Hydraulic modelling in the water resources field: A practical application

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Abstract

In the latter part of the previous decade as well as the early part of this decade considerable time and effort have been spent developing a hydraulic model for the lower reaches of the Orange River (approximately 1 400 km from Vanderkloof Dam to the river mouth) during two Water Research Commission (WRC) managed studies. While the model is relatively coarse and based to a large degree on cross-sections derived from aerial photographs, it has been shown to provide realistic and reliable estimates of the releases as they move downstream.

While such a model normally will assist in the analysis of riverine losses, the attenuation of different release patterns from Vanderkloof Dam and flood events, this model was used as part of the "Pre-Feasibility Study into Measures to Improve the Management of the Lower Orange River" (LORMS) for a number water resource related purposes. These include optimising the release pattern from Vanderkloof Dam, determining the size of the proposed re-regulating dams in the lower reaches, evaluating the theoretical demands patterns from Vanderkloof Dam to the river mouth and evaluating the possibility of utilising the inflows from the Vaal River all which provided some interesting results. This model has also subsequently been used to optimize flow regulation scenarios for blackfly control.

Keywords: *Orange River System, hydraulic modelling, water resources.*

1 Introduction

Water resources planning and large-scale infrastructure feasibility studies normally use the results of water resources system analysis (both the yield as well as planning models). These models, however, uses a monthly time step that does not always provide the required level of detail. Although one-dimensional hydraulic modelling has not been used as a tool in these large-scale water resources studies, it, however, could provide the user with the option of a range of smaller time steps depending on the level of accuracy required.

Considerable time and effort have been spent in the latter part of the previous decade as well as the early part of this decade developing a hydraulic model for certain reaches of the Orange River during 2 previous Water Research Commission (WRC) managed studies. The first study (McKenzie & Craig, 1999) has been used to analyse the river losses from the Orange River in an attempt to derive better estimates of the necessary releases from Vanderkloof Dam. The second study (Fair, 2003) focussed on the development of a real time operational model.

The hydraulic model developed can be used to analyse the attenuation of releases from Vanderkloof Dam as the water travels approximately 1 400 km to the river mouth. For a graphical presentation of the extent of the model, the different reaches and the gauging stations with available daily flow records see Figure 1. While the model is relatively coarse and based to a large degree on cross-sections derived from aerial photographs, it has been shown to provide realistic and reliable estimates of the releases as they move downstream. Such a model can usually assist in various ways including the analysis of riverine losses, different release patterns from Vanderkloof Dam and also the attenuation of specific flood events. This paper, however, discusses the alternative use of such a hydraulic model for a number of water resources related purposes during two studies, requiring smaller time steps than the normal monthly time steps, namely:

- The "Pre-Feasibility Study into Measures to Improve the Management of the Lower Orange River" (LORMS) (Maré et al, 2004):
    - Optimisation of the release pattern from Vanderkloof Dam;

- Evaluation of the theoretical demands patterns from Vanderkloof Dam to the river mouth; and
- Sizing of the proposed re-regulating dams.

- A Water Research Commission study titled "Development of a management plan for controlling pest blackflies along the Orange River" (WRC blackfly study) (Palmer et al, 2007):
  - Optimisation of flow regulation scenarios for blackfly control.

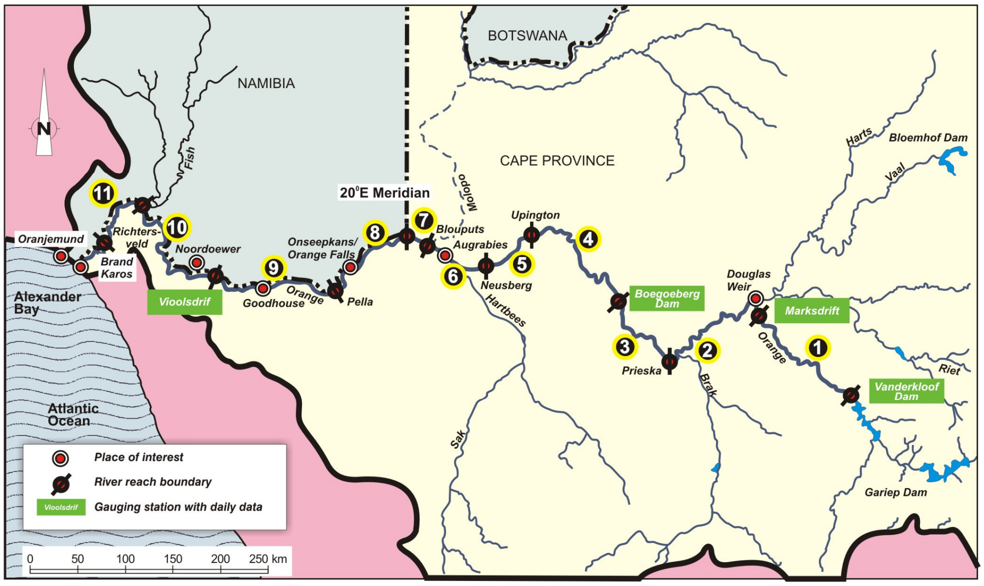

Figure 1. River reach modelled

2 Optimisation of release patterns from Vanderkloof Dam

The release pattern from Vanderkloof Dam in use before 2003, was determined using a 60/40 principle whereby all the requirements for a particular month for all the reaches are summed and then shifted using the 60/40 principle (60% of the demands are released in the previous month and only 40% demands in the current month) to take into account the time lag for releases to reach their destinations.

Running the hydraulic model with these release patterns indicated some problems especially during October to November and January to March periods. To overcome this problem a methodology was developed whereby hydraulic modelling was used through an iterative process to optimise the release patterns from Vanderkloof Dam.

The following assumptions were made:

- The 2003 (LORMS) demand and river requirement patterns were used;
- The hydropower and operating releases by the Regional office of DWAF were not taken into consideration as there are no set pattern for these releases;

From Figure 2 it is clear that the methodology used resulted in a substantially different release patterns during the problem periods (October to November and January to March). This new release pattern when used in the hydraulic modelling runs, results in meeting the downstream requirements at Brandkaros.

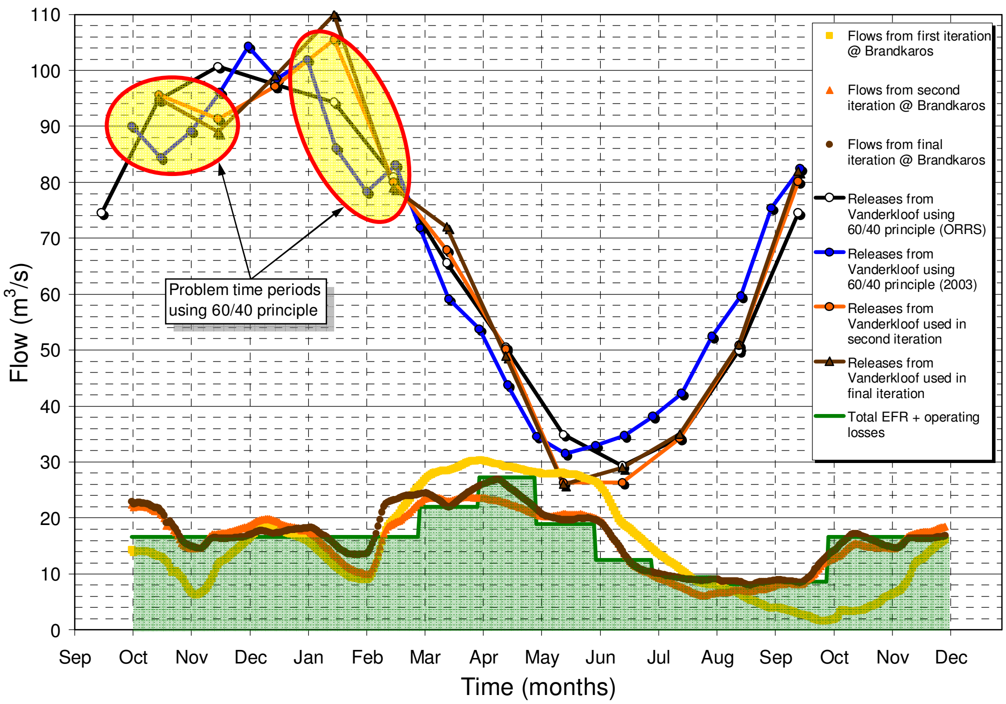

Figure 2. Results of optimisation of release patterns at Vanderkloof Dam

3 Evaluation of theoretical demand patterns

In order to evaluate the theoretical demand patterns especially the irrigation demand patterns, it is necessary to model the Lower Orange River reach using historical inflows and to compare the results with the downstream observed flows. To be able to do this, daily flow records were needed. Enquiries at DWAF lead to the conclusion that daily data is only available for 4 gauging station in the Lower Orange River reach (see Figure 1), namely at Doorenkuilen (D3H012) (just downstream of Vanderkloof Dam), Marksdrift (D3H003), Zeekoebaart (D7H008) (just downstream of Boegoeberg Dam) and Vioolsdrift ((D8H003). Daily flow data of flows in the Vaal River is also available at Douglas (C3R003) which is close to its confluence with the Orange River.

An additional daily data source exists at Vanderkloof Dam namely that of the Regional office of DWAF using release times and turbine openings obtained from ESCOM. A comparison of the daily flow data at Doorenkuilen and the ESCOM values showed an average annual difference of more than 7 m^3/s (more than 220 x 10^6 m^3/a). Due to the uncertainty with regards to the correct data source at Vanderkloof Dam, it was decided to only model the reach downstream of Marksdrift Weir and include the inflows from the Vaal River by assuming that the measured values at Douglas is correct.

After careful consideration it was decided to use the period 1 November 1997 to 31 December 1999 and to split it into two periods, 1 November 1997 to 31 December 1998 (1998 analysis) and 1 November 1998 to 31 December 1999 (1999 analysis). A comparison of the modelled flows with the measured flows at Boegoeberg Weir (Zeekoebaart in the case of the measured flows) indicated during both periods significant differences at low flows - the measured flows being lower than the modelled flows (see Figures 3 and 5 for the 1998 and 1999 analysis periods respectively) highlighting the inaccuracies of the gauging station at Zeekoebaart during low flows.

With regard to Vioolsdrift Weir, the comparison indicated significant differences between the modelled flows and the measured flows using the 2003 (LORMS) demand patterns (Maré et al, 2004) and a fairly good correlation using the ORRS demand patterns (McKenzie and Maré, 1997) (see Figures 4 and 6 for the 1998 and 1999 analysis periods respectively). It can therefore be concluded that the 2003 (LORMS) demand patterns downstream of Boegoeberg is considerably smaller than the actual demand patterns indicating periods of non-compliance (October to November and February to March) with downstream demands especially the river mouth's ecological demands. These periods were also highlighted during the first sub-task as possible problem periods using the 60/40 principle to determine the release patterns from Vanderkloof Dam (see Figure 2).

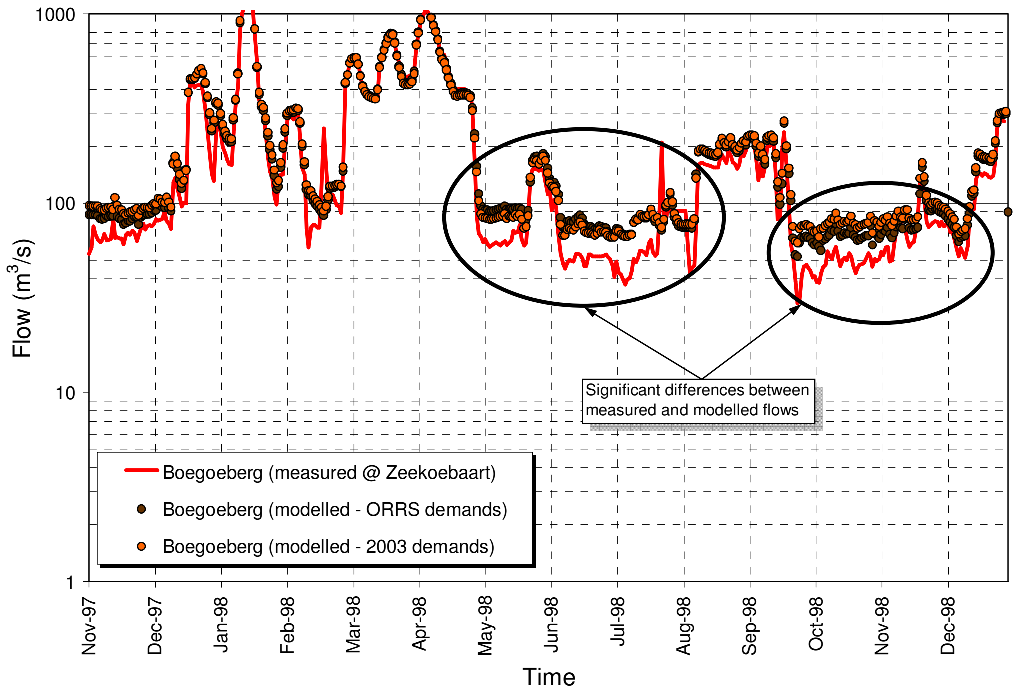

Figure 3: Measured flows versus modelled flows at Boegoeberg (1998)

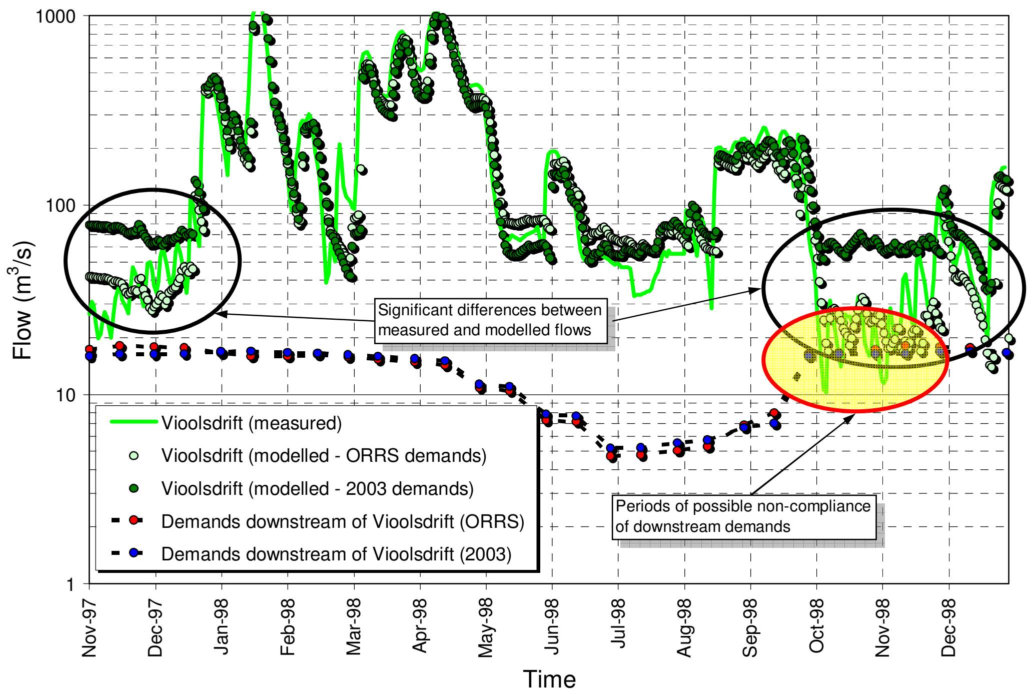

Figure 4: Measured flows versus modelled flows at Vioolsdrift (1998)

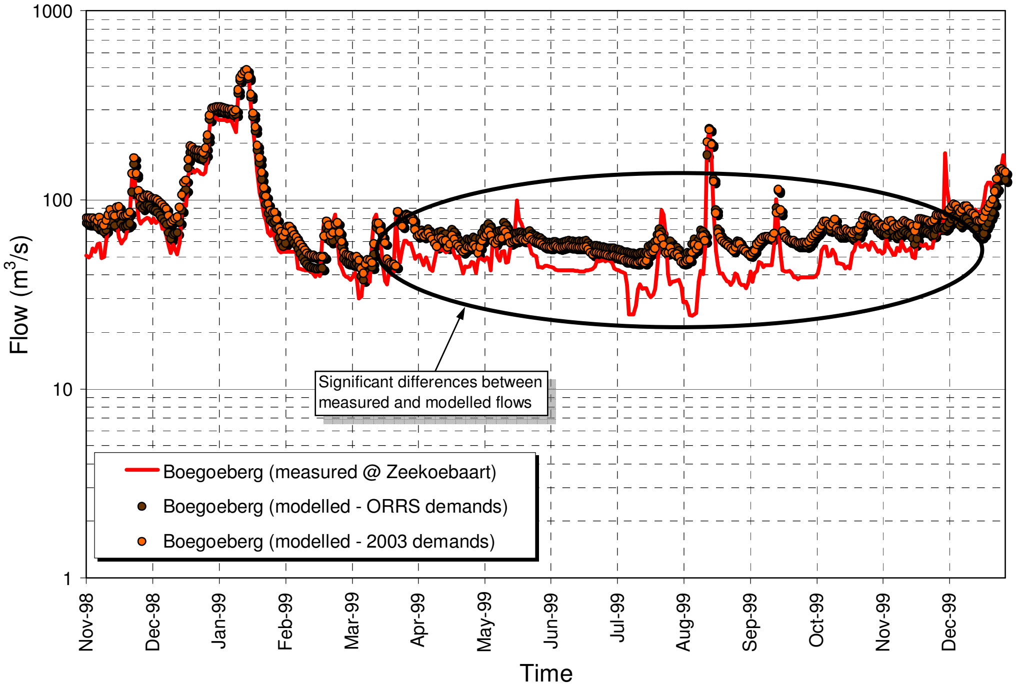

Figure 5: Measured flows versus modelled flows at Boegoeberg (1999)

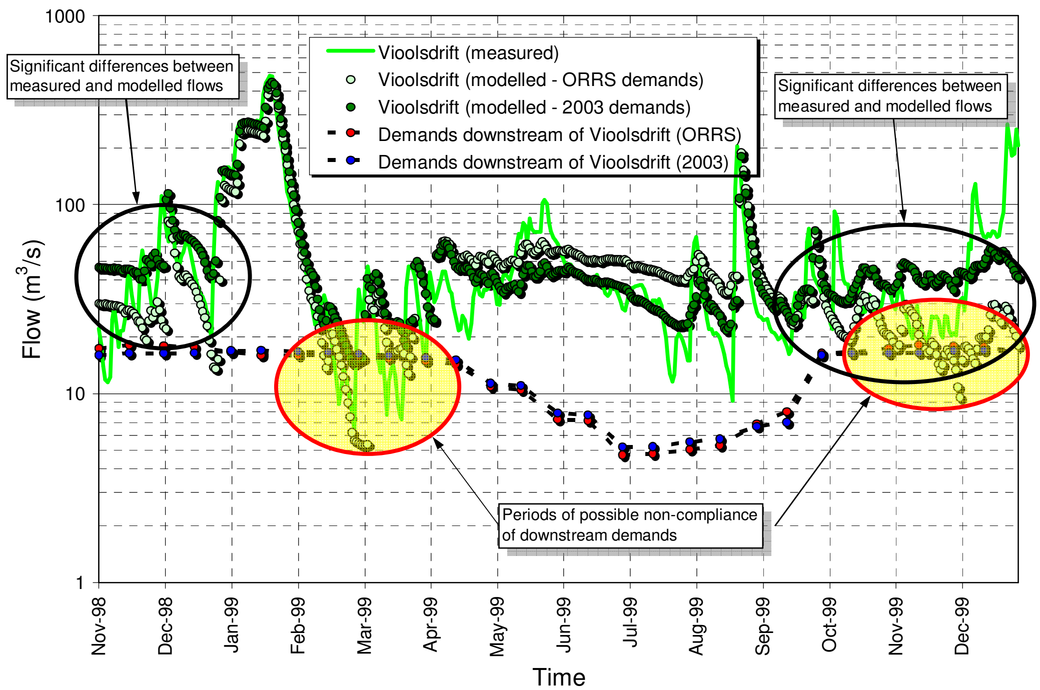

Figure 6: Measured flows versus modelled flows at Vioolsdrift (1999)

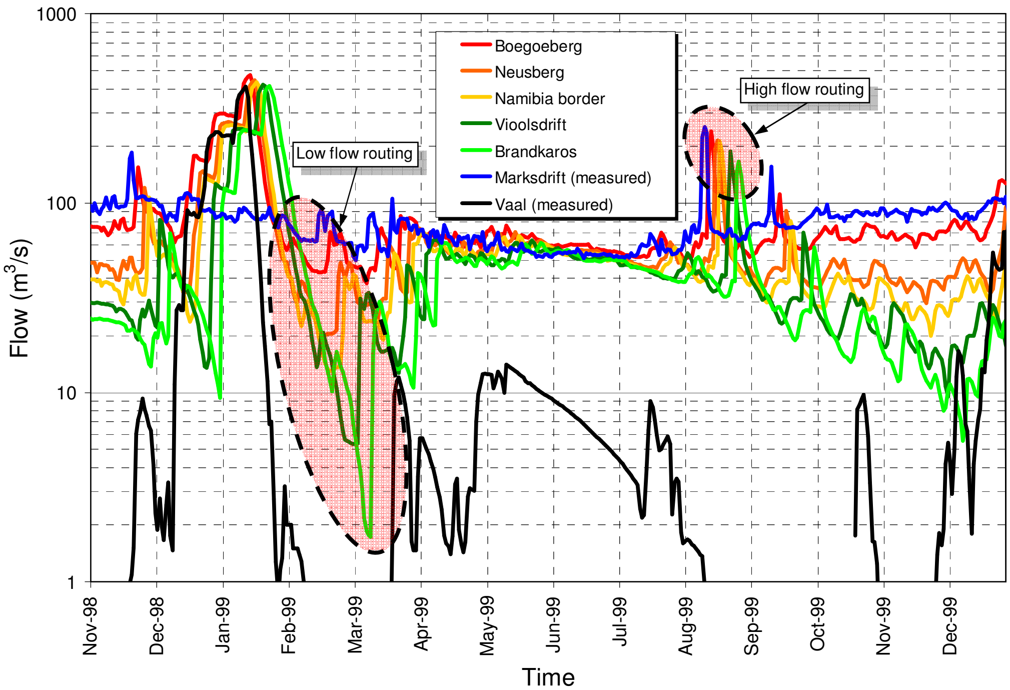

Figure 7: Time lags during high and low flows

A point of interest is also the fact that the hydraulic model could be used to provide an indication of the extent of inflows from downstream tributaries (see the differences in modelled and measured flows during May 1999 in Figure 5 and 6 respectively).

The results of this sub-task were also used to determine the time lag used in the sizing of the proposed re-regulating dams described in more detail in the next section (see Figure 7 for an indication of the different time lags during periods of high and low flows respectively).

4 Sizing of proposed re-regulating dams

The purpose of the proposed re-regulating dams would be to reuse the normal operating releases from Vanderkloof Dam. Basically the same principles that were used by McKenzie and Maré (1997) in the ORRS, have been used to determine the optimal sizes of the proposed re-regulating dams. The major difference is that the results of hydraulic modelling utilising the optimised release patterns from Vanderkloof Dam, was used instead of the results from yield and system analysis as was the case in the ORRS.

It is also important to note that no cognisance was taken with regard to the operating releases decided upon by DWAF's Regional office and the additional hydropower releases made ESCOM.

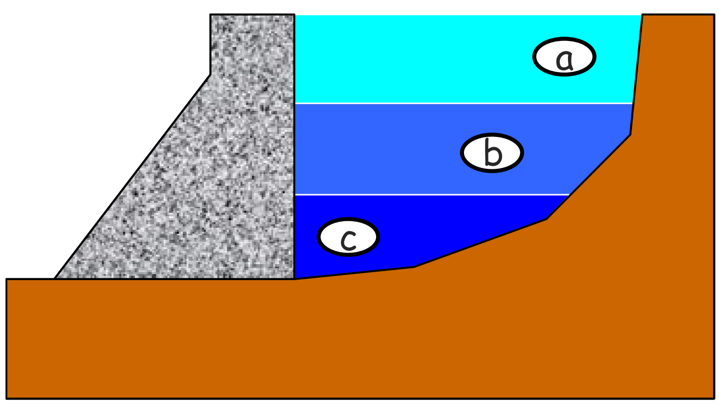

Figure 8: Section through re-regulating dam showing different theoretical storages

The typical storage to ensure the optimal use of the operating releases consists of the following (see Figure 8):

- The upper zone is included as a safety zone and provides some capacity for capturing local inflows, human errors etc. It is calculated by using the middle zone's volume and adjusting it using the time lag involved to get water from Vanderkloof Dam to the proposed re-regulating dam (Zone A);
- The middle zone is equivalent to the maximum monthly saving in operating loss using the results of the hydraulic modelling and taking into account the downstream requirements for the operating loss (which was calculated using a direct relationship between the downstream requirement and the distance from the river mouth) (Zone B); and
- The lower zone is for storage of the downstream requirements for the next month taking into account the time lag involved to get water from Vanderkloof Dam to the proposed re-regulating dam (Zone C);

The total required storage was determined by summing the maximum storage size determined for each zone irrespective whether it is in the same period or not. The maximum saving was calculated subtracting the evaporation (as determined in ORRS by Mckenzie and Maré (1997)) from the monthly saving.

Three possible sites were considered, namely Boegoeberg, Komsberg and Vioolsdrift. It is important to note that no downstream requirement was set for the Vioolsdrift site due to its proximity to the river mouth and therefore the limited time it would take water to reach the river mouth. The results of the sizing exercise are given in Table 1.

Table 1. Sizes of proposed re-regulating dams

	Boegoeberg	Komsberg	Vioolsdrift
Storage required (10^6 m^3)	86	74	102
Net saving (10^6 m^3/a)	62	126	212

From the results it is clear that the Vioolsdrift site will provide the biggest saving. With regards to the storage required it is interesting to note that Komsberg requires the smallest storage followed by Boegoeberg with Vioolsdrift requiring the largest storage. This seemingly strange phenomenon can be attributed to the distribution of the downstream requirements, the difference in time lag from Vanderkloof Dam as well as the fact that the maximum monthly saving occurs during different months at the different sites.

5 Optimisation of flow regulation scenarios for blackfly control

The efficacy of a blackfly control programme initiated by the Department of Agriculture in 1992 declined after the discontinuance of an active WRC research project that ran from 1992 to 1998 with serious outbreaks of blackflies experienced between 2000 and 2002. This had a detrimental impact on the local economy and led to numerous appeals from all sections of the farming industry, tourism organizations, wine cellars, etc. for the problems to be rectified, and for a long-term solution be found to control blackflies effectively. As a result a WRC funded study (Palmer et al, 2007) was conducted between 2004 and 2006. As part of the solution it was proposed to use hydraulic modelling and specifically the setup used for the LORMS to assist in formulating and applying various flow regulation scenarios for blackfly control.

The objectives set for the hydraulic modelling task were to develop flow scenarios, optimise these scenarios and make a recommendation regarding the preferred scenario. Three flow scenarios were evaluated:

- Scenario A (Base): Reduction in flows from Vanderkloof Dam during July with no manipulation of the operation of any of the downstream weirs;
- Scenario B: Same as Scenario A except for emptying Boegoeberg Dam at the same time as the reduction in flows from Vanderkloof Dam to facilitate a shorter period of reduced flows; and
- Scenario C: Same as Scenario B except for emptying Boegoeberg Dam five (5) days earlier than the reduction in flows from Vanderkloof Dam to facilitate an even shorter period of reduced flows.

From the results of the hydraulic modelling the following was evident (see Figure 9 for a comparison between Scenario A and C):

- It will take at least 21 days for reduced releases to reach Onseepkans under normal circumstances. Considering the time it would take to apply some of the other measures to total time of reduced releases could be long as 25 days (nearly four weeks);
- The velocity profile even during the low flows would be more than 0.3 m/s. Getting the majority of velocities below 0.3 m/s over most of the reach would require extremely low flows which could result in some demands not being met in the downstream reaches; and
- With the manipulation of the operation of Boegoeberg Dam (Scenario C) it is possible to decrease the time it will take for low flows to cover the whole reach to 9 days. The total time period of controlled reduced flows however would still be 25 days.

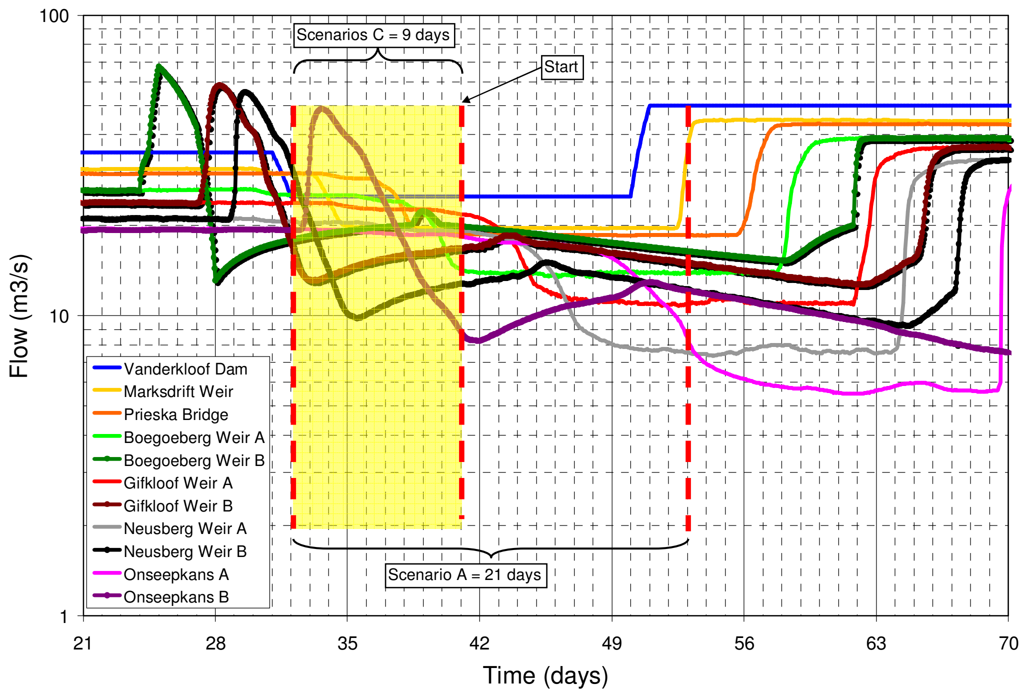

Figure 9. Comparison of modelled flows of Scenarios A and C

6 Conclusions

From the LORMS (Maré et al, 2004) the following conclusions were drawn:

- The 60/40 principle used to determine the release patterns from Vanderkloof Dam was not effective in meeting the downstream requirements effectively. It had been proved that the release patterns could be optimised by the use of hydraulic modelling through an iterative process;
- There is a discrepancy between the measured and modelled flows at Boegeberg/Zeekoebaart gauging stations (the measured flows is significantly lower than the modelled flows) highlighting the inaccuracies of the gauging station at Zeekoebaart during low flows;
- The theoretical demand patterns downstream of Boegoeberg Weir is considerably smaller than the actual demand patterns indicating periods of non-compliance with downstream demands especially the river mouth's ecological demands during October to November and February to March; and
- Using hydraulic modelling to size re-regulating dams resulted in some surprising results not previously evident using water resources system analysis thereby influencing the final recommendation regarding the optimised solution.

From the WRC blackfly control study (Palmer et al, 2007) it was clear that hydraulic modelling provides the means to consider different flow scenarios and to optimise these flow scenarios without having to perform actual releases.

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