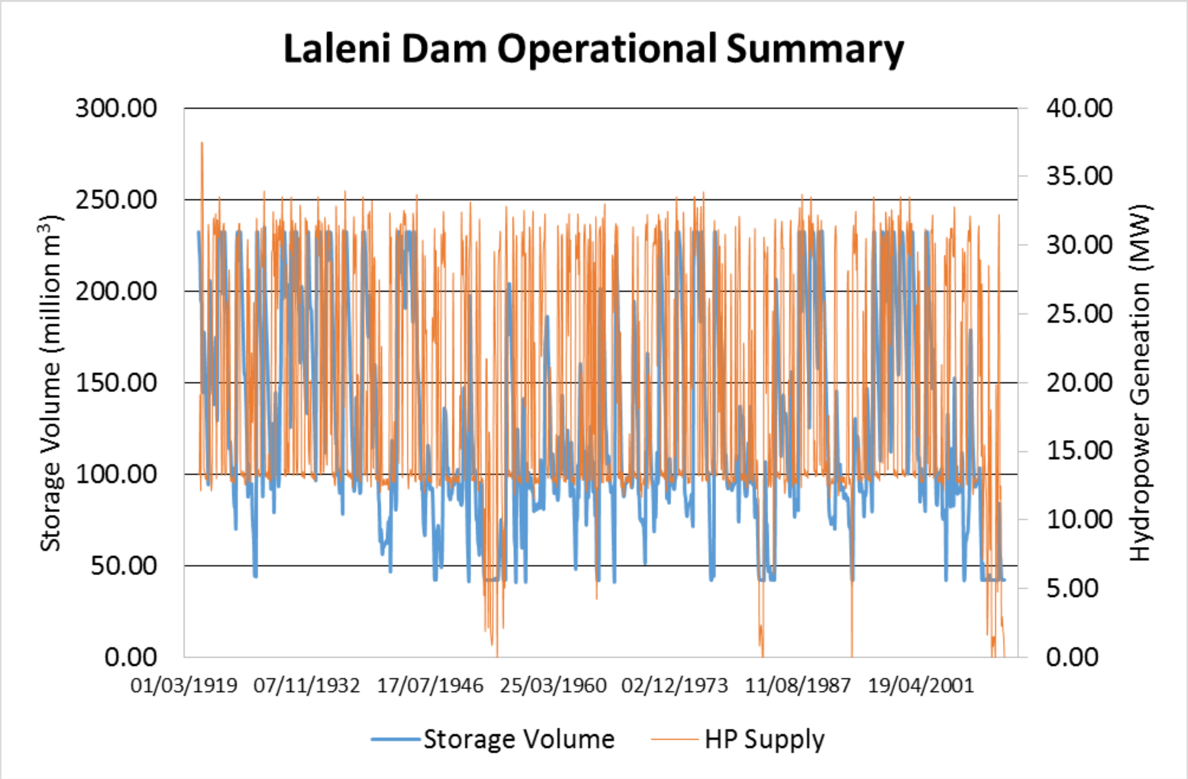


Figure 4-7: Lalini Dam: Water Levels and Hydropower Outputs

Whilst the above examples give the final results of the eventually preferred Lalini Dam capacity and hydropower configuration, the hydropower simulation models were run for a number of different Lalini Dam capacities ranging from 0.1 MAR_{PD} to 0.75 MAR_{PD}, operated conjunctively with the Ntabelanga Dam at its 1.18 MAR_{PD} capacity, the results of which are summarised in the next chapter.

5. HYDROPOWER GENERATION MODELLING RESULTS

Two base case options were investigated for the main Lalini HEP, namely

i) installed capacity 50 MW, and
ii) installed capacity 37.5 MW

The results from the hydropower modelling analyses for a range of Lalini Dam storage volumes are presented in Figures 5-1 and 5-2 and Tables 5-1 and 5-2.

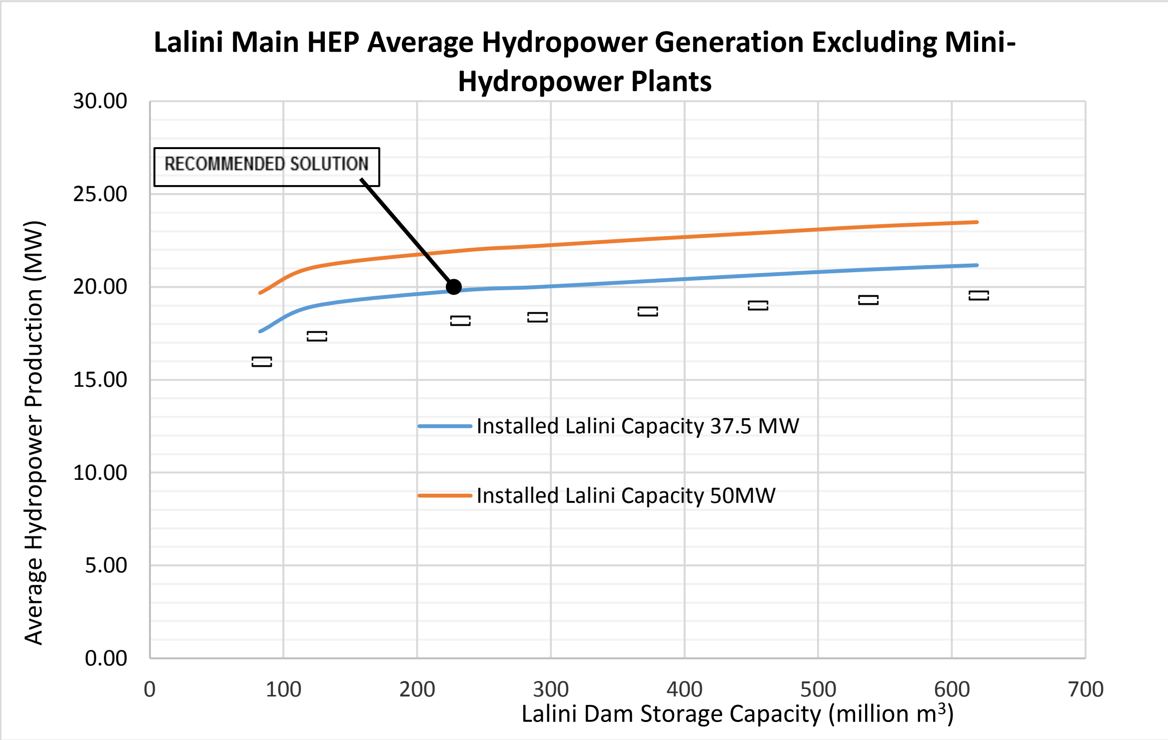


Figure 5-1: Hydropower Analyses Results: Lalini Main HEP

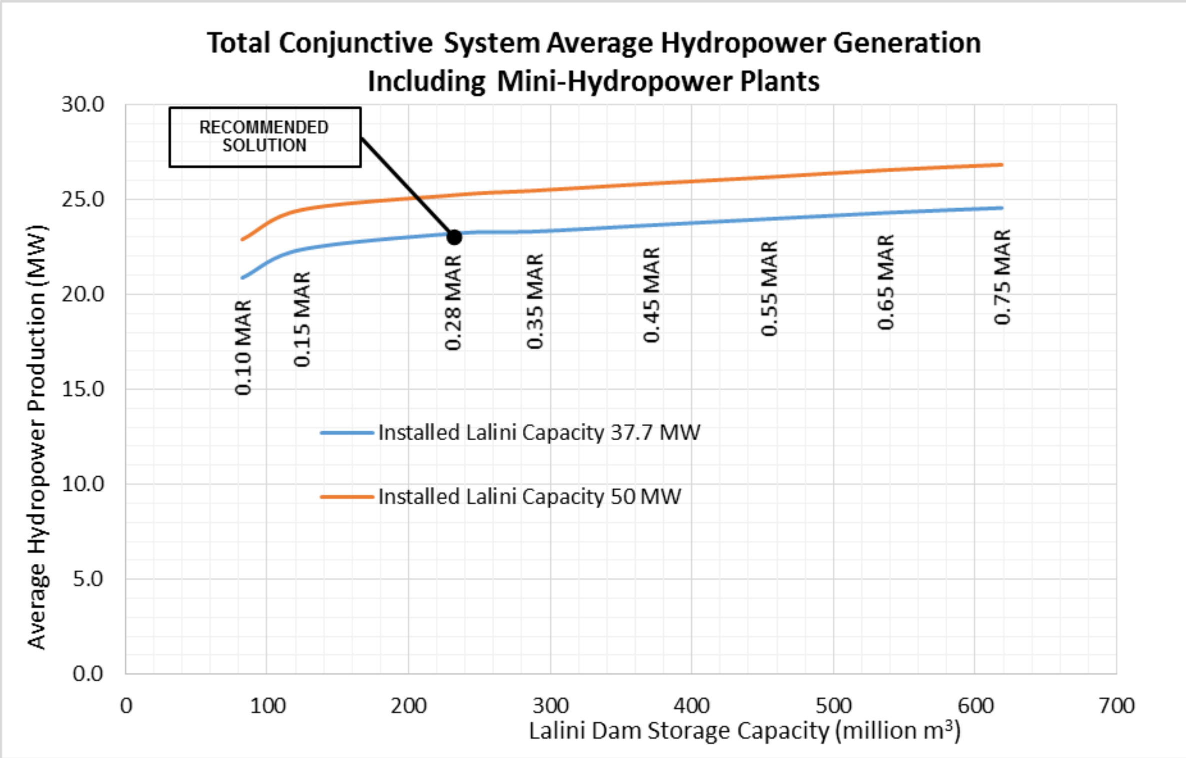


Figure 5-2: Hydropower Analyses Results: Conjunctive Scheme incl Mini-HEPs

Table 5-1: Hydropower Modelling Results: 37.5 MW Installed at Lalini Main HEP

Scenario		Lalini Dam Statistics					Lalini Dam EWR			Ntabelanga Mini-HEP Maximum Installed Capacity	Ntabelanga Mini-HEP Ave. Annual Power Output	Lalini Main HEP Installed Capacity	Lalini Main HEP Ave. Annual Power Output	Lalini Mini-HEP Maximum Installed Capacity	Lalini Mini-HEP Ave. Annual Power Output
No.	Description	FSL	MOL	Gross storage capacity	Live storage capacity	*Area	Class	Requirements		HydroPower	HydroPower	HydroPower	HydroPower	HydroPower	HydroPower
		m.a.s.l	m.a.s.l	million m^3	million m^3	km^2		million m^3/a	% MAR	MW	MW	MW	MW	MW	MW
01	1.18 MAR Ntabelanga + 0.10 MAR Lalini	751.8	745.2	82.5	40.3	7.61	BC	287.1	33.05	5	1.67	37.5	17.60	5	1.60
02	1.18 MAR Ntabelanga + 0.15 MAR Lalini	756.5	745.2	123.8	81.6	9.85	BC	287.1	33.05	5	1.66	37.5	18.98	5	1.71
03	**1.18 MAR Ntabelanga + 0.28 MAR Lalini**	**765.5**	**745.2**	**231.0**	**188.8**	**14.02**	**BC**	**287.1**	**33.05**	**5**	**1.57**	**37.5**	**19.77**	**5**	**1.83**
04	1.18 MAR Ntabelanga + 0.35 MAR Lalini	769.4	745.2	288.8	246.6	15.80	BC	287.1	33.05	5	1.45	37.5	19.99	5	1.87
05	1.18 MAR Ntabelanga + 0.45MAR Lalini	774.2	745.2	371.3	329.1	18.18	BC	287.1	33.05	5	1.40	37.5	20.31	5	1.93
06	1.18 MAR Ntabelanga + 0.55 MAR Lalini	778.4	745.2	453.8	411.6	20.67	BC	287.1	33.05	5	1.35	37.5	20.63	5	1.99
07	1.18 MAR Ntabelanga + 0.65 MAR Lalini	782.3	745.2	536.3	494.1	22.65	BC	287.1	33.05	5	1.31	37.5	20.93	5	2.05
08	1.18 MAR Ntabelanga + 0.75 MAR Lalini	785.8	745.2	618.75	576.56	24.5	BC	287.1	33.05	5	1.28	37.5	21.17	5	2.10

** Surface area at Full Supply Level*

Recommended Scheme

Table 5-2: Hydropower Modelling Results: 50 MW Installed at Lalini Main HEP

Scenario		Lalini Dam Statistics					Lalini Dam EWR			Ntabelanga Mini-HEP Maximum Installed Capacity	Ntabelanga Mini-HEP Ave. Annual Power Output	Lalini Main HEP Installed Capacity	Lalini Main HEP Ave. Annual Power Output	Lalini Mini-HEP Maximum Installed Capacity	Lalini Mini-HEP Ave. Annual Power Output
No.	Description	FSL	MOL	Gross storage capacity	Live storage capacity	*Area	Class	Requirements		HydroPower	HydroPower	HydroPower	HydroPower	HydroPower	HydroPower
		m.a.s.l	m.a.s.l	million m^3	million m^3	km^2		million m^3/a	% MAR	MW	MW	MW	MW	MW	MW
01	1.18 MAR Ntabelanga + 0.10 MAR Lalini	751.8	745.2	82.5	40.3	7.61	BC	287.1	33.05	5	1.65	50	19.68	5	1.56
02	1.18 MAR Ntabelanga + 0.15 MAR Lalini	756.5	745.2	123.8	81.6	9.85	BC	287.1	33.05	5	1.71	50	21.07	5	1.66
03	1.18 MAR Ntabelanga + 0.28 MAR Lalini	765.5	745.2	231.0	188.8	14.02	BC	287.1	33.05	5	1.54	50	21.94	5	1.74
04	1.18 MAR Ntabelanga + 0.35 MAR Lalini	769.4	745.2	288.8	246.6	15.80	BC	287.1	33.05	5	1.47	50	22.20	5	1.79
05	1.18 MAR Ntabelanga + 0.45MAR Lalini	774.2	745.2	371.3	329.1	18.18	BC	287.1	33.05	5	1.41	50	22.57	5	1.85
06	1.18 MAR Ntabelanga + 0.55 MAR Lalini	778.4	745.2	453.8	411.6	20.67	BC	287.1	33.05	5	1.37	50	22.90	5	1.90
07	1.18 MAR Ntabelanga + 0.65 MAR Lalini	782.3	745.2	536.3	494.1	22.65	BC	287.1	33.05	5	1.35	50	23.24	5	1.95
08	1.18 MAR Ntabelanga + 0.75 MAR Lalini	785.8	745.2	618.75	576.56	24.5	BC	287.1	33.05	5	1.34	50	23.49	5	1.99

** Surface area at Full Supply Level*

6. SUMMARY AND CONCLUSIONS

The hydropower assessment of the conjunctive use of the Ntabelanga and Lalini Dams Tsitsa River system, was undertaken using detailed hydrology produced in the earlier analyses stage of this feasibility study, as well as new and highly accurate topographical survey data for the Lalini dam basin.

The analysis was undertaken using the previously recommended Ntabelanga Dam capacity, and for a range of Lalini Dam capacities from 0.10 MAR_{PD} to 0.75 MAR_{PD}.

The optimum Lalini dam size selection should be based on several factors, such as the cost benefits, as well as social and environmental impacts.

The main objective of the hydropower generation assessment was to determine the average amount of energy that can be produced per year from each dam capacity option assuming that the environmental, domestic and agricultural water requirements are met first.

The energy figures thus produced were incorporated into the economic and financial models undertaken to determine the best conjunctive use solution.

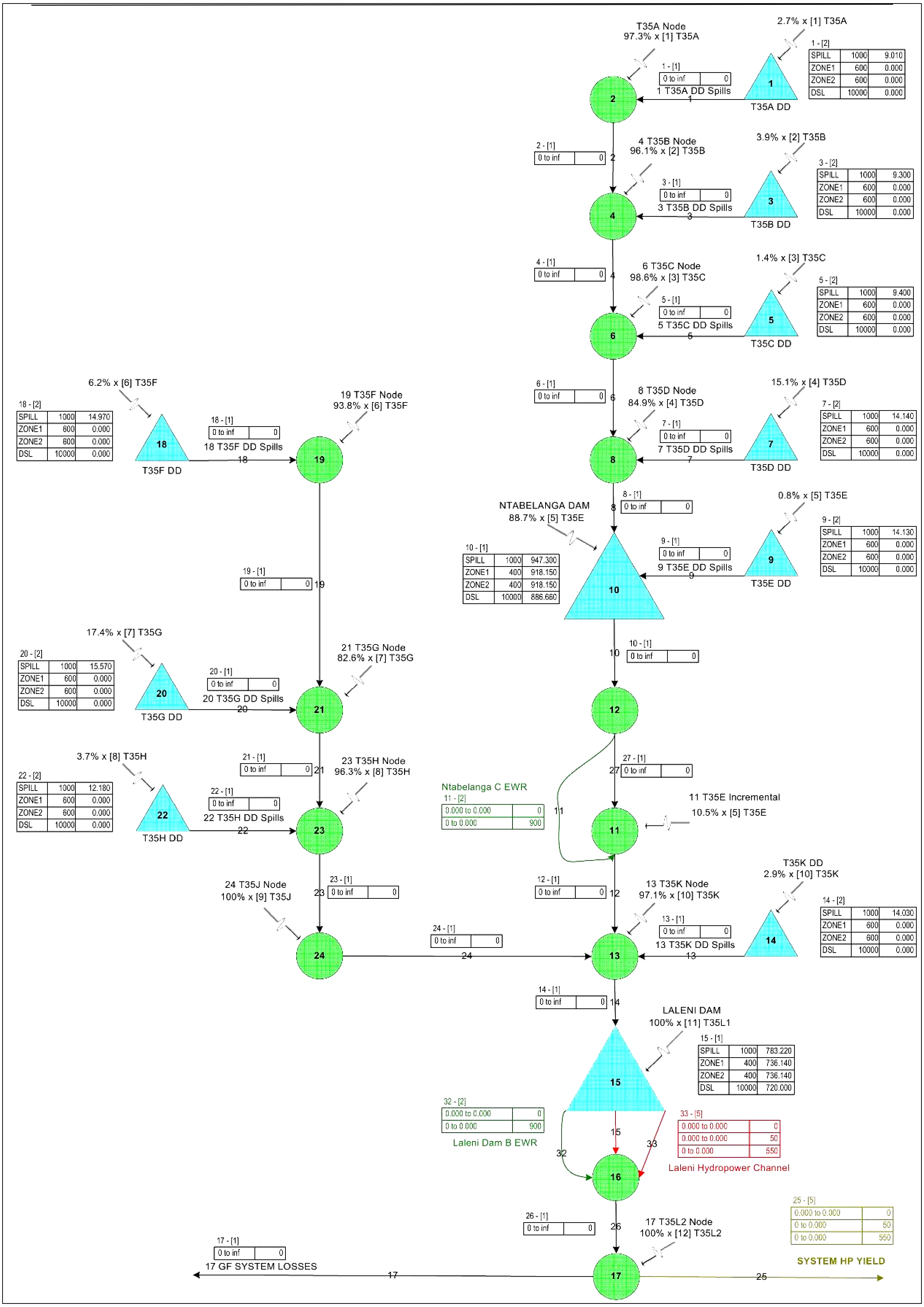
These analyses are described in the Feasibility Design of the Lalini Dam and Hydropower Scheme Report No. P WMA 12/T30/00/5212/19, and in the Cost Estimates and Economic Analysis Report No. P WMA 12/T30/00/5212/15.

As described in the above reports, it is recommended that:

- the Ntabelanga Dam be constructed with a storage capacity of 1.18 MAR_{PD} (490 million m^3),
- the Lalini Dam be constructed with a storage capacity of 0.28 MAR_{PD} (231 million m^3),
- the Ntabelanga Dam mini-HEP be implemented with an installed generating capacity of 5 MW (5 x 1 MW unit), and
- the Lalini Dam mini-HEP be implemented with an installed generating capacity of 5 MW (5 x 1 MW unit), and
- the main Lalini HEP be implemented with an installed generating capacity of 37.5 MW (3 x 12.5 MW units).

APPENDIX A

TSITSA RIVER HYDROPOWER MODELLING CONFIGURATION


T35A Node
97.3% x [1] T35A
2.7% x [1] T35A
1 T35A DD Spills
T35A DD
4 T35B Node
96.1% x [2] T35B
3.9% x [2] T35B
3 T35B DD Spills
T35B DD
6 T35C Node
98.6% x [3] T35C
1.4% x [3] T35C
5 T35C DD Spills
T35C DD
8 T35D Node
84.9% x [4] T35D
15.1% x [4] T35D
7 T35D DD Spills
T35D DD
NTABELANGA DAM
88.7% x [5] T35E
0.8% x [5] T35E
9 T35E DD Spills
T35E DD
6.2% x [6] T35F
18 T35F DD Spills
T35F DD
19 T35F Node
93.8% x [6] T35F
17.4% x [7] T35G
20 T35G DD Spills
T35G DD
21 T35G Node
82.6% x [7] T35G
3.7% x [8] T35H
22 T35H DD Spills
T35H DD
23 T35H Node
96.3% x [8] T35H
Ntabelanga C EWR
11 T35E Incremental
10.5% x [5] T35E
24 T35J Node
100% x [9] T35J
13 T35K Node
97.1% x [10] T35K
T35K DD
2.9% x [10] T35K
13 T35K DD Spills
LALENI DAM
100% x [11] T35L1
Laleni Dam B EWR
Laleni Hydropower Channel
17 T35L2 Node
100% x [12] T35L2
17 GF SYSTEM LOSSES
SYSTEM HP YIELD