Department of Water and Sanitation

Report No: P WMA 03/000/00/6923/9

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CROCODILE EAST WATER PROJECT (CEWP)

MODULE 1: TECHNICAL FEASIBILITY STUDY

Pre-Feasibility Study: Multi-Criteria Analysis of Dam Options Report

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Tel: (012) 336 7500/ +27 12 336 7500
Fax: (012) 336 6731/ +27 12 336 6731

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Author(s):	*Evert Serfontein*
Reviewer	*Lilene Louw*
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Approved for the PSP by:

.....

Lilene Louw
Study Leader

.....

Evert Serfontein
Deputy Study Leader

Approved for the Department of Water and Sanitation by:

.....

Mr Kobus Bester
Chief Engineer:
Water Resource Development Planning (East)

.....

Ms Chriselna Fourie
Director:
Water Resource Development Planning

Prepared by:

iX engineers
Infrastructure Excellence

DOCUMENT INDEX

This report forms part of the series of reports issued as part of the project Crocodile East Water Project (CEWP) Module 1: Technical Feasibility Study.

A document index is provided below.

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	Site Visit Report	P WMA 03/000/00/6923/1/1 Included as Appendix A in the Inception Report.
2	Evaluation of Downstream Ecological Impacts of the Dam Options Report	P WMA 03/000/00/6923/2
3	Yield Analysis Report (this report)	P WMA 03/000/00/6923/3
4	Environmental Screening Report	P WMA 03/000/00/6923/4
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LIST OF ACRONYMS

CEWP	Crocodile East Water Project
CoM	City of Mbombela
D: NWRP	(DWS) Directorate: Integrated Water Resource Planning
D: NWRP	(DWS) Directorate: National Water Resource Planning
D: SWRP	(DWS) Directorate: Strategic Water Resource Planning
D: WRDP	(DWS) Directorate: Water Resource Development Planning
DM	District Municipality
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
EWR	Ecological Water Requirements
FS	Feasibility Study
FSL	Full Supply Level
HFY	Historic Firm Yield
LM	Local Municipality
MAR	Mean Annual Run-Off
NPV	Net Present Value
NOC	Non-Overspill Crest
OA	(DWS) Options Analysis
O & M	Operating and Maintenance
PFS	Pre-Feasibility Study
PSP	Professional Service Provider
PV	Present Value
R	Rands
RCC	Roller Compacted Concrete
SEF	Safety Evaluation Flood

ToR	Terms of Reference
URV	Unit Reference Value
VAT	Value Added Tax
WC/WDM	Water Conservation and Water Demand Management
WMA	Water Management Area
WRYM	Water Resources Yield Model
WSA	Water Services Authority
WSS	Water Supply System

LIST OF UNITS AND SYMBOLS

km	Kilometre
m	Metres
masl	Metres above Sea Level
m^3	Cubic Metres
m^3/a	Cubic Metres per Annum
m^3/s	Cubic Metres per Second
R/m^3	Rand per Cubic Metre
°	Degrees
’	Minutes
”	Seconds

GLOSSARY OF TERMS

Allocation	Water allocation refers to the volume of water that is authorised for abstractions by the regulator (DWS, by means of a Water Use licence).
Catchment	The land area drained by a river and its tributaries.
Water requirement	A measure of the water needs of a water user or users, usually expressed in units of litres per capita per day (ℓ/c/d), million m^3/annum or Mega litres per day (Mℓ/day).
Demand reduction	Measures available to a Water Service Provider to reduce water demand and improve water use efficiency or through water restrictions.
Entitlement	A water entitlement is the general term used to describe water authorities (right to use) granted under the National *Water Act, No. 36 of 1998*. This can be either a water allocation, interim water allocation or a water licence.
Reliable yield	The quantity of water that can be abstracted for a given use from a supply source or supply option with a specified degree of reliability (assurance of supply).
Reliability of supply	The probability of providing a specified water entitlement under given operating conditions for a specified period of time.
Supply option	A potential future water resource, defined as any location-specific change to water availability, infrastructure or reliable off-take that will result in the total available supply being increased or augmented.
Surface water	Surface water is water on the surface of the earth such as in a stream, river, dam, wetland or ocean.
Water balance	Numerical comparison of the water requirement with the available water or yield, for current and future planning years. It is usually provided in graphical form for ease of interpretation.
Yield	The average annual volume that can be drawn from a supply source or supply option to meet a specified requirement at a specified reliability. The volume is usually expressed as million m^3 per annum. Yield is always associated with some measure of probability of an occurrence of a reduced supply, expressed as either the risk of failure or the assurance of supply.

1 INTRODUCTION

1.1 Background to Study

The water of the Crocodile (East) River Catchment in Mpumalanga has been fully allocated, yet the water requirements, especially domestic water requirements, continue to grow. The system is under stress, and it cannot fully meet the environmental water requirements as well as the reliability / assurance of supply for both the agricultural and municipal water uses.

The situation will worsen in the short term if water conservation and water demand management (WC/WDM) measures are not fully implemented. In the medium to long term, WC/WDM measures will not be sufficient to provide for the increase in domestic water requirement. The yield of the water resource will have to be increased by means of **additional storage**.

Both public and commercial sectors have requested development of **additional yield** through **storage** within the **Crocodile (East) River Catchment**. Due to the long lead-time required in developing new dams, the construction of an additional dam in the Crocodile River Catchment has to be investigated without delay.

Taking cognizance of the above-mentioned and based on previous studies and investigations carried out in the past, the following **four proposed dams** within the **Crocodile (East) River Catchment** were recommended for further study as part of this Study (WP11393: Module 1: Technical Feasibility Study):

- Mountain View Dam on the Kaap River.
- Montrose Dam on the Crocodile East River.
- Boschjeskop Dam on the Nels River.
- Strathmore Off-Channel Storage Dam, near the confluence of the Kaap and Crocodile rivers.

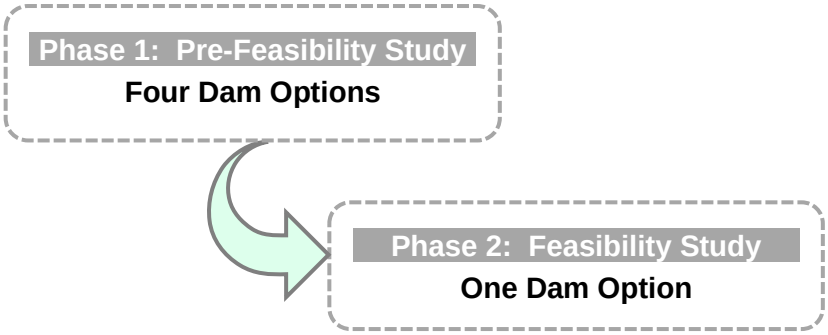
This Technical Feasibility Study will be undertaken in two separate phases, as follows:

Phase 1: Pre-Feasibility Study

The Pre-Feasibility Study (Phase 1) will be undertaken for the above-mentioned **four** proposed dams within the Crocodile (East) River Catchment

Phase 2: Feasibility Study

Under the Phase 1: Pre-Feasibility Study, **one** of the possible four dam options will be selected and recommended for further study and development to a **feasibility level** of detail in the Phase 2: Feasibility Study.



1.2 Study Area

The Crocodile (East) River Catchment in Mpumalanga is located in the north-east of the country and forms part of the larger Inkomati River Basin. The water of the Inkomati River Basin is shared between Mozambique, South Africa and Eswatini. A map of the Study Area is included in **Figure 1-1**.

Engineering investigations and studies for the respective dams and associated infrastructure will **each** have their **specific focus** and **study area** and will also apply to dam access, advanced infrastructure for the dam and the possible relocation of services (roads, rail, etc).

However, with respect to the Water Resources task (water demands, yield analysis, future water balance, the development of short-term stochastic yield reliability curves, updating of the water resources planning model, etc.) of the Study, the study area will cover the **whole** of the **Crocodile (East) River Catchment** (see **Figure 1-1**).

The Crocodile (East) River Catchment comprises the following four tertiary catchments as indicated in **Figure 1-2**:

- Upper Crocodile Catchment (X21)
- Middle Crocodile Catchment (X22)
- Lower Crocodile Catchment (X24)
- Kaap Catchment (X23)

Important tributaries of the Crocodile River include the following:

- Kaap River
- Elands River
- Nels River
- White River

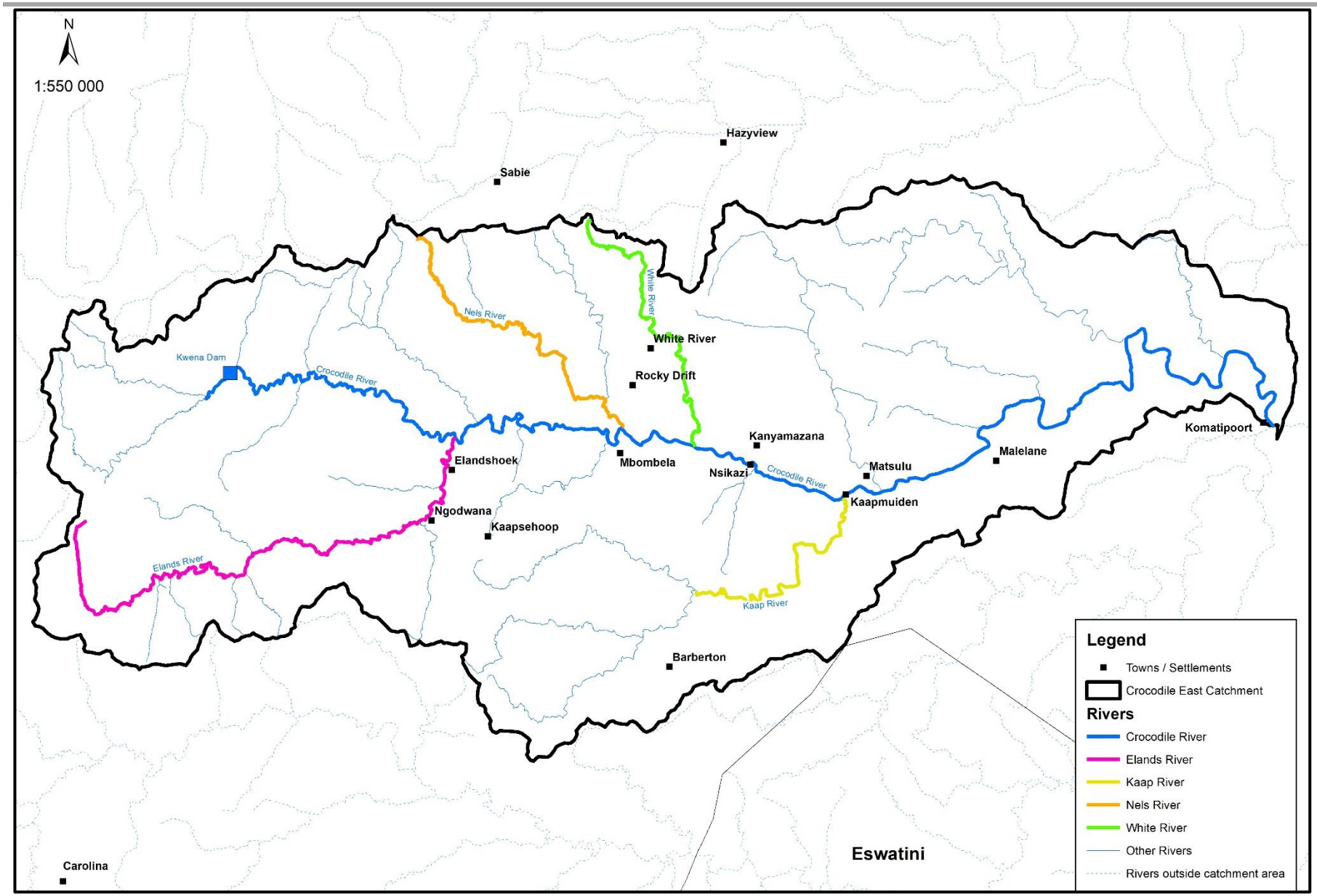


Figure 1-1: Crocodile River Catchment

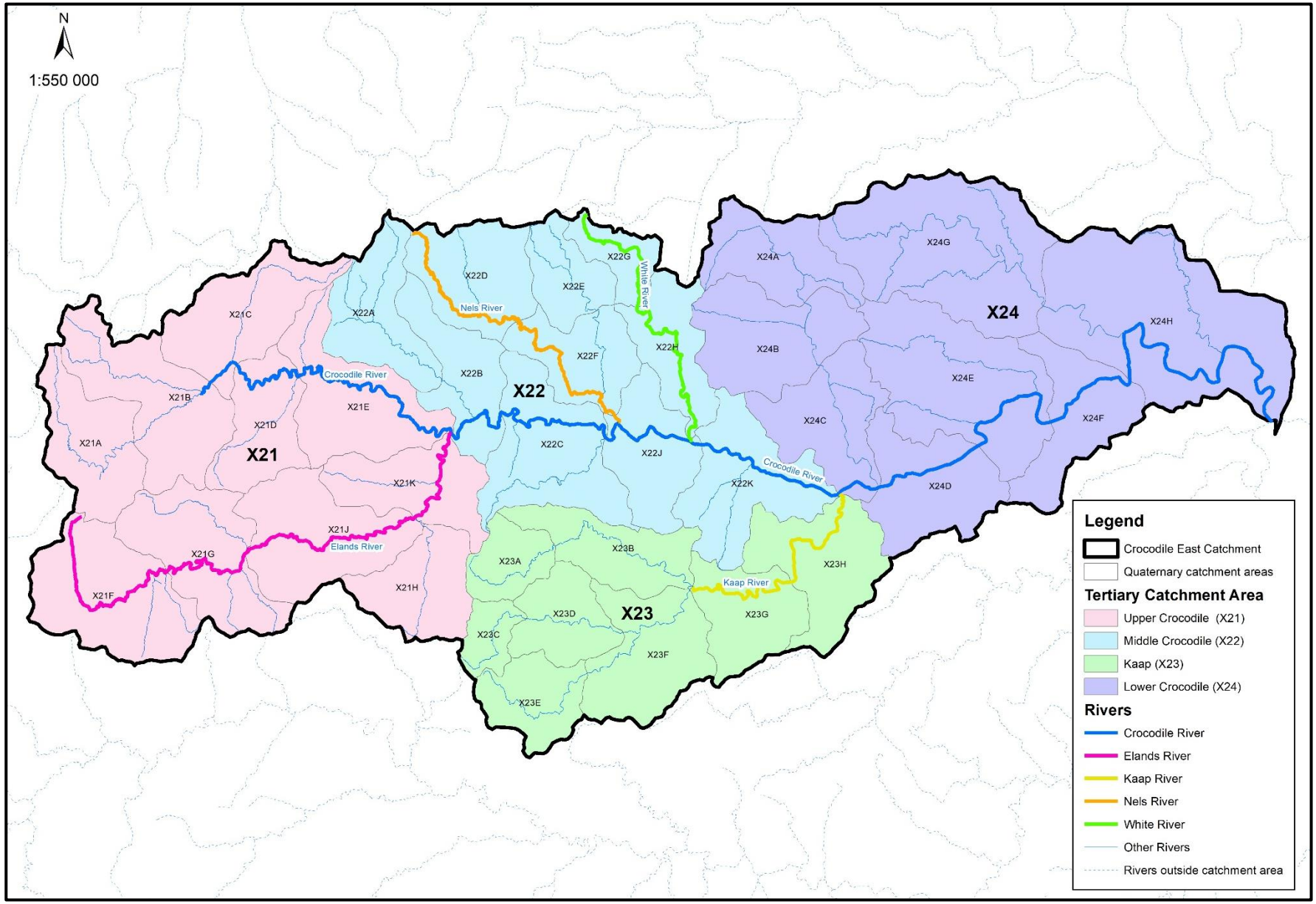


Figure 1-2: Crocodile East River: Tertiary Catchments

The following District and Local Municipalities fall within the Crocodile (East) River Catchment:

- Ehlanzeni District Municipality
  - Bushbuckridge Local Municipality
  - City of Mbombela Local Municipality
  - Nkomazi Local Municipality
  - Thaba Chweu Local Municipality
- Gert Sibande District Municipality
  - Chief Albert Luthuli Local Municipality
- Nkangala District Municipality
  - Emakhazeni Local Municipality

The Crocodile River Catchment is rural in nature, with agriculture being the main economic activity. The high rainfall escarpment catchments of the Upper and Middle Crocodile and Kaap catchments have significant areas of commercial forestry.

The Upper Crocodile Catchment is relatively undeveloped with small domestic and irrigation demands. The Middle Crocodile Catchment has large areas of controlled irrigation and urban demands in the Mbombela LM. The Kaap River Catchment is dominated in the lower eastern part by significant areas of controlled irrigation. Water is transferred into the Kaap River Catchment from the Lomati and Shiyalongubo dams for urban users (Umjindi Local Municipality which was disestablished and merged with Mbombela Local Municipality to establish the City of Mbombela Local Municipality) and agriculture (Louw's Creek Irrigation Board). The Lower Crocodile Catchment has large areas of controlled irrigation and smaller urban/domestic demands for the Nkomazi LM.

The only major dam in the catchment is the Kwena Dam in the Upper Crocodile River Catchment. The dam is approximately 60 km west of Mbombela on the main stem of the Crocodile East River or in the upper reaches of the Crocodile East Catchment. The dam is far from the water demand centers and therefore makes it difficult to regulate and manage water distribution to supply demands as required by the users.

1.3 Proposed Dams

Four proposed dams (listed below) will be investigated during the Pre-Feasibility Phase (Phase 1) of this Study. Only **one** will be selected and recommended for further study in the Feasibility Phase (Phase 2) of the Study. It is, however, possible that the second-best option could be taken forward at a later stage.

- Mountain View Dam on the Kaap River.
- Montrose Dam on the Crocodile East River.
- Boschjeskop Dam on the Nels River.
- Strathmore Off-Channel Storage Dam, near the confluence of the Kaap and Crocodile Rivers.

The regional orientation of the **four proposed dam sites** is indicated in **Figure 1-3**.

1.4 Purpose of Report

The purpose of this report is to present the methodology and results of the multi-criteria analysis that has been undertaken with respect to the four possible dam options that were recommended for further study in the Pre-Feasibility phase of this Study (WP11393: Module 1: Technical Feasibility Study). The report summarizes the results of the multi-criteria analysis and makes a recommendation as to which one of the dam options to be selected for further study in the subsequent Phase 2: Feasibility Study.

1.5 Structure of Report

The following is addressed in the relevant sections of this Report:

- **Section 1** provides a background of the Study and an overview of the Study Area, including the purpose and structure of this Report.
- **Section 2** presents a short technical description of the proposed four dam options.
- **Section 3** describes the purpose and development process of the multi-criteria decision matrix to compare the dam options with each other.
- **Section 4** provides the scoring assigned to the comparison parameters, including the results of the multi-criteria decision matrix and ranking of the dam options.

- **Section 5** presents a discussion on the outcomes of the multi-criteria analysis that was carried out, including the identification and recommendation of the dam option to be selected for further study and development in the Phase 2: Feasibility Study.
- **Section 6** indicates the Study references.

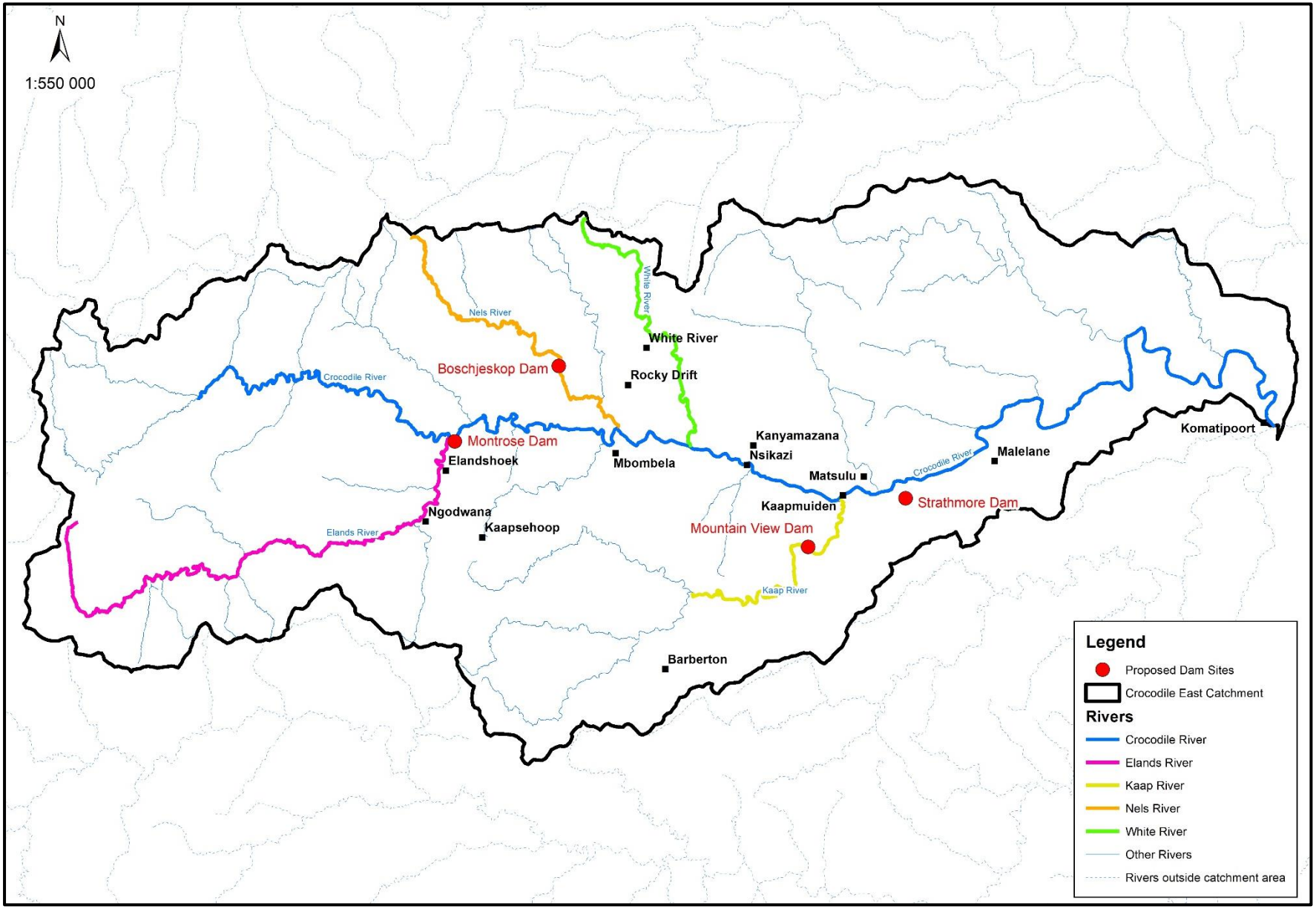


Figure 1-3: Regional Context of Four Proposed Dam Sites

2 DAM DESCRIPTIONS

2.1 Introduction

Four possible dam sites were identified in previous studies for further investigation and assessment as part of this Study. Site visits (DWS (2023a)) of the dam sites were undertaken to gather further information. Preliminary (pre-feasibility) geotechnical and material investigations of the dam sites were undertaken (DWS (2023e)). Yield analyses at each dam site were undertaken (DWS (2023b)). Technical designs were developed to a pre-feasibility level of design (DWS (2023g)). The designs were based on available lidar surveys and additional topographical surveys where suitable surveys did not exist (DWS (2023g)). EWR's were considered in the designs. Designs were developed for two alternatives dam sizes at each site (referred to as *Small Dam* and *Large Dam* in the remainder of the report).

The characteristics and the net benefit to the system yield of the proposed dams are given in **Table 2-1** below.

Table 2-1: Dam Characteristics and Yield

Dam	Small Dam	Large Dam
Boschjeskop		
Height to FSL (m)	44.32	47.30
Capacity (million m^3)	72.67	85.21
FSL (masl)	867.00	870.00
Net Benefit to System Yield (million m^3/a)	40.4	43.5
Mountain View		
Height to FSL (m)	84.08	92.5
Capacity (million m^3)	188.27	259.40
FSL (masl)	470.60	479.00
Net Benefit to System Yield (million m^3/a)	93.4	109.1
Montrose		
Height to FSL (m)	59.00	79.00
Capacity (million m^3)	43.03	111.70
FSL (masl)	800.00	820.00
Net Benefit to System Yield (million m^3/a)	43.4	77.7
Strathmore		
Height to FSL (m)	30.00	40.00
Capacity (million m^3)	42.53	89.45
FSL (masl)	370.00	380.00
Net Benefit to System Yield (million m^3/a)	43.4	59.0

Technical details of the above dams are given in the sub-sections that follow.

2.2 Boschjeskop Dam

The Boschjeskop Dam will be located in the Nels River (a tributary of the Crocodile River). The dam site is located 16 km north-west of Mbombela and the approximate site co-ordinates of the proposed Boschjeskop Dam are:

Latitude 25°21'07" and Longitude 30°52'21".

The dam will be located within a valley with a steep righthand slope and a mild lefthand slope. The dam will comprise of a central concrete gravity wall with an uncontrolled Ogee spillway and stepped downstream face, a concrete gravity wall on the righthand flank and an embankment wall on the lefthand flank. The embankment wall will comprise of a clay core with semi-pervious upstream and downstream fills. The slopes of the embankment wall will be 1:3 upstream and 1:2.5 downstream.

2.3 Mountain View Dam

The Mountain View Dam will be located in the Kaap River (a tributary of the Crocodile River). The dam site is located some 10 km upstream of the confluence with the Crocodile River and the approximate site co-ordinates of the proposed Mountain View Dam are:

Latitude 25°36'45" and Longitude 31°16'15".

The dam will be located within a steeply sided valley. The dam will be a RCC arch dam with a central uncontrolled Ogee overflow.

2.4 Montrose Dam

The Montrose Dam will be located in the Crocodile River, some 2 km downstream of the confluence of the Elands and Crocodile Rivers and 25 km to the west of Mbombela. The approximate site co-ordinates of the proposed Montrose Dam are:

Latitude 25°27'17" and Longitude 30°43'34".

The dam will comprise of a central concrete gravity wall with an uncontrolled Ogee spillway and stepped downstream face, a concrete gravity wall on the lefthand flank and an embankment wall on the righthand flank. The embankment wall will comprise of a clay core

with semi-pervious upstream and downstream fills. The slopes of the embankment wall will be 1:3 upstream and 1:2.5 downstream.

2.5 Strathmore Dam

The Strathmore Dam is located on the southern side of the N4 highway halfway between Kaapmuiden and Malelane. The dam will be an off-channel dam and is to be constructed in a range of hills aligned more-or-less east-west and parallel to the N4 highway. Two dam walls will be required to form the dam and the approximate site co-ordinates of the proposed Strathmore Off-Channel Dam are :

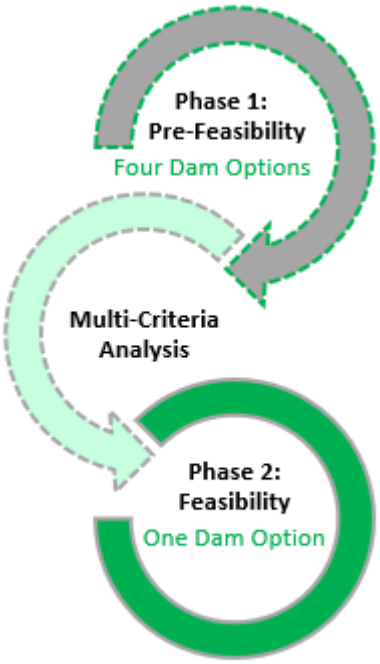
Latitude 25°36'45" and Longitude 31°16'15".
The approximate site co-ordinates of the second wall are:
Latitude 25°32'07" and Longitude 31°25'31".

Both dam walls will be of the embankment type with clay core and semi-pervious upstream and downstream fills. The slopes of the embankment walls will be 1:3 upstream and 1:2.5 downstream. An open channel concrete lined spillway with a 75 m wide Crump control structure will be provided on the righthand flank of the eastern wall of the dam. The dam will be filled from an abstraction weir and pump station located in the Crocodile River, some 2.7 km to the north of the dam.

3 MULTI-CRITERIA ANALYSIS

A key outcome of the Phase 1: Pre-Feasibility Study is the selection of one of the four dams (or a combination of two of the dams) for further study and development to a feasibility level of detail in the Phase 2: Feasibility Study.

Taking cognisance of the significant water deficits in the Crocodile (East) River Catchment it may be possible that the implementation of more than one dam will be required. Therefore, a ranking/scoring system (based on a multi-criteria analysis) rather than an elimination process was adopted, i.e., the highest ranking/scoring dam option will be selected and recommended for further investigation and development at feasibility level.



A multi-criteria decision matrix (ranking system) was developed in order to enable a uniform comparison of the individual four dam options, as well as the combined dam options, with the objective to identify the most feasible option (highest ranking/scoring).

A number of studies and investigations were carried out in the Pre-Feasibility Study with respect to the four dams. The results and outcomes of these studies and investigations were used to develop a multi-criteria decision matrix (ranking system).

The parameters that were used in the multi-criteria decision matrix to compare the dam options with each other, are given below:

Comparison Parameter
Net Benefit to System Yield
Environmental and Downstream River Impacts
Geological/Geotechnical Considerations
Operational Risks (Pumping, Electrical Supply Interruptions, Loadshedding)
Engineering Economic Analyses (Affordability & URV's)

Water quality, with respect to the four dams investigated was not considered in the Phase 1: Pre-Feasibility Study and will be addressed in the Phase 2: Feasibility Study.

A scoring system was used to determine the relative merit of each comparison parameter for each of the dam options. Each of the comparison parameters was assigned points in the range of 1 to 5 for each of the dam options.

Scoring Point System: **1 = Worst** **5 = Best**

Points scored for the comparison parameters were assigned as follows.

- If the impact of a parameter, for a specific dam option, was considered to be more positive, or advantageous, when compared with the impact of the same parameter of another dam option, **more** points were assigned to the parameter of the specific dam option.

Further, each of the comparison parameters was assigned a weight with respect to the other parameters as follows:

Comparison Criterium	Weight
Net Benefit to System Yield	1.0
Environmental and Downstream River Impacts	1.0
Geological/Geotechnical Considerations	1.0
Operational risks (Pumping, Electrical Supply Interruptions, Loadshedding)	1.0
Engineering Economic Analyses (Affordability & URV's)	2.0

The points for each of the comparison parameters with the applied weighting are then aggregated to arrive at a total number of points for each of the dam options.

The highest ranking/scoring dam option will be selected and recommended for further investigation and development at feasibility level.

Highest Ranking/Scoring Dam Option → **Phase 2: Feasibility Study**

4 COMPARISON CRITERIUM RESULTS

The scoring and ranking results of the multi-criteria analysis for the following parameters are addressed in this Section 4 of the Report:

Comparison Criterium
Net Benefit to System Yield
Environmental and Downstream River Impacts
Geological/Geotechnical Considerations
Operational Risks (Pumping, Electrical Supply Interruptions, Loadshedding)
Engineering Economic Analyses (Affordability & URV's)

4.1 Net Benefit to System Yield

Analyses were undertaken to determine the net system yield benefit resulting from the individual dams and combinations of dams. The net benefit to the system yield (million m^3/annum) is the additional water that will be available due to the New Dam.

The following three dam large dam combinations were assessed:

- Boschjeskop (Capacity: 85.2 million m^3) and Strathmore (Capacity 89.4 million m^3);
- Mountain View (Capacity: 259.4 million m^3) and Strathmore (Capacity: 89.4 million m^3);
- Mountain View (Capacity: 259.4 million m^3) and Boschjeskop (Capacity: 85.2 million m^3).

The scoring and ranking results in terms of the net system yield benefit are summarised in **Table 4-1**.

Table 4-1: Scoring and Ranking: Net Benefit to System Yield

Dam	Net Benefit to the System Yield (million m^3/a)	Comparative Scoring	Ranking
Individual Dam Options			
Boschjeskop			
Small Dam (Height = 44.32 m)	40.4	**1.0**	**9**
Large Dam (Height = 47.30 m)	43.5	**1.1**	**8**

Dam	Net Benefit to the System Yield (million m^3/a)	Comparative Scoring	Ranking
Mountain View			
Small Dam (Height = 84.08 m)	93.4	**3.3**	**4**
Large Dam (Height = 92.50 m)	109.1	**3.9**	**3**
Montrose			
Small Dam (Height = 59.00 m)	43.4	**1.1**	**8**
Large Dam (Height = 79.00 m)	77.7	**2.6**	**6**
Strathmore (see Note 1)			
Small Dam (Height = 30.00 m)	43.4	**1.1**	**8**
Large Dam (Height = 40.00 m)	59.0	**1.8**	**7**
Combined Dam Options			
Strathmore (Large, Height = 40.00 m) Boschjeskop (Large, Height = 47.30 m)	84	**2.9**	**5**
Mountain View (Large, Height = 92.50 m) Strathmore (Large, Height = 40.00 m)	134	**5.0**	**1**
Mountain View (Large, Height = 92.50 m) Boschjeskop (Large, Height = 47.30 m)	128	**4.7**	**2**

Note: 1. For Strathmore Dam a maximum pump rate of 4.4 m^3/s from the Crocodile River was used in the yield determination.

2. Dam height measured to FSL.

The highest yielding individual dam is Mountain View which provides a net system benefit of 109.1 million m^3/annum.

The highest yielding combination is Mountain View Dam operating with Strathmore Dam which provides a net system benefit of 134 million m^3/annum.

The results in **Table 4-1** for the combined dam options indicate that the net benefit to the system yield of two dams cannot be determined by adding the net benefits of the individual dams together due to the dynamics in the hydrology and the supply to users.

4.2 Environmental and Downstream River Impacts

An environmental screening and identification of fatal flaws exercise with respect to the four proposed dam options (DWS (2023c)) was carried out as part of the Phase 1: Pre-Feasibility Study. The proposed dam options were evaluated, compared and scored with respect to a number of environmental criteria as indicated in **Table 4-2**.

For the combined dams (Mountain View & Strathmore, Mountain View & Boschjeskop, Strathmore & Boschjeskop, for the large dams), the average of the above scores for each dam was used. The scores were then converted to a score of between 1 to 5 for comparison with other comparison parameters in the decision matrix.

For the Strathmore Dam (off-channel dam with an abstraction weir on the Crocodile River), the environmental impact of the weir on the Crocodile River and the pump station and rising main to the dam, was not considered in the environmental exercise.

An evaluation of the downstream impacts of the proposed dams on the freshwater ecology and the impact of the possible flooding of the Montrose Falls by the proposed Montrose Dam, was carried out as part of the Phase 1: Pre-Feasibility Study (DWS (2023d)). These impacts were considered and formed part of the scoring with respect to the environmental screening carried out (DWS (2023c)).

Table 4-2: Scoring and Ranking: Environmental and Downstream River Impacts

Aspect	Montrose	Mountain View	Boschjeskop	Strathmore
Topography				
Change in topography	2	2	3	3
Soil, Land Use, Land Capability and Agricultural Potential				
Land Use	2	2	4	4
Loss of arable land / high land capability / agricultural potential	2	2	1	1
Rivers, Wetlands and Freshwater Ecosystems				
Strategic Water Source Area	1	4	3	4
NFEPA Rivers and Wetlands	1	2	2	3
Impact on Fish	0	2	1	3
Impact on Aquatic Maro-invertebrates	2	2	2	3
Impact on Freshwater Conservation Targets	0	3	2	2
Impact on downstream freshwater ecology	0	2	0	3
Terrestrial Ecosystem				
Impact on Fauna	2	2	3	3
Impact on Flora	2	3	2	3
Impact on Terrestrial Conservation Targets	0	1	2	3
Threat to Protected Areas or NPAES	2	2	4	4
Heritage and Cultural Resources				
Loss of sites of historical, archaeological and cultural significance	2	3	4	4
Overall Score	**18**	**32**	**33**	**43**
Comparative Score	**1.0**	**3.2**	**3.4**	**5.0**
Ranking	**4**	**3**	**2**	**1**

4.3 Geological/Geotechnical Considerations

A desktop evaluation and assessment of geological, geotechnical and material availability considerations with respect to the proposed four dam sites were carried out as part of the Pre-Feasibility Study (DWS (2023e)). The desktop evaluation and assessment were supported by site visits and site walk-overs. The proposed dam sites were evaluated, compared and scored with respect to a number of relevant criteria as indicated in **Table 4-3**.

Table 4-3: Scoring and Ranking: Geological/Geotechnical Considerations

Parameter	Montrose	Mountain View	Boschjeskop	Strathmore
Geology				
Lithology	3	4	4	2
Structural Geology	3	3	3	3
Dam Site				
Rock outcrop distribution	3	4	2	1
River section conditions	2	3	3	1
Rock mass permeability	3	4	3	1
Basin				
Stability	3	3	4	4
Leakage	4	3	3	3
Materials				
Rock	3	4	1	1
Sand	2	2	2	1
Embankment/Rockfill	1	3	4	3
Overall Score	**27**	**33**	**29**	**20**
Comparative Score	**3.2**	**5.0**	**3.8**	**1.0**
Ranking	**3**	**1**	**2**	**4**

For the combined dams (Mountain View & Strathmore, Mountain View & Boschjeskop, Strathmore & Boschjeskop, for the large dams), the average of the above scores for each dam was used. The scores were then converted to a score of between 1 to 5 for comparison with other comparison parameters in the decision matrix.

4.4 Operational Risks

A comparison of the dam options, based on operational risks, was carried out and was included as one of the comparison parameters in the decision matrix. The requirement for pumping and the operational risks associated with mechanical and electrical equipment (Mechanical and electrical breakdowns, regular refurbishment and upgrades, etc), the interruption of the supply of electricity, and loadshedding were considered as additional operational risks with respect to Strathmore Dam (off-channel dam requiring pumping from the Crocodile River). For the Strathmore Dam, a score of 3 was assigned in the decision matrix. For all other dams, a score of 5 was assigned in the decision matrix (the smaller the score, the bigger the operational risks). The scoring is an attempt to reflect the additional operational risks with respect to the Strathmore Dam.

4.5 Engineering Economic Analyses (Affordability & URV's)

An engineering economic analysis of the proposed dam options and combinations of the dam options (DWS (2023f)) was carried out as part of the Phase 1: Pre-Feasibility Study for the Study. Capital costs, O & M costs (including the costs of electricity) and unit reference values were calculated for all the dam options. The costs of a weir on the Crocodile River and a pump station and rising main, that will be required for the Strathmore Dam (Off-channel dam supplied from the Crocodile River), was included in the capital and O & M costs for Strathmore Dam.

The dam options were then scored based on the URV values (at an 8 % discount rate). The scores were then converted to a score of between 1 and 5 for comparison with other comparison parameters in the decision matrix (see Section 3). For the URV's, the lower the URV, the higher the score out of 5 assigned in the decision matrix.

A summary of the relevant costs and URV's used in scoring the dam options, as well as the comparative scoring and ranking results, are included in **Table 4-3**.

Table 4-4: Scoring and Ranking: Engineering Economic Analyses (Affordability & URV's)

Dam		Capital Cost million R (see Note 1)	O & M Cost million R/a (see Note 2)	URV R/m^3 (see Note 2)	Comparative Score	Ranking
Boschjeskop:	Small	1569.68	65.71	3.8	**4.3**	**3**
	Large	2100.91	82.30	4.7	**2.9**	**6**
Mountain View:	Small	3142.79	122.21	3.3	**5.0**	**1**
	Large	4085.56	151.65	3.6	**4.6**	**2**
Montrose:	Small	2394.88	98.86	5.4	**1.9**	**5**
	Large	4821.47	174.63	6.0	**1.0**	**8**
Strathmore:	Small	1726.32	193.50	4.2	**3.7**	**5**
	Large	2274.22	233.37	4.0	**4.0**	**4**
Mountain View & Strathmore:	Large Dams	6359.98	390.34	4.7	**2.9**	**6**
Mountain View & Boschjeskop:	Large Dams	6186.48	233.95	4.7	**2.9**	**6**
Strathmore & Boschjeskop:	Large Dams	4375.33	327.00	5.5	**1.7**	**7**

Notes: 1. Capital Cost not discounted.
2. O & M costs and URV's are for an 8 % discount rate.

4.6 Multi-Decision Criteria Matrix

A scoring system was used to determine the relative merit of each comparison parameter for each of the dam options. Sections 4.1 to 4.5 addressed the scoring and ranking results for the individual comparison parameters.

Each of the comparison parameters was assigned points in the range of 1 to 5 for each of the dam options, i.e. comparative score.

Scoring Point System: **1 = Worst** **5 = Best**

Further, each of the comparison parameters was assigned a weight with respect to the other parameters. The points for each of the comparison parameters with the applied weighting were then aggregated to arrive at a total number of points for each of the dam options as summarised in **Table 4-5**.

Table 4-5: Multi-Criteria Decision Matrix: Comparative Scoring of Dam Options

Comparison Criterium	Boschjeskop		Mountain View		Montrose		Strathmore		Mountain View Strathmore	Mountain View Boschjeskop	Strathmore Boschjeskop
	Small	Large	Small	Large	Small	Large	Small	Large	Large	Large	Large
Net Benefit to System Yield (Weight = 1.0)	1.0	1.1	3.3	3.9	1.1	2.6	1.1	1.8	5.0	4.7	2.9
Environmental and Downstream River Impacts (Weight = 1.0)	3.4	3.4	3.2	3.2	1.0	1.0	5.0	5.0	4.1	3.3	4.2
Geological/Geotechnical Considerations (Weight = 1.0)	3.8	3.8	5.0	5.0	3.2	3.2	1.0	1.0	3.0	4.4	2.4
Operational Risks (Pumping, Electrical Supply, etc.) (Weight = 1.0)	5.0	5.0	5.0	5.0	5.0	5.0	3.0	3.0	3.0	5.0	3.0
Engineering Economic Analyses (Affordability & URV's) (Weight = 2.0)	4.3	2.9	5.0	4.6	1.9	1.0	3.7	4.0	2.9	2.9	1.7
Total Score	**21.7**	**19.2**	**26.5**	**26.3**	**14.1**	**13.7**	**17.5**	**18.7**	**21.0**	**23.3**	**15.9**
Ranking	**4**	**6**	**1**	**2**	**10**	**11**	**8**	**7**	**5**	**3**	**9**

The points scored by the Mountain View Dam (large and small dams) in **Table 4-5** are higher than any of the points scored by the other dam options (individual and combined). The points scored by the Mountain View Dam options are similar and of the same order. The Mountain View dams also have the highest net benefit to the system yields (**Table 4-1**), compared with the other individual dams.

The Boschjeskop and Strathmore Dams have similar URV's, however the system yields of the Boschjeskop Dam are smaller than that of the Strathmore Dam. Although the system yield for the large Montrose Dam is larger than that of the Boschjeskop and Strathmore Dams, the dam's URV's are higher than the URV's of any of the other dams.

Taking cognisance of the above-mentioned and from a system yield / URV perspective, the ranking of the four dams is indicated in **Table 4-6**.

Table 4-6: Ranking of Dam Options

Ranking	Dam Option	Yield million m^3/a		URV R/m^3	
		Small Dam	Large Dam	Small Dam	Large Dam
1	Mountain View	93.4	109.1	3.3	3.6
2	Strathmore	43.4	59.0	4.2	4.0
3	Boschjeskop	40.4	43.5	3.8	4.7
4	Montrose	43.4	77.7	5.4	6.0

5 CONLUSIONS AND RECOMMENDATIONS

5.1 Potentially Fatal Flows

Both the proposed Boschjeskop and Montrose dams will have a negative impact on the downstream freshwater ecology and a drop in the ecological status of the assessment reaches (DWS (2023c) and DWS (2023d)). This can be considered as potential environmental fatal flaws for the two dams.

Further, both the Montrose dams (large and small) will result in the flooding of the existing Montrose Falls (this was confirmed with the lidar surveys obtained from the Mbombela LM, as the elevation of the Montrose Falls is approximately 783 masl). Other sources give the elevation of the waterfall as 792 masl. Even if the waterfall is located at an elevation of 792 masl, it will be flooded by the Montrose Dam basin as considered in this Pre-Feasibility Study. The large Montrose Dam has its FSL at 820 masl and the small dam has its FSL at 800 masl. The waterfall is a natural migration barrier in the river system and prevents some fish species from colonising the upper reaches of the Crocodile River. This should be seen as a possible environmental fatal flaw of the Montrose Dam.

5.2 Water Requirements and System Yields

Based on allocations, by 2050 the water requirements from the Crocodile River System are estimated at 377 million m^3/a (DWS (2021)). The yield of the system is estimated at 205 million m^3/a (at a low level of assurance). By 2050 there will thus be a large deficit of 172 million m^3/a. The 2023 deficit is estimated at 155 million m^3/a. The four dams considered in this Phase 1: Pre-Feasibility Study, have net benefits to the system yield of 40.0 to 109.1 million m^3/a. The combined dams (Mountain View & Strathmore dams, Mountain View & Boschjeskop dams and Strathmore & Boschjeskop dams) considered in this Phase 1: Pre-Feasibility Study have net benefits to the system yield of 84.0 to134.0 million m^3/a. None of the four individual dams (or combination of dams) can provide enough water to cover the current and future deficits in the system.

From a system yield perspective, the dam (or combination of dams) with the largest net benefit to the system yield must thus be favourably considered. The net benefit to the system yield of any dam option therefor carries a significant weight in the comparison of the dam options.

5.3 Net Benefit to System Yields and Unit Reference Values

The net benefit to the system yield (million m^3/annum) is the additional water that will be available due to the New Dam(s).

From a system yield and URV perspective, the Mountain View Dam is the best individual dam option (see **Table 5-1**). Not only are the URV's of the two Mountain View Dam options (small and large dams), the lowest when compared with any of the other dam options, the system yields of the two dam options are also much larger than the system yields for any of the other individual dam options. In the Crocodile River Catchment with its large water supply deficit, the larger system yields of the Mountain View Dam is important. The two Mountain View dams also scored the most points in the multi-criteria decision matrix (see **Table 5-3**), significantly more than any of the other three dam options.

The Boschjeskop and Strathmore Dams have similar URV's, however the system yields of the Boschjeskop Dam are smaller than that of the Strathmore Dam. Although the system yield for the large Montrose Dam is larger than that of the Boschjeskop and Strathmore Dams, the dam's URV's are higher than the URV's of any of the other dams.

The ranking of the individual dam options from a system yield / URV perspective is included in **Table 5-1**.

Table 5-1: Ranking of Individual Dam Options

Ranking	Dam Option	Net Benefit to the System Yield million m^3/a		URV R/m^3 (see Note 1)	
		Small Dam	Large Dam	Small Dam	Large Dam
1	Mountain View	93.4	109.1	3.3	3.6
2	Strathmore	43.4	59.0	4.2	4.0
3	Boschjeskop	40.4	43.5	3.8	4.7
4	Montrose	43.4	77.7	5.4	6.0

Note: 1. URV's are for an 8 % discount rate.

In addition, three combinations of the proposed dams were considered. To maximize the net benefit to the system yield, only combinations of the large dams were considered.

The following three dam large dam combinations were assessed:

- Boschjeskop (Capacity: 85.2 million m³) and Strathmore (Capacity 89.4 million m³);
- Mountain View (Capacity: 259.4 million m³) and Strathmore (Capacity: 89.4 million m³);
- Mountain View (Capacity: 259.4 million m³) and Boschjeskop (Capacity: 85.2 million m³).

The ranking of the combined dam options from a system yield / URV perspective is included in **Table 5-2**.

Table 5-2: Ranking of Combined Dam Options

Ranking	Dam	Net Benefit to the System Yield million m³/a	URV R/m³ (see Note 1)
1	Mountain View & Strathmore: Large Dams	134.0	4.7
2	Mountain View & Boschjeskop: Large Dams	128.0	4.7
3	Strathmore & Boschjeskop: Large Dams	84.0	5.5

Note: 1. URV's are for an 8 % discount rate.

Although the combined net benefit to the system yield of the combined Mountain View & Strathmore dams and the combined Mountain View & Boschjeskop dams is somewhat larger than that of the single large Mountain View Dam (109.1 million m³/a), the total points scored in the multi-criteria decision matrix (see **Table 5-3**) by the dam combinations are significantly less than that of the single Mountain View Dam. The URV's of the combined dam options are also higher than the URV's of the single Mountain View Dam. It was noted that the combined net benefit to the system yield of a combination of two dams is smaller than the sum of the net benefit to the system yields of the two individual dams, due to the dynamics of the hydrology.

5.4 Multi-Criteria Analysis

The scoring and ranking results (see **Table 4-5**) of the individual and combined dam options are summarised in **Table 5-3**.

Table 5-3: Summary of Scoring and Ranking Results of Dam Options

Dam		Total Score	Ranking
Boschjeskop:	Small	21.7	4
	Large	19.2	6
Mountain View:	Small	26.5	1
	Large	26.3	2
Montrose:	Small	14.1	10
	Large	13.7	11
Strathmore:	Small	17.5	8
	Large	18.7	7
Mountain View & Strathmore:	Large Dams	21.0	5
Mountain View & Boschjeskop:	Large Dams	23.3	3
Strathmore & Boschjeskop:	Large Dams	15.9	9

The points scored by the Mountain View Dam (large and small dams) are higher than any of the points scored by the other dam options (individual and combined). The points scored by the Mountain View Dam options are similar and of the same order. The Mountain View dams also have the highest net benefit to the system yields (see **Table 5-1**), compared with the other individual dams.

The Boschjeskop and Strathmore Dams have similar URV's (see **Table 5-1**), however the system yields of the Boschjeskop Dam are smaller than that of the Strathmore Dam. Although the system yield for the large Montrose Dam is larger than that of the Boschjeskop and Strathmore Dams, the dam's URV's are higher than the URV's of any of the other dams.

Taking cognisance of the above-mentioned the ranking of the four dam options are as follows:

Ranking	Dam Option
1	Mountain View
2	Strathmore
3	Boschjeskop
4	Montrose

5.5 Recommendation

Taking cognisance of the above-mentioned it is recommended that the large Mountain View Dam be selected for further study in the Phase 2: Feasibility Study, due to its larger benefit to the system yield compared to the yield of the small Mountain View Dam.

The net benefit to the system yield of the large Mountain View Dam of 109.1 million m^3/a is still significantly smaller than the current 2023 Crocodile River System deficit of 155 million m^3/a. The implementation of the large Mountain View Dam will add 109.1 million m^3/a to the system yield, leaving a current 2023 deficit of 45.9 million m^3/a. The implementation of the large Strathmore Dam at a later stage will add an additional 24.9 million m^3/a to the system yield, but still leaving a 2050 deficit of 38.0 million m^3/a.

It is recommended that the Strathmore and Boschjeskop dams be investigated in future studies to further augment the yield of the Crocodile River System. However, due to the potential fatal environmental flaws associated with these two dams (Section 5.1), prior environmental impact assessments with respect to the two dams are recommended.

6 STUDY REFERENCES

DWS (2023a) Crocodile East Water Project (CEWP), WP11393, Module 1: Technical Feasibility Study, Inception Report, June 2023, Final. Prepared by iX Engineers, supported by WRP Consulting Engineers and Specialists, for the Department of Water and Sanitation Directorate: National Water Resource Planning, Pretoria, South Africa.

DWS (2023b) Crocodile East Water Project (CEWP), WP11393, Module 1: Technical Feasibility Study, Pre-Feasibility Study: Yield Analyses Report, June 2023, Final. Prepared by iX Engineers, supported by WRP Consulting Engineers and Specialists, for the Department of Water and Sanitation Directorate: National Water Resource Planning, Pretoria, South Africa.

DWS (2023c) Crocodile East Water Project (CEWP), WP11393, Module 1: Technical Feasibility Study, Pre-Feasibility Study: Environmental Screening Report, June 2023, Final. Prepared by iX Engineers, supported by WRP Consulting Engineers and Specialists, for the Department of Water and Sanitation Directorate: National Water Resource Planning, Pretoria, South Africa.

DWS (2023d) Crocodile East Water Project (CEWP), WP11393, Module 1: Technical Feasibility Study, Pre-Feasibility Study: Evaluation of Downstream Ecological Impacts of the Dam Options Report, June 2023, Final. Prepared by iX Engineers, supported by WRP Consulting Engineers and Specialists, for the Department of Water and Sanitation Directorate: National Water Resource Planning, Pretoria, South Africa.

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