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DEVELOPMENT OF A RECONCILIATION STRATEGY FOR THE OLIFANTS RIVER WATER SUPPLY SYSTEM

WP10197

Yield Analysis of the De Hoop and Flag Boshielo Dams

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Yield Analysis of De Hoop and the Flag Boshielo Dams	**P WMA 04/B50/00/8310/16**

EXECUTIVE SUMMARY

The Olifants River Water Resources Development Project (ORWRDP) was initiated to secure water for envisaged developments within the Olifants River catchment, as well as improve the water supply to rural communities within the Olifants Water Management Area. This development entails, inter alia, the raising of Flag Boshielo Dam, which has already been completed and construction of the De Hoop Dam, which is currently under construction. The yields of these dams were determined as part of the ORWRDP Feasibility Study which was completed in 2005. A more recent study, referred to as the Olifants Water Availability Assessment Study (OWAAS) updated the hydrology for the whole Water Management Area (WMA), set up detailed water resources models (more detailed than those used before) and re-assessed the yields of all the dams in the Olifants River system, which included the Flag Boshielo and De Hoop Dams. The yields of these two dams, according to this more recent study, are significantly lower than estimated during the Feasibility Study. See ***Table A****.*

Table A: Summary of the Yields of the Flag Boshielo and De Hoop Dams

Dam	***1 in 50 year Yield (million m^3/annum)***	
	ORWRDP (2005)	***OWAAS (2010)***
Flag Boshielo	*84*	*44.5*
De Hoop	*80*	*64*
Total	***164***	***108.5***

In December 2009, the Department of Water Affairs commissioned the Olifants Reconciliation Strategy, the purpose of which is to consider both management and infrastructure options to meet growing water requirements in the Olifants Water Management Area up to the year 2030. As an additional task, the Reconciliation Team were requested to review the yields of the Flag Boshielo and De Hoop Dams and document the reasons for these changes from the 2005 to the 2009 estimates. The changes in yield relate mostly to new information that became available as a result of the OWAAS study, which had access to better water use information, as well as updated hydrology. Other factors relate to how the dams upstream of the Flag Boshielo Dam will be operated in future.

The change in yield of the De Hoop Dam can be attributed mostly to the increased irrigation upstream of the dam and updated hydrology while return flows which were not modelled consistently from one study to the next and allowance for sediment also contributed to the change. The ecological Reserve was modelled differently in the OWAAS study (which had different objectives to the ORWRDP) and this also changed the yield significantly. Although the Mean Annual Runoff (MAR) of the ORWRDP and the OWAAS hydrology is very similar, the change of stochastic (1 in 50 year) yields derived from

the two hydrological data sets exhibits a larger difference which can be attributed to the higher standard deviation of the updated hydrology. A summary of how these factors affect the yield is given in ***Table B****.*

***Table B**: Change in Yield of the De Hoop Dam: ORWRDP to OWAAS*

Parameter Changed	***Change in Yield (million m^3/annum)***
Change in hydrology	*-5*
Increase irrigation	*-10*
Return flows	*+1.6*
Ecological flow requirements	*-3.5*
Sedimentation	*+0.9*

The situation with the Flag Boshielo Dam is more complex, with many factors influencing the change in yield. These changes are summarised in ***Tables C and D****.*

***Table C**: Change in Yield of the Flag Boshielo Dam: ORWRDP to OWAAS*

Parameter Changed	***Change in Yield***
Change in hydrology	*-17.3*
Increased irrigation upstream of the dam	*-10.0*
Inclusion of farms dams in the Yield Model	*-4.0*
Water Court Orders	*-8.2*

The yield of the De Hoop and Flag Boshielo Dams were also checked as part of this review process. A few minor refinements to the modelling process were made to the De Hoop Dam model, specifically return flows and ecological flows, the result being a slightly increased yield for the De Hoop Dam. The yield of the Flag Boshielo Dam, on the other hand, is influenced by the operation of the Loskop Dam and the assumptions relating to the operation of the Loskop Dam were revisited. Based on the assumption that the Water Court Order which requires a release of 8,2 million m^3/annum from Loskop Dam is re-instated, and that there will be return flows from irrigators supplied from the Loskop Dam, the yield of Flag Boshielo Dam is significantly higher than stated in the OWAAS report. To summarise, the revised yields of these two dams is as indicated in ***Table D****.*

Table D: Revised Yields of the Flag Boshielo and De Hoop Dams

Dam	***ORWRDP***	***Recon Study (2010)***	
	1 in 50 year Yield (million m^3/annum)	***Historical Firm Yield (million m^3/annum)***	***1 in 50 year Yield (million m^3/annum)***
Flag Boshielo	*84*	53	*56*
De Hoop	*80*	65	*66*
Total	***164***	**118**	***122***

The reasons for the change in yield from the ORWRDP to the Recon Study is summarised in Table E. Note that when considering the change in yield from the ORWRD to the ORS, factors such as the ecological Reserve and the allowance for sediment (De Hoop Dam) and Water Court Orders (Flag Boshielo Dam) do not influence the change in yield since these are common to both studies.

Table E: Change in yield: ORWRDP to ORS

Parameter Changed	***Change in Yield (%)***	
	De Hoop Dam	Flag Boshielo Dam
Change in hydrology	-39%	-56%
Increase irrigation	-71%	-31%
Return flows	+10%	N/A
Include farm dams	N/A	-13%

The balance of the 1 in 50 year yield against the water allocation is as follows:

De Hoop Dam

Original (ORWRDP): {Primary(37.3) + Mining(37.3) + Irrigation(5.4)} = 80.0
Proposed: {Primary(30.3) + Mining(30.3) + Irrigation(5.4)} = 66.0

Flag Boshielo Dam

Original (ORWRDP): {Transfer to Mokopane(40) + Reserve(18.6) + Irrigation(18) } = 76.6
Proposed: {Transfer to Mokopane(19.4) + Reserve(18.6) + Irrigation(18) } = 56.0

Glossary of Terms

Allocable Water

Water which is available to allocate for consumptive use.

Database

Accessible and internally consistent sets of data, either electronic or hard copy with spatial attributes wherever possible.

Environmental Water Requirement

The quantity, quality and seasonal patterns of water needed to maintain aquatic ecosystems within a particular ecological condition (management category), excluding operational and management considerations.

Integrated Water Resource Management (IWRM) Objectives

The objectives and priorities for water resource management, for a given time frame, which have been agreed by the parties as those which will best support the agreed socio economic development plans for the basin.

IWRM Plans

A set of agreed activities with expected outcomes, time frames, responsibilities and resource requirements that underpin the objectives of IWRM.

Management Information System

Systems such as GIS which provide a user friendly interface between databases and information users.

Resource Classification

A process of determining the management class of resources by achieving a balance between the Reserve needs and the beneficial use of the resources.

Acid Mine Drainage

Decanting water from defunct mines which have become polluted and acidic and that reach the resource.

Level of Assurance

The probability that water will be supplied without any curtailments. The opposite of Level of Assurance is the risk of failure.

Internal Strategic Perspective

A DWA status quo report of the catchment outlining the current situation and how the catchment will be managed in the interim until a Catchment Management Strategy of a CMA is established.

Yield

The yield from a water resource system is the volume of water that can be abstracted at a certain rate over a specified period of time, generally expressed in million m^3/annum.

Historical Firm Yield

Historical firm yield is the yield determined by using the historical flow in the catchment. The assumption made in the Historic Firm yield is that the dam from which the yield is abstracted does not fail over the period of the historic flow record.

1 in 50 Year Yield

The historical yield is determined so that the dam will never fail based on historical hydrology, but droughts in the future might be more severe than those experiences over the relatively short period of the historical record. By using many possible hydrological sequences, referred to as stochastic hydrology, the probability of achieving a particular yield without the dam failing can be determined. Hence, a 1 in 50 yield is the amount of water that can be abstracted from a dam with a 1 in 50 chance of the dam emptying in any one year.

List of Abbreviations & Acronyms

ARC	Agricultural Research Council
DWA	Department of Water Affairs
DWAF	former Department of Water Affairs and Forestry
ER	Ecological Reserve
EWR	Ecological Water Requirements (Ecological Component of the Reserve)
IB	Irrigation Board
IDP	Integrated Development Plan
ISP	Internal Strategic Perspective
IWRM	Integrated Water Resources Management
IWRMP	Integrated Water Resources Management Plan
MAR	Mean Annual Runoff
ORS	Olifants Reconciliation Study
ORWRDP	Olifants River Water Resources Development Project
OWAAS	Olifants Water Availability Assessment Study
Rod	Record of Decisions
WWMA	Water Management Area
WRYM	Water Resource Yield Model

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APPENDICES

1. Introduction

The Olifants River Water Resources Development Project (ORWRDP) is well into its implementation phase, with the raising of the Flag Boshielo Dam completed in 2005 and the construction of the De Hoop Dam far advanced with impoundment envisaged to commence in 2012. The planning of this development was based on 1 in 50 year yields (98% assurance) of 164 million m^3/a, consisting of 84 million m^3/a from the raised Flag Boshielo Dam and 80 million m^3/a from the De Hoop Dam. These estimated yields were extracted from the Water Resources report of the ORWRDP suite of reports (DWAF, 2005).

A subsequent study, referred to as the Olifants Water Availability Assessment Study (OWAAS), commenced in 2006 and a draft report on Water Resources Yield Model Analysis (WRYM) became available in 2009 (DWAF, 2009a). Based on this later study, the estimated 1 in 50 year yield of the Flag Boshielo and De Hoop Dams are 44.5 and 64.0 million m^3/a, respectively. This difference in yield between the 2005 and 2009 studies is reason for concern. Hence, the Study Team for the Development of a Reconciliation Strategy for the Olifants Water Supply System Study (ORS) were tasked to investigate this difference, verify the latest estimates, and update these estimates if inconsistencies were found, and to clarify in a report why the yields had changed. A separate study, referred to as the Integrated Water Resources Management Plan for the Upper and Middle Olifants Catchment (Integrated Water Resources Management Plan (IWRMP)) dealt with the hydrology and yield analyses of the Upper Olifants River catchment. During the final stages of the OWAAS study, the water resources models developed as part of the two studies, IWRMP and OWAAS, were combined into a single model which was then used to update the yield of the Flag Boshielo Dam.

The deliverables from this analysis are therefore as follows:

- Confirmation of the yields given in the OWAAS report;
- An update of the yields indicating the discrepancies found and changes made to the yield model in order to derive the yield of these two dams; and
- A comparative analysis of the yield model configurations used in the ORWRDP and the OWAAS in order to quantify these changes and explain why the yield changed.

2. Review of Previous Analysis

2.1 ORWRDP

The ORWRDP analysis was somewhat simplistic compared to the latest IWRMP (DWAF, 2009b) and OWAAS (DWA, 2009a) studies. For example, the ORWRDP modelled the Flag Boshielo Dam catchment as several large sub-catchments consisting of the catchments of the major dams upstream of Flag Boshielo, including Bronkhorstspruit, Witbank, Middelburg, Loskop, Rust de Winter and Mkombo Dams. The OWAAS model, on the other hand, is very detailed with sub-catchments typically consisting of sub-quaternary tributaries. By modelling a system in more detail, invariably more attention is given to the water demands within the system, which has led to the identification and modelling of additional demands that were not in the earlier ORWRDP model.

2.2 OWAAS

The modelling task for the OWAAS was completed late in 2009 and a draft report released in early 2010. This study had the advantage of water use information derived from the Verification and Validation Study of 2006 (DWAF, 2006) and hence, was able to include many demands, especially irrigation demands, into the model that previous modellers were not even aware of. It is these additional demands that are one of the major causes of the decreased yields of the De Hoop and Flag Boshielo Dams.

The OWAAS determined yields that were much lower than the ORWRDP and the consultants responsible for these studies were therefore asked to review their analyses. Based on this re-evaluation, the yield of the De Hoop Dam was revised upwards and a revised report issued in August 2010.

2.3 Results from Previous Analyses

A summary of the results from previous analyses is given in **Tables 2.1** and **2.2**.

Table 2.1: De Hoop Dam (with EWR)

Analysis Date	Project	Historical Firm Yield (million m^3/a)	1: 50 year Yield (million m^3/a)
2005	ORWRDP	74.1	80
2010	OWAAS	63.8	64

Table 2.2: Flag Boshielo Dam (without EWR)

Analysis Date	Project	Historical Firm Yield (million m^3/a)	1: 50 year Yield (million m^3/a)
2005	ORWRDP	85.1	84
2010	OWAAS	36.4	44.5

Note: The ORWRDP model was run in 2005 without provision for the Environmental Water Requirements (EWRs). An estimate of 18.6 million m^3/a for the ecological Reserve was then taken into account when recommending allocations from the yield of 84 million m^3/a.

3. Evaluation Procedure and Results

3.1 Methodology

There are numerous parameters that influence the yield of a dam and these must all be systematically checked and corrected where necessary. Apart from the physical attributes of the dam, the yield of the dam is determined by the inflow into the dam. Therefore, a fundamental check on the yield of a dam is to compare the inflows into the dam (as modelled by different models) and how these vary from the natural flow. Hence, a comparison of the assumed water use upstream of the dam is also essential. A third important check is the outflow from the dam. This will typically consist of uncontrolled spills from the dam, but depending on the operating rules of the dam, releases to downstream users and for the Ecological Reserve (ER), are often modelled and not considered to be part of the available yield. Also, the use of a penalty structure type of solver, such as used in the WRYM, can result in a high-priority downstream user inadvertently drawing water out of the dam. Hence, it is crucial to always check the outflows from a dam when checking or comparing yields. Evaporation losses from the surface of the dam can also be considered to be an outflow and must be checked.

The yield available for use from a dam is also influenced by the releases; it is required to make to meet the downstream EWRs. There are several ways of modelling these releases and an important check to carry out, is to confirm that the method used is realistic in term of how the EWR will eventually be operated.

3.2 De Hoop Dam

3.2.1 Physical Attributes of the Dam

Table 3.1: Physical Attributes of the De Hoop Dam

Attribute	
Full Supply Capacity	347.4 million m^3
Full Supply Area	16.9 km^2
Dead Storage	2.9 million m^3
Location	Confluence of B41E and B41F
Natural MAR:	134 million m^3/a

Allowance for Sediment

In the ORWRDP report, an estimated 50 year sediment volume of 20 million m^3 is quoted. This was taken into account in the ORWRDP yield analysis, but not the OWAAS yield analysis.

3.2.2 The Location of the Dam

While this may seem to be a trivial aspect to check, there are examples of dams that have been modelled at the wrong location and hence, the inflow into the dam would not be correct. This would typically be identified by checking the natural hydrology of the dam's catchment (as modelled).

3.2.3 Upstream Water Use

Water use upstream of De Hoop Dam is relatively limited and consists mostly of irrigation from run-of-river. There is a small area of afforestation which results in a limited stream flow reduction.

The water use assumed in the three studied is given in **Table 3.2**.

Table 3.2: Water Use and Streamflow Reduction Upstream of the De Hoop Dam (Units: million m³/a)

Quaternary Catchment	Irrigation			Urban and Industrial			SFR		
	ORWRDP	OWAAS	Recon	ORWRDP	OWAAS	Recon	ORWRDP	OWAAS	Recon
B41A	0.0	1.89	1.89	0.8	0.89	1.00	2.21	1.72	2.00
B41B	1.3	8.33	8.33	0.0	0.00	0.00	0.03	0.37	0.23
B41C	1.6	1.07	1.07	0.6	0.60	0.60	0.00	0.00	0.05
B41D	0.9	1.20	1.20	0.0	0.00	0.00	0.00	0.00	0.02
B41E	0.0	0.00	0.00	0.0	0.00	0.00	0.00	0.00	0.02
B41F	0.0	1.58	1.58	0.0	0.00	0.00	0.00	0.57	0.08
Total	**3.8**	**14.07**	**14.07**	**1.4**	**1.49**	**1.60**	**2.24**	**2.66**	**2.40**

3.2.4 Downstream Water Use

There is limited existing irrigation downstream of the De Hoop Dam (estimated at 5.37 million m^3/a) that will need to be compensated due to the reduced river flows that will result once De Hoop Dam starts storing water. In the ORWRDP, the assumption was made that this compensation will come out of allocable yield of the dam; hence, when determining the yield of the dam, this irrigation was not supplied from the dam. The same assumption was made in the OWAAS study and in this latest review of the yield of the dam.

3.2.5 Ecological Water Requirements

The EWR requirement that must be met from the De Hoop Dam is estimated to be 31.6 million m^3/a on average. This EWR is documented in the Record of Decision (RoD) for the construction of De Hoop Dam (DWAF, 2006c).

3.3 Flag Boshielo Dam

3.3.1 Physical Attributes of the Dam

Table 3.3: Physical Attributes of the Flag Boshielo Dam

Attribute	
Full Supply Capacity	198.8 million m^3
Full Supply Area	20.52 km^2
Dead Storage	0.50 million m^3
Location	B51B
Natural MAR	711.7 million m^3/a

Allowance for Sediment:

It does not appear as if any of the previous studies made an allowance for the loss of live storage due to sedimentation. However, due to the location of Flag Boshielo Dam downstream of other large dams, it is assumed that significant sediment will be trapped in these upper dams and the incremental sediment load will be small.

3.3.2 The Location of the Dam

The Flag Boshielo dam is located at the end of quaternary catchment B51B. There are numerous dams upstream of the Flag Boshielo Dam, notably the Loskop and Mkombo Dams and the incremental natural runoff downstream of these dams, based on the latest hydrology, is only 130.9 million m^3/a.

3.3.3 Upstream Water Use

Water use upstream of Flag Boshielo Dam consists mostly of irrigation, but there are also large abstractions for urban use. The water use for mining is sourced mostly from groundwater.

The water use assumed in the three studies is given in **Table 3.4**. This has been grouped in the catchments upstream of the major dams. The 'Remainder' in the table

refers to the catchment downstream of the Loskop and Mkombo Dams, but upstream of the Flag Boshielo Dam.

Table 3.4: Water Demands and Streamflow Reduction Upstream of the Flag Boshielo Dam (Units: million m^3 /a)

Catchment	Irrigation		Urban / Mining / Industrial	
	ORWRDP	OWAAS/ IWRMP	ORWRDP	OWAAS
Wilge Dam	12.1	26.5	37.9	22.5
Middleburg Dam	5.1	17.7	18.3	14.0
Witbank Dam	4.3	22.1	37.9	50.5
Loskop Dam	20.9	18.9	0.0	1.3
Mkombo Dam	22.6	14.2	9.8	8.2
Remainder	179.0	240.1	2.4	0
Total	244.0	339.5	106.3	96.5

3.3.4 Water Balance of the Flag Boshielo Dam

Simulations carried out on the system up to and including the Flag Boshielo Dam revealed that during the critical period of the Flag Boshielo Dam the Loskop Dam does not spill, at least not significantly. Water use and operating rules upstream of Loskop Dam will therefore not influence the yield of Flag Boshielo Dam. The focus of this review was therefore limited to the catchment between the Loskop and Flag Boshielo Dams.

4. Quantification of Parameters Influencing Yield Changes from the ORWRDP to the OWAAS

4.1 General Principles

There are a number of possible reasons for the yield of a dam changing from one analysis to the next and it is a requirement of this review to identify these reasons and quantify the extent to which they are responsible for the change in yield. Typical reasons for a change in yield that were investigated as part of this review are:

- Updated and change in natural flow;
- Updated and change in water use upstream of the dams; and
- Changed assumptions regarding the operation of the dams, for example, releases out of the dam for downstream users.

4.2 Change in Natural Flow

Tables 4.1 and **4.2** indicate the change in natural flow from the ORWRDP to the OWAAS for the De Hoop and Flag Boshielo Dams. In the case of the De Hoop Dam, the hydrology is given at quaternary scale, while for the much larger Flag Boshielo Dam catchment, the hydrology has been simplified to sub-catchments, defined by the major dams upstream of the Flag Boshielo Dam.

Table 4.1: Hydrology of the De Hoop Dam

Quaternary Catchment	MAR (million m^3/a)		% Change
	ORWRDP	OWAAS	
B41A	41.7	42.0	1%
B41B	39.1	40.6	4%
B41C	13.7	14.8	7%
B41D	13.5	16.1	16%
B41E	6.3	3.6	-44%
B41F	19.5	17.3	-11%
De Hoop	**133.9**	**134.4**	0%

Table 4.2: Hydrology of the Flag Boshielo Dam

Quaternary Catchment	MAR (million m^3/a)		% Change
	ORWRDP	OWAAS	
Bronkhorstspruit	51.2	52.5	3%
Premier Mine	67.5	58.4	-16%
Middelburg	40.7	53.4	31%
Witbank	123.1	163.5	33%
Loskop	186.5	200.5	8%
Rust de Winter	37.3	33.5	-11%
Mkombo	26.2	26.4	1%
Flag Boshielo	170.4	130.9	-30%
Total	**703**	**719**	2%

While it appears that there has not been a significant change in the hydrology of the De Hoop Dam, there is a significant change in the hydrology of the Flag Boshielo Dam, especially the catchment downstream of the Loskop Dam (shaded area) which includes Rust de Winter and Mkombo Dams. The Natural MAR of the Flag Boshielo catchment has decreased from 233.9 million m^3/a (37.3 + 26.2 + 170.4) to 190.8 million m^3/a (33.5 + 26.4 + 130.9). This change is significant and necessitated an evaluation of the impact that the revised hydrology has on the yield of the dam. However, the ORWRDP and OWAAS models are very different in their structure, with the ORWRDP model consisting of approximately 100 nodes, while the much more detailed OWAAS model consists of over 1000 nodes. Hence, it would be a very time consuming exercise to convert the hydrology used in the ORWRDP to the OWAAS models or vice versa. To overcome this problem, a simplified model consisting of only the major dams up to and including the Flag Boshielo Dam was set up and, using the natural aggregated hydrology from the ORWRDP and OWAAS natural time series as two separate scenarios, the yields of the Flag Boshielo Dam were determined. The system diagram associated with this analysis is attached in **Appendix A**, while **Table 4.3** summarised the results of this analysis.

Table 4.3: Impact of Changes in the Natural Hydrology on Dam Yields

Sub-catchment	Historical Yield (without system demands) (million m^3/a)		Change in Yield (%)
	ORWRDP Hydrology	OWAAS Hydrology	
Bronkhorstspruit	21.9	23.0	5%
Premier Mine	6.6	7.4	11%
Middelburg	23.3	24.5	5%
Witbank	46.2	57.5	20%
Loskop	154.2	150.4	-3%
Rust de Winter	16.9	14.5	-17%
Mkombo	14.7	14.4	-2%
Flag Boshielo	104.0	86.6	-21%

4.3 Change in Water Use

4.3.1 De Hoop Dam

The water use upstream of the De Hoop Dam, or least estimates of this water use, has increased significantly since the ORWRDP yield analysis of 2005. See **Table 4.4**.

Table 4.4: Summary of Water Use Upstream of the De Hoop Dam (Units: million m^3/annum)

Water Use Sector	ORWRDP (2005)	OWAAS (2010)
Domestic/industrial	1.6	1.5
Irrigation	4.4	14.1
SFR	2.2	2.2

The water use upstream of the De Hoop Dam seems to be at a high level of assurance since there is ample water in farm dams and from run-of-river to supply these demands. The result of this is that any abstraction upstream of the De Hoop Dam has a direct impact on the yield of this Dam. Hence, the increased water use of approximately 10 million m^3/a results in a yield reduction of 10 million m^3/a.

4.3.2 Flag Boshielo Dam

The water use in the catchment of the Flag Boshielo Dam has changed significantly since the ORWRDP yield analysis carried out in 2005. Better information, especially on irrigation

water use, became available as a result of the Validation Study (DWAF, 2006a). Details of these differences are summarised in **Table 4.5**.

Table 4.5: Irrigation in the Flag Boshielo Incremental Catchment (Units: million m^3/a)

Location of Irrigator	Demand		Supply	
	ORWRDP	OWAAS	ORWRDP	OWAAS
Irrigation board supplied by canal	135.8	118.9	127.8	118.9
Irrigation boards supplied by releases into the river	45.8	32.8	31.8	32.8
Supplied from Rust de Winter Dam	15.2	1.8	8.3	1.8
Diffuse irrigation in the B31 catchment	14.7	55.0	14.3	27.7
Diffuse irrigation in the B32 catchment	2.2	55.6	2.2	23.3
Total	**213.7**	**264.1**	**184.4**	**204.5**

Supply to urban users is essentially the same in both models.

4.4 Change in Return Flows

4.4.1 Flag Boshielo Dam

During the Flag Boshielo Dam yield analysis that was carried out as part of the OWAAS, demands on major upstream dams was modelled as historical firm yields. A comparison of allocated water use and historical yields revealed that this is a good assumption since dams upstream of Loskop Dam are fully utilised, but this assumption is probably not correct when applied on the Loskop Dam, the main reason being the loss of return flows (in the modelling process), which contributes significantly to the yield of Flag Boshielo Dam.

Modelling Loskop Dam with actual irrigation demands and related return flow, results in the yield of Flag Boshielo Dam increasing by about 10 million m^3/annum.

4.4.2 De Hoop Dam

Return flows in the De Hoop Dam catchment were not modelled in a consistent manner from one study to the next. Return flows in this catchment do not, however, have a large impact on the yield and were estimated to increase the yield by about 3 million m^3/a.

4.5 Change in Storage (Farm Dams)

4.5.1 Flag Boshielo Dam

Farms dams upstream of a major dam can have an influence on the yield of the major dam due to evaporation losses and also due to delaying the flow into the major dam at the onset of a wet period. In the case of the Flag Boshielo Dam, this is a significant factor influencing the yield of the dam. In the ORWRDP, only one small farm dam was incorporated into the modelled catchment between the Loskop and Flag Boshielo Dams, while in the OWAAS model, there are a total of 13 'dummy' dams representing the many farm dams in most of the quaternary catchments. The difference in terms of storage and surface area is very significant. See **Table 4.6** for a summary of the difference in farm dams and **Appendix B** for details of each 'dummy' dam.

Table 4.6: Farm Dams in the Flag Boshielo Dam Catchment

Model	Full Supply Capacity (million m^3)	Full Supply Area (km^2)
ORWRDP	4.1	1.2
OWAAS	69.4	35.6

The influence of these dams is to reduce the yield of the Flag Boshielo Dam by about 4 million m^3/a.

4.5.2 De Hoop Dam

Farm dams do not have a significant influence of the yield of the De Hoop Dam and this aspect is therefore not significant as a possible reason for the change in yield of the dam.

5. Updated Yields from the Reconciliation Strategy

There are different ways to model the yield of a dam and these different approaches are often the reason for discrepancies in yield estimates from one study to the next or when determined by different modellers. The modelling philosophy adopted for this review of the yields is as follows:

- Upstream use will be modelled as allocated if this is known, otherwise as the best estimate of the current water use.

- If this allocated or estimated use exceeds the yields of the upstream dams, then the upstream use will be limited to the historic yield of the upstream dam.

- Ecological Reserves in the Steelpoort System will be modelled at the EWR sites and supplied as the highest priority water users. The Reserve used is that documented in the RoD relating to the construction of the De Hoop Dam (DWAF, 2006b). The ER requirement that must be met from the De Hoop Dam, is approximately 31.6 million m^3/a.

- For Flag Boshielo Dam, the model has been run with no allowance for the Reserve. The yield of the dam must be determined as before, i.e. without Reserve allowances and the total allowance of 18.6 million m^3/a must be subtracted afterwards.

- It is assumed that small farm dams upstream cannot release any water for the purposes of Reserve implementation.

- The big areas of invasive and alien plants (IAPs) which were recently reported by the Agricultural Research Council (ARC) need to be verified and catered for in the Reconciliation Strategy. For the purpose of this exercise, the IAP water requirements that are currently in the model will be retained.

- The full yield of Rust de Winter Dam has been abstracted in this updated model as it is likely that any remaining yield after satisfying the irrigation requirements will be allocated, either to the Western Highveld for domestic purposes, or to emerging farmers for irrigation.

- The demands on the Mkombo Dam (abstracted at the Weltevreden Weir) were left as modelled in the OWAAS study. Because these demands are greater than the yield of

the dam, the Mkombo Dam very seldom spills and hence, water use upstream of the Mkombo Dam does not influence the yield of the Mkombo Dam.

The recommended refinements to the OWAAS model are as follows:

De Hoop Dam:

- Return flows from irrigation in the OWAAS model were found to be about 20%, which are probably too high. These were adjusted down to 10%.
- The Ecological Reserve (modelled as Desktop Reserves at every node in OWAAS) was replaced by the approved Reserve at the EWR9 site, just downstream of the dam.
- The allowance for a 50 year sediment load of 20 million m^3 was re-instated; this was modelled in the ORWRDP, but not the OWAAS.

The resulting in changes in yield as indicated in **Table C2 of Appendix C**.

Flag Boshielo Dam:

The following changes to the Flag Boshielo Dam model are recommended:

- Model the Loskop Dam as it is currently operated, i.e. with flow diverted via canals to the Loskop Irrigation Board (IB) and released into the river for the Hereford and Olifants IBs. This then assumes that return flows from irrigators will become available as yield in the Flag Boshielo Dam.
- There is a Water Court order which requires the release of 8.16 million m^3/a from the Loskop Dam for irrigators below the Flag Boshielo Dam. It is recommended that this Court Order be enforced and implemented in order to make this yield available at Flag Boshielo.

The above changes resulted in increased yield as indicated in **Table D2 in Appendix D**.

6. Impact of Changes in Land Use and Other Assumptions on 1 in 50 year Yield

This section summarises the reasons for the changes in yield, from the original ORWRDP model through to the yield determined as part of the Olifants Reconciliation Study (ORS).

6.1 ORWRDP to OWAAS

6.1.1 De Hoop Dam

The change in yield of the De Hoop Dam can be attributed mostly to the increased irrigation upstream of the dam, although the different approaches to modelling the ecological Reserve and return flows also has a significant influence. Although the MAR of the ORWRDP and the OWAAS (and ORS) hydrology is very similar, the relationship between the historic and 1 in 50 year yields is different when determined, using these two hydrological data sets, resulting in a reduction (about 4 million m^3/a in the 1 in 50 year yield). A summary of how the above factors affect the 1 in 50 year yield, is given in **Table 6.1**.

Table 6.1: De Hoop Dam: Change in Yield: ORWRDP to OWAAS

Parameter Changed	***Change in Yield (%)***
Change in hydrology	-34%
Increase irrigation	-63%
No allowance for sedimentation	+6%
Return flows included	+10%

6.1.2 Flag Boshielo Dam

The change in yield of the Flag Boshielo Dam is more complex and can be attributed to the factors listed in **Table 6.2**. These changes are between the ORWRDP and the OWAAS studies but, other than the Water Court Order, these changes were accepted as valid changes in the ORS.

Table 6.2: Change in Yield: ORWRDP to OWAAS

Parameter Changed	Change in Yield (%)
Change in hydrology	-45%
Increased irrigation	-25%
Include farms dams	-10%
Water Court Order	-20%

6.2 Updated Yields from the Olifants Reconciliation Study

6.2.1 Flag Boshielo Dam

The following changes, if implemented as recommended, will result in an increased yield of the Flag Boshielo Dam as indicated in **Table 6.3**.

Table 6.3: Change in Yield: OWAAS to ORS

Parameter	Change in Yield (million m^3/a)
Return flow from irrigation available as yield	+ 10
Reinstate the Loskop Water Court Order	+8

The revised long-term yield curve for the Flag Boshielo Dam is shown in **Appendix F** from which the 1 in 50 year yield of 56 million m^3/a has been derived.

6.2.2 De Hoop Dam

The revised long-term yield curve for the De Hoop Dam is shown in **Annexure E** from which the 1 in 50 year yield of 66 million m^3/a has been derived. This is very similar the OWAAS study and hence, the small changes in the yield model undertaken as part of the Reconciliation Study, are not discussed further here. The reader is referred to **Annexure D** for more detail.

6.3 Updated Yields: Change from ORWRP to ORS

In sections 6.1 and 6.2, the change in yield from the OWRDP to the OWAAS and then the OWAAS to the latest estimates made as part of the ORS are presented. However, the change from the ORWRDP to the latest estimates made as part of the ORS and the explanation of the overall change is more relevant and this overall change in therefore presented in this section.

6.3.1 De Hoop Dam

The overall change in the 1 in 50 year yield of the De Hoop Dam (from the ORWRDP to the ORS study) is 14 million m^3/a. This can be mostly attributed to increased irrigation and the updated hydrology, although the improved modelling of return flow in the ORS also has a small influence. See Table 6.4. Note that when considering the change in yield from the ORWRDP to the ORS, factors such as the ecological Reserve and the allowance for sediment do not influence the change in yield since these are common to both studies.

Table 6.4 De Hoop Dam: Change in Yield: ORWRDP to ORS

Parameter Changed	***Change in Yield (%)***
Change in hydrology	-39%
Increase irrigation	-71%
Return flows	+10%

6.3.2 Flag Boshielo Dam

As with the De Hoop Dam, there are factors which are common to both the ORWRDP and ORS model setups and which therefore do not affect the overall change in yield even though they did contribute to the substantially lower yield of the OWAAS study. These factors are the Water Court Order and return flows. Hence the remaining factors affecting the change in yield are the hydrology, farm dams and additional irrigation. See Table 6-5.

Table 6.5: Flag Boshielo Dam: Change in Yield: ORWRDP to ORS

Parameter Changed	***Change in Yield (%)***
Change in hydrology	-56%
Increase irrigation	-31%
Include farm dams	+13%

6.4 Suggested Allocations

Due to the reduction in yield, the allocations from the De Hoop and Flag Boshielo Dams will need to be reviewed. A suggestion as to how these allocations could change is given below.

The balance of the 1 in 50 year yield against the water allocation is as follows:

De Hoop Dam
Original (ORWRDP): {Primary(37.3) + Mining(37.3) + Irrigation(5.4)} = 80.0
Proposed: {Primary(30.3) + Mining(30.3) + Irrigation(5.4)} = 66.0

Flag Boshielo Dam
Original (ORWRDP): {Transfer to Mokopane(40) + Reserve(18.6) + Irrigation(18) } = 76.6
Proposed: {Transfer to Mokopane(19.4) + Reserve(18.6) + Irrigation(18) } = 56.0

7. Conclusions and Recommendations

There are many parameters that affect the yield of a dam, such as the natural hydrology, water use upstream of the dam, and the manner in which the dam is operated. The sensitivity of the yield of the De Hoop and Flag Boshielo Dams has been investigated, and through numerous comparative analyses, the reasons why the estimated yields of these dams changed across a range of water resource studies were determined. The updated yield models were then used to provide new estimates of the yields of these dams. The yields of the De Hoop and Flag Boshielo Dams are now estimated to be as follows:

Table 7.1: Yield of De Hoop and Flag Boshielo Dams

Dam	ORWRDP	Recon Study (2010)	
	1 in 50 Year Yield (million m^3/a)	Historical Firm Yield (million m^3/a)	1 in 50 Year Yield (million m^3/a)
Flag Boshielo	*84*	53	*56*
De Hoop	*80*	65	*66*
Total	***164***	**118**	***122***

However, not only is there a measure of uncertainty in all the parameters influencing the yield of a dam, these factors also changes over time and hence, the yield of dams is likely to change. In order to realise the yields calculated during the planning phase of a dam, the catchment managers should be made aware of the assumptions made and operate the catchment accordingly. The important assumptions to note are as follows:

- The De Hoop Dam will be very sensitive to any additional water use upstream of the dam. In order to the secure the yield of the dam; a moratorium should be placed on the issuing of new licences upstream of the dam. The yield will need to be re-calculated should the verified water use prove to be different from the water use obtained from the Validation Study (DWAF, 2006a).
- The yield of the Flag Boshielo Dam is sensitive to the operating rule of Loskop Dam with respect to water supply to the IBs. The assumption has been made that the current demands will be supplied and not the full allocations. Further, it is assumed that return flows from irrigators will return to the river and become available as allocable yield from the Flag Boshielo Dam. Hence, if irrigators supplied from Loskop Dam improve their efficiency some of the saved water should be returned (i.e. allocations reduced) to compensate for the loss of return flows.

- The Water Court Order that requires a release of 8.16 million m^3/a from Loskop Dam must be reinstated and measures introduced to ensure that riparian irrigators between Loskop and Flag Boshielo Dams do not use this water unlawfully.
- The lawfulness of the irrigation use (outside of the IB) upstream of the Flag Boshielo Dam needs to be verified.

8. References

Department of Water Affairs and Forestry, 2005. Olifants River Water Resources Development Project. Surface Water Resources. Report no. P WMA 04/B50/00/1404.

Department of Water Affairs and Forestry, 2006a. Undertake the validation and verification of registered water use in the Olifants and Inkomati Water Management Areas.

Department of Water Affairs and Forestry, 2006b. Olifants River Water Resources Development Project. Dam on the Steelpoort River at De Hoop (Phase 2A). Report no. P WMA 04/B50/00/5009.

Department of Water Affairs and Forestry, 2006c. Olifants River Water Resources Development Project. Dam on the Steelpoort River at De Hoop. Record of Implementation Decision. P WMA 04/B50/00/5009.

Department of Water Affairs and Forestry, 2009a. Assessment of Water Availability in the Olifants WMA by means of Water Resource Related Models: Water Resources Yield Model Analysis. Report no. P WMA 04/000/00/5507.

Department of Water Affairs and Forestry, 2009b. Integrated Water Resources Management Plan for the Upper and Middle Olifants River Catchment. IWRMP Report. Report no. P WMA 04/000/00/7007.

Appendix A: System Diagrams

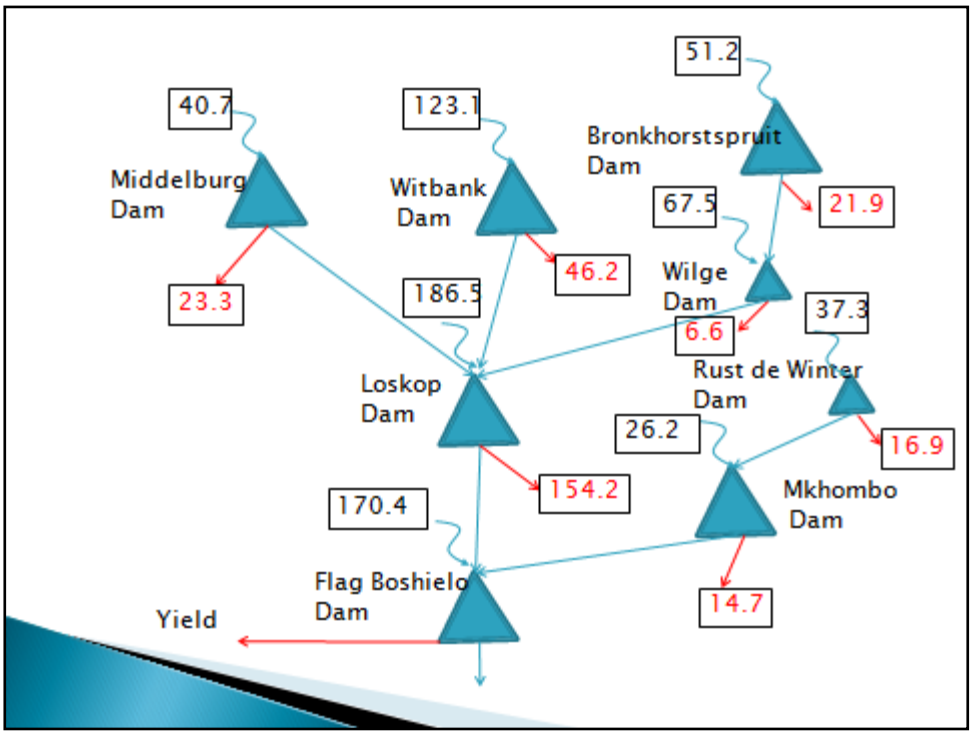


Figure A. 1: Simplified System with ORWRDP Hydrology

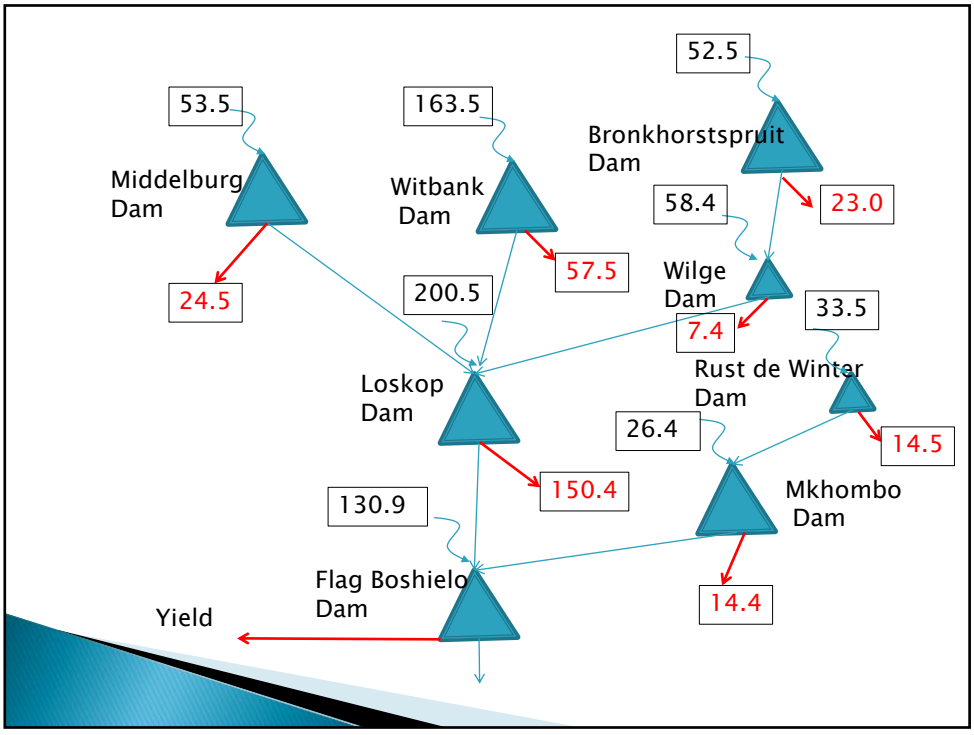


Figure A. 2: Simplified System with OWAAS Hydrology

Appendix B: 'Dummy' Farm Dams Downstream of Loskop Dam

	Catchment	FSC (million m^3)	FSA (km2)
ORWRDP	I7	4.07	1.16
OWAAS	B32B	16.32	1.93
	B32D	1.93	0.4
	B32E	2.16	0.9
	B32F	6	0.08
	B32J	14.16	2.52
	B32H	2.52	0.57
	B31A	4.58	2.06
	B31D	2.12	14.96
	B31E	1.27	2.76
	B31H	0.64	1.96
	B31J	15.9	6.5
	B52A	1.76	0.99
	Total	**69.36**	**35.63**

Appendix C: Detailed Analysis of the Reason for the Change in Historic Firm Yield of the De Hoop Dam

The historical firm yield of De Hoop Dam, calculated during the ORWRDP, was 74 million m^3/a. The following changes in the historic yield, through the various studies, are tabled below.

Table C.1: Change in Historic Firm Yield: ORWRDP to OWAAS

Parameter Changed	**Change in Yield (million m^3/a)**
Increased upstream irrigation by 10 (million m^3/a)	-10
Return flows included	+1.6
Ecological flow requirements models as Desktop Reserves	-3
No allowance for Sedimentation	+0.9
Total change	-10.5

Revised historical firm yield: 63.5 million m^3/annum

Table C.2: Change in Historic Firm Yield: OWAAS to ORS

Parameter Changed	**Change in Yield (million m^3/a)**
Irrigation Return flows reduced to 10%	- 1.4
Replace Desktop Reserves with approved EWR9 reserve	+3.0
Reinstate allowance for sediment	-0.9

Revised yield: 65 million m^3/a

The revised long-term yield curve for the De Hoop Dam is shown in **Appendix E** from which the 1 in 50 year yield of 66 million m^3/a has been derived.

Appendix D: Detailed Analysis of the Reason for the Change in the Historic Firm Yield of the Flag Boshielo Dam

The historical yield of the Flag Boshielo Dam is given in the ORWRDP as 85.1 million m^3/a. This changed due to new assumptions in later studies as summarised in **Tables D1** to **D3**.

Table D1: Change in Yield: ORWRDP to OWAAS 1

Parameter Changed	Change in Yield (million m^3/a)
Change in hydrology	-18
Increase irrigation	-10
Include farms dams	-4
Remove Water Court Order	-8

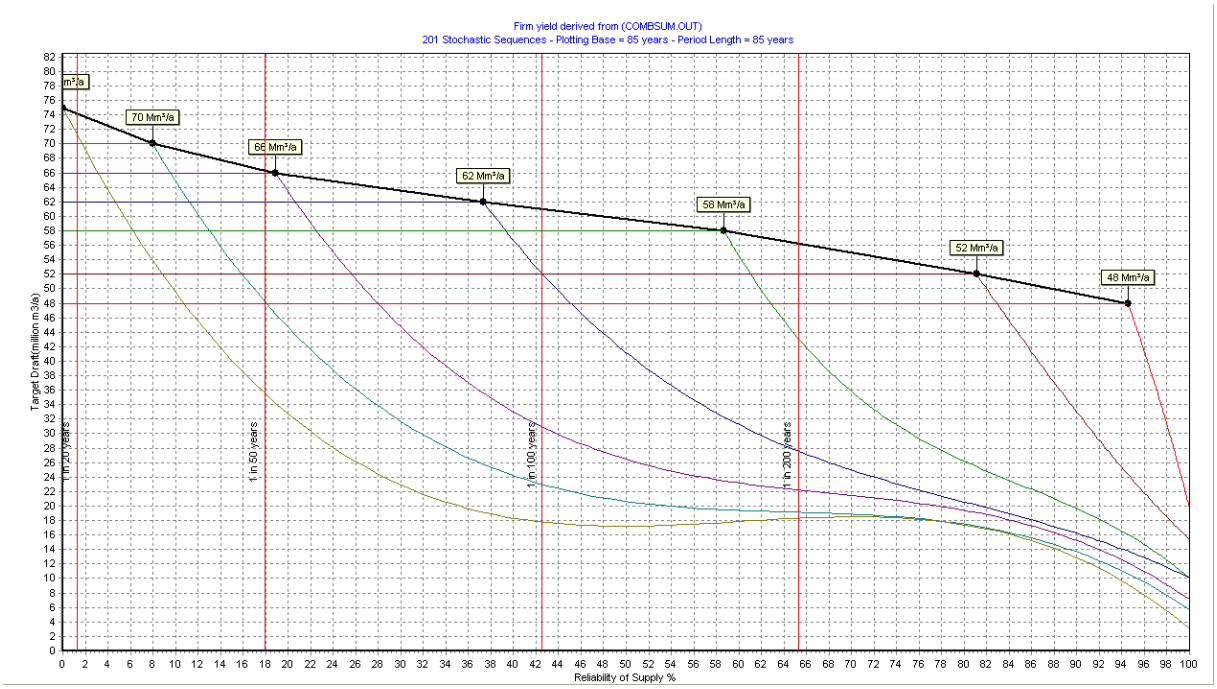
The above changes do not account for the full change in yield from 85 down to 36 million m^3/a. It is not clear exactly what is causing the remaining change, but it is suggested that the total change is not the sum of the changes due to isolated parameter changes, and that the combined effect of these changes result in a greater reduction in yield, rather than the simple sum of the changes. Accepting that this is the case, the change in yield can be expressed as percentage changes as indicated in **Table D4**.

Table D2: Change in Yield: ORWRDP to OWAAS

Parameter Changed	Change in Yield (%)
Change in hydrology	45%
Increase irrigation	25%
Include farms dams	10%
Remove Water Court Order	20%

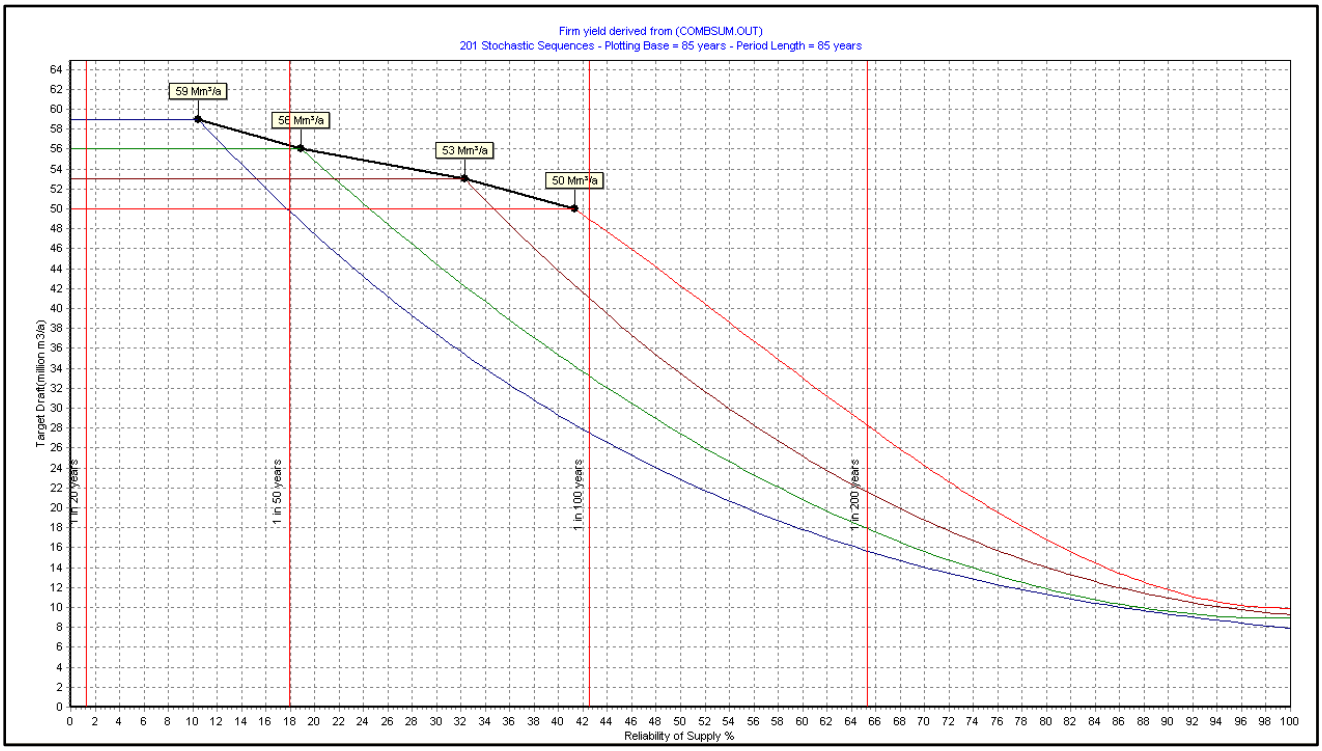
The change in the 1 in 50 year yield (80 (million m^3/a) down to 44.5 (million m^3/a) is not as great as the change in the historical yield, and the above percentage changes are probably a fair reflection of the parameters driving the change in the 1 in 50 year yield.

Appendix E: Long-Term Yield Curve of the De Hoop Dam



Long-Term Yield Curve of the De Hoop Dam

Appendix F: Long-Term Yield Curve of the Flag Boshielo Dam



Long-term Yield for the Flag Boshielo Dam (201 hydrology sequences, with return flows and Water Court Order releases)