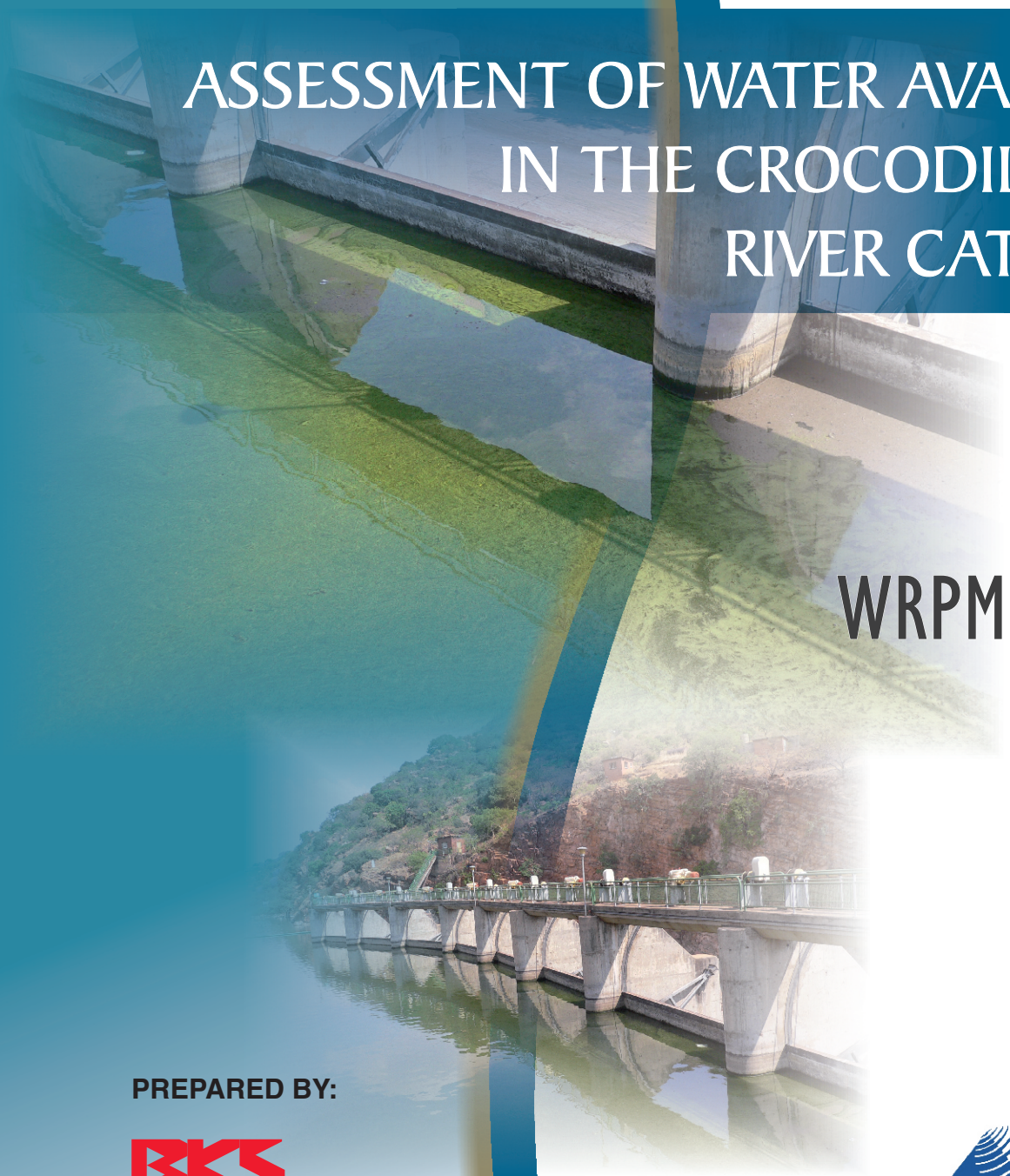
water & forestry
Department:
Water Affairs and Forestry
REPUBLIC OF SOUTH AFRICA

P WMA 03/000/00/3708

ASSESSMENT OF WATER AVAILABILITY IN THE CROCODILE (WEST) RIVER CATCHMENT



WRPM ANALYSES

SEPTEMBER 2009

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LIST OF STUDY REPORTS

THE DEVELOPMENT OF A RECONCILIATION STRATEGY FOT THE CROCODILE (WEST) WATER SUPPLY SYSTEM:	REPORT NUMBER	
	DWAF	BKS
Inception Report	P WMA 03/000/00/3307	H4125-01
Summary of Previous and Current Studies	P WMA 03/000/00/3408	H4125-02
Current and Future Water Requirements and Return Flows and Urban Water Conservation and Demand Management	P WMA 03/000/00/3508	H4125-05
Water Resource Reconciliation Strategy: Version 1	P WMA 03/000/00/3608	H4125-06
WRPM Analyses	**P WMA 03/000/00/3708**	**H4125-07**
Executive Summary	P WMA 03/000/00/3908	H4125-09
Water Requirements and Availability Scenarios for the Lephalale Area	P WMA 03/000/00/4008	H4125-10

This report is to be referred to in bibliographies as:

Department of Water Affairs and Forestry, South Africa, 2009:
The Development of a Reconciliation Strategy for the Crocodile (West) Water Supply System: WRPM Analyses

Prepared by the Consultant: BKS (Pty) Ltd in association with Arcus Gibb (Pty) Ltd
Report No. P WMA 03/000/00/3708

Title:	***WRPM Analyses***
Authors:	*JH Schroder (BKS)*
Project Name:	*The development of a reconciliation strategy for the Crocodile (West) water supply system*
DWAF Report No:	*P WMA 03/000/00/3708*
Status of Report:	*Final*
PSP Report No:	*H4125-07*
First Issue:	*September 2009*
Final Issue:	*September 2009*

PROFESSIONAL SERVICE PROVIDER

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DEPARTMENT OF WATER AFFAIRS AND FORESTRY

Directorate: National Water Resource Planning

Accepted for the Department of Water Affairs and Forestry:

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The development of a reconciliation strategy for the Crocodile (West) water supply system

WRPM ANALYSES

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APPENDICES

LIST OF ACRONYMS

CWCS	Crocodile (West) Catchment Study
CWMS	Crocodile (West) Modelling Study
CWRS	Crocodile (West) Reconciliation Strategy
DWA	Department of Water Affairs
EWR	Ecological Water Requirement
GWS	Government Water Scheme
IB	Irrigation Board
IMS	Integrated Management System
Mm^3	Million m^3
MW	Magalies Water
RW	Rand Water
SFR	Streamflow Reduction Activity
WRPM	Water Resources Planning Model
WRSM2000	Water Resources Simulation Model (enhanced)
WRYM	Water Resources Yield Model

1. INTRODUCTION

1.1 BACKGROUND

The Department of Water Affairs and Forestry (DWAF) initiated a study "*The assessment of water availability in the Crocodile (West) River catchment by means of water resource related models in support of the planned future licensing process*". This study is hereafter referred to as the *Crocodile (West) Modelling Study* (CWMS).

Another parallel study was initiated by the DWAF to develop a reconciliation strategy for the Crocodile (West) River system. This is referred to as the *Crocodile (West) Reconciliation Strategy* (CWRS).

The purpose of the CWRS is to focus on strategies for resolving imbalances between water requirements and water availability based on data gathered for and results from the Water Resources Yield (WRYM) and Water Resources Planning (WRPM) models to be set up as part of the CWMS.

1.2 DESCRIPTION OF THE STUDY AREA

The study area covers the Crocodile (West) River catchment, which forms the major part of the Crocodile (West) and Marico Water Management Area (WMA), but excludes the Marico River. The study area is shown in **Appendix A**, **Map A-1**.

1.3 PURPPOSE OF THE WATER RESOURCES PLANNING MODEL TASK

The purpose of the Crocodile (West) River water resources planning analysis task was to set-up the WRPM for the Crocodile (West) River catchment. The task was originally part of the Crocodile (West) modelling study (CWMS), but has been moved over to the Crocodile (West) reconciliation study (CWRS).

1.4 PURPOSE OF THE REPORT

This report describes the work carried out as part of the WRPM system analyses task. The WRPM setup was completed and the input data files were populated. All the input data files are read correctly, but the model, however, did not function correctly when allocating the water to the different users. The Study Team assessed the fortran codes for the WRPM, and could identify where the problem was, but was unfortunately not in the position to solve the problem. All the WRPM input data files together with the hydrology files were forwarded to Mr Pieter van Rooyen, who is contracted for updating the WRPM, on 9 September 2009 to rectify the problem. We were informed by Mr Pieter van Rooyen, that the software developers, with whom he was working, needed to conduct additional work to finalise new features in the model, and solve the problem. As of 21 September 2009, when finalising this draft report, a solution to the problem had not yet been found.

This report summarises the work conducted up to 21 September 2009.

The results from the WRYM were used as inputs into the WRPM along with the additional work conducted for this task. The WRYM task is described in a separate report as part of the CWMS (*DWAF Report No P WMA 03/000/00/2708 – WRYM Analyses).*

1.5 METHODOLOGY

The Study Team set up the configuration and data base for the Crocodile (West) River catchment using the latest available version of the Water Resources Planning Model (WRPM). The WRPM is currently not incorporated in the Water Resources Information Management System (WRIMS) which was recently developed by DWAF.

A very high level of detail was used for the configuration of the WRYM for the Crocodile (West) River catchment, and the same high detail network was used for the WRPM. The configuration was based on 99 modelling zones, which are sub-divisions of the 40 quaternary catchments within the Crocodile (West) River catchment.

The Crocodile (West) River catchment was modelled as a single system and not split into the four sub-catchments as was done for the Water Resource Simulation Model (WRSM2000). The hydrological input files cover the hydrological period October 1920 to September 2004.

The WRYM set-up forms the base for the WRPM and a summary of the yield analysis is thus provided as background.

2. YIELD ANALYSES

2.1 GENERAL

The yield analyses for the study area were executed with the latest version of the Water Resource Yield Model (WRYM) incorporated in the Water Resource Information Management System (WRIMS). The reference year for the yield analyses was taken as 2003.

Intensive model testing was carried out to confirm that the correct input data was included in the system and that the WRYM was giving satisfactory results. Discrepancies between the modelled and actual behaviour of the system necessitated the “calibration” of the WRYM to ensure that the system presents a true reflection of how the Crocodile (West) system is currently being operated.

Subsequent to this verification the following yield and scenario analyses were carried out:

- Historic firm yield analyses (with and without ecological water requirements (EWRs)) from the 15 major dams in the catchment;

- Long-term stochastic yield analyses from Roodeplaat, Klipvoor, Hartbeespoort, Roodekopjes and Vaalkop dams;
- Short-term stochastic yield analyses from Roodeplaat, Klipvoor, Hartbeespoort, Roodekopjes and Vaalkop dams; and
- Scenario analyses:
    - Present (2003 base year) and future (2030 time slice) scenario;
    - Impact of different operating levels on the yields and water levels of Hartbeespoort Dam;
    - Impact of invasive alien plants (IAPs) on the yields from dams; and
    - Impact of lawful irrigation requirements on water availability.

More information on the yields and scenario analyses can be found in the DWA report No. P WMA 03/000/00/2708, entitled *WRYM analyses.*

2.2 STOCHASTIC SHORT-TERM CURVES

The short-term stochastic analyses were undertaken with the WRYM for the Hartbeespoort, Vaalkop, Roodeplaat and Roodekopjes-Klipvoor systems using the same penalty structures and operating policies as used in the historic and long-term stochastic analyses. The 2003 demands were abstracted from upstream dams when determining the short-term stochastic yields at the five major dams. The short-term stochastic analyses assessed the system with 6 particular boundary conditions for 501 sequences. These boundary conditions are reservoir starting storages of 100%, 80%, 60%, 40%, 20%, and 10% of the live storage of each dam.

As for the long-term stochastic analyses, ecological water requirements (EWRs) were excluded from the system. Operating decisions for the Hartbeespoort GWS and Crocodile (West) Irrigation Board (IB) are taken at the beginning of October of each year, therefore September was taken as the start month for the analyses to allow for time to evaluate the results from the analyses during September, so that a decision can be made on allocations by early October.

The short-term yield characteristic curves for each system are presented in **Appendix B** and are used as input to the WRPM, to make operating decisions.

A base of five years was utilised when determining the short-term characteristic curves. However, taking into account that as the starting storage decreases the critical period decreases, the most conservative short term period length often became less than five years, and this was determined for each stating storage boundary condition. The critical period that gave the lowest yield reliability curve was utilised to determine the final short-term characteristic curves, but no period of less than two years was used.

In order for the system to be operated correctly with the WRPM, the upstream demands and return flows included when deriving the short term characteristic curves in the WRYM, need to be known.

If any changes occur in future in the system configuration (e.g. a dam is raised), new short-term characteristic curves need to be derived with the changes included in the system as these are "characteristic" of the system in a specific state. As such it is necessary to mention the manner in which the transfer of water from Hartbeespoort Dam to Vaalkop Dam was handled. This transfer link, although included in the system network, was not included from Hartbeespoort to Vaalkop when determining the short-term yields. This is because the transfer of water is made available from the yield of Hartbeespoort Dam and is thus a possible demand on Hartbeespoort Dam, and adds to the yield of Vaalkop Dam, if the transfer occurs.

3. WATER RESOURCES PLANNING MODEL (WRPM)

3.1 GENERAL

The WRPM is a more comprehensive model than the WRYM and includes the capability to make allocations and apply curtailments of water use, and can handle a dynamic system (i.e. a system with growing requirements, new infrastructure and changing operating rules). The WRPM utilises data files and output from the WRYM as input, together with additional information on the water resource system. The WRPM further also has the capability to model water quality (salinity), with inputs, derived from output from the water quality model (WQT), included in the WRPM. The network diagram for the WRPM is included as **Appendix C**.

3.2 INPUT DATA FILES

3.2.1 Compatibility with the WRYM

Most of the input data files for the WRPM are the same as the WRYM input data files:

F01.DAT: Scenario definition and control data (some minor changes to the WRYM F01.DAT file are required)

F02.DAT: Reservoir characteristics and hydrology inflow definitions

F03.DAT: Channel definitions (some minor changes to the WRYM F01.DAT file is required)

F04.DAT: Control structure definitions

F05.DAT: Reservoir storage zone, rule curve and penalty structure definitions

F06.DAT: Reservoir starting storage levels

F07.DAT: Hydropower channel definitions (not required for this study)

F08.DAT: Minimum hydropower generation demands (not required for this study)

F09.DAT: Irrigation area definitions (not required for this study)

F10.DAT: Diversion channel demands (not required for this study)

F11.DAT: Minimum flow and loss channel definitions

F12.DAT: Multi-purpose min-max channel definitions

F13.DAT: Minimum power demand and distribution of water master control channel demand (some minor changes to the WRYM F13.DAT file are required)

F14.DAT: IFR channel definitions

The F15.DAT to F21.DAT files, included in the latest version of the WRYM, are traditionally not included in the WRPM. These files are listed below:

F15.DAT: Curtailment and drought restriction structure definitions

F16.DAT: Demand reconciliation analysis

F17.DAT: Irrigation block sub-model definitions

F18.DAT: Wetland sub-model definitions

F19.DAT: Demand Centre sub-model definitions

F20.DAT: Streamflow Reduction (SFR) sub-model definitions

F21.DAT: Mine sub-model definitions

The F17.DAT file has, however, recently been included into the WRPM to accommodate type 1 and type 2 "yield only" irrigation blocks as included in the WRYM. Traditionally irrigation blocks were included together with the WQT model input data files. It must, however, be noted that the functionality of the F17.DAT irrigation blocks within the WRPM is currently incomplete, and the irrigation demands incurred by the irrigation blocks in the F17.DAT file cannot be imposed on the short-term curves, and as such cannot be curtailed.

The WRPM input data files are included on a CD in **Appendix D**.

3.2.2 Additional files for the WRPM

In addition to the above files the following specific WRPM data files are also prepared:

DAM.DAT Reservoir planning

DBF.DAT Disbenefit functions for each demand

GTH.DAT Annual growth factor for demand channels, min-max channels, afforestation, irrigation and urban demands

HST.DAT Monthly historic requirements in first year (per month in m^3/s)

HYD.DAT Hydropower allocation control data

PMP.DAT Pumping channel control data

PUR.DAT Purification channel control data

REC.DAT Reclamation plant control data

RET.DAT	Return flow channel specification
SW*.DAT	Channel switch control data
TAR.DAT	Tariff structure for demand channels
ALO.DAT	Allocation channel control data
REL.DAT	Controlled release structure data file (water quality mode)
WRPM.DAT	System file prefix name and directory reference
Water quality	Several files containing the water quality network definition and calibration data (only required if the water quality sub-model is activated)

3.3 CONFIGURATION OF THE WRPM FOR THE CROCODILE (WEST) RIVER

3.3.1 General

The WRPM was set up outside the WRIMS, as the WRIMS is still in the process of being finalised.

A serious, time-consuming and frustrating problem is the fact that the WRPM manual is incomplete and outdated. The existing manual is virtually the same as that used in the *Crocodile West River Catchment Study* completed in 1993.

Many changes and updates were incorporated in the WRPM and the manual has not been amended accordingly. It is recommended that the manual be updated as a matter of priority. Once that is done WRPM training courses with practical examples should be held to disseminate the knowledge and experience to other users. If this is not done, it might lead to the situation that less and less people are able to use the model in the near future.

3.3.2 Water allocation

Four user categories were included in the WRPM, namely:

1. Irrigation
2. Domestic/urban
3. Mining, industry and power generation
4. Return flows

For these user categories, four priority levels or classes were provided for into which the demand is allocated, namely:

1. High (1:200 recurrence level)
2. Medium high (1:100 recurrence level)
3. Medium low (1:50 recurrence level)
4. Low (1:20 recurrence level)

3.3.3 Dummy channels

The short-term curves are based on 2003 level water requirements and return flows. The WRPM is set-up to start in September 2009. Growth in upstream water requirements and return flows needs to be included in the short-term curves, as this growth changes the water availability. Because the 2003 level water return flows were already included when the short-term curves were generated, adding the growing upstream water return flows to the short-term curves would be counting the 2003 level portion of the return flows twice. As such, "dummy" demand channels were included at constant 2003 volumes. By reducing the growing return flow by the 2003 volume, one is essentially adding only the growth to the system.

An example of this is presented in **Figure 1**.

The 2003 return flow volume of 11 Mm^3/a is already incorporated when the level short-term curves are generated. The growing return flows (up to approx. 25 Mm^3/a in 2015), are imposed on the short term curve as a negative value, thereby adding to the water availability. The 2003 level portion of the return flows (green area) is however counted twice. As such a dummy demand channel of 11 Mm^3/a (green area) is also included, thereby cancelling out the double counting of 2003 level return flows, and only the post-2003 level return flow growth volumes (hatched area) are added to the short term curve. This was the easiest manner to accommodate growth in return flows without having to re-generate a number of short-term curves, which would be very time consuming.

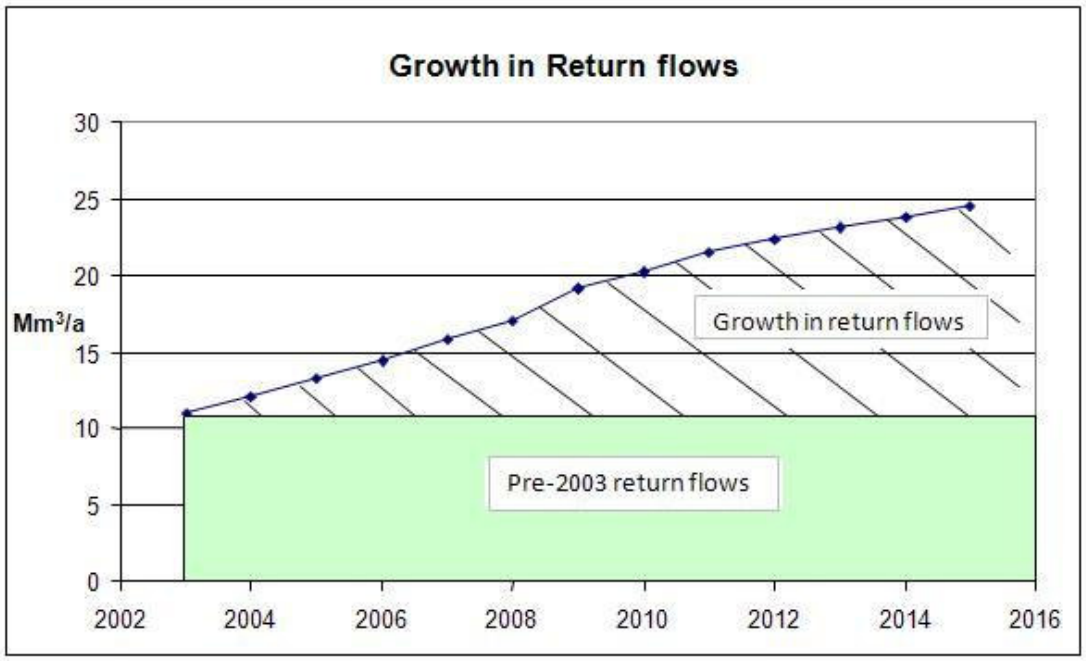

Figure 1: Example of a dummy channel

The functionality of the WRPM with regard to irrigation blocks included in the F17.dat file is being amended to allow curtailment of the irrigation. The Study Team set up the

F17.DAT-file representing the irrigation blocks, but the associated irrigation demand and curtailments thereof could not yet be imposed onto the short-term curves. As such "dummy" channels with demands equal to the average irrigation demand were imposed on the appropriate short term curves of the various sub-systems.

All "dummy" channels were included in the F01.DAT, F03.DAT, GTH.DAT and FM*.DAT files as part of an external network going from node zero back to node zero, and not connected to the Crocodile (West) network. This is because the dummy channels were only included to correct the allocation procedure and not to route water through the network.

3.3.4 Water transfer from Hartbeespoort Dam to Vaalkop Dam

The water requirements from Vaalkop Dam are greater than the availability. Water can, however, be released from Hartbeespoort Dam in the Crocodile (West) River and diverted at Roodekopjes Dam to Vaalkop Dam, via the Roodekopjes-Vaalkop Canal.

This canal has a transfer capacity of 4 m^3/s, which is greater than the water requirements from Vaalkop Dam. As such, no planning in advance is needed to determine the volume that is required for the transfer, as this volume of water required for transfer is not limited by infrastructure capacity constraints.

Because no advanced planning is needed for the transfer of water, the transfer channel is not included in the WRPM as a sub-system transfer support channel, although the Vaalkop sub-system is supported by the Hartbeespoort sub-system in the allocation procedure. If additional water is needed by the Vaalkop sub-system, it is allocated from the available water in Hartbeespoort Dam, but the transfer happens during the network routing by virtue of the penalty structures of the dams and connecting channels.

3.4 TESTING OF THE WRPM

All the input data files are being correctly read by the model software. As mentioned in paragraph 1.4, an error occurs during the allocation procedure. Mr. Pieter van Rooyen was requested to address the problem, and software programmers are conducting the necessary amendments. Once this has been completed, testing of the allocation procedure can be conducted.

3.5 WORK TO BE COMPLETED IN FOLLOWING STUDIES

The Crocodile (West) River catchment system has been set-up in the WRPM model and includes "yield only", F17.dat file irrigation blocks. At present these irrigation blocks cannot be included as demands on the short-term curves, as explained in paragraph 3.3.3. The DWA is currently updating the WRPM to include the F17.DAT irrigation blocks as demands to be included in the FM*.DAT files, which will allow modelling of the curtailment of irrigation.

Once the model has been successfully amended, the relevant abstraction channels and return flow channels of the irrigation blocks need to be included in the allocation and curtailment procedure (F01.DAT, F03.DAT, and FM*.DAT files). These abstraction and return flow channels are listed at the bottom of the F01.DAT file for ease of updating the file in future. Correspondingly, the dummy channels representing the irrigation block demands should then be removed from the relevant files.

Possible water transfers to the Lephalale area in the neighbouring Mokolo River catchment and bringing additional water from the Vaal River system into the Crocodile (West) River catchment have not been optimised through scenario analyses.

4. CONCLUSIONS

The WRPM has been set-up for the Crocodile (West) River catchment at the same high level of detail as the WRYM set-up. The WRPM data files are being correctly read by the model, but an error occurs during the allocation procedure.

Furthermore, some of the new modules, such as the “yield only” irrigation blocks in the F17.DAT file, are not fully functional in the WRPM yet. The DWA is in the process of amending the WRPM to include these irrigation blocks in the allocation procedure, and solve the allocation error. Once this has been completed and the model is fully functional, the necessary steps to update the data files, which have been summarised in this report, can be finalised.

One of the main difficulties of setting up a complex system such as the Crocodile (West) River in the WRPM is that the user manual is incomplete and outdated. Changes within the program without the necessary documentation resulted in confusion, duplication of work and subsequent delays. The Crocodile (West) River system was configured to assess the possible scenario of transferring water to Lephalale. No scenario analyses have yet been conducted, and the operating rules and timing of further transfers from the Vaal River to the Crocodile (West) River to augment local water availability, have not been optimised in this regard.

5. RECOMMENDATIONS

Once the WRPM model has been amended to allow irrigation blocks to be included in the allocation and curtailment procedure, the necessary data files should be updated as described in this report. The allocation procedure should then be tested and if necessary, the allocation procedure along with the short term curves be reviewed to achieve the desired operation of the dams.

It is recommended that the WRPM manual be updated as a matter of urgency.

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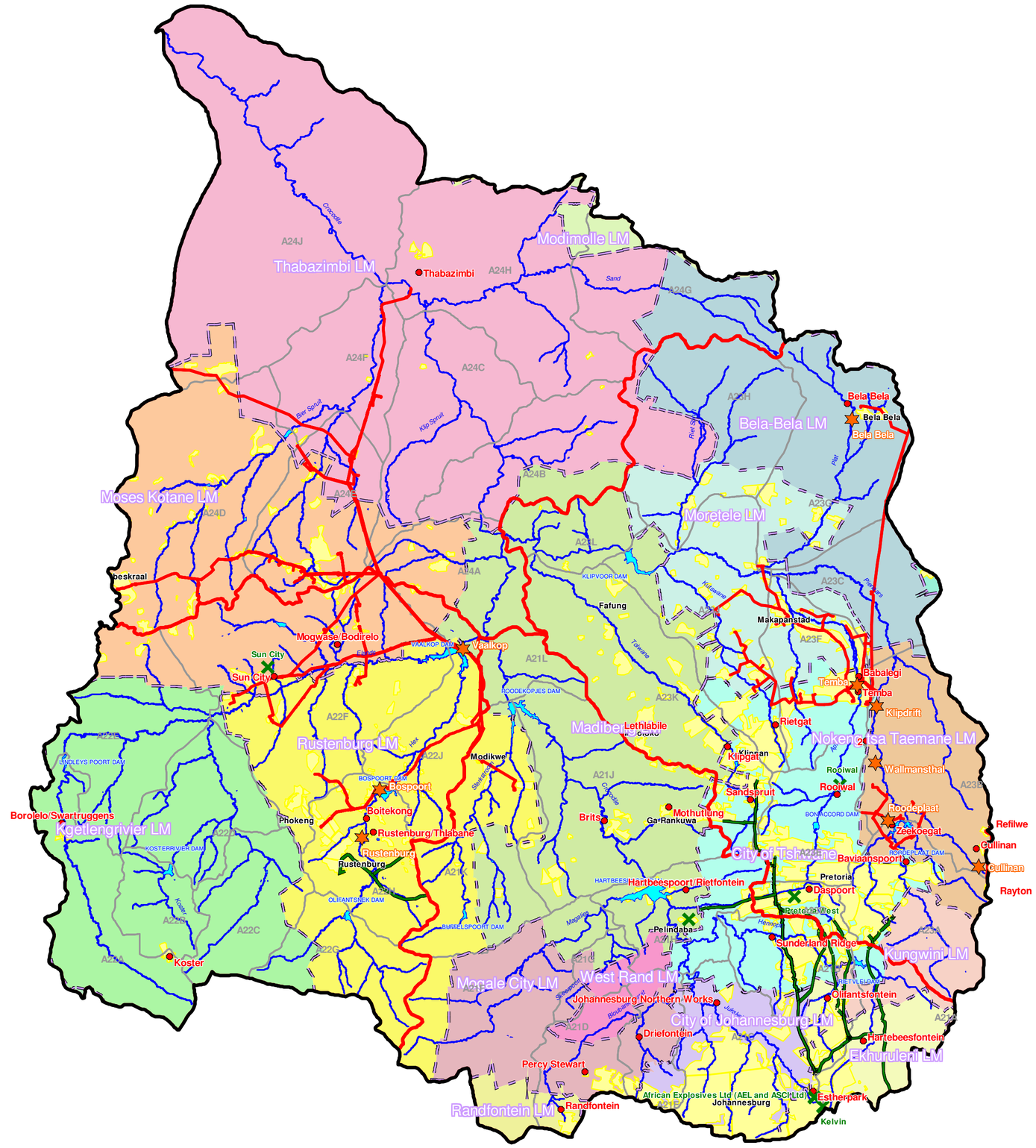
Appendix A

Map of the Crocodile (West) River catchment

Legend

- Local Municipality Boundaries
- Crocodile West Catchment
- Quatenary Catchments
- Urban Areas
- Rivers
- Dams
- Magalies Water Pipelines
- Rand Water Pipes
- WWTW
- Water Purification Works
- Power Stations & Industries



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Scale 1:650000

0 5 10 20 30 40 50 km

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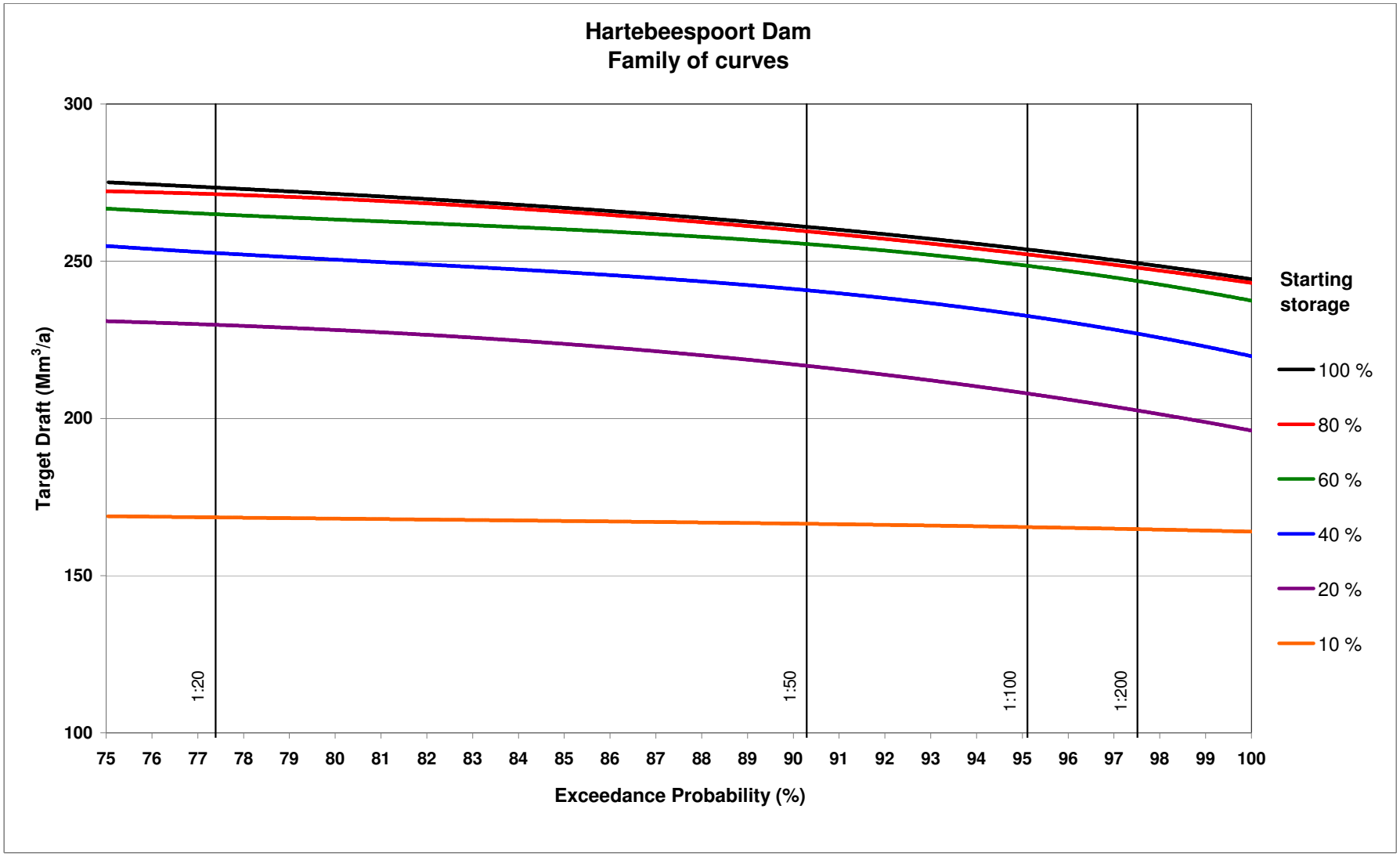
CROCODILE WEST RECONCILIATION STRATEGY

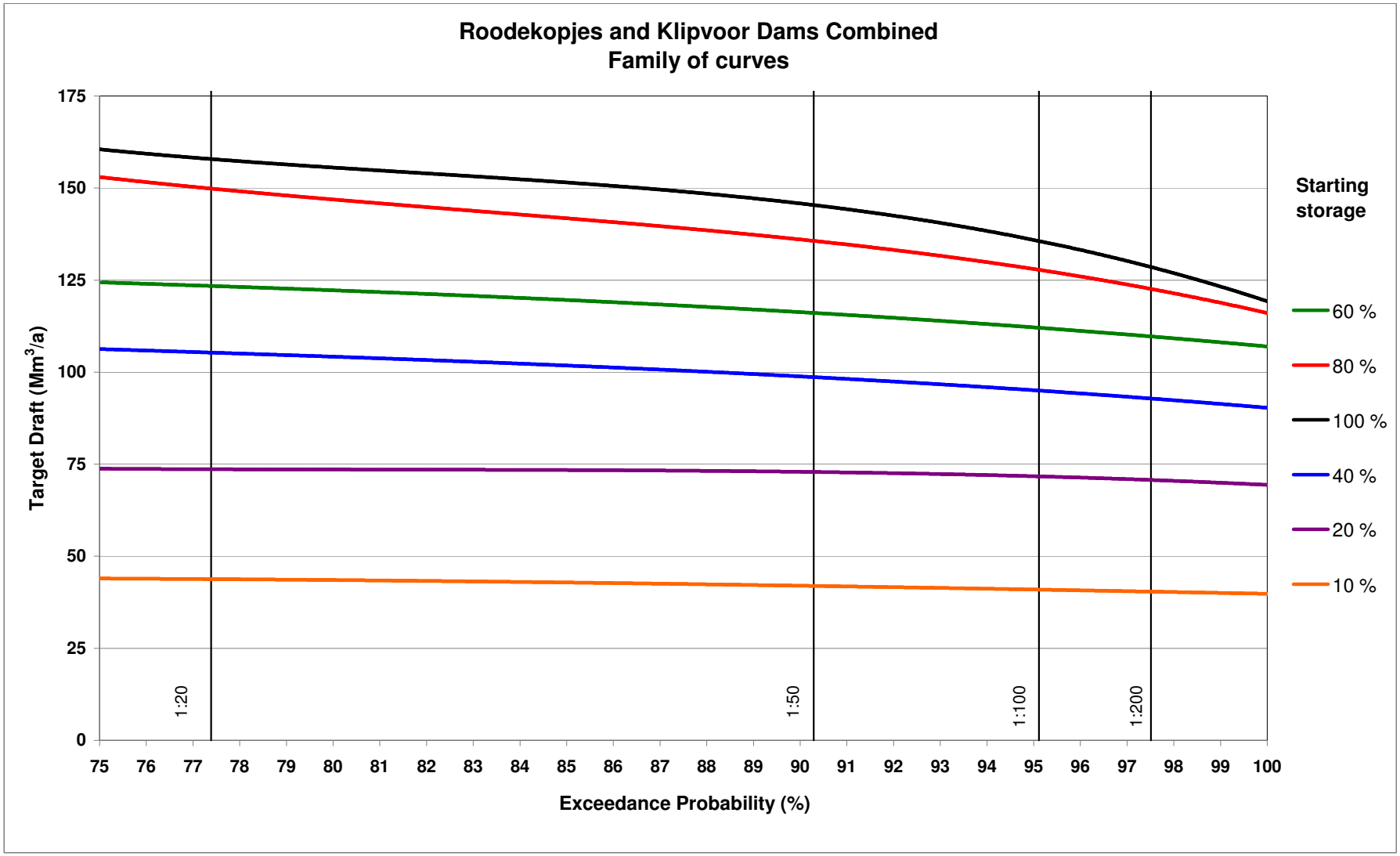
Study Area

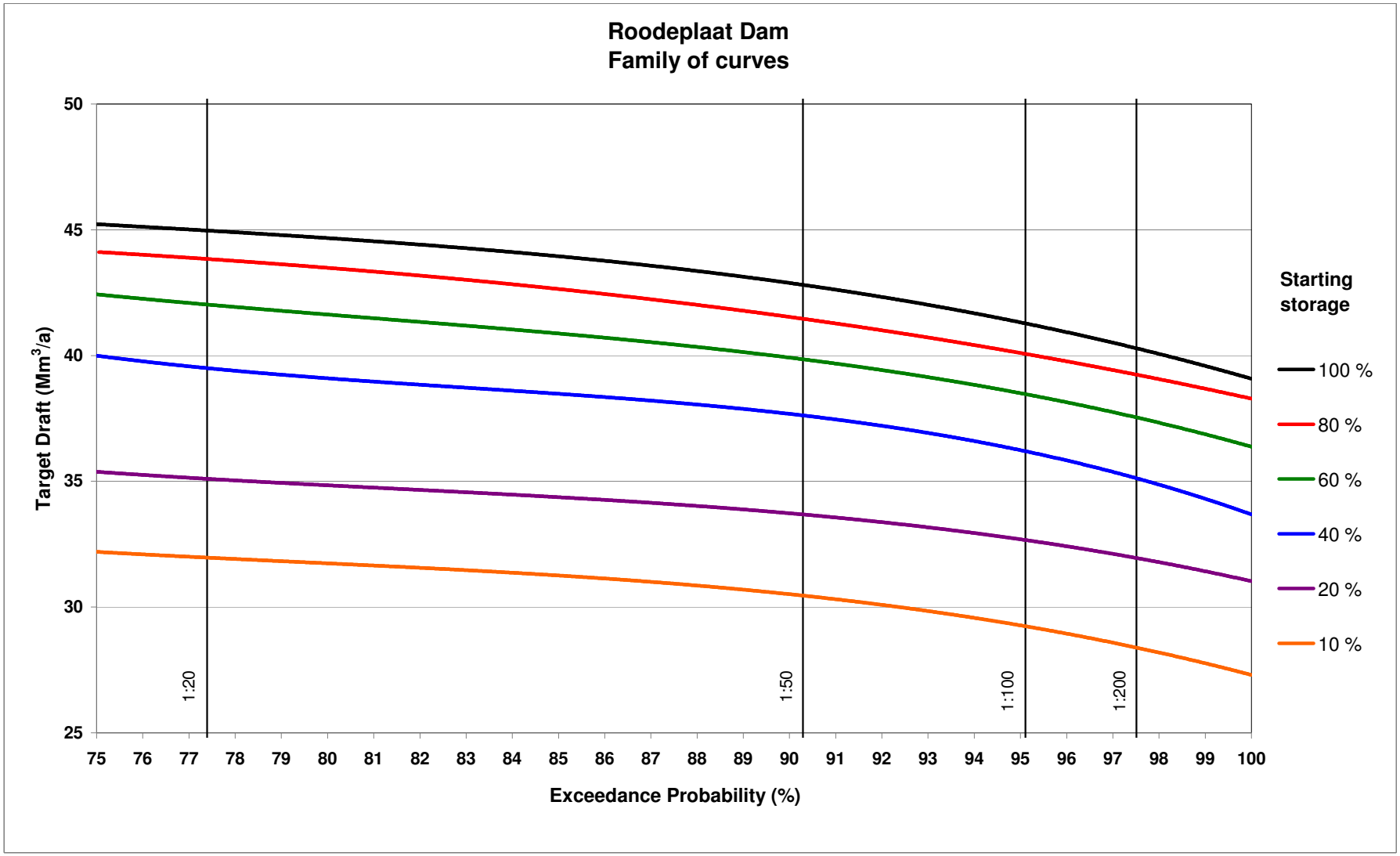
MAP A-1

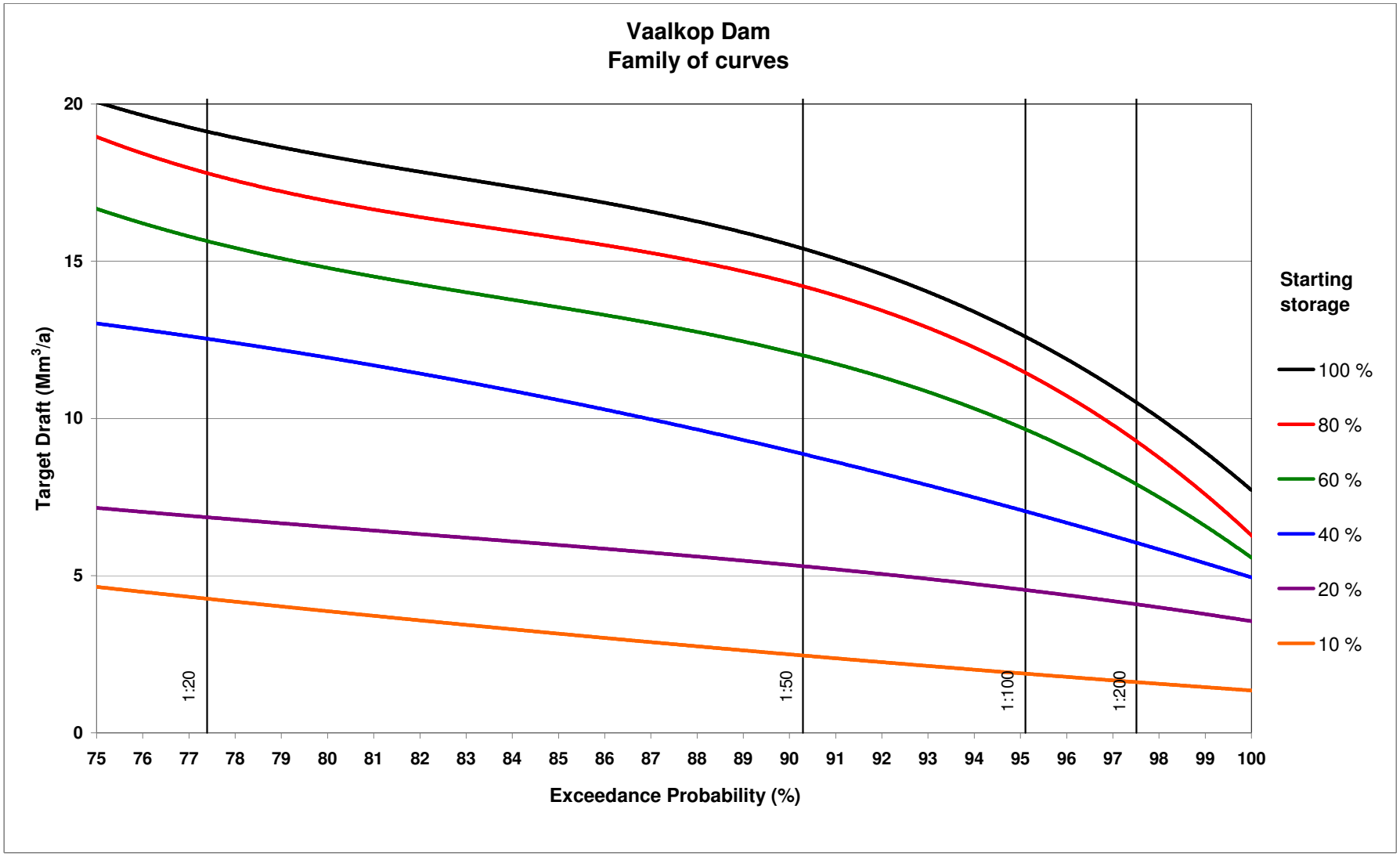
Appendix B

Short-term curves


Hartebeespoort Dam
Family of curves
Target Draft (Mm3/a)
300
250
200
150
100
1:20
1:50
1:100
1:200
75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100
Exceedance Probability (%)
Starting storage
100 %
80 %
60 %
40 %
20 %
10 %


Roodekopjes and Klipvoor Dams Combined
Family of curves
Target Draft (Mm³/a)
175
150
125
100
75
50
25
0
1:20
1:50
1:100
1:200
75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100
Exceedance Probability (%)
Starting storage
60 %
80 %
100 %
40 %
20 %
10 %


Roodeplaat Dam
Family of curves
Target Draft (Mm3/a)
50
45
40
35
30
25
1:20
1:50
1:100
1:200
75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100
Exceedance Probability (%)
Starting storage
100 %
80 %
60 %
40 %
20 %
10 %


Vaalkop Dam
Family of curves
Target Draft (Mm3/a)
20
15
10
5
0
75
76
77
78
79
80
81
82
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84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
100
Exceedance Probability (%)
1:20
1:50
1:100
1:200
Starting storage
100 %
80 %
60 %
40 %
20 %
10 %

Appendix C

Network diagram

LOWER CROCODILE

ELANDS

APIES PIENAARS

UPPER CROCODILE

LEGEND

Node (WRYM)

Resevoir (WRYM)

Channel (WRYM)

Reservoir Penality

Channel Penality

Inflow

Irrigation block

Demand Centre

SFRA Sub Catchment

Dummy System

CROCODILE WEST RECONCILIATION STRATEGY

APPENDIX C: WRPM NETWORK DIAGRAM

Appendix D

WRPM input data files