Department of Water and Sanitation

Report No: P WMA 03/000/00/6923/3

WP11393

CROCODILE EAST WATER PROJECT (CEWP)

MODULE 1: TECHNICAL FEASIBILITY STUDY

Pre-Feasibility Study: Yield Analyses Report

June 2023

Final

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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.

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	Site Visit Report	P WMA 03/000/00/6923/1/1 Included as Appendix A in the Inception Report.
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CEWP	Crocodile East Water Project
CMF	Catchment Management Forum
COGTA	Cooperative Governance and Traditional Affairs
CAPEX	Capital Expenditure
CoM	City of Mbombela
DARDLEA	Department of Agriculture, Rural Development, Land and Environmental Affairs
DEDT	Department of Economic Development and Tourism
DFFE	Department of Forestry, Fisheries and the Environment
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
DOR	Drought Operating Rules
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
EAP	Environmental Assessment Practitioner
EWR	Ecological Water Requirements
EME	Exempted Micro Enterprise
FS	Feasibility Study
FSL	Full Supply Level
RO: NWRI	(DWS) Regional Office: National Water Resources Infrastructure
GT	(DWS) Graduate Trainee
HDI	Historically Disadvantaged Individual
HFY	Historic Firm Yield

IDP	Integrated Development Plan
IIMA	Interim Inco-Maputo Agreement
IUCMA	Inkomati Usuthu Catchment Management Agency
IWAAS	Inkomati Water Availability Assessment Study
IWRP	Integrated Water Resources Planning
KOBWA	Komati Basin Water Authority
KWSAP	Komati Water Supply Augmentation Project
LM	Local Municipality
LNW	Lepelle Northern Water
MAR	Mean Annual Run-Off
MPTA	Mpumalanga Tourism and Park Agency
NOC	Non-Overspill Crest
NRW	Non-Revenue Water
OA	(DWS) Options Analysis
OPEX	Operational Expenditure
PPP	Public Private Partnership
PFS	Pre-Feasibility Study
PRIMA	Progressive Realisation of the IncoMaputo Agreement
PSP	Professional Service Provider
PMC	Project Management Committee
PMCM	Project Management Committee Meetings
PSC	Project Steering Committee
PSCM	Project Steering Committee Meetings
R	Rands
RBIG	Regional Bulk Infrastructure Grant
RQO	Resource Quality Objectives
SAWQG	South African Water Quality Guidelines
STOMSA	Stochastic Model of South Africa

SEF	Safety Evaluation Flood
ToR	Terms of Reference
TSG	Technical Support Group
V&V	Validation and Verification
VAT	Value Added Tax
WAAS	Water Availability Assessment Study
WARMS	Water Allocation and Registration Management System
WC/WDM	Water Conservation and Water Demand Management
WMA	Water Management Area
WQ	Water Quality
WR2012	Water Resources of South Africa 2012
WRC	Water Research Commission
WRMF	Water Resources Management Framework
WReMP	Water Resources Modelling Platform
WRPM	Water Resources Planning Model
WRPS	(DWS) Water Resources Planning Systems
WRYM	Water Resources Yield Model
WSA	Water Services Authority
WSDP	Water Services Development Plan
WSS	Water Supply System

LIST OF UNITS AND SYMBOLS

km	Kilometre
km²	Square Kilometre
mamsl	Metres above Mean Sea Level
m	Metres
m³	Cubic Metres
m³/a	Cubic Metres per Annum
m³/s	Cubic Metres per Second
°	Degrees
’	Minutes
”	Seconds

GLOSSARY OF TERMS

Aquifer	An aquifer is an underground layer of water-bearing permeable rock or unconsolidated materials (gravel, sand, silt, or clay) from which groundwater can be abstracted.
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.
Groundwater	Groundwater is the water located beneath the earth's surface in soil pore spaces and in the fractures of rock formations. A unit of rock or an unconsolidated deposit is called an aquifer when it can yield a usable quantity of water.
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 cognisance 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.

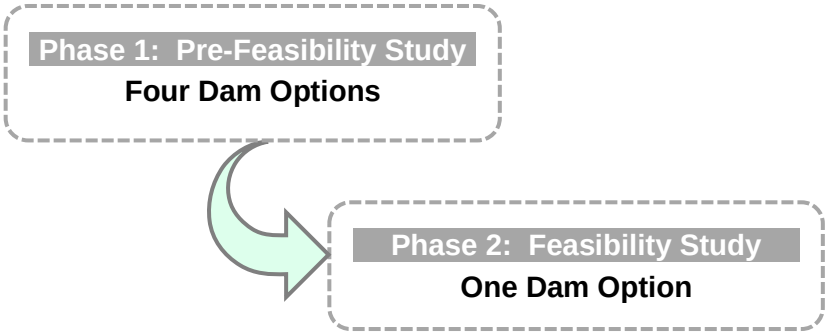
This Technical Feasibility Study will be undertaken in two separate phases, as follows:

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 of 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

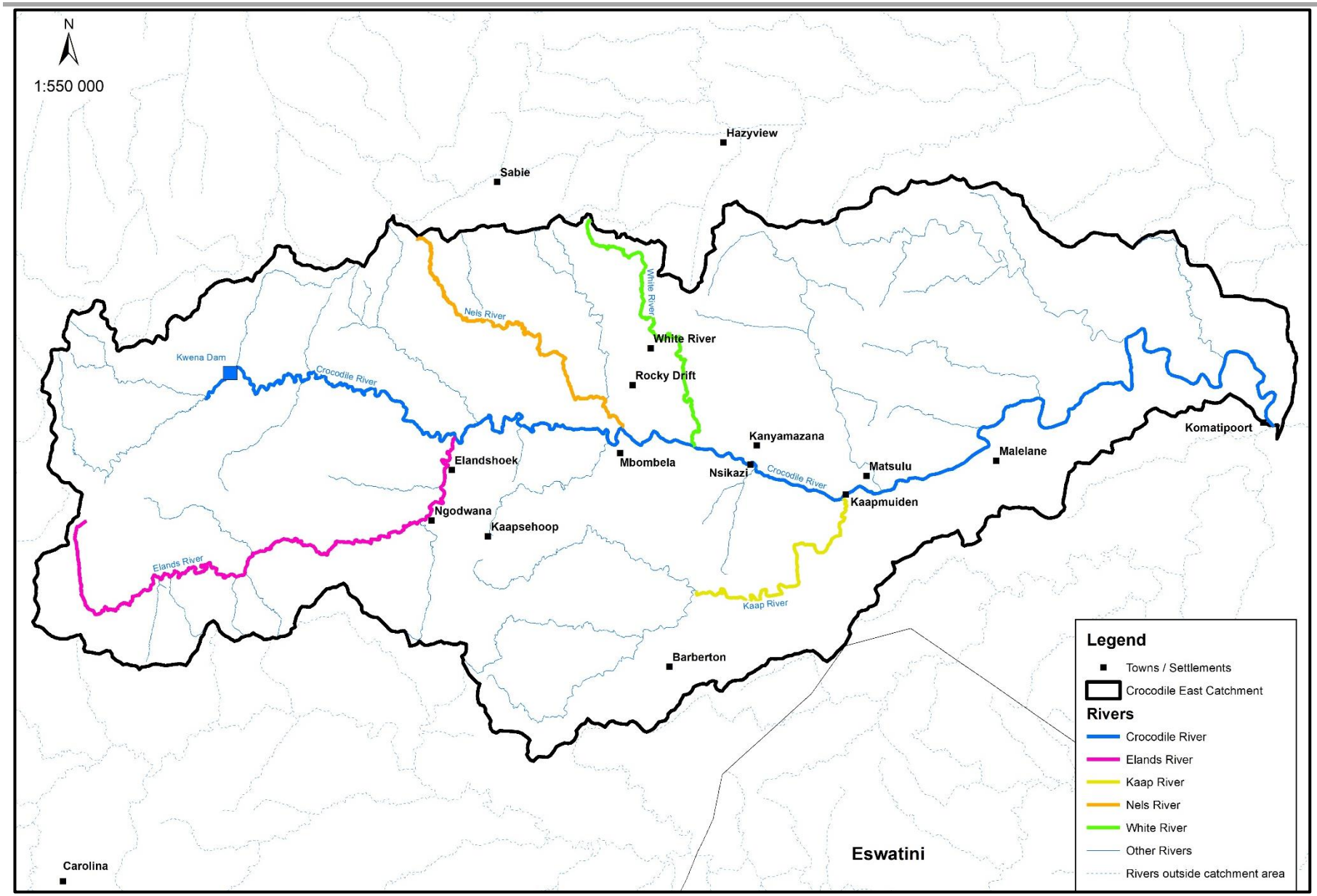


Figure 1-1: Crocodile River Catchment

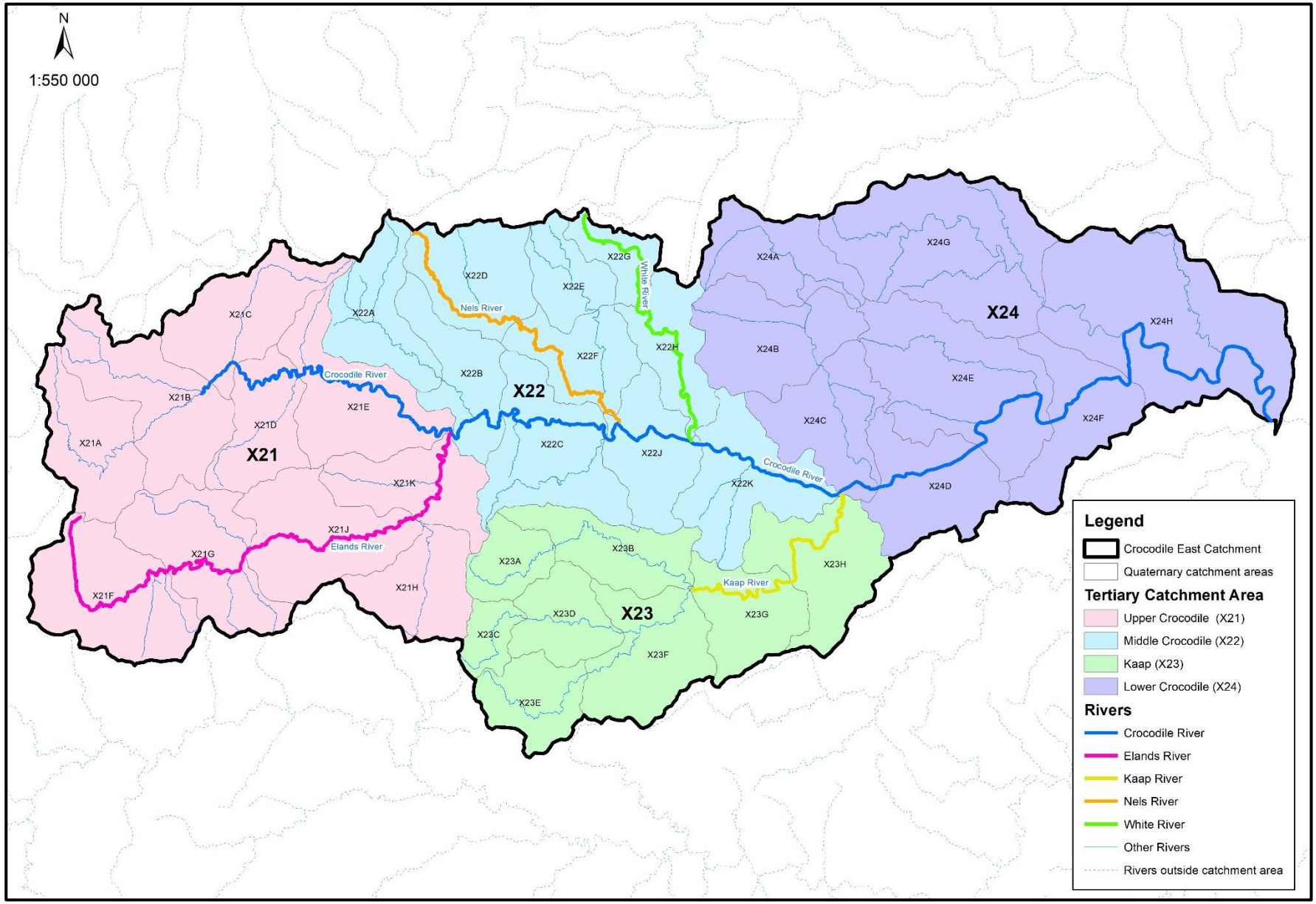


Figure 1-2: Crocodile East River: Tertiary Catchments

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 results of the preliminary yield analyses that has been undertaken on the four proposed dams. The report summarizes the configuration of the Water Resources Yield Model (WRYM) that has been used for the assessment. The approach to undertake the yield analyses as well as the main water resources components of the system have been described in this report.

1.5 Structure of Report

The report is structured as follows:

- **Section 1** provides a background of the Study, an overview of the Study Area, including the purpose and structure of this Report.
- **Section 2** presents a history of relevant water resources studies that have been undertaken in the Crocodile (East) Catchment and includes a summary of the latest available hydrology for the catchment.
- **Section 3** then presents the yield analyses approach and scenarios that have been undertaken as well as the results obtained.
- **Section 4** concludes the report and includes recommendations.
- **Section 5** indicates the Study references.

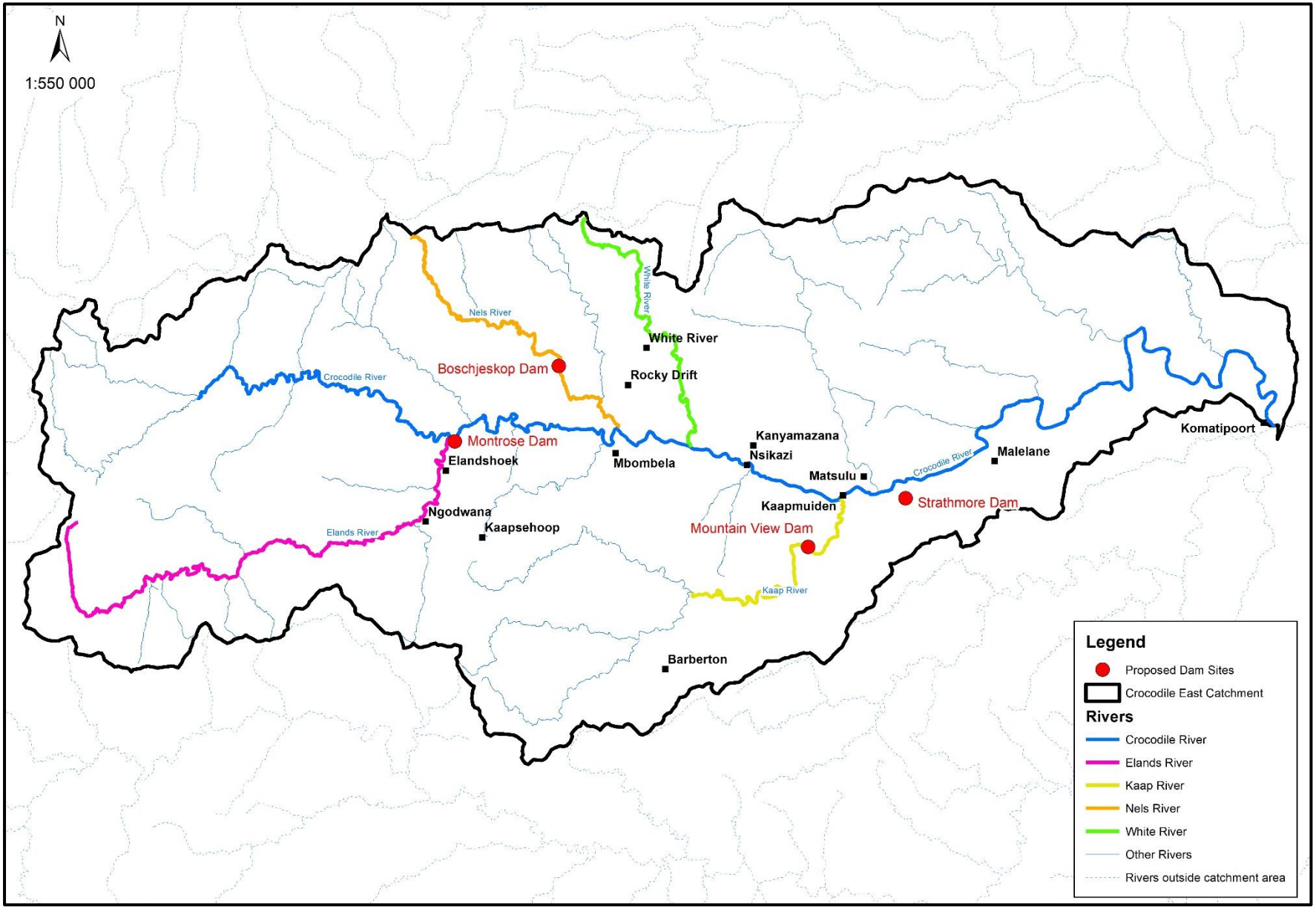


Figure 1-3: Regional Context of Four Proposed Dam Sites

2 BACKGROUND INFORMATION

2.1 Past/Parallel Water Resources Studies

A number of hydrological and water resources studies have been undertaken in the Crocodile East catchment in the past. The hydrology was first prepared in 1985 as part of a Departmental Study in the Inkomati River Basin (DWA, 1985). It was later extended in 1990 in a study which also assessed the system yield (DWA, 1990). Further updates were then carried out as part of the Joint Inkomati Basin Study (JIBS, 1995).

The following sub-sections provide a summary of the more recent, relevant past and ongoing parallel studies undertaken in the catchment.

2.1.1 IWAAS

The Inkomati Water Availability Assessment Study (IWAAS) was the first detailed water resources investigation in the catchment. The IWAAS (DWAF, 2009) was completed in 2009, and covered the entire Crocodile East, Sabie/Sand and Komati Catchments. Detailed rainfall-runoff calibrations using the WRSM2000/Pitman Model were carried out, and the hydrology was produced for the hydrological years dating 1920 to 2004. A complete land use assessment was undertaken in the process of developing the hydrology.

The DWS standard Water Resources Yield Model (WRYM) was configured and yield analyses were undertaken for the major dams in the catchments. The IWAAS is considered a comprehensive study and is often referenced in subsequent study reports relating to the catchment.

2.1.2 IWAAS Maintenance

Following the IWAAS which was completed in 2009, a “Maintenance” Study took place which was completed in 2012 (DWA, 2012). Some minor changes and updates were made to the hydrology. The review of the IWAAS hydrology of the Crocodile East catchment was prompted by data errors related to S-pan and A-pan evaporation in some X22 sub-catchments and all X23 sub-catchments. The hydrological record period remained 1920 to 2004 in the Maintenance Study and only very minor adjustments to the MARs were made.

2.1.3 Mbombela Reconciliation Strategy Phase 1

The Water Requirements and Availability Reconciliation Strategy for the Mbombela Municipal Area (DWA, 2014a) purely focused on the City of Mbombela Local Municipality and its demand

centres. The water resources information quoted in the Strategy was obtained from the IWAAS, and no updated hydrology was produced nor was a detailed water resources analysis undertaken.

2.1.4 Classification Study

The Determination of Water Resource Classes and Associated Resource Quality Objectives in the Inkomati Water Management Area, known as the Classification Study (DWA, 2014b) produced recommended Environmental Water Requirements (EWRs) for the Study Area that were subsequently Gazetted as part of the Classification process. An assessment of the Study, and subsequent communication with the Study Team, determined that water resources analyses was carried out using the Water Resources Modelling Platform (WReMP). The WRYM was therefore not updated nor used for the Classification Study

2.1.5 Continuation of Mbombela Reconciliation Strategy (Phase 2)

The continuation of the strategy carried out by DWS (DWS, 2021) involved two components, namely (1) an update and footprint expansion of the 2014 Strategy to cover the full Crocodile East Catchment, and (2) the monitoring of the implementation of the recommendations of the 2014 Strategy. The IWAAS hydrology was again used as a basis for the water resources analyses, however, the WRYM was updated to include the EWRs determined in the Classification Study. Furthermore, the Water Resources Planning Model (WRPM) was configured and used in the Study.

2.1.6 IUCMA Hydrology Updates

In a parallel process to Reconciliation Strategy update (DWS, 2021), a Study was undertaken by the IUCMA to update and extend the hydrology of the entire Crocodile East River Catchment, including the Kaap River (IUCMA, 2019). The IWAAS hydrology was extended to cover the historical period from 1920 to 2016. The final hydrology was not completed in time for use in the Reconciliation Strategy update Study. The Validation and Verification of land use in the catchment has not been completed, and the hydrology update was therefore based largely on the detailed IWAAS assessment and further assumptions related to the land use.

2.1.7 Eastern Region Reconciliation Strategies

The latest phase of the Reconciliation Strategy (Phase 3) is currently ongoing as a sub-component of a larger Study covering all the areas within the Eastern Region Water Management Area. The Crocodile East component relates to the monitoring of progress of implementing the Strategy (2021) intervention options. Main deliverables of this Study are

Annual Status Reports which summarise progress as well as aspects that have changed in the catchment that affect the Strategy. Furthermore, a task has been completed as part of this Study to incorporate the new hydrology and land use (IUCMA, 2019) into the WRYM and WRPM and to determine the impacts.

2.2 Hydrology

The model representing the Crocodile East catchment makes use of 82 incremental hydrology files. These are mostly disaggregated into sub-catchments on a sub-quaternary catchment basis, as presented in **Figure 2-1** (larger version in **Appendix A**, **Figure A-1**). The details of the process to produce the latest available hydrology are included in IUCMA, 2019.

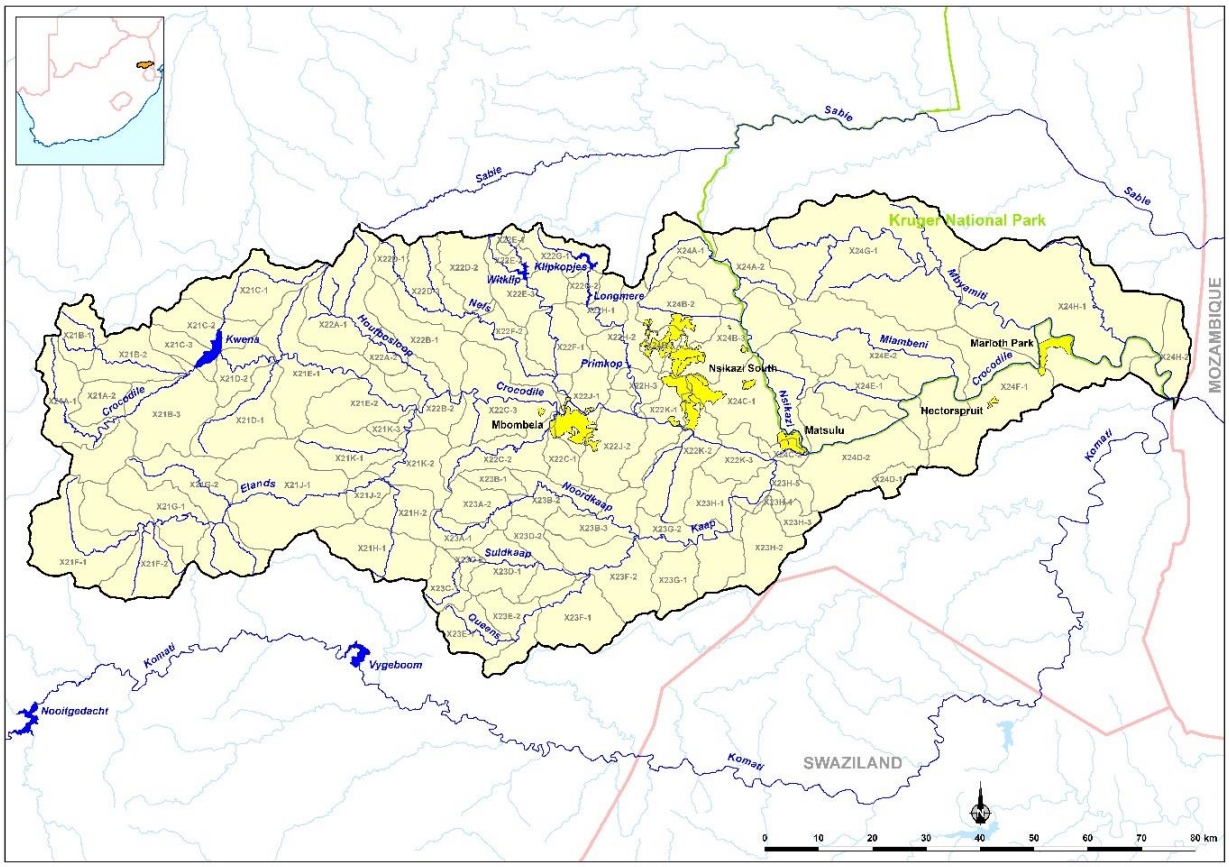


Figure 2-1: Sub-Catchments of the Crocodile East Main Catchment

Table 2-1 presents the natural Mean Annual Runoff (MAR) of each sub-catchment included in the Crocodile East. The table compares the latest available hydrology (IUCMA, 2019) with that previously determined in the IWAAS Maintenance (DWA, 2012).

Table 2-1: Mean Annual Runoff (MAR) Comparison, IWAAS and Update

Sub-Catchment	MAR (IWAAS) 1920 - 2004	MAR (IUCMA, 2019) 1920 - 2004	MAR (IUCMA, 2019) 1920 - 2016
X21A1.INC	19.2	21.16	21.26
X21A2.INC	17.5	19.49	19.52
X21B1.INC	13.4	14.58	14.65
X21B2.INC	12.4	13.76	13.78
X21B3.INC	16.6	18.54	18.48
X21C1.INC	23.5	25.63	25.76
X21C2.INC	9.9	10.79	10.82
X21C3.INC	5.9	6.04	6.05
X21D1.INC	16.9	18.21	18.26
X21D2.INC	6.4	6.89	6.90
X21E1.INC	30.3	32.72	32.69
X21E2.INC	25.7	27.25	27.27
X21F1.INC	26	26.72	26.58
X21F2.INC	24.9	25.57	25.46
X21G1.INC	13.7	14.20	14.16
X21G2.INC	25.6	27.68	27.64
X21H1.INC	39.4	40.43	40.54
X21H2.INC	20.2	20.78	20.85
X21J1.INC	53.6	55.35	55.54
X21J2.INC	7.9	8.11	8.14
X21K1.INC	29.4	29.89	29.98
X21K2.INC	23.9	24.40	24.50
X21K3.INC	5.0	5.18	5.21
X22A1.INC	56.31	57.16	56.93
X22A2.INC	9.61	9.81	9.76
X22B1.INC	32.61	33.07	32.93
X22B2.INC	20.18	20.46	20.35
X22C1.INC	3.24	3.24	3.20
X22C2.INC	13.02	13.08	13.10
X22C3.INC	18.07	17.74	17.60
X22D1.INC	11.04	11.13	11.15
X22D2.INC	26.56	26.81	26.85
X22D3.INC	29.26	29.58	29.55
X22E1.INC	5.82	6.86	6.88
X22E2.INC	13.95	16.42	16.46

Sub-Catchment	MAR (IWAAS) 1920 - 2004	MAR (IUCMA, 2019) 1920 - 2004	MAR (IUCMA, 2019) 1920 - 2016
X22E3.INC	19.49	19.68	19.73
X22F1.INC	9.63	9.73	9.64
X22F2.INC	9.66	9.76	9.66
X22G1.INC	23.44	12.27	12.31
X22G2.INC	7.8	8.92	8.95
X22H1.INC	10.3	11.60	11.70
X22H2.INC	10.65	13.71	13.78
X22H3.INC	3.07	5.12	5.11
X22J1.INC	8.87	7.15	7.11
X22J2.INC	10.19	10.32	10.25
X22K1.INC	5.79	5.63	5.53
X22K2.INC	13.91	13.65	13.46
X22K3.INC	9.38	9.27	9.15
X23A1.INC	15.89	16.65	16.66
X23A2.INC	18.69	19.83	19.85
X23B1.INC	2.91	3.46	3.45
X23B2.INC	5.64	6.01	5.98
X23B3.INC	5.81	6.21	6.18
X23C1.INC	24.91	25.38	25.39
X23D1.INC	22.55	19.72	19.72
X23D2.INC	11.63	12.86	12.84
X23E1.INC	14.72	15.44	15.47
X23E2.INC	13.26	13.97	13.98
X23F1.INC	9.25	10.61	10.57
X23F2.INC	8.21	9.55	9.50
X23G1.INC	7.99	10.40	10.29
X23G2.INC	10.00	11.30	11.19
X23H1.INC	6.26	7.03	6.96
X23H2.INC	9.51	12.49	12.37
X23H3.INC	3.37	4.24	4.20
X23H4.INC	0.44	0.47	0.47
X23H5.INC	4.32	4.87	4.81
X24A1.INC	4.9	5.01	4.96
X24A2.INC	5.9	6.09	6.02
X24B1.INC	2.1	2.19	2.17
X24B2.INC	6.3	6.45	6.38

Sub-Catchment	MAR (IWAAS) 1920 - 2004	MAR (IUCMA, 2019) 1920 - 2004	MAR (IUCMA, 2019) 1920 - 2016
X24B3.INC	4.6	6.03	5.96
X24C1.INC	11.4	11.93	11.80
X24C2.INC	1.3	1.40	1.38
X24D1.INC	3.5	3.50	3.48
X24D2.INC	18.3	17.85	17.58
X24E1.INC	4.9	8.66	8.54
X24E2.INC	9.6	10.19	10.01
X24F1.INC	7.4	9.34	9.20
X24G1.INC	15.3	14.55	14.52
X24H1.INC	10.2	9.27	9.03
X24H2.INC	0.9	0.93	0.90
TOTAL	**1 151.11**	**1 199.39**	**1 196.98**

2.3 Yield Model Configuration

As mentioned in **Sections 2.1.5** and **2.1.7**, the latest version of the WRYM has been configured as part of the Reconciliation Strategy Studies of DWS. The reader is referred to DWS, 2021 for the detailed background descriptions of all the various components of the model, including water requirements, infrastructure and system configuration. Updates included as part of this Pre-Feasibility Study include the incorporation of all four proposed dams into the WRYM.

The figures in **Appendix A** present the WRYM network diagrams. **Figure A-2** relates to the Upper Crocodile East River catchment and shows the proposed positions of Montrose and Boschjeskop Dams. **Figure A-3**, the Lower Crocodile East River Catchment, includes the proposed locations of Mountain View and Strathmore Dams relative to other components included in the model.

Table 2-2 provides the dam characteristics incorporated into the WRYM as received by members of this project Team (DWS, 2023). Two sizes were assessed for each dam as indicated in the table. A detailed description of how the two sizes were arrived at is presented in the report.

Table 2-2: Dam Characteristics incorporated into WRYM

Boschjeskop	Point 1	Point 2	Point 3	Point 4	Point 5	Size 1	Size 2
Height	0.00	7.30	17.30	27.30	37.30	44.32	47.30
Elevation (mamsl)	822.70	830.00	840.00	850.00	860.00	867.02	870.00
Volume (million m^3)	0.000	0.153	3.869	16.636	43.060	72.670	85.212
Area (km^2)	0.000	0.042	0.701	1.852	3.433	4.215	4.998
Mountain View	**Point 1**	**Point 2**	**Point 3**	**Point 4**	**Point 5**	**Size 1**	**Size 2**
Height	0.00	13.50	33.50	53.50	73.50	84.08	92.50
Elevation (mamsl)	386.50	400.00	420.00	440.00	460.00	470.58	479.00
Volume (million m^3)	0.00	1.04	10.89	43.22	121.51	188.27	259.40
Area (km^2)	0.00	0.18	0.88	2.54	5.39	6.31	9.39
Montrose	**Point 1**	**Point 2**	**Point 3**	**Point 4**	**Point 5**	**Size 1**	**Size 2**
Height	0	9	19	29	49	59	79
Elevation (mamsl)	741	750	760	770	790	800	820
Volume (million m^3)	0.00	0.68	3.38	8.41	26.41	43.03	111.70
Area (km^2)	0	0.150	0.391	0.613	1.265	2.060	5.093
Strathmore	**Point 1**	**Point 2**	**Point 3**	**Point 4**	**Point 5**	**Size 1**	**Size 2**
Height	-	-	0	10	20	30	40
Elevation (mamsl)	-	-	340	350	360	370	380
Volume (million m^3)	-	-	0.00	2.13	14.15	42.53	89.45
Area (km^2)	-	-	0.000	0.540	1.864	3.813	5.570

3 YIELD MODELLING

3.1 Approach to Yield Analyses

When conducting a system analysis in the Crocodile East catchment, it is important to note that one cannot only take the yield derived from Kwena Dam as the available water to be used by end-users and or the reserve. Abstraction point locations, inflows from tributaries below Kwena Dam as well as releases from Kwena Dam are all factors that affect the existing system yield. Furthermore, the impact of including a proposed new dam should be considered in the context of improved supply to existing users.

Figure 3-1 presents a locality map of the main users along the Crocodile River. The locations of the proposed dams are also included in the figure for completeness. The abstraction volumes used in the yield assessment are presented in **Table 3-1**.

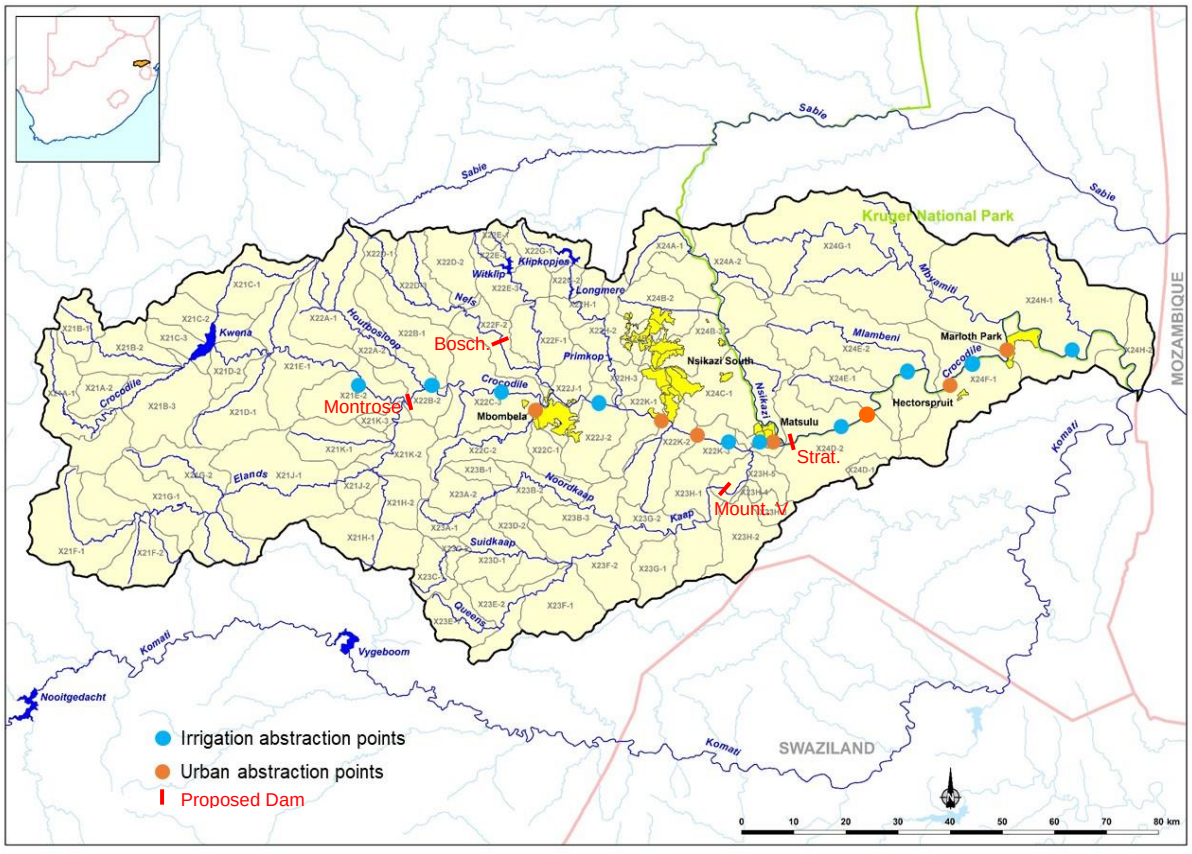


Figure 3-1: Locations of Abstraction Points along the Crocodile River

Table 3-1: Volume of Abstractions from the Crocodile River

Type	User	Use (million m^3/annum)
Irrigation	Crocodile Irrigation Board (divided into 10 individual point abstractions based on location)	304
Domestic	City of Mbombela for Nelspruit, including Rocky Drift	17.50
Domestic	City of Mbombela for Emoyeni from Crocodile and Karino	0.95
Domestic	City of Mbombela for Nsikazi South	25.40
Domestic	City of Mbombela for Matsulu	6.26
Domestic	Malelane	0.75
Domestic	Hectorspruit	0.22
Domestic	Marloth Park	0.95
Total		**356.03**

Two approaches were used to determine the yields of the four proposed dam options for comparison purposes. The first involved the traditional approach of merely determining the historical firm yield at the dam site being assessed. The second approach determined the increase in supply to all users at their point of abstraction and therefore represents the improvement to the system's yield as a result of the new proposed dam.

Figure 3-2 represents the two yield approaches for the example of Kwena Dam. In the first case, the abstraction channel used to determine the yield is placed at Kwena Dam and the yield is determined at that point. In the second case, the supply to all users at their point of abstraction is combined together at one yield node to determine the system yield.

Additional configuration aspects were included as follows:

- The yield of approximately 22 million m^3 was abstracted (removed) from the White River Resources (Primkop, Kleinkopje and Longmere Dams), and these were not added to the yield node. This is because the White River dams operate as a separate sub-system in the catchment and are not used to support the Crocodile East Catchment.
- The abstractions were scaled downwards based on the current operation of the system (irrigators restricted prior to domestic users) until the point that the Kwena Dam just fails once in the historic time period.

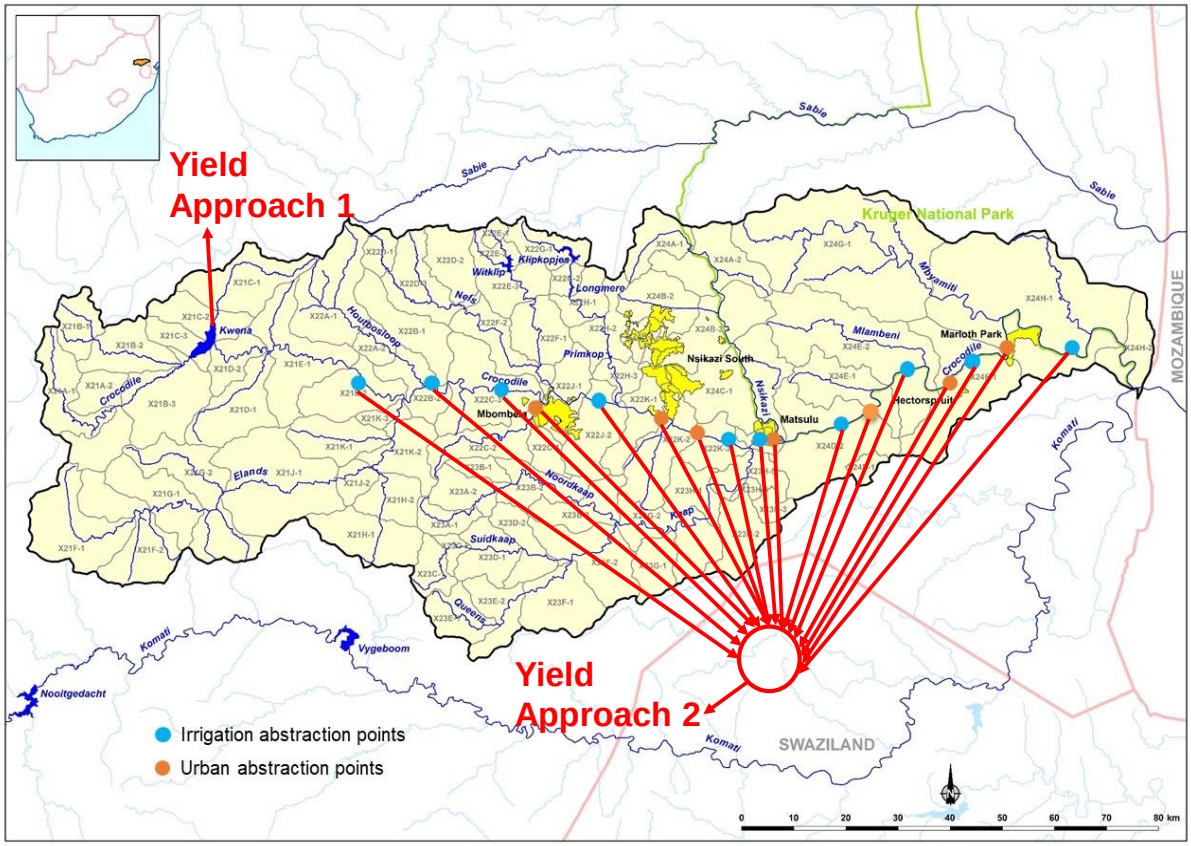


Figure 3-2: Representation of Two Yield Analyses Approaches

3.2 Existing System Yield

For the base scenario (i.e., no proposed dams included) the following yields were obtained using the two approaches:

- Historic Firm Yield (HFY) of 51.2 million m³/a for Kwena dam with yield channel placed at dam.
- Supply of 100% to the domestic sector and 46% to the irrigation sector which equates to a HFY of the Crocodile system of 191.8 million m³/annum. Comparing that with the yield of Kwena Dam alone implies that the flows from incremental runoff provide an additional 140.6 million m³/a to the system yield.

The benefit to users as a result of the inclusion of each proposed dam was determined by comparing the overall system yield (including the new proposed dam) with the baseline results (described above).

3.3 Proposed Dam Yields (individual)

Table 3-2 presents the yield results of the proposed Boschjeskop Dam for two dam sizes (indicated in the Table) and assuming the yield channel is (1) placed at the dam and (2) determining a system yield by abstracting user requirements at their relative abstraction points. **Figure 3-3** and **Figure 3-4** show the behaviour of Kwena and Boschjeskop (large) dams for the system yield configuration. Boschjeskop Dam is well utilized. Kwena Dam is the secondary source and remains relatively high for most of the historical record period.

Table 3-2: Yield Analyses Results for Boschjeskop Dam

Yield Analyses approach	Dam	Boschjeskop Storage: 72.7 million m³ Wall Height: 44.3 m	Boschjeskop Storage: 85.2 million m³ Wall Height: 47.3 m
1	HFY (million m³/annum): Yield Channel at Dam	35	36
2	New System Yield / Supply to Users (million m³/annum)	232.2	235.3
	Percentage per User Sector including New Dam	100% domestic 59% irrigation	100% domestic 60% irrigation
	Net Benefit of New Dam (million m³/annum)	40.4	43.5

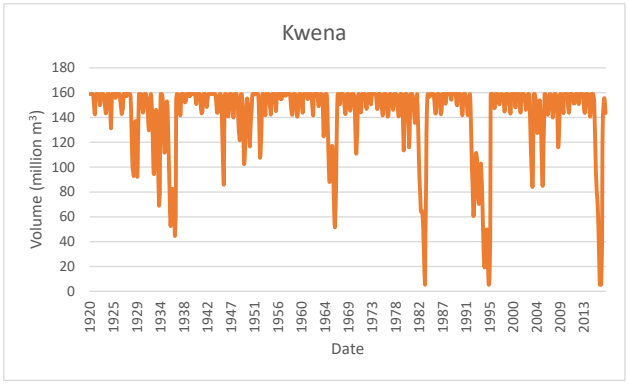


Figure 3-3: Kwena Dam projection resulting from Analysis to determine System Yield for large size Boschjeskop Dam

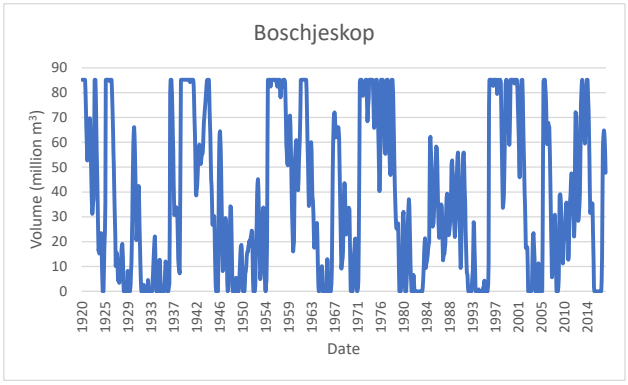


Figure 3-4: Boschjeskop Dam projection under System Yield Configuration

Table 3-3 presents the yield results of the proposed Mountain View Dam for two dam sizes (indicated in the table) and assuming the yield channel is (1) placed at the dam and (2) determining a system yield by abstracting user requirements at their relative abstraction points. **Figure 3-5** and **Figure 3-6** show the behaviour of Kwena and Mountain View (large) dams for the system yield configuration. The large Mountain View Dam is significantly bigger than all the other proposed dam options, and this is evident by the historical trajectory plot which shows it is drawn down on fewer occasions than the others. Kwena Dam is better utilized when acting in combination with Mountain View Dam than it is with Boschjeskop Dam, as it is drawn down lower. The net benefit of the yield for the system is the highest with Mountain View Dam.

Table 3-3: Yield Analyses Results for Mountain View Dam

Yield Analyses Approach	Dam	Mountain View Storage: 188.3 million m^3 Wall Height: 84.1 m	Mountain View Storage: 259.4 million m^3 Wall Height: 92.5 m
1	HFY (million m^3/annum): Yield Channel at Dam	50	58
2	New System Yield / Supply to Users (million m^3/annum)	282.2	300.9
	Percentage per User Sector including New Dam	100% domestic 76% irrigation	100% domestic 81% irrigation
	Net Benefit of New Dam (million m^3/annum)	93.4	109.1

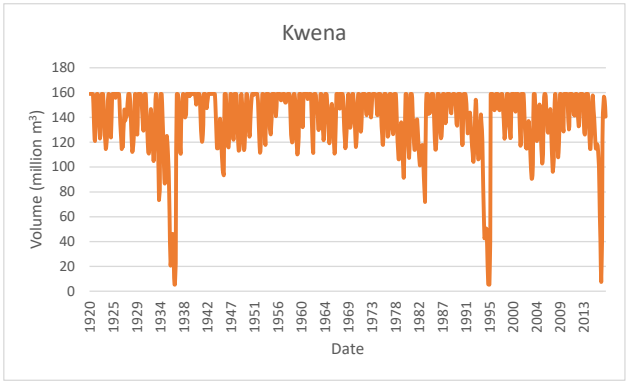


Figure 3-5: Kwena Dam projection resulting from Analysis to determine System Yield for large size Mountain View Dam

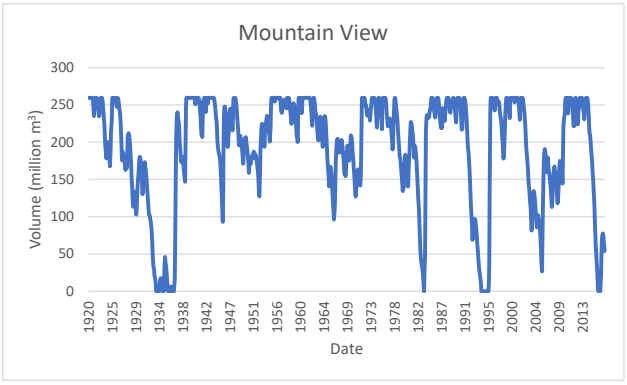


Figure 3-6: Mountain View Dam projection under System Yield configuration

Montrose Dam is located on the Crocodile River, downstream of Kwena Dam. In order to determine the yield of Montrose Dam, the existing HFY (51.2 million m^3/annum) was abstracted from Kwena Dam. **Table 3-4** presents the yield results of the proposed Montrose Dam for two dam sizes (indicated in the table) and assuming the yield channel is (1) placed at the dam and (2) determining a system yield by abstracting user requirements at their relative abstraction points. **Figure 3-7** and **Figure 3-8** show the behaviour of Kwena and Montrose (large) dams for the system yield configuration. It is interesting to note that, in the case of Montrose Dam, the yield is larger when determined at the dam than the net benefit of the new dam from a system's perspective. This is caused by the dynamics of the location of the abstractions and the hydrology of the catchments contributing to the dam. It can also be seen from **Figure 3-7** that Kwena Dam remains fairly full throughout the historical period when acting in conjunction with Montrose Dam downstream.

Table 3-4: Yield Analyses Results for Montrose Dam

Yield Analyses Approach	Dam	Montrose Storage: 43 million m^3 Wall Height: 59 m	Montrose Storage: 111.7 million m^3 Wall Height: 79 m
1	HFY (million m^3/annum): Yield Channel at Dam	79	106
2	New System Yield / Supply to Users (million m^3/annum)	235.2	269.5
	Percentage per User Sector including New Dam	100% domestic 60% irrigation	100% domestic 71% irrigation
	Net Benefit of New Dam (million m^3/annum)	43.4	77.7

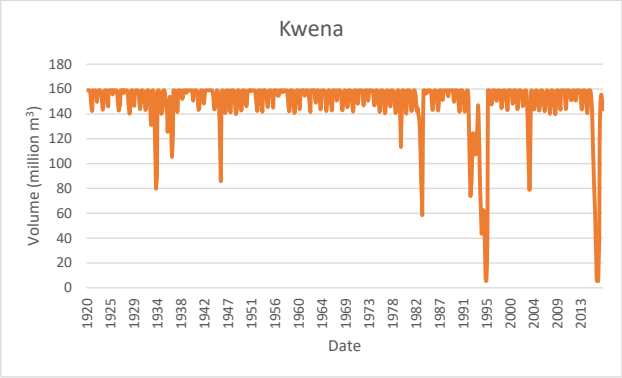


Figure 3-7: Kwena Dam projection resulting from Analysis to determine System Yield for large size Montrose Dam

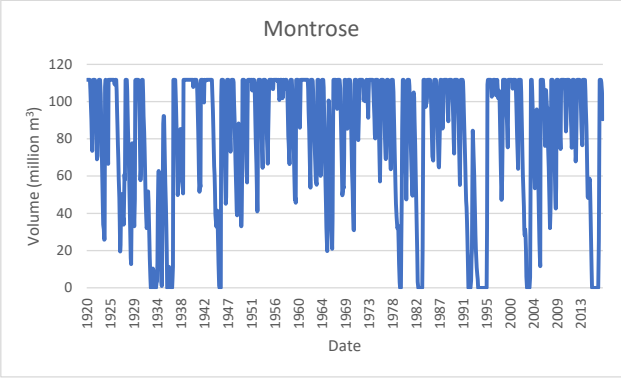


Figure 3-8: Montrose Dam projection under System Yield Configuration

As with Montrose Dam, the HFY was abstracted from Kwena Dam when determining the yield of Strathmore Dam. No additional users were supplied between Kwena and the Strathmore Dam offtake point in order to determine the maximum HFY available from the dam. Furthermore, a maximum pumping rate of 4.44 m^3/s was assumed for the abstraction from the Crocodile River to the Strathmore Dam. **Table 3-5** presents the yield results of the proposed Strathmore Dam for two dam sizes (indicated in the table) and assuming the yield channel is (1) placed at the dam and (2) determining a system yield by abstracting user requirements at their relative abstraction points. **Figure 3-9** and **Figure 3-10** show the behaviour of Kwena and Strathmore (large) dams for the system yield configuration. Similar to Mountain View, Kwena Dam is better utilised when acting in combination with Strathmore Dam.

Table 3-5: Yield Analyses Results for Strathmore Dam

Yield Analyses Approach	Dam	Strathmore Storage: 42.5 million m^3 Wall Height: 30 m	Strathmore Storage: 89.4 million m^3 Wall Height: 40 m
1	HFY (million m^3/annum): Yield Channel at Dam	74	84
2	New System Yield / Supply to Users (million m^3/annum)	235.2	250.8
	Percentage per User Sector including New Dam	100% domestic 60% irrigation	100% domestic 65% irrigation
	Net Benefit of New Dam (million m^3/annum)	43.4	59.0

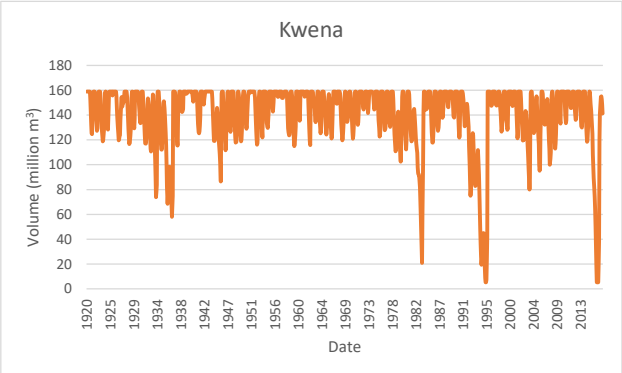


Figure 3-9: Kwena Dam projection resulting from Analysis to determine System Yield for large size Strathmore Dam

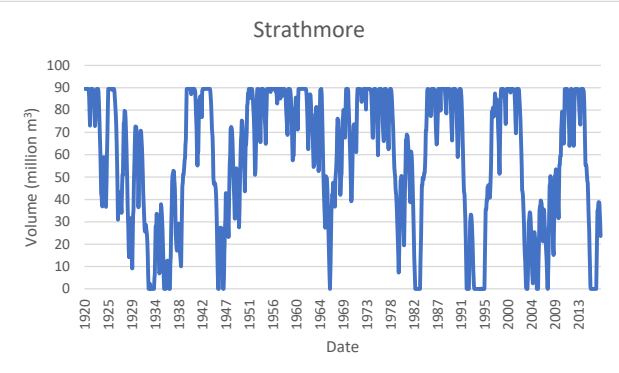


Figure 3-10: Strathmore Dam projection under System Yield configuration

Additional analyses were undertaken in order to see the impact of the pumping rate on the yield. The HFY was determined with different pumping rates and the results are presented in **Table 3-6**.

Table 3-6: Impact of Pumping Capacity on HFY

Pumping Rate (m^3/s)	HFY (million m^3/annum)
2.2	52
4.4	84
6.6	94

3.4 Combinations of Proposed Dam Yields (individual)

Further analyses were undertaken in order to determine the net system yield benefit resulting from combinations of dams. This was to assist with the decision of which dam should be taken forward into the feasibility phase and to compare results of individual dams with those of a combination of dams in terms of providing the greatest yield. The following three combinations were assessed and are presented as the Scenario reference indicated:

- Scenario A: Boschjeskop (85.2 million m^3) and Strathmore (89.4 million m^3);
- Scenario B: Mountain View (259.4 million m^3) and Strathmore (89.4 million m^3);
- Scenario C: Mountain View (259.4 million m^3) and Boschjeskop (85.2 million m^3).

The results in terms of system yield are presented in **Table 3-7**.

Table 3-7: Net System Yield resulting from Combinations of Proposed Dams

Scenario	Net Benefit of New Dam Combinations (million m^3/annum)
A	84
B	134
C	128

The results 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 CONCLUSIONS AND RECOMMENDATIONS

The Crocodile East River Catchment is in a severe deficit and requires maximum additional yield, amongst other interventions, in order to supply its existing users at a satisfactory assurance of supply and to accommodate growth in requirements. The results of the yield benefit to the total system have been considered in order to rank the dam options. These are presented in **Table 4-1**.

Table 4-1: Ranked Order of Proposed Dams based on System Yield Benefit

Order	Dam	Size (million m^3)	Net Benefit to System Yield (million m^3/a)
1	Mountain View	259	109
2	Mountain View	188	93
3	Montrose	112	78
4	Strathmore	89	59
5	Boschjeskop	85	44
6	Strathmore	42.5	43.4
7	Montrose	43	43.4
8	Boschjeskop	73	40

The large Mountain View Dam provides the greatest yield benefit to the system. It is recommended that Mountain View Dam be taken forward to the Feasibility Study Phase from a yield benefit perspective. From a water resources perspective, the ranked order of dams from best to worst is Mountain View, Montrose, Strathmore and Boschjeskop.

The results obtained from analysing two new dams in combination do not change the recommendation that Mountain View Dam be further assessed in the Feasibility Phase. The combination of Strathmore and Boschjeskop Dams yield less than the large Mountain View Dam alone. The highest yielding combination is Mountain View Dam operating with Strathmore Dam which provides a net system benefit of 134 million m^3/annum.

5 STUDY REFERENCES

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APPENDICES

Appendix A Figures

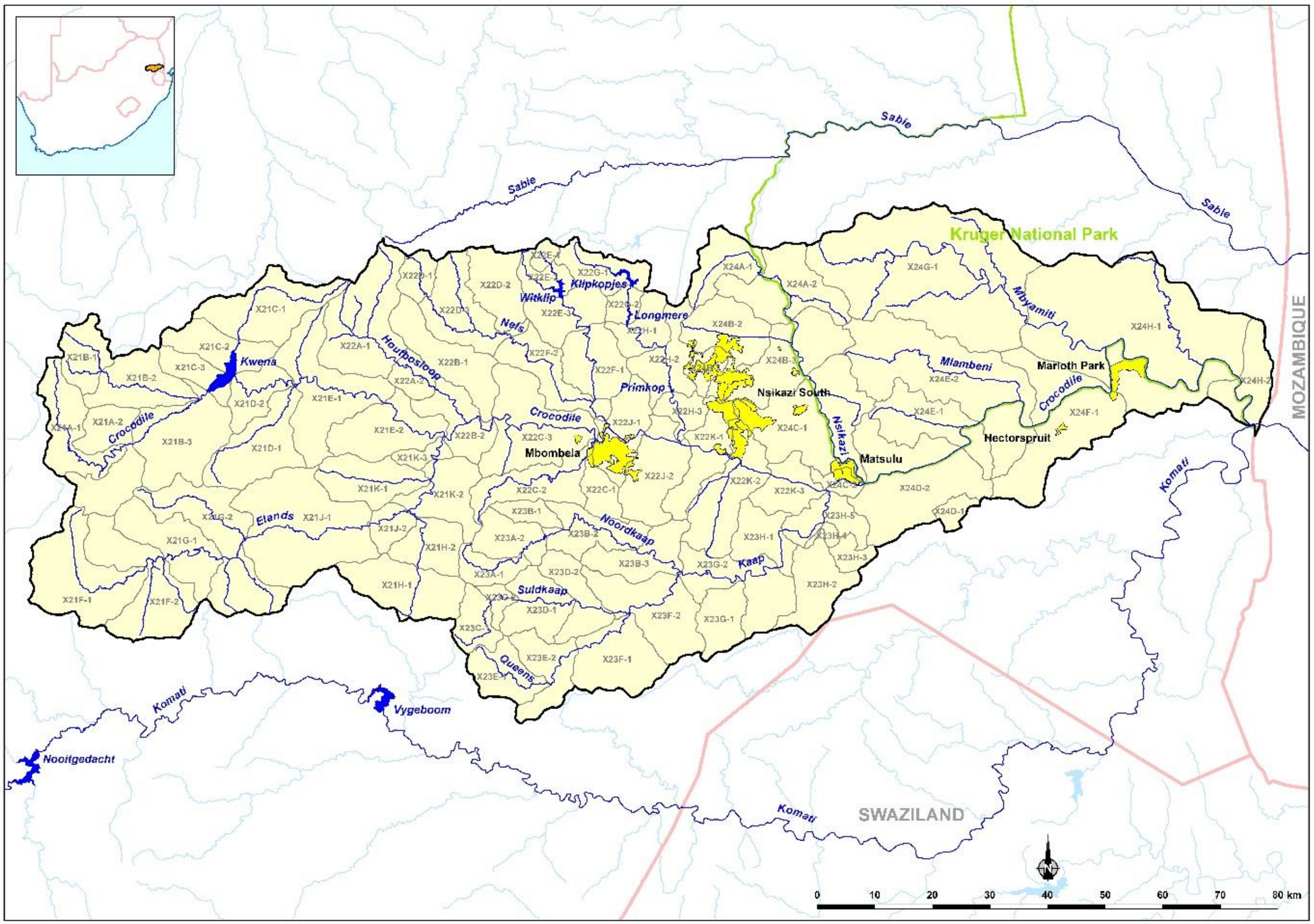
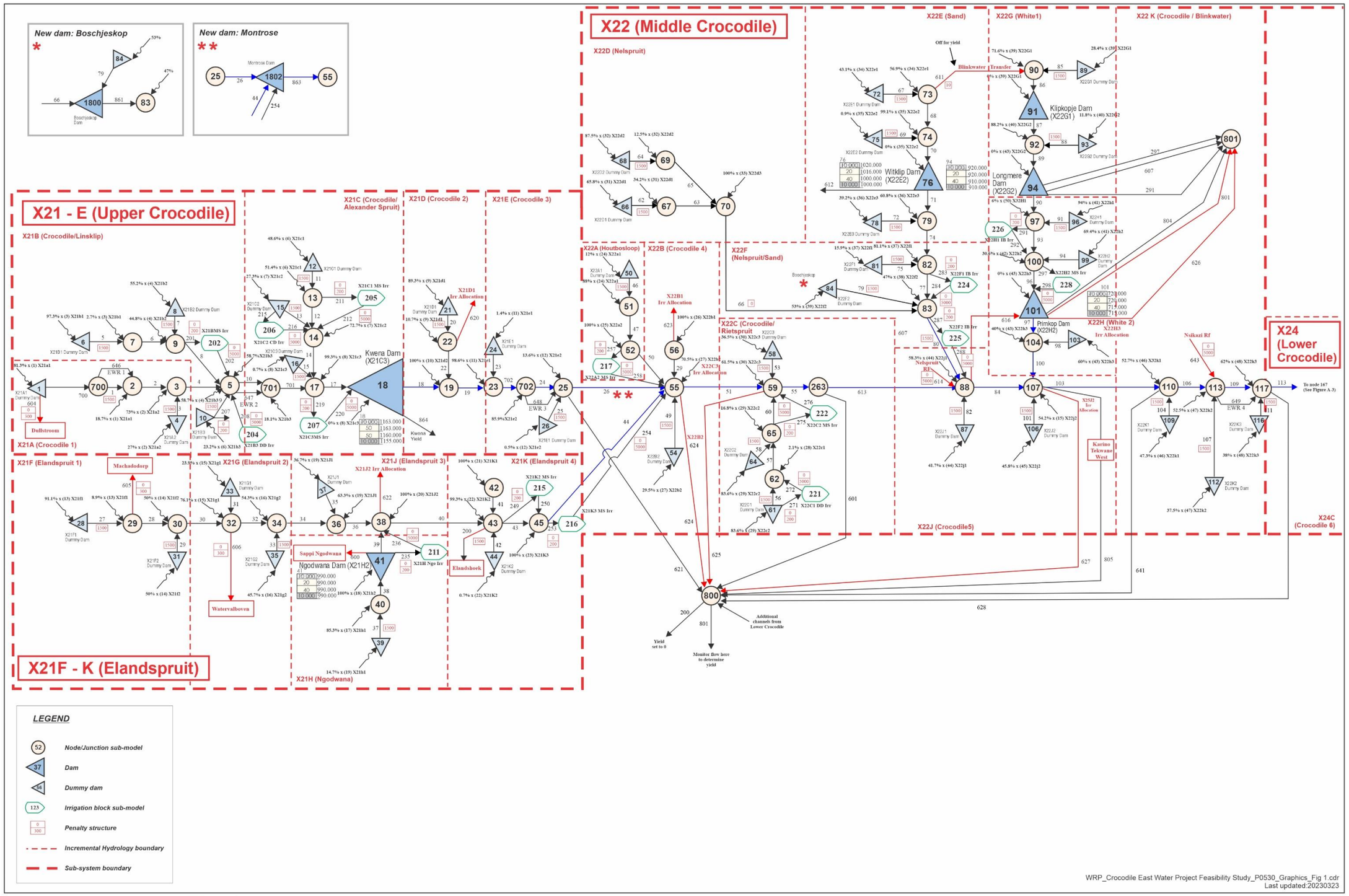
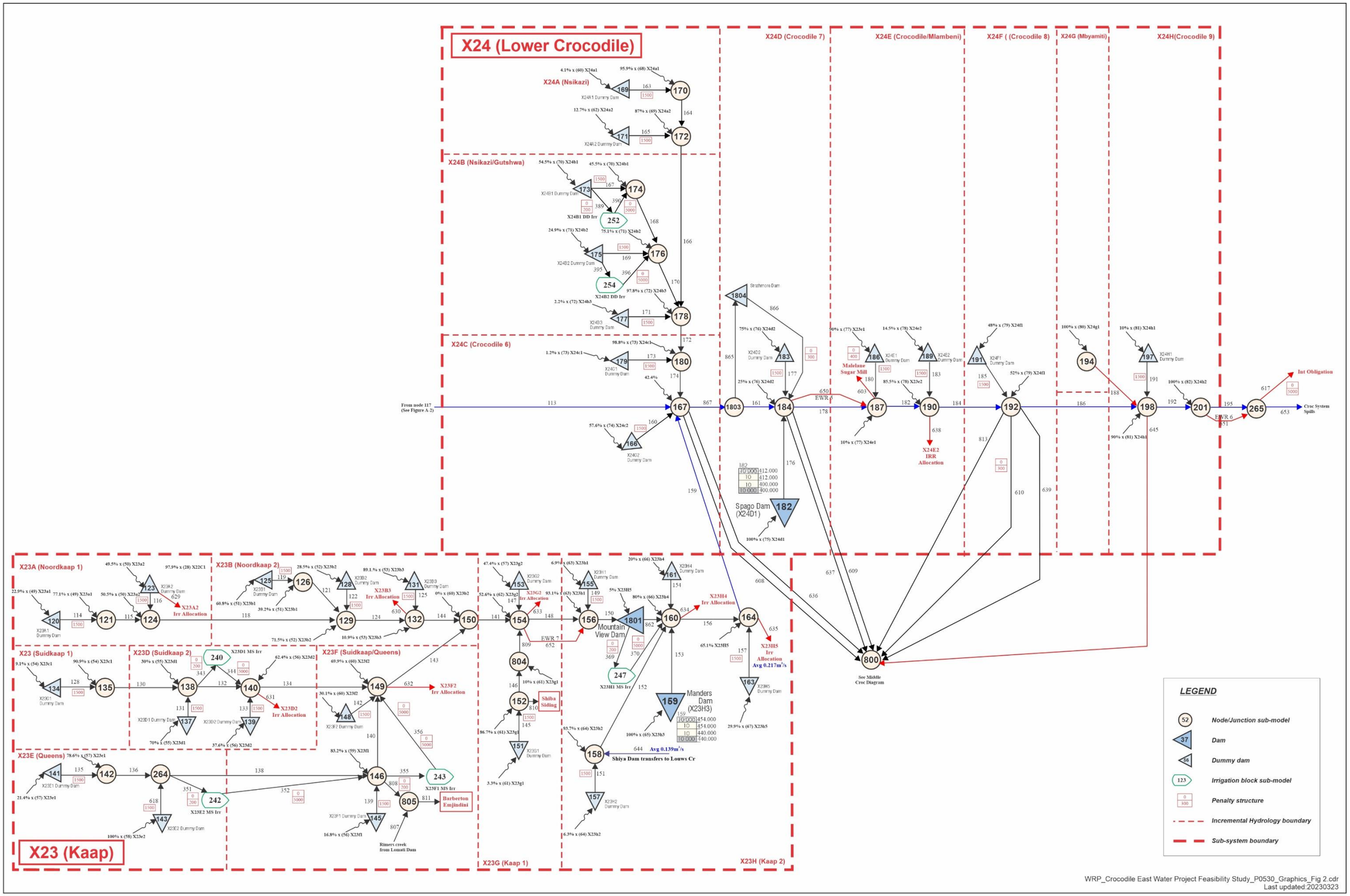


Figure A-1: Sub-Catchments of the Crocodile East Main Catchment


New dam: Boschjeskop
New dam: Montrose
X22 (Middle Crocodile)
X22E (Sand)
X22G (White1)
X22 K (Crocodile / Blinkwater)
X22D (Nelspruit)
X21 - E (Upper Crocodile)
X21B (Crocodile/Linsklip)
X21C (Crocodile/ Alexander Spruit)
X21D (Crocodile 2)
X21E (Crocodile 3)
X22A (Houtbosloop)
X22B (Crocodile 4)
X22F (Nelspruit/Sand)
X22C (Crocodile/ Rietspruit
X24 (Lower Crocodile)
X21F (Elandspruit 1)
X21G (Elandspruit 2)
X21J (Elandspruit 3)
X21K (Elandspruit 4)
X21F - K (Elandspruit)
X21H (Ngodwana)
X22J (Crocodile5)
X24C (Crocodile 6)
Kwena Dam (X21C3)
Witklip Dam (X22E2)
Klipkopje Dam (X22G1)
Longmere Dam (X22G2)
Primkop Dam (X22H2)
Ngodwana Dam (X21H2)
Dullstroom
Machadodorp
Watervalboven
Sappi Ngodwana
Elandshoek
Blinkwater Transfer
Nsikazi Rf
Karino Tekwane West
Additional channels from Lower Crocodile
Yield set to 0
Monitor flow here to determine yield
To node 167 (See Figure A-3)
LEGEND
Node/Junction sub-model
Dam
Dummy dam
Irrigation block sub-model
Penalty structure
Incremental Hydrology boundary
Sub-system boundary
WRP_Crocodile East Water Project Feasibility Study_P0530_Graphics_Fig 1.cdr
Last updated:20230323



WRP_Crocodile East Water Project Feasibility Study_P0530_Graphics_Fig 2.cdr
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