Operating Rules for Dams with High Evaporation Losses

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Abstract

The purpose of this assessment was to determine general and drought curtailment rules for the major dams situated within the Great Marico River System. The climate of the Marico catchment is semi-arid with the result that flow in the Marico River is highly variable and intermittent. The Water Resources Yield Model (WRYM) was used for the historic as well as the long-term and short-term stochastic yield analyses that were undertaken for each of the major dams. The short-term yield characteristics of the identified sub-systems together with the required assurance of supply of the different user groups in the system were subsequently incorporated in the more advanced Water Resources Planning Model (WRPM). Well established principles of system operation were applied and the WRPM was used to develop simplified curtailment curves for each sub-system. Alternative operating rules were assessed and the impact of the extremely high evaporation losses from reservoirs on the supply from the water resources was found to be significant. Consequently it was established that the average supply to water users could be increased by implementing less severe restrictions, i.e. when the water resources are operated at lower storage levels, the evaporation losses are reduced and the average supply to the users is increased.

Keywords: *Curtailment rules, high evaporation losses.*

1 Introduction

The Marico River generally flows in a northerly and north-easterly direction before joining the Crocodile River. The Crocodile River in turn is a major tributary of the Limpopo River which has an international basin shared with Botswana, Zimbabwe and Mozambique. The Marico River acts as the boundary between Botswana and South Africa along part of its length. The Marico River catchment is located within the North West Province and forms part of the Crocodile (West) Marico Water Management Area (WMA). A locality map of the Marico River catchment is shown in **Figure 1**.

The climate of the Marico catchment is semi-arid and the Mean Annual Precipitation (MAP) over the catchment varies from 650 mm upstream of Marico Bosveld Dam to 526 mm at Molatedi Dam. There is a relatively small variation in the Mean Annual Evaporation (MAE) over the catchment from 1850 mm in the south to around 1950 mm in the drier northern part of the catchment at Molatedi Dam. The impact of evaporation losses from the exposed water surfaces of impoundments proved to be very significant in this catchment.

The topography is generally flat with undulating areas in the Lower Marico catchment. The total effective catchment area of the Great Marico River upstream of Molatedi Dam has been assessed at 8640 km^2 and the corresponding natural Mean Annual Runoff (MAR) for the catchment amounts to 110 million m^3/a (MAR for 1920 to 1993 record period). The flow in the Marico River is highly variable and intermittent. Runoff within the Molatedi Dam catchment is regulated by the Klein Maricopoort, Kromellenboog, Marico Bosveld, Pella, Madikwe and Sehujwane dams as well as other smaller farm dams. Although the Marico Bosveld Dam's catchment area of 1230 km^2 amounts to only 14% of the total study area, 36% of the natural MAR is generated in this catchment.

The main water use sectors are commercial irrigation farming, urban water use in the main towns of Ramoshwere Moiloa (former Zeerust) and Groot Marico, as well as domestic water use in rural villages such as Madikwe, Pella, Motswedi and surrounding smaller villages. Irrigation water requirements comprise about 75% (48 million m^3/a) of the total system's water use and were assumed to remain constant over the entire analysis period. Urban/industrial/rural demands, which are dependant on surface water resources, are estimated at 9 million m^3/a at the 2006 development level, and is expected to increase to 10 million m^3/a by 2020. Ramoshwere Moiloa is supplied from groundwater resources. Botswana has an allocation of 7.3 million m^3/a from Molatedi Dam. This international allocation forms part of the TSWASA Agreement (DWAF, 1988) which determines all the water allocations from Molatedi Dam .

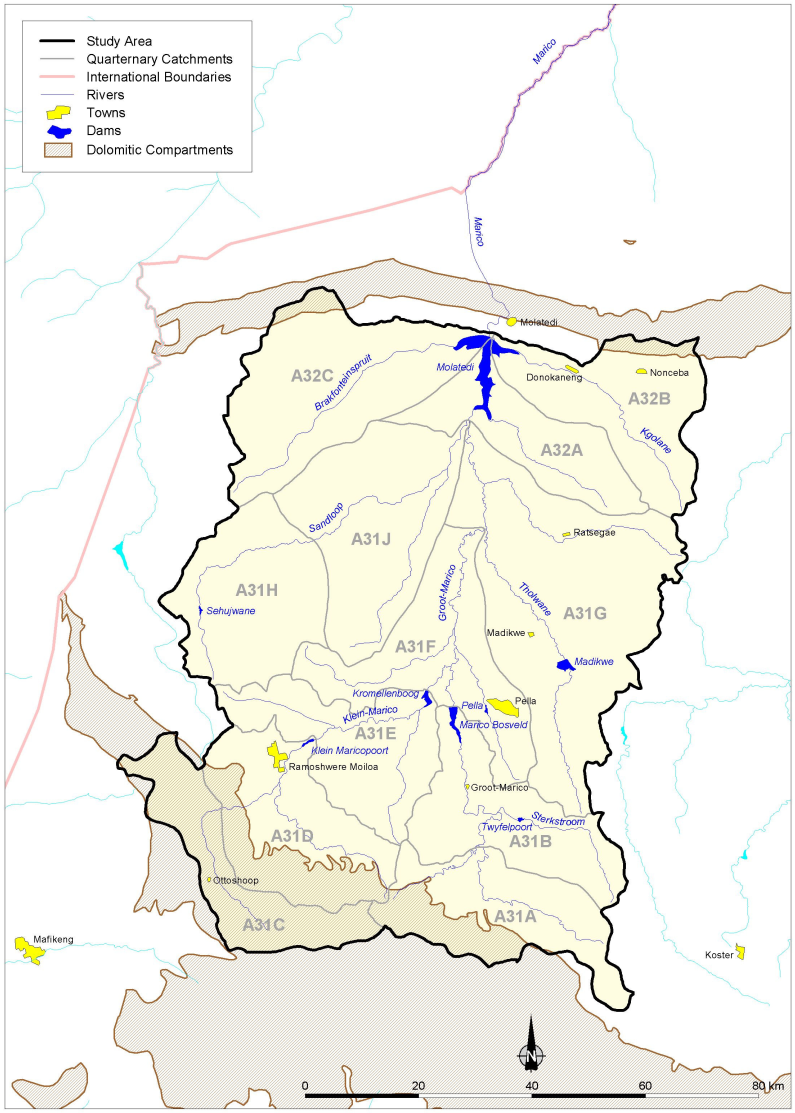

Figure 1: Layout of Molatedi Dam catchment

2 Study Objectives

The main objective of this study was to update the existing hydrological models for the Great Marico River System and to develop operating rules and a decision support system for the Klein Maricopoort, Kromellenboog, Marico Bosveld, Pella, Madikwe, Sehujwane and Molatedi dams. These operating rules and decision support system need to be applied on an annual basis for the effective management of the water resources of the system. As part of the operating rule assessment monitoring systems were identified to keep track of the movement of water and storage in the system. For this purpose reservoir storage trajectories have to be developed for continuous evaluation of the reservoir responses. For detailed information not presented in this paper, the reader is referred to the study report (DWAF, 2007).

3 Water Requirements and Return Flows

The first task of this study involved the gathering of information on water requirements and return flows from previous studies that were undertaken by the DWAF and other stakeholders. All usable data from the available reports and existing databases were extracted and comparisons of the different sources of current and projected water requirement and return flow data were compiled. These comparisons were used to identify discrepancies and to compile the most appropriate water requirement database to be adopted for this study. This was achieved through the discussion of the summarised data with stakeholders. Other DWAF Professional Service Providers who had undertaken studies on behalf of the DWAF in the study area were also consulted.

Pella, Madikwe and Sehujwane dams supply water for domestic use only. The domestic water users identified within the study area, as well as their water resources and requirement projections that were finally adopted for the analyses, are summarised in Table 1.

Table 1: Summary of Domestic Water Requirements

Description of water user	**Water resource**	**Water requirement projections (million m^3/a)**			
		2006	**2010**	**2015**	**2020**
Ramoshwere Moiloa	Groundwater	4.400	4.820	5.391	6.030
Groot Marico Municipality	Great Marico River	1.700	1.700	1.700	1.700
Swartruggens	Rietvlei Spruit	0.360	0.360	0.360	0.360
Pella and nearby villages	Pella Dam	0.237	0.266	0.307	0.355
Madikwe and nearby villages	Madikwe Dam	0.883	0.993	1.150	1.332
Motswedi and nearby villages	Sehujwane Dam	0.814	0.916	1.062	1.230
Molatedi (RSA Domestic)	Molatedi Dam	5.000	5.000	5.000	5.000
International (Botswana)	Molatedi Dam	7.300	7.300	7.300	7.300
Total water requirements:		**20.7**	**21.4**	**22.3**	**23.3**
Total water requirements supplied from surface resources:		**16.3**	**16.5**	**16.9**	**17.3**

Swartruggens has a fixed allocation from the Rietvleispruit. Owing to lack of information, the water requirements of Groot Marico Municipality were assumed to be equal to their allocation. Since projections for the remaining towns and villages were only provided up to the year 2010, the necessary extrapolation thereof to the year 2020 was based on the annual growth calculated over the period 2006 to 2010. The annual growth determined for Pella village was in the order of 3.4% whereas that of Madikwe and Motswedi villages amounted to almost 3%. The future International (Botswana) requirements were kept constant at 7.3 million m^3/a.

Water abstracted from Klein Maricopoort, Marico Bosveld and Kromellenboog dams are used for irrigation purposes only. Marico Bosveld and Kromellenboog dams supply water to the Marico Bosveld Government Water Scheme (GWS). System operators indicated that about 10% of the water use of the Marico Bosveld GWS's is supplied from Kromellenboog Dam and the remainder from Marico Bosveld Dam. Molatedi Dam is the only dam within the study area that provides water for both domestic and agricultural water use. A summary of the irrigation water requirements finally adopted for this study is provided in Table 2.

Table 2: Summary of irrigation water requirements adopted for this study

Description	**Water Requirement (million m^3/a)**
Klein Maricopoort Dam Sub-system	
Malmanie Irrigation Area	0.470
Vergenoegd Irrigation Area	1.590
Klein Maricopoort Irrigation Scheme	2.17
Sub-total for Klein Maricopoort Dam Sub-system:	**4.23**
Kromellenboog Dam Sub-system	
Mainstream Irrigation in A31E	0.678
Marico Bosveld GWS (10%)	1.870
Sub-total for Kromellenboog Dam Sub-system:	**2.55**
Marico Bosveld Dam Sub-system	
Twyfelpoort Irrigation	1.030
Rondawel and other irrigation areas	11.970
Marico Bosveld GWS (90%)	16.820
Sub-total for Marico Bosveld Dam Sub-system:	**29.82**

Description	Water Requirement (million m^3/a)
Molatedi Dam Sub-system	
Mainstream Irrigation in A31F	0.147
Mainstream Irrigation in A31H	0.525
Mainstream Irrigation in A31J	0.184
Derdepoort IB	10.600
Sub-total for Molatedi Dam Sub-system:	**11.46**
Total study area:	**48.1**

4 Hydrology

The water resources of the Great Marico River Catchment have been the subject of the study "Yield Analysis: Molatedi Dam" undertaken by the DWAF in 1996 (DWAF, 1996). The hydrological time series database resulting from the DWAF 1996 study covering the period from October 1920 to September 1994 (i.e. extending over a period of 74 years) was adopted for the operating analysis of this study. The hydrology of the catchment upstream of Klein Maricopoort Dam was updated to include the impact of increased abstractions from the dolomitic compartments on the spring flows. The hydrological modelling was done on a quaternary catchment basis and the hydrological information is summarised in Table 3. There is no commercial afforestation within the study area.

Table 3: Summary of hydrological data for the Great Marico River System

Incremental Sub-Catchment Name	Sub-Catchment Reference Number	Net Incremental Catchment Area (km^2)	Natural MAR (&) (1920-1993) (million m^3/a)	MAP ($) : 1920 - 1993 (mm)
A31A	I1	633	21.03	569
A31B	I2	597	18.97	629
A31CDN	I3	1191	10.75	566
A31E	I4	602	5.60	579
A31F	I5	703	7.29	588
A31G	I6	1427	14.19	580
A31H	I7	685	6.50	576
A31J	I8	846	6.64	0
A32AB	I9	1115	11.93	0
A32C	I10	841 (#)	7.45	526
Total for Great Marico Catchment		**8640**	**110.4**	

Note: (#) With the exception of quaternary catchment A32C (gross area of 904 km^2) the remaining sub-catchments have no endoreic areas (i.e. gross areas are equal to net areas).
(&) Mean Annual Runoff
($) Mean Annual Precipitation

5 System Layout and Storage Structures

Streamflow within the Great Marico catchment is regulated by four major dams situated on the main stem of the Marico River as well as a few smaller dams located on the main tributaries. A total of nine existing dams were included in the simulation of the Great Marico catchment of which the Molatedi Dam, situated at the outlet of the catchment, is the largest. A list of all the dams and their relevant information is given in Table 4. The physical locations of these dams are shown in Figure 1 and Figure 2 is a simplified schematic diagram of the Great Marico River system.

The Water Resources Yield Model (WRYM) configuration of the Great Marico River catchment was refined to explicitly simulate the dams indicated in Figure 2.

Table 4: List of dams located in the Great Marico River catchment

Name	DWAF No	River	Natural MAR (million m^3)	Gross capacity (million m^3)	Gross capacity (% MAR)	User Group supplied from dam
Twyfelpoort	-	Sterkstroom	6.46	0.75	12	Irrigation
Marico Bosveld	A3R001	Great Marico	40.0	26.96	67	Irrigation
Klein Maricopoort	A3R002	Klein Marico	10.75	7.07	66	Irrigation
Kromellenboog	A3R003	Klein Marico	16.35	8.96	55	Irrigation
Pella	-	Letlhakana	0.80	2.17	271	Domestic
Rooisloot	-	Rooisloot	0.36	0.55	153	None
Madikwe	-	Tholwane	2.98	15.94	535	Domestic
Sehujwane	A3R005	Sehujwane	1.69	3.77	223	Domestic
Molatedi	A3R004	Great Marico	110.35	200.95	182	Domestic and irrigation

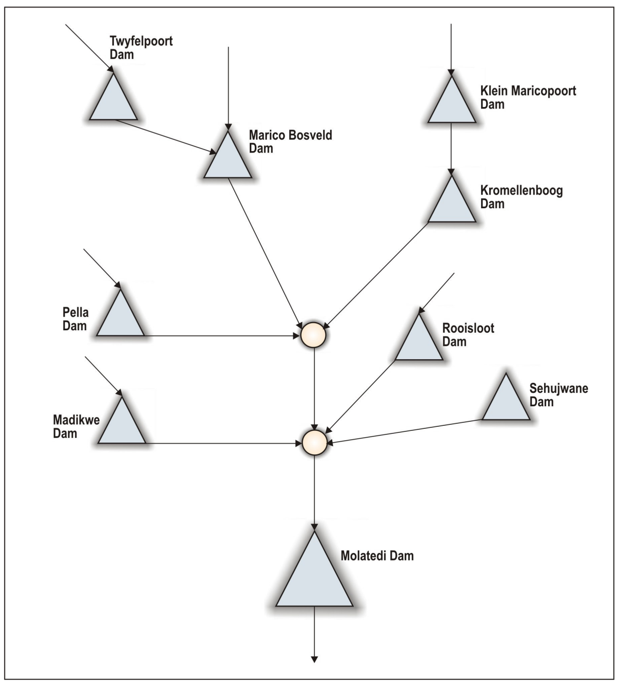

Figure 2: Simplified schematic diagram of the Great Marico River System

6 Yield Analyses

6.1 Long-term Analysis

Historic Firm Yield (HFY) and long-term stochastic analyses were carried out for all the major dams using the updated Water Resource Yield Model (WRYM) configuration and the revised hydrology as presented in Table 3. The yield results obtained as part of this study are summarised in Table 5.

Important findings from the yield analyses include the following:

- Yield analysis results clearly showed that all the sub-systems are totally over allocated. This can be seen from Table 5 by comparing the 2006 demand of each dam (shown in column 1) with the corresponding yield results.
- Sensitivity analyses showed that the highest assurance of supply to the Marico Bosveld GWS is achieved when 90% of the scheme's water requirements are supplied from Marico Bosveld Dam and the remaining 10% of the demand is supplied from Kromellenboog Dam.
- It was found that the net evaporation losses from the exposed water surfaces of the reservoirs in the Marico River catchment are extremely high (refer to Section 7.5 for details).

Table 5: Summary of yield characteristics for major dams

Dam Name 2006 Demand (million m^3/a)	Historic Firm Yield in million m^3/a (Recurrence interval in years)	Long-term Stochastic Firm Yield (million m^3/a) at indicated recurrence intervals			
		1:20 year	1:50 year	1:100 year	1:200 year
Klein Maricopoort 2.17	0.57 (1: 144)*	1.80	1.00	0.68	0.49
Kromellenboog 1.87	1.28 (1: 162)*	2.22	1.69	1.40	1.21
Marico Bosveld 16.82	8.85 (1: 57)*	10.80	9.30	8.00	7.06
Pella 0.237	0.143 (1: 186)*	0.280	0.210	0.166	0.138
Madikwe 0.883	0.220 (> 1: 200)*	0.650	0.435	0.340	0.248
Sehujwane 0.814	0.324 (> 1: 200)*	0.607	0.460	0.382	0.330
Molatedi 22.90	11.81 (1: 108)*	21.20	15.00	12.00	9.79

*Note: * - Value in brackets represents the Recurrence Interval (RI)*

6.2 Short-term Analysis

The long-term yield/reliability curves capture the long-term yield capabilities of the water resource sub-system, providing perspective on the long-term average behaviour thereof. However, the Water Resource Planning Model (WRPM) need information on the short-term yield capability of a sub-system to make operational allocation decisions which include the implementation of restrictions during drought periods.

For relatively large water resource systems with over-year storage and where major operational decisions are taken on an annual basis, a period of 5 years is considered realistic for the projection of the probabilistic short-term behaviour of a sub-system. Since the initial storage level of a reservoir significantly influences the short-term yield it is required that short-term yield characteristics be determined for different starting storage levels. Short-term yield curves were developed for starting storages of 100%, 80%, 60%, 40%, 20% and 10%. A set of short-term curves was determined for each of the identified sub-systems and 501 stochastically generated flow sequences, each 5 years in length, were used in the analyses.

7 System Operating Analysis

7.1 Operating Principles and Priority Classification

The proposed new operating rules that were developed for the different sub-systems within the Great Marico River System are based on the knowledge gained from the yield analyses, existing operating rules, understanding of the total system and its requirements, as well as important operating principles.

These operating principles include the following:

- **General operating principle** – Operate the system as an integrated system in order to obtain the maximum yield benefit from the system.
- **Maintain the assurance of supply to users** – This is the primary objective of the operating rules and for the operation of the Great Marico River System.
- **Restriction of demands** – The operation of the system needs to be based on the principle that demands are restricted during severe drought events.
    - The objective of these restrictions is to reduce supply to less essential use to be able to protect the assurance of supply to more essential use.
    - The basis on which restrictions are implemented is defined by means of the user priority classification definition as given in Table 6.

The WRPM uses the short-term yield characteristics as obtained from the WRYM in combination with the user priority classification to implement the drought curtailment rules. Irrigation or urban garden watering will, for example, be supplied at a lower assurance than strategic industries (i.e. they are curtailed first during drought events). For the purpose of the WRPM analyses it is, therefore, important to sub-divide the demand of the different user categories into three or four priority classes, which represent different assurance of supply or reliability levels. This was discussed at a Stakeholder Forum Meeting and a specific priority classification was agreed on as given in Table 6.

As shown in Table 6, four user categories and four assurance levels were identified for the Great Marico River System.

Table 6: User category and priority classifications for the Great Marico River System as proposed by the Stakeholders

User Category	**Priority Classification and assurance of supply**			
	Low (90% assurance) (1:10 year)	**Medium Low (98% assurance) (1:50 year)**	**Medium High (99% assurance) (1:100 year)**	**High (99,5% assurance) (1:200 Year)**
	Portion of water requirement supplied (%)			
Domestic	10%	10%	20%	60%
Mining and Industrial	40%	30%	20%	10%
International	10%	10%	20%	60%
Irrigation	40%	30%	20%	10%
Curtailment level **0**	**1**	**2**	**3**	**4**

7.2 Configuration of the WRPM

In the final configuration of the WRPM the data sets were defined to enable the model to impose separate curtailments to the following six sub-systems:

- Klein Maricopoort Sub-system;
- Marico Bosveld and Kromellenboog Sub-system;
- Pella Sub-system;
- Madikwe Sub-system;
- Sehujwane Sub-system; and
- Molatedi Sub-system.

7.3 Presentation of WRPM Results

Although similar results were obtained for the six identified sub-systems, the Marico Bosveld and Kromellenboog Sub-system was selected for the purposes of illustrating the relevant findings of the WRPM scenario analyses. Detailed results for all the sub-systems can be found in the study report (DWAF, 2007).

The behaviour of selected system components (e.g. projected reservoir storages and simulated flows through water abstraction/supply routes) is presented as probabilistic distribution plots (box plots). A typical box plot indicating the various lines that depict specified exceedance probabilities of a probability distribution is provided in Figure 3.

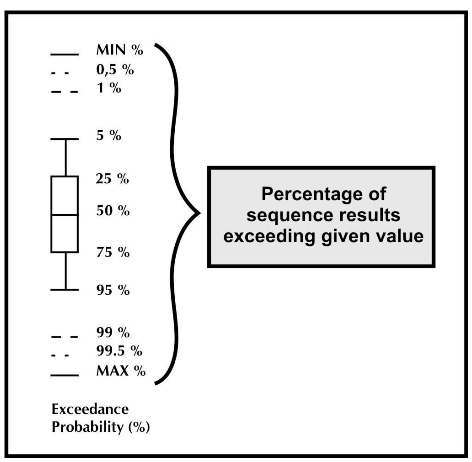

Figure 3: Graphical depiction of a probability distribution or box plot

7.4 Initial Results for Marico Bosveld and Kromellenboog Sub-system

The Marico Bosveld and Kromellenboog Sub-system supplies water to the Marico Bosveld Government Water Scheme (GWS) which has a total demand of 18.7 million m^3/a. It was assumed that 90% (16.8 million m^3/a) of the total demand is released from Marico Bosveld Dam. The user priority classification for irrigation as defined in Table 6 was adopted for the initial WRPM analysis (**Scenario 1**). This implied that 40% of the total irrigation demand (i.e. 7.5 million m^3/a) be allocated to the 90% assurance, 30% (5.6 million m^3/a) to the 98% assurance, 20% (3.7 million m^3/a) to the 99% assurance and 10%

(1.9 million m^3/a) to the 99.5% assurance. The resulting projected water supply from Marico Bosveld Dam to the Marico Bosveld GWS is shown in Figure 4.

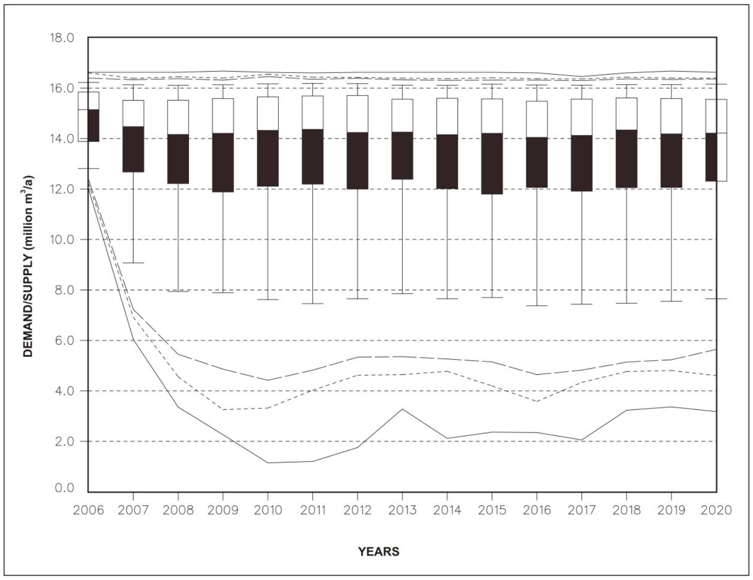

Figure 4: Supply to Marico Bosveld GWS from Marico Bosveld Dam

From Figure 4 it is clear that the average annual supply to the Marico Bosveld GWS appears to be relatively low. The annual supply at the 50% exceedance probability level fluctuates around 14 million m^3/a, whilst the full requirements are not even being met at the 0.5% exceedance probability level.

In order to obtain an improved understanding of the system response, long-term historic analyses were undertaken and it was found that significant evaporation losses occur when the dams are operated at relatively high storage levels. These findings lead to an assessment of the evaporation losses as described in Section 7.5 below.

7.5 Assessment of Evaporation Losses

The following two long-term historic scenario analyses were undertaken for the assessment of the net evaporation losses:

- **Scenario 1**: Allow the WRPM Allocation Procedure to supply sub-system demands according to the user priority classification as defined in Table 6.
- **Scenario 2**: De-activate the WRPM Allocation Procedure. This means that no curtailments were implemented and the supply to the various users was only influenced by the water resource availability.

Evaluation of the scenario results revealed that the net evaporation losses from the exposed water surfaces of reservoirs within the Great Marico River System are exceptionally high and that these losses are reduced when the reservoirs are operated at low levels. Consequently it was also found that the average annual supply from all the water resources within the Molatedi River System based on **Scenario 2** (no curtailments) was higher than that of **Scenario 1** where curtailment operating rules were applied. The average annual supply to the Marico Bosveld GWS amounted to 79% and 92% of the total demand for **Scenarios 1** and **2** respectively. However, for **Scenario 2** the water resources were depleted during severe drought events and corresponding failures in supply occurred.

Information on the net evaporation losses that were simulated for the individual reservoirs is provided in Table 7. The results presented in Table 7 were obtained from the long-term historic analyses undertaken for **Scenarios 1** and **2**. For each of these scenarios the average annual net evaporation losses were expressed as a percentage of the average annual simulated inflow to the reservoir. To further illustrate the significance of the evaporation losses, the 2006 water requirements to be supplied from the reservoirs are also shown in Table 7.

From Table 7 it can be seen that for **Scenario 1** the net evaporation losses from Pella, Madikwe, Sehujwane and Molatedi dams amount to more than 30% of the simulated inflow to these dams. Madikwe Dam has the highest evaporation losses due to the fact that the dam basin is relatively flat with a fairly large surface area. Furthermore, the net evaporation losses from Pella, Madikwe and Molatedi dams are in excess of the water requirements to be supplied from these dams. The advantage of operating the dams at lower storage levels is shown in the results for **Scenario 2** where no curtailments were implemented and maximum utilisation of the resources took place.

The net evaporation losses from major dams within the Integrated Vaal River System (IVRS) were also assessed and it was found that the highest net evaporation losses from dams within the IVRS were in the order of 30% of the average annual simulated inflow to the dams. This confirms the significance of net evaporation losses from exposed water surfaces of reservoirs within the Great Marico River System.

Table 7: Comparison of net evaporation losses from reservoirs

Dam Name	**Scenario 1: Net evaporation losses**		**Scenario 2: Net evaporation losses**		**Current (2006) demand**
	(million m^3/a)	**% of inflow**	**(million m^3/a)**	**% of inflow**	**(million m^3/a)**
Klein Maricopoort	1.36	14.29	1.17	12.29	2.17
Kromellenboog	1.80	14.88	1.61	13.78	1.87
Marico Bosveld	3.22	9.89	2.75	8.44	16.82
Pella	0.32	40.00	0.28	36.00	0.237
Madikwe	2.11	71.28	1.77	59.57	0.883
Sehujwane	0.54	31.48	0.41	24.07	0.814
Molatedi	30.26	40.64	25.72	35.56	22.90
Total:	39.60	-	33.70	-	45.694

7.6 Results of Alternative Operating Rule for Marico Bosveld and Kromellenboog Sub-system

Results from the initial operating analyses (**Scenario 1**) and the assessment of the net evaporation losses, prompted a re-assessment of the priority classification for the irrigation water user group. The aim of the re-assessment was to implement less stringent curtailments that would in turn result in increased utilisation of the water resources and reduced net evaporation losses. The alternative user priority classification is shown in Table 8 and requires that 100% of the irrigation water use be allocated to the 90% assurance level. The priority classifications for the remaining three user groups were not adjusted.

Table 8: User category and priority classifications proposed to be used in the Great Marico River System

User Category	**Priority Classification and assurance of supply**			
	Low (90% assurance) (1:10 year)	**Medium Low (98% assurance) (1:50 year)**	**Medium High (99% assurance) (1:100 year)**	**High (99,5% assurance) (1:200 Year)**
	Portion of water requirement supplied (%)			
Domestic	10%	10%	20%	60%
Mining and Industrial	40%	30%	20%	10%
International	10%	10%	20%	60%
Irrigation	100%	0%	0%	0%
Curtailment level **0**	**1**	**2**	**3**	**4**

The revised user priority classification presented in Table 8 was subsequently incorporated in the WRPM configuration and analysed (**Scenario 3**) to ensure that lower curtailment levels are implemented during drought periods and that the water resources are also adequately protected (i.e. dams are not depleted during drought events).

The resulting **Scenario 3** projected water supply to the Marico Bosveld GWS from Marico Bosveld Dam is shown in Figure 5. Comparisons with the results of **Scenario 1** (presented in Figure 4) show that although the supply at the lower exceedance probability levels is similar, the supply results for **Scenario 3** are much higher for exceedance probabilities lower than 95%. For **Scenario 3** the median supply values (supply at the 50% exceedance probability) fluctuate around 16.4 million m^3/a whilst the total requirements are being met at the 25% exceedance probability level.

The projected storage trajectories of the Marico Bosveld and Kromellenboog Sub-system resulting from the **Scenario 3** analysis are shown in Figure 6. Based on the adopted reliability criteria, the sub-system should not be emptied at the 99.5% exceedance probability level. From Figure 6 it can be seen that the sub-system storage is only depleted for the worst sequence during drought events. The sub-system is, however, never drawn down to its dead storage level at the 99.5% exceedance probability level.

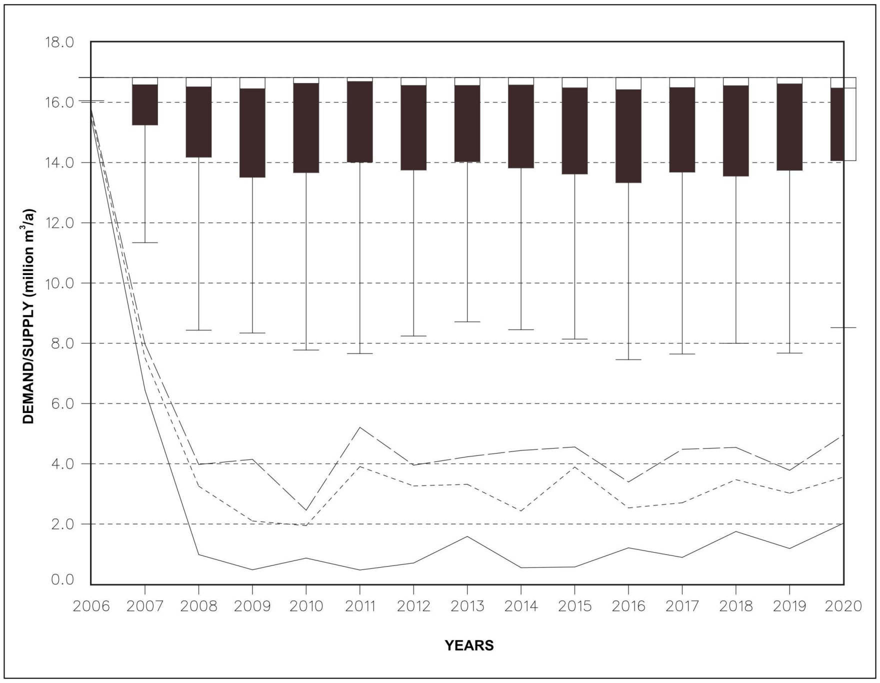

Figure 5: Supply to Marico Bosveld GWS from Marico Bosveld Dam (Scenario 3)

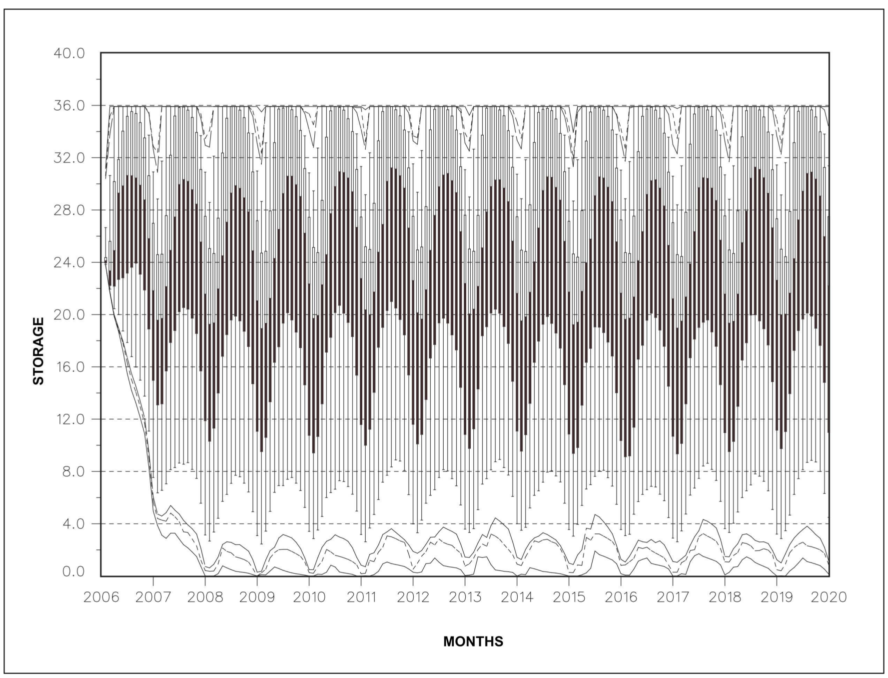

Figure 6: Marico Bosveld and Kromellenboog Sub-system storage (million m^3) for Scenario 3

The advantage of adopting the operating rule based on the alternative priority classification is illustrated by means of the simplified curtailment curves (HG Maré, et al, 2007) derived for the Marico Bosveld and Kromellenboog Sub-system. A comparison of the simplified curtailment curves based on the results of the original (Table 6) and the recommended (Table 8) user priority classifications are shown in Figure 7. From Figure 7 it can be seen that when applying the original curtailment curve (**Scenario 1**), a curtailment level of 0.1 needs to be implemented even when the Marico Bosveld and Kromellenboog

Sub-system storage is at its full supply capacity. However, when adopting the recommended curtailment rule (**Scenario 3**), curtailments are only required when the sub-system storage drops below 22 million m^3.

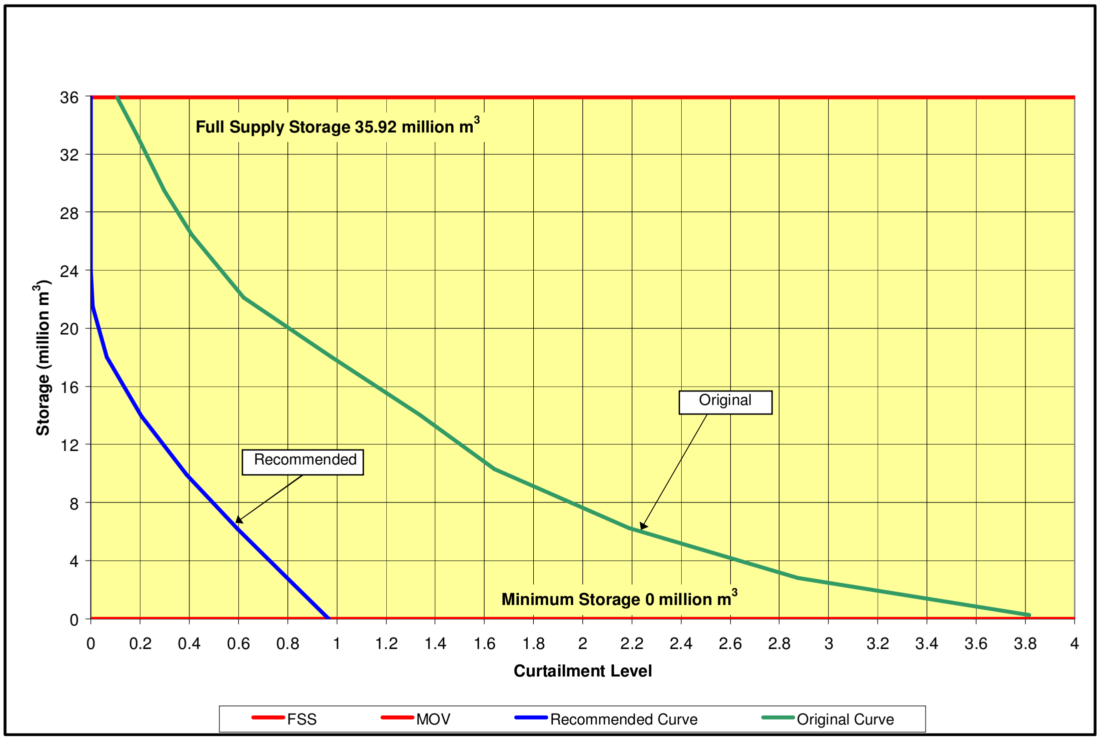

Figure 7: Comparison of simplified curtailment curves for Marico Bosveld and Kromellenboog Sub-system

8 Conclusions

Important findings from the yield analysis were**:**

- The yield analysis results clearly showed that all the sub-systems are totally over allocated. For all the sub-systems it was found that the current (2006) demands exceed the long-term yield available from the relevant sub-system (refer to results presented in Table 5).

Important findings from the operating analysis included the following:

- The user priority classification proposed by the Stakeholders (Table 6) resulted in relatively high curtailment levels to be implemented. The high curtailment levels and significant evaporation losses prompted the assessment of an alternative priority classification (Table 8) which has finally been recommended for use in the study area.
- The new proposed operating rules, which include the use of the short-term stochastic yield results and the recommended priority classification (Table 8), proved to work well, and were able to protect the resources, even though all the sub-systems are totally over allocated.
- Although all the water resources of the various sub-systems were sufficiently protected by the new operating rules, it was not possible to supply the users at their required assurances.
- All the sub-systems required curtailments for the 2006/07 planning year.
- The net evaporation losses that occur from the exposed water surfaces of the reservoirs within the Great Marico River catchment are extremely high and can be reduced when dams are operated at lower storage levels.

9 Recommendations

Based on the results from the analyses, the following recommendations are made:

- The alternative user priority classification as presented in Table 8 should be adopted for the Great Marico River System.
- The proposed simplified curtailment curves should be adopted for the operation of the existing surface water resources. These new operating rules should be implemented as soon as possible.
- The hydrological database should be updated. Twelve years of valuable information could be added when a hydrological update study is undertaken for the Great Marico catchment. As mentioned in Section 7.5 Evaporation losses were found to be significant and it is essential that representative information be obtained.

10 Acknowledgements

DWAF and Groot Marico stakeholders

References

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