Development of Simplified Drought Operating Rules

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Abstract

The purpose of this development was to produce simplified curtailment curves that can be used to decide when and how severe curtailments need to be in periods of water shortage. At the same time it is also important to maintain the vast amount of knowledge and system characteristics captured from detail stochastic yield and planning analyses, obtained by utilizing the power full and advanced Water Resources Yield Model (WRYM) and Water Resources Planning Model (WRPM). The simplified curtailment curves were developed based on the output obtained from the WRPM. The required assurance of supply of the users is built into the curves. The curves are a simple tool which can be used, without running the WRPM each year, to quickly read of the curtailments that need to be imposed on the system, depending on the storage level in the dam. The curves will remain an effective tool so long as the hydrology and/or demands in the system have not significantly changed, where after another set of curves may have to be established. The curtailment curves were successfully developed and tested for the Luvuvhu system.

Keywords: *simplified drought operating rule curtailments*

1 Introduction

The development of the simplified curtailment curves was carried out as part of the Luvuvhu River System Annual Operating Anaysis For the purpose of this paper the focus will be on the development of the simplified drought operating rules. It is, however, important to also provide some of the study background and results, to enable the reader to understand and see the broader picture.

The Luvuvhu River is located in the north eastern part of South Africa, and is a tributary of the Limpopo River, which is an international water course shared by South Africa, Botswana, Zimbabwe and Mozambique. The Luvuvhu River transverses the northern section of the Kruger National Park, where the Luvuvhu (Lanner) Gorge and the Pafuri floodplain are prominent features. Rainfall in the Luvuvhu catchment varies from in excess of 2000 mm per annum (for a relatively small portion of the catchment) to about 400 mm per annum in the eastern and western parts of the catchment. The total catchment area for the Luvuvhu River, excluding the Mutale tributary, is 3 425 km² and produces 333.6 million m³/a (MAR for 1924 to 1992 record period) runoff under natural conditions.

Water use by afforestation, irrigation, and more recently domestic use to supply the large population in the Luvuvhu River catchment with water, as well as the construction of large dams in the catchment, has an adverse effect on the flow in the Luvuvhu River, particularly in the Kruger National Park. Steps are therefore required to ensure that the consumptive water requirements from the Luvuvhu River can be supplied without harming the riverine and riparian ecosystems. The current water use by afforestation is estimated at almost 20 million m³/a. Irrigation is the largest consumer of water with the current total use estimated at 126 million m³/a. Urban/Industrial/rural demands, which are dependant on surface water resources, are estimated at 17 million m³/a at the 2003 development level, and is expected to increase to 24 million m³/a by 2025.

The new Nandoni Dam and Xikundu Weir, together with the existing Albasini, Vondo, Phiphidi and Tshakhuma dams (and the associated bulk purified water supply infrastructure) are known as the Luvuvhu River Government Water Scheme. This scheme needs to be managed as an integrated system, in order to supply water for domestic/industrial, irrigation and the ecological component of the reserve.

2 Study Objectives

The main objective of this study was to update the existing hydrological models for the Luvuvhu River System and to develop operating rules and a decision support system for the Albasini, Vondo, Damani, Tshakhuma, Phiphidi and Nandoni dams. These operating rules and decision support system need to be applied on an annual basis and must include reservoir storage trajectories. The operating rules and curtailment curves needed to be simplified so that it could be used easily by DWAF regional offices to enable them to determine the required curtailment during drought periods and to impose restrictions in water use accordingly. As part of the operating rule, monitoring systems need to be identified to track the movement of water and storage in the system.

3 Basis used for the Operating Rules

The new operating rules that were developed for the different sub-systems within the greater Luvuvhu System were 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 Luvuvhu System.
- Cost saving operating rules – The secondary objective of the operating rules is to implement rules that will, where possible, reduce the cost of water supply.
- 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 1 of Section 4**.**

Two trigger mechanisms are generally used in the operating rules. The first trigger mechanism used is specifically selected fixed levels in dams which are widely used to control the event when supply to a specific user should cease or commence, and to be able to reserve water for users that can only be supplied from this resource.

The second trigger mechanism is the use of the short-term yield capability of the sub-system which is compared with the demand imposed on the sub-system. When the balance is negative, water from another possible resource needs to be used or curtailments need to be imposed. This option or trigger mechanism was used for all the sub-systems and was, in some cases, combined with the trigger mechanism one (fixed dam levels). The benefit of the second trigger mechanism is that the short-term yield as well as the demand imposed on the system can be compared at the desired assurance levels of supply.

4 Assurance of Supply

In arid and semi arid regions it is generally not economical feasible to develop and operate a water resource system to meet all the demands at all times This means that 100% of the demand can not be supplied for 100% of the time and shortfalls in the supply will occur from time to time. If shortfalls occur frequently the supply will have a low assurance and relative few shortfalls represents a high assurance in supply. Restrictions in supply during dry periods is therefore one of the few management tools available for operators to cope with the highly variable streamflow conditions we have in South Africa.

It is fairly obvious that different types of user groups or categories will require a different assurance of supply. Irrigation will typically be supplied at a lower assurance than water for domestic and industrial purposes and water for strategic industries such as power generation at even higher assurances. It is also logic to sub-divide the supply to irrigation into different assurance levels, as permanent crops such as export grapes would require a higher assurance than for example cash crops.

Using only the available historic flow record of 50 to 70 years it is not possible to provide yield results representing the yield available at high assurances such as a 99% or 99.5% assurance, which means a possible failure of 1 in 100years and 1 in 200 years, respectively. By using stochastic yield analysis it is possible to determine the system yield at different reliabilities or assurance levels. At low reliability levels the system can typically provide a higher yield than would be available at a high reliability level. The stochastic yield characteristics therefore make it possible to supply the system demands at the required level of assurance in planning and operational analyses, as well as in practice. For the purpose of these 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 or reliability levels.

For the purpose of the study, the demands from the different user groups or categories were sub-divided into four priority classes, which represent different assurance or reliability levels. This was discussed at one of the Stakeholder Forum Meetings and a specific priority classification was agreed on, as given in Table 1.

The priority classification can also be referred to as a set of guidelines on how to implement water restrictions within a water supply system. The user categories that were decided on were Domestic/Industrial, Irrigation, EFR and Losses.

The user categories were each split into four different levels of assurance of supply as indicated in Table 1. In this way a portion of the demand for a specific user category (for instance Domestic/Industrial) can be supplied at a high level of assurance (e.g. domestic consumption), while the remaining portion of the demand can be supplied at a lower level of assurance (e.g. garden watering).

Table 1: User category and priority classifications as agreed to be used in the Luvuvhu System

System and User Category	**Priority Classification (%)**			
	Low (90% assurance) (1:10 year)	**Medium Low (95% assurance) (1:20 year)**	**Medium High (98% assurance) (1:50 year)**	**High (99,5% assurance) (1:200 Year)**
Domestic/Industrial	15%	15%	40%	30%
Irrigation	30%	30%	30%	10%
Losses	25%	25%	25%	25%
EFR	20%	0%	0%	80%
Curtailment level **0**		**1**	**2**	**3** **4**

Restrictions in water supply are applied first to the water use allocated to the low assurance level, which in this case is the 90% assurance level (possibility of a shortage in the supply of an average, once in 10 years). One will only start to impose curtailments on the water use allocated to the 95% assurance level, when 100% of the water use that is allocated to the low assurance level has been curtailed (curtailment level 1). In a similar way curtailments will each time only be imposed on the higher assurance level if all the water allocated to the lower assurance level, had been curtailed in full.

These curtailments are determined by comparing the short-term stochastic yield characteristic curves that were determined with the Water Resources Yield Model (WRYM) for various start storage levels, with the demands imposed on the system at different assurance levels. The short-term yield is very sensitive to the available storage in the dam at the beginning of a short-term planning period. When the dams are 100% full, the short-term available yield will typically be higher than the long-term stochastic yield at the same assurance level of supply. At the other extreme, when the dams are at a low level at the beginning of the short-term planning period, the short-term yield will again be significantly lower than the long-term yield at the same assurance level of supply. Under such conditions it would then be required to curtail the demand to a level that will protect the water resource and allow the water supply to not exceed the predetermined risk of failure, as defined for the different user categories.

5 Yield characteristics

Long-term stochastic yield analyses were carried out as part of the Luvuvhu River Dam Feasibility Study, and were used to obtain the long-term yield at different assurance levels. This information cannot be obtained from the historic firm yield analyses, as these only represent a 100% supply over the historic period. Long-term stochastic yield analyses were therefore

Table 2: Sub-system summary of yield characteristics

Sub-system 2005 Demand (million m^3/a)	**Historic Firm Yield recurrence interval (years)**	**Long-term Stochastic firm Yield at indicated recurrence intervals (million m^3/a)**				
		1:10 year	**1:20 year**	**1:50 year**	**1:100 year**	**1:200 year**
Albasini 22.3	> 1: 200 (10.38)*	16.4	16.0	13.7	12.5	11.7
Vondo 16.1	1: 70 (13.4)*	17.6	17.4	14.6	13.3	12.1
Tshakhuma 2.87	1: 142 (2.71)*	2.87	2.87	2.80	2.75	2.67
Damani 6.52	1: 84 (5.67)*	7.10	6.90	6.05	5.60	5.27
Nandoni 36.2#	> 1: 200 (46.7)*	93.5	91.5	76.5	69.0	61.0

Note: # - 36.2 represents the projected demand for 2025.
* - Value in brackets represents the historic firm yield

carried out for the final selected scenarios. Results from these final selected scenarios for the different sub-systems are summarized in Table 2.

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 behavior thereof. However, these curves do not contain sufficient information to make short-term operational decisions. Decisions with respect to real time water allocations cannot only be based on the current situation, but should also account for safeguarding the supply for the future. 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 behavior of a sub-system. The fact that the initial storage level of a reservoir significantly influences the short-term yield, requires that short-term yield characteristics need to be determined for different starting storage levels. For the purpose of this study starting storages of 100%, 80%, 60%, 40%, 20% and 10% were used and 501 generated flow sequences, each of 5 years in length, were used in the analyses. Results from the short-term stochastic analysis for the five sub-systems are summarized in Table 3.

Table 3: Summary of short-term stochastic firm yield results for different Sub-systems

Scenario	**Start Storage (As % of live storage)**	**Short-term Stochastic firm Yield at indicated recurrence intervals (million m^3/a)**				
		1:10 year	**1:20 year**	**1:50 year**	**1:100 year**	**1:200 year**
Albasini Sub-system						
A4	100%	19.5	17.1	14.8	13.8	13.3
	80%	17.9	15.4	13.2	12.05	11.7
	60%	16.70	14.40	12.05	11.05	10.50
	40%	13.10	11.70	10.40	9.70	8.85
	20%	8.70	7.80	6.95	6.25	5.55
	10%	4.00	3.30	2.40	2.20	1.80
Vondo Sub-system						
V1	100%	22.5	19.0	16.0	15.0	13.6
	80%	21.7	18.4	15.3	14.0	13.0
	60%	20.0	17.0	14.4	12.0	11.0
	40%	16.5	13.7	11.4	10.0	8.8
	20%	12.2	10.3	8.3	6.0	5.3
	10%	10.7	8.8	7.0	5.8	5.3
Nandoni Sub-system						
N10	100%	121.00	104.50	90.80	82.50	77.00
	80%	115.50	99.70	87.00	77.50	73.00
	60%	107.00	93.30	80.00	69.00	65.00
	40%	92.00	77.00	67.80	58.50	53.00
	20%	67.00	56.00	49.70	44.00	39.60
	10%	48.50	43.00	37.00	35.00	32.00
Tshakhuma Sub-system						
T2	100%	2.88	2.84	2.76	2.70	2.63
	80%	-	-	-	-	-
	60%	2.88	2.84	2.73	2.63	2.53
	40%	2.88	2.82	2.72	2.62	2.22
	20%	2.88	2.83	2.72	2.62	1.87
	10%	2.88	2.8	2.68	2.52	1.73
Damani Sub-system						
D1	100%	8.85	7.8	6.7	6.3	5.8
	80%	8.6	7.5	6.35	5.8	5.35
	60%	7.95	6.75	5.7	5.2	4.75
	40%	6.65	5.7	4.9	4.35	3.9
	20%	4.85	4.15	3.6	3.35	3.1
	10%	3.8	3.2	2.75	2.55	2.4

Important findings from the yield analyses also include the following:

- Yield analysis results clearly showed that Albasini Sub-system is totally over allocated and that canal losses are quite high. Even when the demand for Makhado is not imposed on Albasini Dam and is supplied from Nandoni Dam (from 2010 onwards) the remaining demand imposed on Albasini still exceeds the long-term yield available by approximately 2.6 million m³/a.
- Irrigation from the Luvuvhu mainstream as well as irrigation from tributaries within the Albasini Government Water Scheme, has a significant impact on the yield available from the Albasini Sub-system.
- The yield from Vondo Dam is almost in balance with the demand imposed on the dam, and Vondo Dam will therefore soon require support from another source to be able to supply its current supply area.

- The yield from Tshakhuma Dam is in excess of the capacity of the Water Treatment Works (WTW) at the dam and it seems that this dam can be utilized to supply a larger area.
- The yield available for Damani Dam is almost in balance with the demand.
- The yield from the Nandoni Sub-system can significantly be increased when the incremental flow between Nandoni Dam and Mhinga Weir is also utilized.
- The IFR estimates from the Desktop model severely impacted on the yield available from the Nandoni Sub-system.
- With the "White Paper IFR" in place the remaining yield available from Nandoni Dam is still more than the current demand and even the projected demand for 2025.

6 Curtailments based on short-term yield characteristics

The Albasini Sub-system was selected for the purposes to illustrate how the short-term yield characteristics are used to decide on the implementation of curtailments. From the long-term stochastic yield analyses it was clear that the Albasini Sub-system is currently totally over allocated. This can also be illustrated by comparing the short-term stochastic yield characteristics for the scenario where Albasini Dam is at 100% full, with the current demand imposed on the system. According to the agreed priority classification the demand imposed on the Albasini Sub-system at the different assurance levels, is as shown in Table 4.

Table 4: Priority Classification for Albasini Sub-system demands

User Category	Priority Classification & Assurance of Supply				Total
	Low 1:10 year	Medium Low 1:20 year	Medium High 1:50 year	High 1 in 200 year	
Domestic/Industrial	0.40	0.40	1.06	0.79	**2.64**
Irrigation	4.55	4.55	4.55	1.52	**15.15**
Losses	0.00	0.00	0.00	4.54	**4.54**
Total	**4.94**	**4.94**	**5.60**	**6.85**	**22.33**
Cumulative*	**22.33**	**17.39**	**12.45**	**6.85**	

* Note: Cumulative is calculated from the high to low assurance, as used to plot on yield curves

The Albasini Sub-system demands at the required assurance levels (blue lines) are first imposed on the short-term yield characteristic curve for Albasini Dam, for the 100% starting storage condition (see Figure 1). The maximum target draft that can be imposed on this Sub-system based on the typical demand allocation to different assurance levels is 15.5 million m³/a, and the yield line representing this target draft is shown by the dotted blue line. Comparing the yield line (dotted blue line) with the demands imposed on the curve, it is clear that demands allocated to the high and medium high assurance classes are lying below the yield line. This means that with the dam at 100% storage on 1 April, the available yield is only sufficient to fully supply the demands allocated to the high and medium high assurances.

It is important to note that the demands allocated to the medium low and low assurance classes are exceeding the yield line, resulting in a deficit of 6.83 million m³/a. This means that 100% of the demands allocated to the low assurance class (4.94 million m³/a) need to be curtailed and 1.89 million m³/a or 38.3% of the demand allocated to the medium low assurance class to be able to balance the available yield with the demands to be supplied.

7 Water Resources Planning Model (WRPM) Analysis

The Water Resources Planning Model (WRPM) is an extremely power full tool for operational and planning analyses of water resource systems, in particular when systems are fairly complex such as the Luvuvhu System. The WRPM uses the short-term stochastic yield characteristics as obtained from the WRYM, in planning and operational analyses to supply the system demands at the required level of assurance. For the purpose of these analyses the priority classification as defined in Table 1, is included in the WRPM data sets, where it is used in combination with the short-term stochastic yield characteristics to allocate the water supply to demand centers and to impose restrictions when and where required.

Operating analyses using the WRPM usually need to be carried out on an annual basis. For the Luvuvhu system it was decided to do these analyses on the 1st of April each year or soon thereafter, as most of the summer rainfall has by then entered the storage dams. For the purpose of this study the new proposed operating rules and most recent demand projections were included in the WRPM setup for the Luvuvhu system. The total system was analyzed by using 1000 stochastically generated flow sequences for 5 year and 20 year projection periods.

The operating analysis was carried to achieve the following:

- To check and verify the system model to ensure that the modeled results are representative of what is observed in practice;
- To improve our understanding of the system behavior and to refine operating rules;
- To check that the operating rules are working and that the desired goals were achieved with the new proposed operating rules;

- To carry out sensitivity analyses to improve our understanding of the system and to determine the effect on results due to uncertainties around the correctness of some of the input data;
- To determine whether curtailments need to be imposed on some of the sub-systems during this operating year (2005/06);
- To determine the severity of the curtailments required;
- To produce reservoir storage projections, which can be compared with the observed reservoir storage during this operating year;
- To determine when intervention measures are required to be able to supply the users at their required assurance over the long term; and
- To determine whether the existing sub-systems are able to supply the current users at the selected assurance levels as indicated in the accepted priority classification.
- To use results from the analyses to produce simplified curtailment curves that can easily be used to determine the required restriction, without having to re-run the WRPM each year.

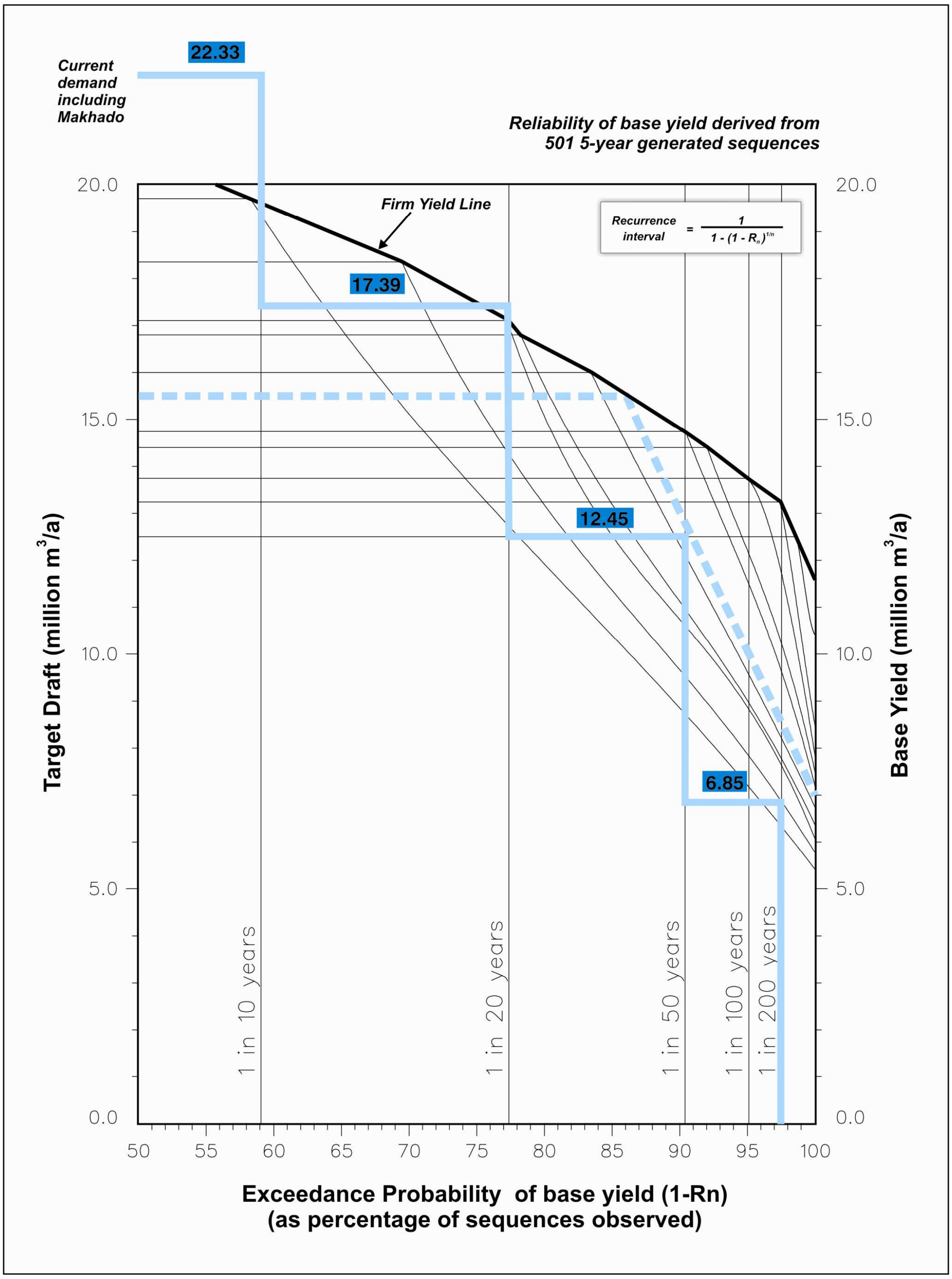

Figure 1: Albasini Sub-system short-term stochastic yield curve for 100% starting storage and 2005 demands imposed on the curve

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

- Albasini Sub-system;
- Damani Sub-system;
- Nandoni Sub-system; and
- Vondo & Tshakhuma Sub-systems.

Important findings from the operating analysis included the following:

- The new proposed operating rules, which include the use of the short-term stochastic yield results, were proven to work well, and were able to protect the resources, even for the Albasini Sub-system which is totally over allocated.
- Although the Albasini Sub-system was sufficiently protected by the new operating rule, it was not possible to supply the users at their required assurances, even from 2010 onwards, when the Makhado demand was supplied from the Nandoni Sub-system.
- The Albasini Sub-system was the only sub-system that required curtailments for the 2005/06 planning year. The base scenario required irrigation to be curtailed by 51% and urban/industrial by 26%.
- In general the storage projection plots obtained from the operating analyses compared very well with the observed storage levels. This indicates that the modeled results are representative of the physical Luvuvhu system.
- From 2014 onwards the curtailment criteria for the Vondo Sub-system were violated. This shows that Nandoni Dam needs to supply a larger area of Thohoyandou than only 50% of the current R5 and R7 supply areas, to be able to sufficiently decrease the future load imposed on Vondo Dam.
- Curtailment criteria for the Damani Sub-system were exceeded from 2020 onwards and therefore currently do not impose an immediate threat.
- Some of the projected demands supplied from Nandoni Dam and Tshakhuma Dam are currently totally exceeded by observed demands. This is true for the Malamulele, Tshakhuma and Xikundu abstractions which are all in excess of 300% of the projected demand, and therefore raises serious questions with regards to the observed use as well as the projected demands for these areas.
- The curtailment criteria for the Nandoni Sub-system were only slightly violated for the maximum high scenario and mainly for the initial filling period. This agrees with the yield results showing that the yield available from the Nandoni Sub-system is in excess of the projected 2025 demand.

8 Simplified Drought Operating Rule

Simplified curtailment curves were produced for the main storage dams in the system to be able to assist operators at these dams. These curves are a simple tool, which can be used to obtain a fairly good indication of the curtailments that need to be imposed on the system, based on the 1st April storage level in the dams. These curves are however only applicable for the next approximately 3 to 5 years due to changes in demand and infrastructure within the Luvuvhu system. The active time periods for each sub-system curve differ and are dependent on several conditions for each of the sub-systems.

Two of the main sub-systems i.e. Albasini and Vondo, will be used to show and illustrate the use of the simplified curtailment curves in stead of running and updating the WRPM. From the WRPM analysis output, the gross storage and related curtailment levels as imposed on each of the sub-systems were obtained for all of the1 000 flow sequences analyzed. A curtailment level versus gross storage was then created as shown in Figure 2 for the Albasini sub-system.

8.1 Albasini Sub-system

A brief description of the new operating rule developed for the Albasini Sub-system, developed as part of the ‘Luvuvhu River System Annual Operating Analysis’ Study, is as follows:

- Each year on 1st April, use the curtailment curve based on short-term stochastic yield characteristics to determine whether there is a surplus or deficit in the sub-system. When there is a deficit in the sub-system, use this curve to determine the required curtailment level. (See the Albasini Dam curtailment procedure example included)
- With a deficit in the sub-system, impose curtailments according to the agreed priority classification as given in Table 4. First curtail the low assurance use, then the medium low followed by the medium high and high assurance use.
- The required curtailment needs to be spread evenly over the 12 months until 1st April of the next year, when the curtailment will be adjusted based on the storage level in the dam at that time.
- Under conditions when the flow diverted into Latonyanda and Levubu canals is less than the allocation for that year, support these users from Albasini Dam to the maximum indicated by the curtailment curve on the 1st April that year.
- When the flow diverted into these two canals exceeds the allocated volume for that year, the additional water can be used by the users from the two canals up to the maximum of their long-term allocation.
- A storage projection plot for the current year is included and the actual observed storage on first of each month must be plotted on the storage projection to monitor the behavior of the system. If the observed storage is plotting outside the projection plot, management need to be informed as additional actions might be required to protect the

resource.

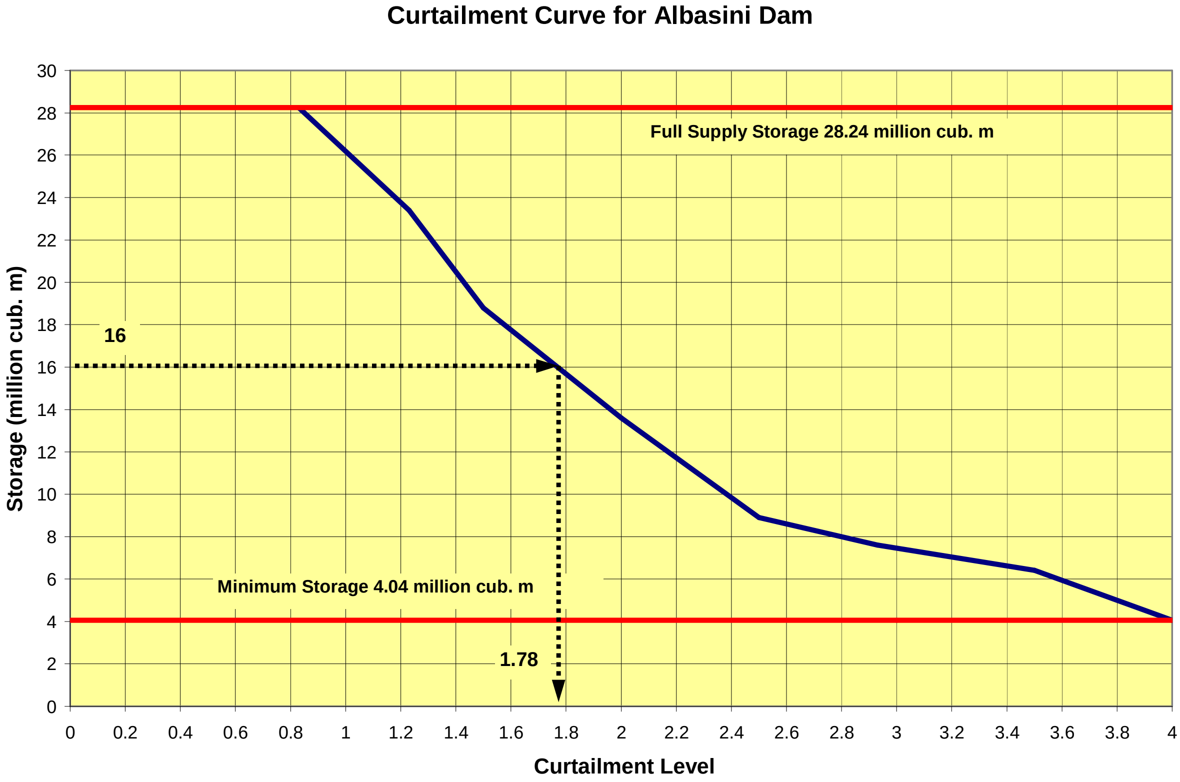

Figure 2: Albasini sub-system Curtailment Curve

The simplified curtailment graph is however only valid under the following conditions:

- Priority Classification is as given in Table 5.
- Urban demands between 2.6 & 3.6 million m³/a
- Irrigation demands at the current ±15.15 million m³/a
- Irrigation canal losses ± 4.54 million m³/a
- Total system demand, losses included, between 22 to 24 million m³/a
- Decision date for implementation of curtailments 1st April each year
- Physical water infrastructure in or upstream of the Albasini Sub-system the same as in 2005 with no significant changes.
- Hydrology and/or short-term stochastic yield characteristics remain as given in the “Luvuvhu River System Annual Operating Analysis – 2005”. (Updated hydrology and short-term stochastic yield characteristics will also require an updated curtailment curve.)

The purpose of this curtailment procedure is to protect the resource from complete failure, but also to be able to supply the different user groups or categories (Domestic/Industrial, Irrigation & Losses) at their required assurance of supply. For the Luvuvhu System each of the user categories were split into four different levels of assurance, Low, Medium Low, Medium High and High assurance, as indicated in Tables 4 & 5. When curtailments need to be imposed, the water use allocated to the low assurance will first be curtailed, in this case 15% of domestic/industrial, 30% of irrigation and 25% of system losses. Only when the portions allocated to **Level 1** (Low assurance) are fully curtailed, will curtailments be imposed on the demands allocated to **Level 2** followed by **Level 3** and finally by **Level 4**.

Table 5: Priority Classification for Albasini Sub-system demands

User Category	**Priority Classification & Assurance of Supply**				**2005 demand million m³/a**
	Level 1 (Low) 1:10 year	**Level 2 (Medium Low) 1:20 year**	**Level 3 (Medium High) 1:50 year**	**Level 4 (High) 1 in 200 year**	
Domestic/Industrial	15%	15%	40%	30%	2.64
Irrigation	30%	30%	30%	10%	15.15
Losses	25%	25%	25%	25%	4.54

If for example the storage in Albasini Dam on the 1st April is 16 million m³, as indicated by the dotted line on the curtailment graph, it is evident from the graph that it will require a **Curtailment level** of **1.78**. This means that **100%** of the demands allocated to **Level 1** need to be curtailed and **78%** of the demands allocated to **Level 2**. The total **domestic/industrial** demand therefore needs to be curtailed by ((1x15%)+(0.78x15%)) = **26.7%**, **Irrigation** by ((1x30%)+(0.78x30%)) = **53.4%** and **losses** by ((1x25%)+(0.78x25%)) = **44.5%**. For a higher curtailment level of 2.8 it will therefore mean that **100%** of the demands allocated to **Levels 1 & 2** need to be curtailed, and **80%** of the demands allocated to **Level 3.**

8.2 Vondo Sub-system

The Vondo sub-system includes Vondo, Tshakhuma & Phiphidi dams as well as the run-of-river abstractions at Dzingahe and Dzindi. Demands imposed on this sub-system therefore include Thohoyandou & Vuwani areas as well as irrigation supplied from Vondo Dam. A brief description of the new operating rule developed for the Vodo Sub-system, developed as part of the 'Luvuvhu River System Annual Operating Analysis' Study, is as follows:

- Each year on 1 April, use the curtailment curve based on short-term stochastic yield characteristics to determine whether there is a surplus or deficit in the sub-system. When there is a deficit in the sub-system, use this curve to determine the required curtailment level.
- When there is a deficit in the Vondo/Tshakhuma Sub-system, first increase the supply from Nandoni Dam to the common Nandoni/Vondo supply area before imposing curtailments.
- The support from Nandoni Dam also depends on the surplus available from Nandoni Dam at the time and needs to be verified using the Nandoni sub-system curtailment curve. The infrastructure to make this support possible is expected to be in place only from 2008 onwards and will also be limited by the physical constraints in the bulk and internal distribution system.
- If there is still a deficit in the sub-system, impose curtailments according to the agreed priority classification as given in Table 6. First curtail the low assurance use, then the medium low followed by the medium high and high assurance use.
- The required curtailment need to be spread evenly over the 12 months until 1 April of the next year, when the curtailment will be adjusted, based on the storage level in the dam at that time.
- If there is a surplus in Vondo Dam or when Vondo is spilling, allocate the surplus to the common Nandoni/Vondo supply area to reduce pumping costs.
- Supply the maximum possible from Tshakhuma Dam to the Tshakhuma service area.
- Supply whatever is available from the run-of-river abstractions at Dzindi and Dzingahe into the system. When water from the run-of-river abstractions is not sufficient, the relevant supply areas must be supported from Vondo or Nandoni Dam.
- A storage projection plot for the current year is included and the actual observed storage on first of each month must be plotted on the storage projection to monitor the behaviour of the system. If the observed storage is plotting outside the projection plot, management need to be informed as additional actions might be required to protect the resource.

Table 6: Priority Classification for Vondo/Tshakhuma demands

User Category	**Priority Classification & Assurance of Supply**				**2005 demand million m³/a**
	Level 1 (Low) 1:10 year	**Level 2 (Medium Low) 1:20 year**	**Level 3 (Medium High) 1:50 year**	**Level 4 (High) 1 in 200 year**	
Domestic/Industrial	15%	15%	40%	30%	16.57
Irrigation	30%	30%	30%	10%	0.0

The simplified curtailment graph is however only valid under the following conditions:

- Priority Classification is as given in Table 6,
- Capacities of the purification plants at Tshakhuma, Dzingahe and Dzindi remain at current average capacities of 1.41, 0.73 and 0.73 million m³/a respectively,
- Decision date for implementation of curtailments 1st April each year,
- No significant changes with regards to physical water infrastructure in or upstream of the Vondo, Tshakhuma and Phiphidi dams as well as upstream of the run-of-river abstraction points,
- No new resources are used to supply the requirements within the sub-system. (This means that as soon as part of the system demand is supplied from Nandoni Dam, which is expected by 2008, a new curtailment curve will be required),
- For a total system demand between 16 to 18 million m³/a, and
- When hydrology and/or short-term stochastic yield characteristics remain as given in the "Luvuvhu River System Annual Operating Analysis – 2005". (Updated hydrology and short-term stochastic yield characteristics will also require an updated curtailment curve.)

If for example the combined storage in Vondo & Tshakhuma dams on the 1st April is 16 million m³ as indicated by the dotted line on the curtailment graph (see Figure 3), it is evident from the graph that it will require a **Curtailment level** of **1.13**. This means that **100%** of the demands allocated to **Level 1** need to be curtailed, and **13%** of the demands allocated to **Level 2**. The total **urban/industrial** required therefore need to be curtailed by ((1x15%)+(0.13x15%)) = **16.95%** and for **Irrigation** by ((1x30%)+(0.13x30%)) = **33.9%**. For a higher curtailment level of 2.8 it will therefore mean that **100%** of the demands allocated to **Levels 1 & 2** will be curtailed and **80%** of the demands allocated to **Level 3.**

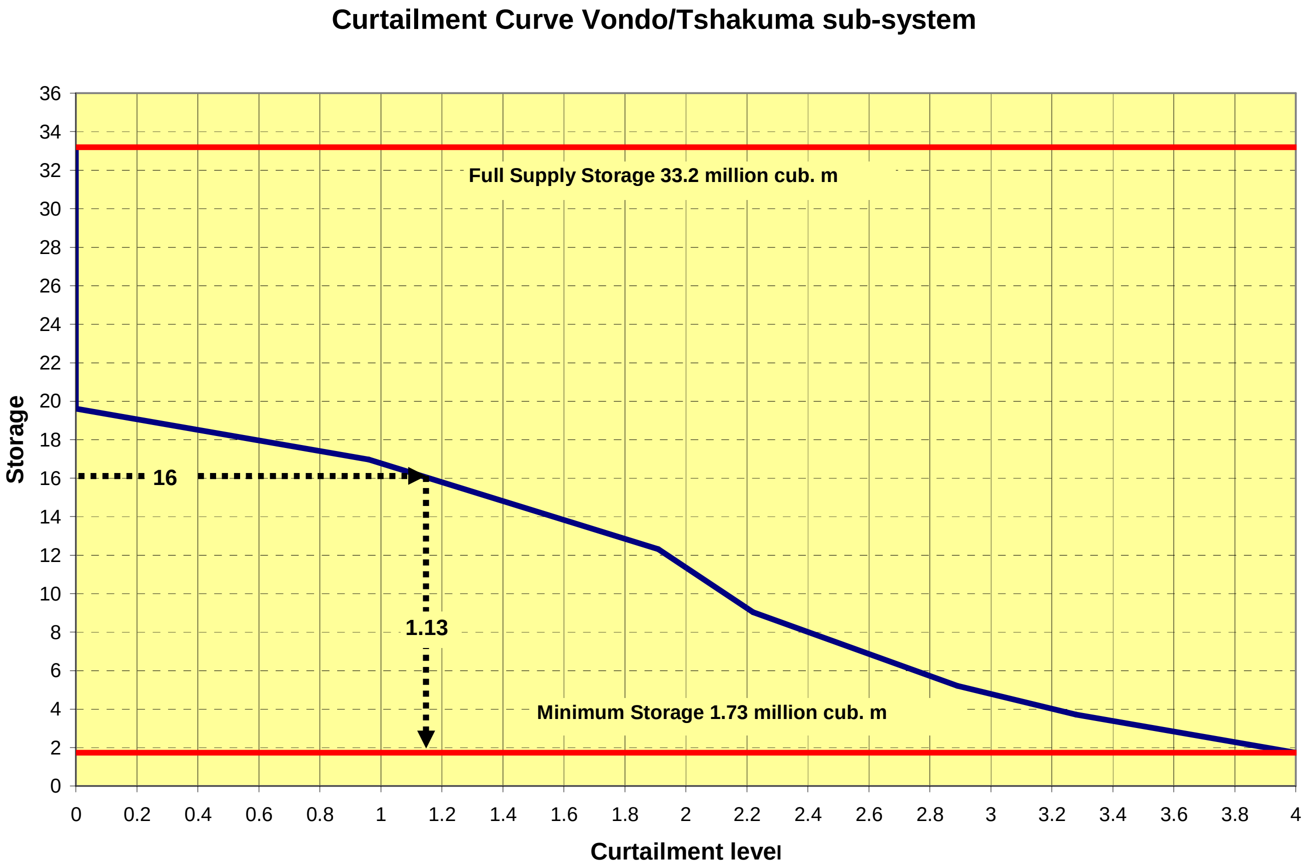

Figure 3: Vondo sub-system Curtailment Curve

References

Project Team. 2006. Luvuvhu River System Annual Operating Analysis. Development of a Decision Support System and excecuting of the 2005/2006 annual operating analysis. For the DWAF RSA by WRP & DMM Report number PNMA 02/000/00/0305.

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