Towards improving the assessment and implementation of the Reserve:

Real-time assessment and implementation of the Ecological Reserve

Report to the
Water Research Commission

by

Sharon Pollard[1]
Stephen Mallory[2]
Edward Riddell[3]
Tendai Sawunyama[2]
1 Association for Water & Rural Development (AWARD)
2 Water for Africa (IWR Water Resources)
3 University of KwaZulu-Natal

WRC Report No. KV 282/11
ISBN 978-1-4312-0164-8

JANUARY 2012

The publication of this report emanates from a WRC project titled *Towards improving the assessment and implementation of the reserve: Real-time assessment and implementation of the ecological reserve* (WRC Project No. K8/881).

Executive Summary

When the Olifants River in north-east South Africa ceased flowing in 2005, widespread calls were made for an integrated focus on all of the easterly-flowing rivers of the lowveld of South Africa. These are the Luvuvhu, Letaba, Olifants, Sabie-Sand, Crocodile and Komati Rivers in Water Management Areas 2, 4 and 5. Most of these rivers appeared to be deteriorating in terms of water quantity and quality despite the 1998 National Water Act (NWA). As most of the rivers flow through Kruger National Park (KNP) and all of them form part of international systems the implications of their degradation were profound and of international significance (Pollard and Du Toit 2010).

The aims of this study were to assess the state of compliance with the Ecological Reserve (ER) – as a benchmark for sustainability – in these rivers and some of their tributaries. It also explored the problems associated with an assessment of compliance. In short these include the lack of planning and integration of ER determination methods with operations and the difficulties associated with real-time predictions of ER requirements. These factors severely constrain planning, monitoring and the management action to mitigate non-compliance.

In South Africa, the ER is defined as a function of the natural flow which, because the natural flow in a system is not known at any point in time, is creating problems with real-time implementation. To estimate the natural flow, real-time hydrological models with accurate daily rainfall are needed but such rainfall data are lacking in many catchments. This problem is unlikely to be resolved in the short- or medium-term. Although an alternative is to use a flow gauge located in an undeveloped catchment there are shortcomings which are discussed. The other problem is that water users, especially irrigators, would like to know <u>in advance</u> how much water will be available to them over the next growing season. Existing water resources models can give estimates of available water in the short-term but cannot indicate how much water will be required for the ER because the future flow is not known. Possible solutions to the problem of estimating real-time natural flows and predicting ecological flows into the future are addressed in this report.

In terms of historical compliance, the study focused on water quantity, comparing the monthly flow duration curves for the ER for specific points along these rivers with monthly flow duration curves (FDC) compiled from measured daily flow data. This revealed the months in which flows were on average lower than the Reserve. Where possible, the analysis interrogated this data on two or more different time periods to assess if the situation was improving since the promulgation of the NWA and other changes to the status-quo of management in the catchment.

The results are probably somewhat of an under-estimate of non-compliance because they do not show individual days when Reserve flows might not have been met. Table A provides a summary of the analysis showing the % time the ER was not met, based on intersection of the FDC produced from historical gauged flow data against the FDC for the ER of each river. In no instance was there complete compliance with the ER since hydrological records began, whilst the highest level of non-compliance (88% of the time) was shown for the Klein Letaba.

With the exception of the Sabie River the situation has worsened since the 1998 NWA (Figure A). Whilst presenting a somewhat dismal picture overall, there are some exceptions. Recent management interventions in the Inkomati WMA suggest that the situation will improve substantially in the next decade, particularly in the Crocodile River. This is equally true in the Groot Letaba River.

The analysis also interrogated periods of interest in more detail, most notably those after the 1998 NWA, using daily flow data, which doesn't suffer the same drawbacks as monthly averaging. In most cases the incidence of non-compliance increased under this analysis, even in the case of the relatively pristine Sabie River for example. Startling as it may seem, the same analysis revealed the almost 100% non-compliance with the ER for the Blyde River during the winter dry season months, whose dam was built to meet in-part the ER requirements for the Olifants river. Moreover, this analysis revealed unexpected in-sights into reserve non-compliance that occurred during the wetter summer months, as was noted for the Groot Letaba and the Olifants for example. The analysis then explored the volumetric magnitude by which the ER was infringed, and despite distinct results for each river, there was a general trend of increasing disparity in volumetric requirements of ER and the volume that actually flowed as the dry winter months progressed.

Whilst this document details the rationale for the ER and suggests novel methods in which compliance with meeting the ER can be monitored and assessed retrospectively, we also propose new methods based on naturalization of the flow hydrograph using case studies in two catchments the Groot Letaba and Crocodile (East) River systems. This can be incorporated into real-time monitoring and forecasting in hydrological modeling systems.

Table A: Non-compliance in meeting the quantity component of the Ecological Reserve in lowveld rivers

WMA	River	1st period (Development without IWRM)	2nd period (improved policy &/or management)	2nd period (improved policy &/or management)	Worst month	Compliance improving?
		Monthly Data		Daily data		
2	**Luvuvhu**	38.8	as previous	N/A	August	Not known
	Letaba	40.7	21.9	48.5	February	Improving since 1994
	Klein Letaba	see daily	see daily	88.4	September	Not known
4	**Lower Olifants**	46.8	44.8	56.3	August, September	No improvement
	Blyde	N/A	72.9	99.1	April to October	Not known
5	**Sand**	37.7	(13.6) 39.0	58.4	September	Declining
	Sabie	*38.7	**(23.3) 27.7	37.8	August, September	Declining
	Crocodile	14.4	(34.8) 50.0	55.5	September	Declining
	Komati	19.8	(53.7) 37.1	44.0	July	Declining
	Lomati	12.8	(9.0) 0.0	18.7	June, July	Improving

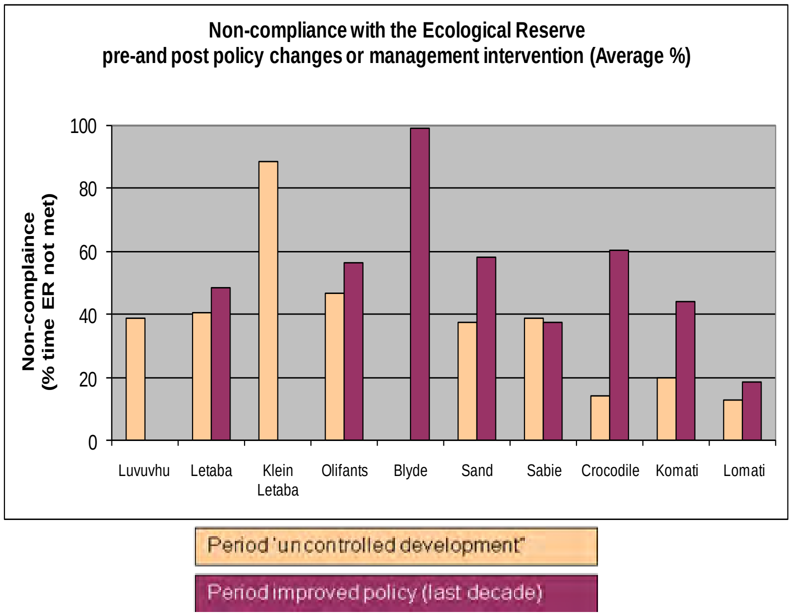


Figure A: A summary of the incidence of non-compliance with the flow component of the Ecological Reserve in the lowveld rivers over two developmental periods (pre- and post-NWA of 1998, monthly and daily data respectively)

For an assessment of potential reasons underlying non-compliance, readers are referred to a report in which regulators, water users, operations and maintenance staff, researchers and other stakeholders explored this issue (Pollard & Du Toit 2011).

In order to (a) monitor Reserve compliance and (b) to provide a reasonable prediction of future ER requirements (say over the next year) practitioners, government and academics need to be mindful of the realities of attempting to operationalise the Reserve. There are a number of constraints to this which are discussed. Importantly water resources managers need to be given guidance and support to do this particularly as Catchment Management Agencies come on line and take over functions that have direct bearing on meeting the commitment to the Reserve.

Acknowledgements

We would like to thank the Water Research Commission for support for the project. Stacey Gouws worked hard to produce the maps of the EWR sites. Harry Biggs provided comments on some of the earlier drafts. Ramin Pejan is thanked for his discussions on the legal interpretations of compliance.

Table of Contents

List of Figures

List of Tables

List of Acronyms

CMA	Catchment Management Agency
DWA	Department of Water Affairs
ER	Ecological Reserve
EWR	Environmental Water Requirement
FDC	Flow Duration Curve
IBT	Inter-Basin Transfer
ICMA	Inkomati Catchment Management Agency
IFR	In-stream Flow Requirement
KNP	Kruger National Park
KOBWA	Komati Basin Water Authority
MAR	Mean Annual Runoff
NIB	National Infrastructure Branch
NWA	National Water Act 1998
NWRS	National Water Resources Strategy
PES	Present Ecological Status
RDM	Resource Directed Measures
REC	Recommended Ecological Class
RO	Regional Office
SANParks	South African National Parks
SDC	Source Directed Controls
SFR	Streamflow Reduction
SRI	Shared Rivers Initiative
TPC	Threshold of Potential Concern

SECTION A Overview

1. Objectives and overview of the study area

1.1. Introduction and objectives

This report was undertaken as part of the Shared Rivers Programme Phase 1, one component of which focused on factors that enable or constrain compliance with the Reserve in the lowveld rivers, namely the Luvuvhu, Letaba, Olifants, Sabie-Sand, Crocodile and Komati rivers (Pollard and Du Toit 2011). It emerged from problems that were confronted in attempting to assess non-compliance with the ecological Reserve (see Box 1), which in South Africa is a proxy or benchmark for the policy commitment to sustainability (Pollard & Du Toit 2009). Two key questions guided the work and this report seeks to address problems being confronted with the first of these:

1. Is the Reserve being met? (i.e. **is there** compliance with the Reserve?)
2. What factors enable or constrain this (i.e. **why** is this so?).

In attempting to answer the first question for each of the rivers in question, a number of constraints were encountered – the central aspect of which is difficulties in determining the Reserve 'today' (i.e. real-time) and difficulties in predictive capacity. Both issues are critical for the operationalisation of the Reserve. The former is an important component of regulation from a management perspective as a catchment manager needs to know that there was non-compliance today and not as a retrospective ('sometime during the month') which would make taking action very difficult. Also it is critical for a catchment manager to be able to set the Reserve for the up-coming period so that the allocation schedule, curtailments and issues of delivery can be planned for.

The difficulties outlined above reflect the current situation such that the Catchment Management Agencies (the proto-CMA in the Limpopo and the Inkomati CMA), and/or the relevant DWAF were unable to take action in terms of the Reserve compliance and this work helped to deepen the understanding. In keeping with the overarching aim of the Shared Rivers Initiative (SRI) – namely to support the ***perationalisation*** of the ecological Reserve (ER) from a water resource manager's perspective – the objective of the analysis was to provide guidance on how to improve compliance.

Key issues under examination

It is important to recognise that although it was initially assumed that answering the first question would be a fairly straightforward exercise this was not the case. A number of problems were confronted in attempting to examine and assess non-compliance (see Deliverable 1) and are summarised here as:

a) In South Africa the ecological Reserve is defined as a function of natural flow. While this is a useful method to describe the ecological flow requirements, it is creating problems with real-time implementation of the Reserve simply because the natural flow in a system is not known at any point in time. In order to determine the natural flows, rainfall data are required but a serious short-coming in models which are currently attempting to implement the Reserve in real-time is the lack of real-time rainfall data to drive the hydrological model. Also – and this is important to recognise – rainfall data is not kept up-to-date so by the Department of Water Affairs. The last up-dated, nationally available data set is for 2004 (WRC 2008). Thus the ER requirements can only be determined up to 2004. Consequently determining the ER since then when improvements in compliance are expected or in real-time (today) is not currently possible. This constrains tracking and monitoring ER compliance as well as making projections for future requirements for the purposes of management. This problem in unlikely to be resolved in the short- or medium-term since a number of constraints limit the commitment of any single organization in South Africa being able to undertake need for real-time rainfall data. The South African Weather Services have closed down most of their rainfall stations and while they are developing radar and satellite techniques for recording rainfall, these techniques are not yet accurate enough for use in hydrological models. An alternative to the use of a hydrological model is to use a flow gauge located in an undeveloped catchment. The short-coming of this approach is that there are very few undeveloped gauged catchments in the areas where catchment managers wish to implement the Reserve. Also, this does not solve the problem in developed catchments.

b) The Reserve determination outputs are not suitable for operationalisation. The outputs of the determination study need to be 'translated' into operational Reserve requirements and support needs to be given to managers to do this. Water resources managers need to (a) <u>monitor</u> compliance with the Reserve on a daily (or weekly) basis so that transgressions can be correctly identified and timeously addressed. This means knowing what the ER requirement is "today" and comparing it to observed flows; and (b) to <u>make projections</u> for the ER requirement for a specified upcoming period, say six months, so that water users can plan and regulate appropriately. The Reserve determination study outputs (a Flow Duration Curve, FDC (monthly) or time series) does not facilitate either of these management objectives directly.

c) Pollard & Du Toit (2011) reported that a number of managers noted that current ER determination methods are undertaken in a vacuum, without thinking about realities of operationalising these. They highlighted the lack of support from DWA (and consultants) in making this critical step of building the ER into planning and operations through a real-time water resources management model. They noted that they simply often defaulted to a minimum flow.

d) The other problem emerging from the attempted implementation of real-time water use management systems is that water users, especially irrigators, would like to know in advance how much water will be available to them over the next growing season so that they can decide what area of crops to cultivate. Existing water resources models can give estimates of available water in the short-term but cannot indicate how much water will be required for the Reserve, simply because the future flow is not known.

e) Also planning for the ER, monitoring and taking mitigatory actions for compliance are all constrained by:
   - the inability to establish ecological Reserve requirements in real-time and;
   - the fact that not all Ecological Water Requirement (EWR) sites can be monitored (no gauges; gauges far from EWR sites).

Given these constraints, this sub-project of the Shared Rivers Initiative was undertaken in a project entitled ***Towards improving the assessment and implementation of the Reserve: (Real-time assessment & implementation of the ecological Reserve).*** The aims of the project are as follows: To support the operationalisation (assessment and implementation) of the Reserve by addressing two constraints, viz.

(a) difficulties in determining the Reserve 'today' (i.e. real-time) and

(b) difficulties in predictive capacity, through:

- Development and testing of real-time estimation of the ecological Reserve for two water resource management situations (the Letaba and Crocodile Rivers)
- Development of a predictive model of the future requirements (mainly the stressed low-flow period for the forthcoming dry season) in support of water resources curtailments for users.

Possible solutions to the problem of estimating real-time natural flows and predicting ecological flows into the future are addressed in this report. It must be stressed, however, that the methodology suggested in this report is but one of many and that each methodology has its strengths and weaknesses. As part of this study, a brief review of the currently available reserve implementation methodologies is given and suggestions made and to which methodologies are applicable under which circumstances.

1.2. Study area

When the Olifants River in north-east South Africa ceased flowing in 2005, widespread calls were made for an integrated focus on all of the easterly-flowing rivers of the lowveld of South Africa. These are the Luvuvhu, Letaba, Olifants, Sabie-Sand, Crocodile and Komati Rivers in Water Management Areas 2, 4 and 5. Most of these rivers appeared to be deteriorating in terms of water quantity and quality despite the 1998 National Water Act (NWA). As most of the rivers flow through Kruger National Park (KNP) and all of them form part of international systems the implications of their degradation were profound and of international significance (Pollard and Du Toit 2011). These catchments are described in detail in the main SRI final report (Pollard & Du Toit 2011) and their location is given in Figure 1.

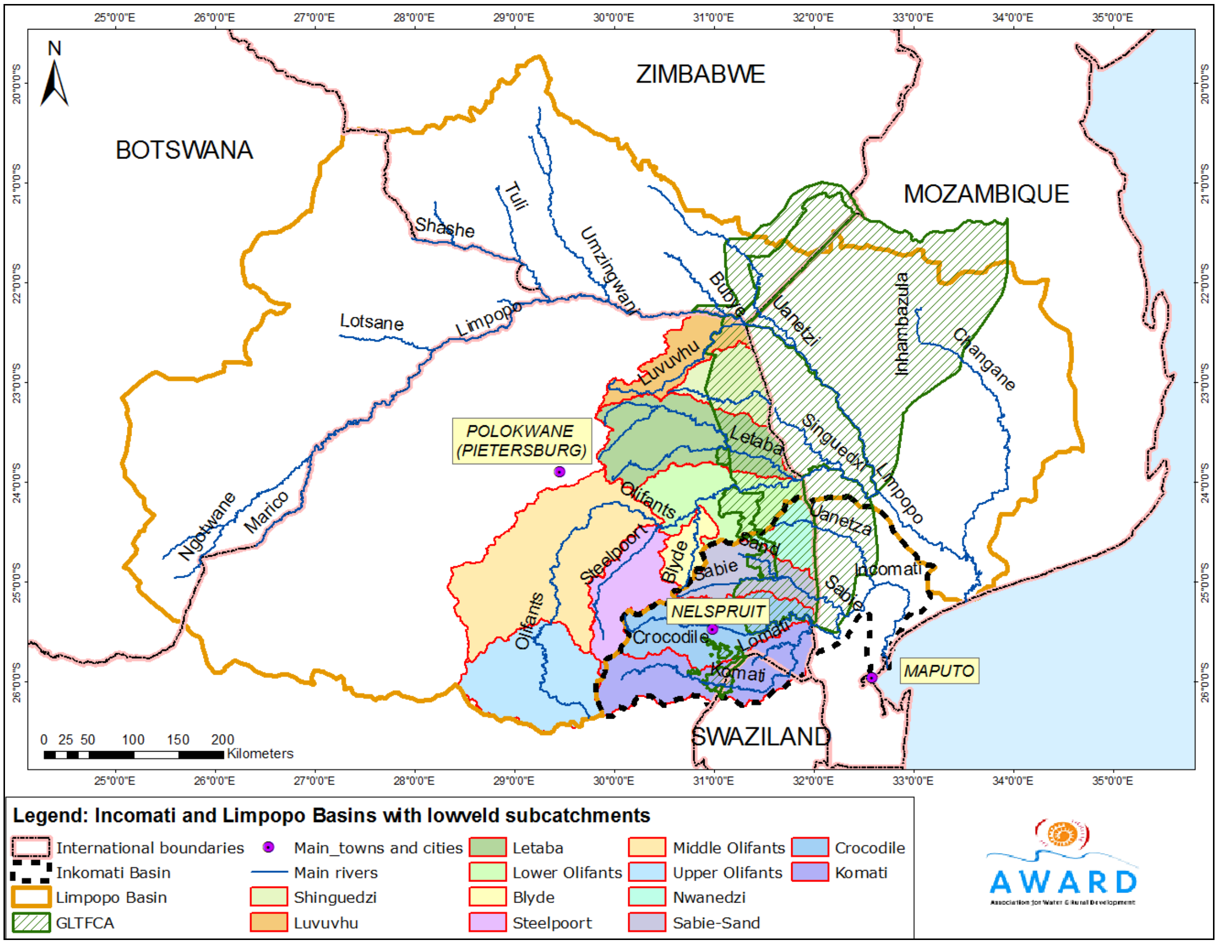


Figure 1 Map of lowveld rivers (from Pollard & Du Toit 2011)

1.3. Report layout

The report is divided into three Sections A, B and C. Section A provides an introduction, whilst Section B presents a detailed analysis of historical compliance with the Ecological Reserve. It also discusses the principles relating to an assessment of *'compliance'* with the Reserve. Section C examines potential approaches to the real-time assessment of the Reserve through a comparison of Reserve implementation using natural and gauged flows for the Crocodile and Letaba River. Section D concludes the report with a discussion of the major issues and some recommendations for the way forward.

SECTION B Assessment of compliance with the ecological Reserve

2. Compliance with the Reserve

2.1. Introduction and motivation

In keeping with the overarching aim of the SRI – namely to support the ***operationalisation*** of the ER from a water resource manager's perspective – the objective of the analysis was to provide guidance on how to improve compliance. The question of Reserve compliance can be asked in two ways.

First it can be questioned from a historical perspective, so that one is asking if the situation has been improving over a certain period, in particular over the last decade since the introduction of new legislative measures or in other words, what are the trends? (question 1). As a corollary one would want to know why this is so (question 2) so as to inform management practices and potentially also policy.

Secondly, compliance can be examined from a more immediate or real-time perspective (monitoring at the scale of a daily timestep for example) so as to take immediate action through regulation and enforcement. In this case the manager wants to know if there is compliance *currently*, that is, in real-time. This is an important component of regulation from a management perspective as a manager needs to know that there was non-compliance today and not as a retrospective ('*sometime during the past*') which would make taking action very difficult.

This section focuses on the first timescale; that is the so-called '*historical*' compliance whilst the latter real-time monitoring is dealt with in Section 3 Readers are also referred to the catchment-specific reports on factors that constrain or enable meeting the ecological Reserve (Du Toit and Pollard 2009a, b; Pollard and Du Toit 2009b, a; Pollard and Agterkamp in prep, Pollard and Mallory in prep.).

Two key questions guided the analysis:

1. What is the trend in flows (i.e. sustainability) in each of the rivers over the last 50 years?
   A 50 year time period was chosen because this represents, on average, a period of escalating development and increased water demand. The ecological Reserve acts as a proxy for monitoring sustainability.

2. Has there been compliance with the Reserve in each of the rivers in the period following the promulgation of the National Water Act, NWA (1999-2008)?

   Two sub-questions were examined:
   i. What is the trend? (are things getting better or worse)
   ii. Is this a result of climate or management?

2.2. Key concepts being examined

This question of compliance has raised a number of additional and critical issues for assessments of ER compliance. This includes understanding firstly, how the Reserve is represented formally as part of a

Reserve determination, and secondly, how this gets 'translated' into an operational tool for implementation and monitoring. Thirdly, if there are transgressions what are the actions that can be taken to mitigate these? Is the Reserve defensible legally or in other words what constitutes compliance?

2.2.1. What does Reserve implementation refer to?

With regard to terminology, it is important to define what is meant by key terms such as implementation, ecological Reserve determination and operationalisation. In this report we consider implementation of the ER as the umbrella concept comprising a wide range of important strategic actions. It includes ensuring that the concept is captured in policy, that there has been institutional and strategic realignment and that the Reserve can be determined. Thus it includes both the determination and operationalisation. In discussions on compliance it is important to distinguish the macro-planning process (which includes Reserve determination) from operationalisation in which we include operational planning (e.g. projecting ER requirements for a pre-defined management period), monitoring, regulation, enforcement, reflection and learning.

Box 1: What is the Reserve? (NWA 1998)

The Reserve refers to the quantity and quality of water required:

(a) to satisfy basic human needs

(b) to protect aquatic ecosystems in order to secure ecologically sustainable development and use of the relevant water resource; The ecological Reserve refers to the modified EWR where operational limitations and stakeholder considerations are taken into account.

The ER **comprises a number of components** including magnitude, duration and frequency as well as water quality parameters.

Due to resource constraints we focus only on the quantity component of the ER; in other words compliance in terms of quantity for which a number of indicators were chosen. However as we point out in Section 5, compliance with the water quality aspects of the ER is also required. Moreover, excessively high flows can also constitute cases of non-compliance. Finally it is worth noting that although we have focused on the ecological component, the Reserve also considers additional water to meet the basic human needs (the Basic Human Needs Reserve; see for example Smits, Pollard et al. 2004) for estimates in the Sand River).

2.2.2. The ecological Reserve and what constitutes compliance

Few answers are available with respect to what constitutes compliance, other than a simplistic one that states 'anything below the Reserve'. In an associated discussion document (deliverable 5, Pollard & Mallory) we discuss this issue at some length. For the purposes of this report we highlight some of the key aspects of this discussion. It is important to note right from the start that the **Reserve is no longer a fixed daily value** (as the In-stream Flow Requirement, or IFR was); it is a variable value that is contingent on the prevailing climatic conditions. If the methods and technical expertise to derive these are not available or are sub-standard, this **throws into question the derived Reserve values** (i.e. they may be an over- or under-estimate). By implication, the accuracy of compliance assessment is called into question. This implies that we have to have a high level of confidence in order to deem 'any flow less than the Reserve as non-compliant'.

Bearing these constraints in mind let us turn to the issue of compliance. The first question that arises is this: Is any flow that is less than the specified Reserve flow to be designated as non-compliance? In other words, the Reserve must be met all the time (100% assurance) or is, for example, a 98% assurance acceptable (7 days a year or less than once a month the flow is less than the Reserve)? Aside from our constraints to determine the Reserve, this simple example demonstrates that the concept of compliance is not a simple one. Conceptually one may consider any failure to be non-compliant but when the practicalities[1] – and the legal implications – are considered many would be reticent to deem the above case as one of non-compliance and hence a transgression of the law. It might be more useful to note the failures (timing, duration and so on) and examine underlying causes so as to improve the system. The issue of litigation however requires a rigorous definition and is one that may require additional thinking (see Shared Rivers II; Legal sub-component).

Two additional considerations regarding the definition of non-compliance must be addressed. The first is apparent when one looks at the catchment as a whole. Currently, one or two sites 'drive' the system, particularly in terms of establishing the operating rules for a water resource. These are generally (but not always) the most downstream site. Whilst the Reserve may be met at the EWR site, this does little to indicate if the EWR is met at all sites. The Letaba Catchment is a case in point where the Reserve is almost exclusively delivered by the main stem whilst the major tributaries experience severely reduced flows. The intention of the Act was to maintain water-resource health from a catchment perspective and not to simply ensure the delivery of water at one site. This re-affirms that the EWR must be delivered at all of the sites but currently a number of constraints, mainly the lack of monitoring, pose challenges that remain to be addressed.

Secondly, the EWRs – and hence compliance – comprise a number of components including magnitude, duration and frequency as well as water quality parameters (see Box 1). Thus whilst the quantity of water may be acceptable, the timing (including duration and frequency of freshes) may not meet the requirements of the Reserve. Equally the flows may be met but the water quality may be problematic. This again is an issue that requires addressing since currently, monitoring and management defaults to a simpler system. For example, for a long period the operator of the Tzaneen Dam on the Groot Letaba system attempted to maintain a flow of 0.6 m^3 into the Kruger Park (the 'old' operating rule) because of difficulties in interpreting the ER determinations and hence operationalising the ER (Pollard & Du Toit 2008). Moreover, the EWR is a hypothesis (based on best available information and expert opinion) as to flow requirements (magnitude, duration and timing) to sustain the ecology in a certain state (Recommended Ecological Class, REC). Thus as an example, it might be acceptable if the flow is not fully met in one month but is provided in the following month. On the other hand it may be critical that freshes are delivered in a one of two months (i.e. some flexibility) but this must be at the start of the rainy season. It is well recognised that in unpredictable systems such as those of the lowveld, such variability is common, leading Davies et al. (1995) to coin the phrase 'predictably unpredictable'. However, we go on to point out that the dry season has a high degree of predictability – an important consideration for potential approaches to setting the Reserve in practice and an issue we will return to

[1] In 2005 a release was made from Tzaneen dam to meet the ER requirements in the Kruger Park. This flow never reached the border of the Park demonstrating that the hydrology of the lower part of the Groot Letaba River is poorly understood.

later. For the purposes of this project a number of characteristics were selected to examine non-compliance, focusing specifically on minimum flow compliance. These are elaborated in Section 2.4).

Representing the Reserve to facilitate operation and monitoring

Outputs of the Reserve determination need to be in a format that is useful for managers both in terms of (a) setting (and hence operationalising) a ecological Reserve requirement for the upcoming period and (b) for monitoring compliance with the ecological Reserve. In order to explore how compliance could best be represented, the Sand River – a well-known system to the researchers – was selected. The Sand was the site of an original IFR study (DWAF 1996) which is currently being upgraded to a Comprehensive Reserve Determination. Although not yet formally accepted, a tentative REC of B at EWR 8 was used as the basis of the work[2]. The Reserve was represented in a number of ways:

1. As a Flow Duration Curve, FDC (monthly) in the format of the Reserve determination document. The Reserve determination is represented as assurance tables for each site which provides the frequency information (natural and recommended ecological category).

2. As a time series: Observed versus required. Using the natural flow as an indicator, the EWR for each month is determined from the EWR duration curves. Hence the EWR is determined as a time series. Note however that the natural flows are still required and hence this is subject to the same constraints discussed above.

However as discussed by Pollard & Mallory, it is clear that FDCs are not an ideal indicator for Reserve compliance, i.e. for management. Not only is some change in the time of release is permissible but for monitoring purposes the FDC do not indicate if the EWR is met on average. As noted, a time series plot of how the observed flow is deviating from the Reserve requirement is useful but the implication of this tool for assessing compliance is that an estimate of the natural flow is required in near real-time order to determine the EWR (Hughes and Münster 2000). Hence hydrology models are required in all catchments to estimate natural flow. This is currently done using recorded rainfall although with improved technology it should be possible in the near future to do this using satellite rainfall data (see Sawunyama and Hughes 2008).

2.3. Overall approach and methods

2.3.1. Overall process and site selection

As noted in Chapter 1, the IFR outputs are gradually being replaced by the more sophisticated Ecological EWR suite of methods (Drift and Stressor-Response). The output of the former provides single values on a monthly basis, whilst that of the latter is a dynamic rule curve. Thus at the start of the project, two methods were developed namely:

[2] Note that this must still also go through a process of classification

1. for sites in which only IFR values are available, and

2. for sites at which the EWR had been determined (i.e. available as a rule table)

However over the duration of the project EWR rule tables became available for all sites and so the second method was used in all cases. However, the IFR methodology is given to support researchers and managers in cases where only an IFR output is available. As explained in Chapter 1, only the water quantity aspect of the ER was examined and with a specific focus on non-compliance in terms of the minimum quantity.

The overall approach that was followed is shown in Figure 2.

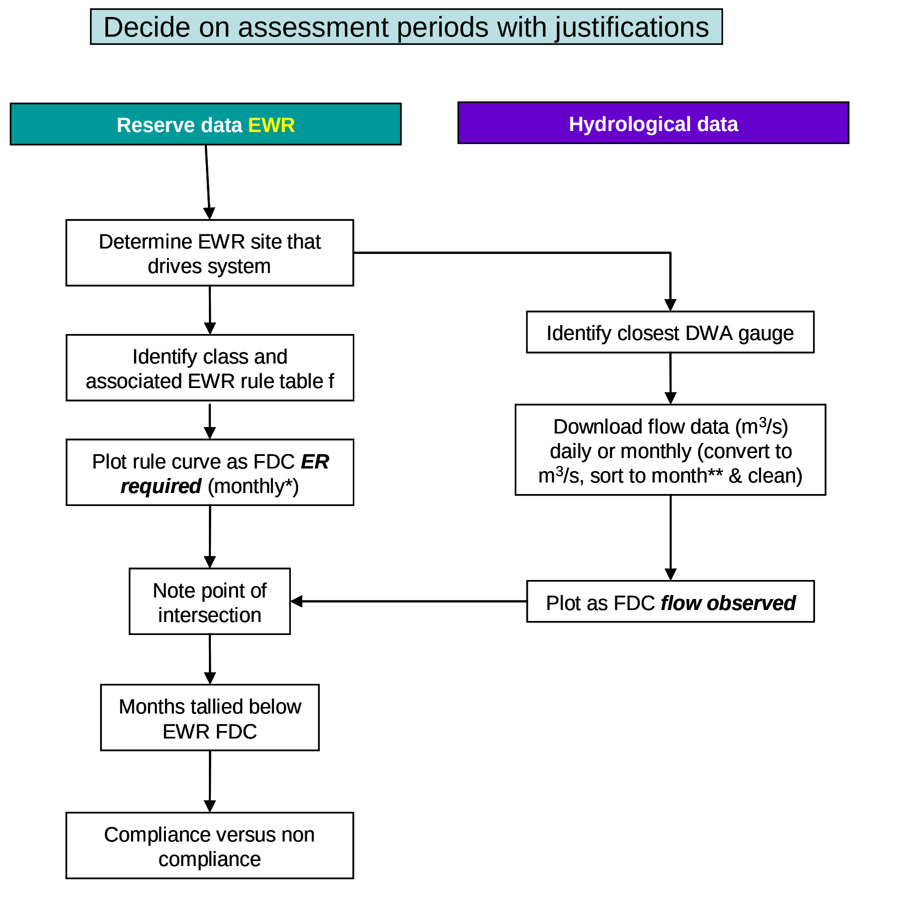


Figure 2 Overview of methodology used (EWR sites).
* rule curves are only available on month basis; ** sort flow data into appropriate month so that they can be plotted against the EWR curve for month in question

A total of ten EWR sites were examined. As a rule at least one site per sub-catchment of the lowveld rivers was assessed (Table 2). This required the identification of the most downstream EWR sites, mostly close to the border of – or within – the Kruger National Park (KNP). This also ensured consistency with the EWR methodologies when a critical site, generally the downstream site, is considered to drive the system. Three additional sites were added to examine compliance in the Blyde, Lomati and Klein-Letaba sub-catchments. This is because they are regarded as sufficiently different in terms of management and/or biophysical conditions to warrant an assessment separate to those of their larger catchments (Olifants, Komati and Letaba catchments respectively).

Before proceeding, clarity on the various terms used to describe the outputs of an ER study is required. As EWR approaches became more sophisticated in South Africa, the Reserve was represented as a dynamic water requirement based on antecedent stream flow conditions (see Section 1). In South Africa (and globally) a variety of terms are used and interchanged for these flow duration curves (FDC), including % exceedence, probability / frequency distribution curve and frequency distribution curve. These all refer to essentially the same thing. In this section we will use the term flow duration curve or FDC. This is captured in the ecological Reserve determination studies as a rule-table (see for example Table 4). These are used to construct an FDC. These FDCs display the relationship between streamflow and the percentage of time that it is exceeded. In general a FDC is derived from all the data rather than just the low or high flows (Gordon et al. 2004).

2.3.2. Defining developmental periods for assessment

Data were examined principally for two time periods of interest although in some cases a third period was added if deemed necessary. Defining these periods was guided by the key questions elaborated in Chapter 1, namely (a) the trend since development increased (in particular, that of irrigated agriculture) as well as (b) compliance in the last decade. The first period related to an era where water-based growth increased largely as a function of demand. In other words as water was needed, so use increased without being considered within a wider catchment-based perspective. This period started, with some variability, in the 1960s and 70s and continued through until the political changes in South Africa in the early 1990s, and is referred to as "***development without IWRM***". As water became scarcer there was recognition of the need for a more integrated, catchment perspective. This was supported with political reform in the mid-1990s and the promulgation of the NWA in 1998 which adopted an integrated approach through Integrated Water Resources Management (IWRM) as well as a strong focus on stakeholder involvement. Both of these factors are regarded as cornerstones for improving sustainability and equity. Institutional re-alignment followed. Although this re-orientation started in some areas a few years earlier than the formal enactment, lag affects of policy changes being reflected in practice were apparent (see Pollard & Du Toit 2008). To allow for this and to start to pick up any appreciable impacts of change, the team selected 2000 onwards as a reasonable representation of the new policies and management. This period is referred to as the ***"start of IWRM"*** so as to reflect the fact that change is still in its early stages and that it is ongoing.

Two sources of information were used to define the development periods for each catchment. Firstly expert knowledge on major infrastructural and management interventions specific to each catchment guided the delimitation of time periods (Table 1). Secondly, where possible, data from Water Resources 2005 (WRC 2008) were examined for selected quaternary catchments for evidence of increased land and water use as shown in Figure 3 These data were informative in delimiting the dates between '*development without IWRM*' and '*IWRM*'.

In the case of the first period from about 1960 to about 2000, a monthly time-scale was considered to be adequate. This was because the intention was not to identify specific days on which non-compliance occurred but rather months and years in order to examine the overall pattern. However, given the interest in the pattern over the latest period (*Start of IWRM*) it was decided that a daily time-step would be used where possible. The interest stems principally from a management perspective thus requiring a greater degree of accuracy so as to understand better the characteristics of compliance (see Table 7).

Since daily data are not based on averages, they are likely to provide more accurate reflection of variability and incidences of compliance (i.e. to be less conservative).

Figure 3 Periods of growth in irrigated agriculture in selected quaternaries in study catchments

Table 1 Key periods for the historical assessment of compliance per catchment. Key dates are given in square brackets. The EWR sites are indicated in the first column

River and EWR site	**Development without IWRM**	**Start of IWRM**	
	Period 1	**Period 2**	**Period 3**
1. Luvuvhu A91H_C	**1. 1989-2008** *[1989 – Gauged data starts; [1952 – Albasini Dam, wall raised 1970; 1999-2005 start and completion Nondoni Dam]*	N/A	N/A
2. Groot Letaba EWR 4	**1. 1960-1993** *[1977 – Tzaneen Dam]*	**2. 1994-2008** *[1994 – Concerted management from Tzaneen Dam]*	
3. Klein Letaba EWR 5	**1. 1985-1986** *[1984 – Middle Letaba Dam]*	**2. 1987-2008** *[1985 – Gauged data starts]*	
4. Olifants Lower Olifants at barrage (B73 H EWR 15/16)	**1. 1987-2000** *[1987 gauged data starts at B7H015]*	**2. 2001-2008** *Post 2000 floods and a period in which improvements can be expected given IWRM.*	N/A
5. Blyde EWR12 (B60J)		**1. 2001-2008** *Check contribution to Olifants flows*	
6. Sand EWR 8	**1. 1967-1993**	**2. 1994-2000**	**3. 2001-2008** *[2000 – both Injaka on line and ORs for Sand]*
7. Sabie EWR 3	**1. 1960-1993**	**2. 1994-2000**	**3. 2001-2008** *[2000 – both Injaka on line and ORs for Sand]*
8. Crocodile EWR 6 – Tenbosch	**1. 1960-1983**	**2. 1984-2000** *[1984 – Kwena Dam constructed]*	**3. 2001-2010** *[1999 Piggs Peak Ag. 2000 – WRM in earnest 2002 – IIMA]*
9. Komati EWR 3	**1. 1960-1997**	**2. 1998-2005** *[1998 – DrieKoppies Dam on Lomati; Early 2000s – negative impacts of Maguga Dam evident, e.g. periods of no-flow*	**3. 2006-2008**[3] *2006 – Maguga only started full ORs. Before 2006 were restricting users. After dam filled should be meeting ER*
10. Lomati EWR 1	**1. 1968-1997**	**2. 1998-2005** *[As above]*	**3. 2006-2008** *[As above]*

[3] Only analysed daily-monthly data insufficient to draw FDC

2.3.3. EWR site, status and selection of management class

All Reserve determinations are currently regarded as preliminary until such time as stakeholders set the management class for the water resource (see Section 4). Thus since it was not possible to use the ecological Reserve associated with an approved management class, the recommended EcoStatus category was used for the EWR site in question. These are shown in Table 3.2. Maps of each of the catchments indicating the EWR sites were given in Deliverable 2

Table 2 Summary of EWR site used, location and the associated PES and REC and details of the closest gauge (DWA). PES = present ecological status; REC = recommended ecological status

Catchment	EWR site used	co-ordinates	Status of Reserve determination	PES	REC	Gauge no.	co-ordinates
Luvuvhu	desktop quat. A91H		Desktop WR90			A9H012	22 46 06.5 30 53 21.6
Groot Letaba	EWR4	S23 °40′39.1; E31 °05′55.1	CRD 2006	C	C/D	B8H008	23 39 31.6 31 02 59.2
Klein Letaba	EWR5	S23 °15′02.9; E30 29 44.6	CRD 2006	C	B	B8H033	23 14 26.7 30 28 32.2
Olifants	EWR16 (B73H)	24°3'4.2"S; 31°43'56.3"E	Comp 2002	C	B	B7H015	24 03 58.6 31 14 34.4
Blyde	EWR12 (B60J)	24°24'31"S; 30°49'35"E.	Comp 2002	B	B	B6H004	24 27 33.5 30 49 38.5
Sand	EWR8	24° 58′ 02.7″S; 31° 37′ 38.4″E.	Prelim estimates CRC in prog	D	B	X3H008	24 46 12.1 31 23 19.0
Sabie 1st period	EWR 3	24° 59′ 15.3″S; 31° 17′ 34.3″E.	Prelim estimates CRC in prog	B	A/B	X3H006	25 01 50.3 31 07 35.2
Sabie 2nd period	EWR 3	24° 59′ 15.3″S; 31° 17′ 34.3″E.	Prelim estimates CRC in prog	B	A/B	X3H021	24 58 06.5 31 30 55.5
Crocodile	EWR6	25° 23′ 25.8″S; 31° 58′ 28.0″E.	Prelim estimates CRC in prog	D	C	X2H016	25 21 49.9 31 57 20.6
Komati	EWR K3	25°40'01.1"S 31 °48'04.8"E	CRD 2006	D	D	X1H003	25 40 56.1 31 46 54.8
Lomati	EWR L1	25°38'58.0"S: 31 °37'23.5"E	CRD 2006	C/D	D	X1H014	25 40 25.9 31 34 31.0

Data acquisition

As noted above, data for the EWR was accessed for the REC since the final class had not yet been set at the time of data analysis[4]. Care was taken to ensure that the most up-to-date EWR rule curves, for the correct management class in a particular river, were selected for use in the analysis. These rule curve data were acquired from the consultants who undertook the reserve determination on a particular river and/or the RDM office. We use Olifants data to illustrate methods below:

In addition the closest Department of Water Affairs (DWA) gauge to these EWR sites was also identified using a GIS/Google Earth with the DWA gauge co-ordinates, available at
http://www.dwa.gov.za/hydrology/cgi-bin/his/cgihis.exe/StatCat?Region=B&StationType=H
(where 'Region=B' signifies the drainage water management area, WMA, in this case B is the Olifants WMA)

The monthly (Mm^3/m) and daily (m^3/s) data for the respective gauge station was accessed via the DWA hydrology page: at http://www.dwa.gov.za/hydrology/cgi-bin/his/cgihis.exe/station

Data correction and formatting

The DWA gauge data was then 'cleaned' to remove poor or inconsistent data. In terms of daily flow data missing data was generally flagged with consistent m^3/s values greater than 150, and this data was removed from the dataset. Monthly data was flagged according to:

+ = Above rating
E = Estimated Data
* = Calculated estimate
m = Greater than
M = Less than
# = record incomplete or does not exist

Data denoted with M and # were removed from the monthly average flow dataset.

Since most EWR rule tables are in units of m^3/s the daily flow data required no conversion (this is an average for the day in question). However monthly average flow data are given in decimal power values of million m^3 per month. These were then corrected to average daily flow equivalent in m^3/s according to the following formula:

Eq. 1
$$Q = \frac{Qm * 1000000}{86400d}$$

Where: Q is daily average flow; Qm is monthly average flow; 86400 is the number of seconds in a day; and d is the number of days in a given month.

With respect to the analysis based on monthly values, data were then sorted into yearly flows per month (in the hydrological year), so as to compare with EWR curve for that month. Month number 1 relates to

[4] Data analysis for this report was undertaken between June 2009-June 2010

October and 12 to September. For instance all the average daily flows for the month of October between 1960 and 2008 were sorted in one column in a spreadsheet as shown in Table 3.

Table 3 Example of converted monthly values of average daily flow (m^3/s) using the Olifants River

Year	October average Q (m^3/s)	Year	November average Q (m^3/s)
1988/1989	22.60	1988/1989	16.40
1989/1990	10.60	1990/1991	6.14
1990/1991	5.89	1992/1993	12.10
1991/1992	7.26	1993/1994	8.49
1992/1993	3.89	1994/1995	12.10
1993/1994	3.66	1995/1996	41.20
1994/1995	4.21	1997/1998	131.00
1995/1996	1.98	1998/1999	38.10
1997/1998	45.40	1999/2000	512.00
1998/1999	24.40	2001/2002	329.00
1999/2000	16.80	2004/2005	20.90
2000/2001	28.20	2005/2006	28.50
2001/2002	164.00	2006/2007	40.70
2004/2005	0.87	2007/2008	134.00
2005/2006	0.11		
2006/2007	5.76		
2007/2008	15.90		

These monthly data, as well as the daily data[5] were then separated into periods of interest for each river which, in the case of the Olifants River, was 1998-2000 and 2001-2008. Care was taken with respect to the monthly data so that October, November, and December were ascribed to the first value in the year column, and then January-September the second value (e.g. first row in Table 3.3, Oct-Dec would have belonged to 1988, whilst Jan-Sept would have belonged to 1989).

These data, both daily and monthly, were then transformed to the same format as the EWR rule tables, in the form of FDC. In most cases the units for the EWR rule tables were given in m^3/s. However, data for the Olifants was given in Mm^3/m and had to be converted to m^3/s equivalents using Eq. 1. Where possible the rule-curve tables for low flows were used but in some cases the tables included both low and high flows and so these had to be used. The implication is that in wet, summer months the estimation of non-compliance will be greater; but dry, winter low-flow periods should not be a problem as there are very few – if any – high flows. It was only in the case of the Olifants & Blyde River rule curves that no distinction was made between low and high flows.

[5] for the most recent period excluding the Luvuvhu

Table 4 EWR rule curves for Olifants EWR16 (top) against assumed natural flow (bottom), note the rule curve in this case was in million m^3 and was converted to m^3/s by way of eq. 1.

Total Runoff: Cumulative up to IFR site 16(24°29'47.4"S; 30°23'56.4"E) in Catchment B73H
Regional Type: Olifants
EMC = B
Data are given in m^3 * 10^6 monthly flow volume

Month	% Points								
	10%	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**99%**
Oct	23.582	23.409	23.017	22.206	20.695	18.205	14.692	10.646	7.187	5.579
Nov	40.773	40.530	40.024	39.022	37.146	33.870	28.660	21.421	13.352	8.275
Dec	44.964	44.697	44.139	43.037	40.971	37.365	31.630	23.660	14.778	9.189
Jan	64.694	62.593	60.442	57.885	54.356	48.296	40.902	30.627	19.174	11.968
Feb	121.472	112.643	104.733	97.086	88.705	74.551	62.602	45.998	27.490	15.845
Mar	67.494	65.426	63.278	60.679	57.033	50.767	42.978	32.154	20.090	12.499
Apr	42.526	42.204	41.474	39.964	37.150	32.514	25.971	18.438	11.997	9.002
May	35.182	34.921	34.327	33.100	30.813	27.046	21.729	15.607	10.373	7.939
Jun	29.095	28.880	28.390	27.378	25.491	22.384	17.997	12.947	8.629	6.622
Jul	26.277	26.033	25.593	24.683	22.987	20.192	16.248	11.707	7.825	6.020
Aug	23.670	23.498	23.108	22.300	20.794	18.315	14.815	10.785	7.340	5.738
Sep	21.669	21.512	21.155	20.417	19.042	16.777	13.579	9.898	6.751	5.287
Natural Duration curves										
	10%	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**99%**
Oct	95.687	75.272	57.072	52.561	46.020	38.079	33.506	30.282	27.285	22.073
Nov	446.268	316.354	192.517	130.542	120.108	91.413	75.530	62.768	48.513	29.201
Dec	450.563	335.759	296.053	239.145	159.928	147.609	124.754	88.415	70.606	42.498
Jan	908.192	600.109	356.905	240.289	222.511	179.148	136.115	114.526	93.009	68.742
Feb	991.262	697.835	366.433	234.366	196.606	133.189	117.049	103.268	83.863	71.204
Mar	549.371	420.096	339.066	236.982	156.622	115.226	100.734	83.904	79.990	57.196
Apr	243.677	217.752	165.068	131.531	115.309	104.195	88.106	73.686	57.278	50.645
May	139.297	125.248	110.880	87.354	80.330	76.076	66.816	55.538	47.473	44.599
Jun	100.641	87.20	75.829	65.910	62.027	57.464	49.378	44.949	39.233	36.647
Jul	78.929	69.834	60.832	55.311	49.419	47.277	45.032	39.346	33.310	31.055
Aug	63.633	55.043	50.964	46.196	41.633	38.800	36.761	33.877	30.128	27.491
Sep	77.786	50.068	43.414	39.923	38.223	35.381	32.435	28.840	26.481	23.227

In order to derive a FDC from the daily/monthly flow data, the flow values were ranked within the entire dataset for each month, and then the rank expressed as a percentage of the total number of values in the dataset for that month (e.g. Table 5). The data were then sorted by the percentage values in descending order (Table 6), such that the lowest flow value had the highest percentage value and vice-versa, i.e. lowest flows occur more frequently than the highest flows.

Table 5 Rank and percentage values for flows in October months

October			
Number of flow values		17	
	Q	Rank	%
1988/1989	22.6	5	27.78
1989/1990	10.6	8	44.44
1990/1991	5.89	10	55.56
1991/1992	7.26	9	50.00
1992/1993	3.89	13	72.22
1993/1994	3.66	14	77.78
1994/1995	4.21	12	66.67
1995/1996	1.98	15	83.33
1997/1998	45.4	2	11.11
1998/1999	24.4	4	22.22
1999/2000	16.8	6	33.33
2000/2001	28.2	3	16.67
2001/2002	164	1	5.56
2004/2005	0.865	16	88.89
2005/2006	0.114	17	94.44
2006/2007	5.76	11	61.11
2007/2008	15.9	7	38.89

Table 6 Rank and percentage values for flows in October months sorted into descending order by % values.

October			
Number of flow values		17	
	Q	Rank	%
2005/2006	0.114	17	94.44
2004/2005	0.865	16	88.89
1995/1996	1.98	15	83.33
1993/1994	3.66	14	77.78
1992/1993	3.89	13	72.22
1994/1995	4.21	12	66.67
2006/2007	5.76	11	61.11
1990/1991	5.89	10	55.56
1991/1992	7.26	9	50.00
1989/1990	10.6	8	44.44
2007/2008	15.9	7	38.89
1999/2000	16.8	6	33.33
1988/1989	22.6	5	27.78
1998/1999	24.4	4	22.22
2000/2001	28.2	3	16.67
1997/1998	45.4	2	11.11
2001/2002	164	1	5.56

2.4. Determination of Reserve compliance/non-compliance

2.4.1. Characteristics of non-compliance examined for this project

For the purposes of this project, a number of characteristics of compliance were identified to better understand the nature and severity of failure to meet the ER (i.e. non-compliance). These, designed as indicators in response to key questions, are given in Table 7.

Table 7 Key characteristics examined in order to assess the pattern and severity of failure to meet the Reserve

Question	Indicator
How often did the Reserve fail?	% time
By how much did it fail?	Volumetric difference
Consistency – Did the Reserve fail consistently or as discrete, short events?	No of contiguous events
When did it fail?	Which months – low flow and high flow periods?

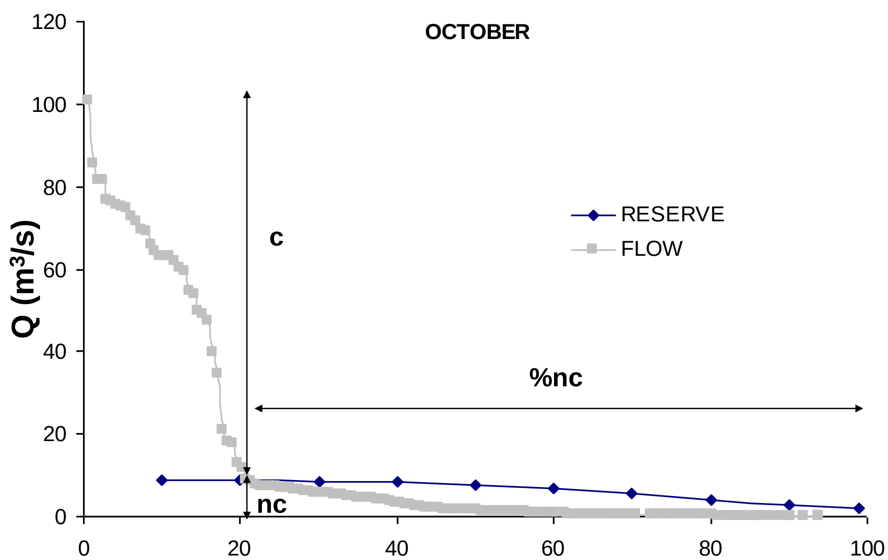


Figure 4 Flow duration curve for daily average flows at Olifants River gauge B7H015 and the ecological reserve flow duration curve for Olifants EWR 16 for the month of October between 2001-08.

Distance c represents compliant flows; nc represents non-compliant fl flows during October's (in this case ~ 79%).

The resultant percentage values were then incorporated into an XY scatter plot with daily average flow (Q) plotted on the Y- and percentage on the X-axis, as in Figure 4. The EWR duration curve for that month was also plotted on the same chart. The point at which the average daily flow falls below the EWR curve was taken as the point where flows in a particular river were deemed non-compliant with the reserve. Thus this point is read-off from the X-axis and subtracted from 100% to yield the percentage of time within the sum of a month that the ecological reserve was not met. In the example shown in Figure 4, the point at which arrow 'c' and arrow 'nc' meet is where the daily average flows fall below the reserve rule curve for that month, i.e. percentage point 21. The distance '%nc' represents the percent time that the reserve was not met, in other words all flows were below the reserve requirement, and the percent of time this represents is 100-21, i.e. the ecological reserve was not met during Octobers between 2001-2008 for 79% of the time at this point in the river.

This analysis was repeated for each month using daily average flows (m^3/s) estimated from the monthly record for all periods of interest. Actual daily average flows were used for specific periods of interest (see Table 2.1).

The tallied results allow one to assess the extent of non-compliance with the ecological reserve in terms of:

- percentage of time this occurred during any given months
- total number of months non-compliance occurred over a period of interest
- seasonality, i.e. did non-compliance occur during wet months (Nov-Mar) or dry months (May-Oct).

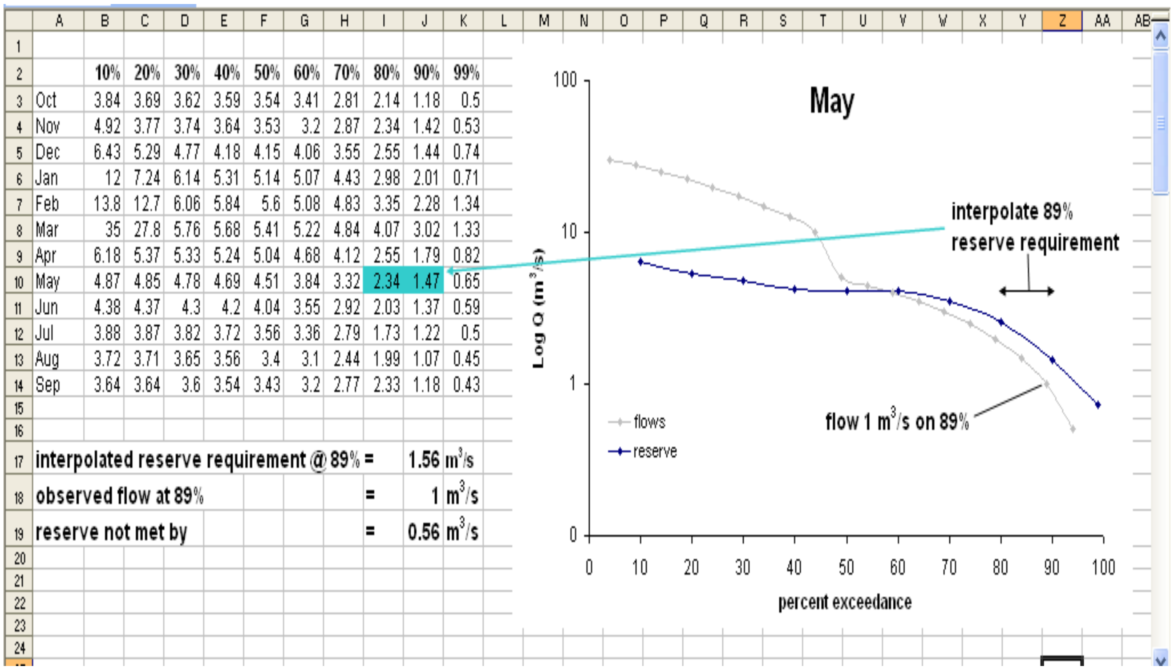
Analysis of Magnitudes

Whilst the methods just described revealed the extent and timing of non-compliance with the ecological reserve, further analysis was required to determine the magnitudes by which the ecological Reserve was not met. This necessitated conversion of both the non-compliant flow and its' corresponding reserve value into volumetric equivalents for the month. An example is shown in Figure 5 where a flow is observed to be below the reserve requirement between the 80^{th} and 90^{th} percentile. In this case a daily average flow value of 1 m^3/s was recorded during a certain May month in the period of interest, and it was distributed on the 89^{th} percentile. Since the actual flow value is known but the reserve requirement is not known for the 89^{th} percentile, this value is interpolated based on known reserve requirements at the 80^{th} and 90^{th} percentile, which is calculated as 1.56 m^3/s. Thus the reserve was not met in this particular case by 0.56 m^3/s.

The total monthly equivalent volume for both the ecological reserve and the non-compliant flow are then determined by rearrangement of equation 1 yielding:

Eq. 2 $$Qm = Q * (86400d) * 1000000$$

So that in the example described in Figure 3.4 the total monthly volumetric reserve requirement was 4.18 x 10^{12} million m^3, the average monthly flow was 2.68 x 10^{12} million m^3 and so the reserve was not met by some 1.5 x 10^{12} million m^3. Interpretation of this is represented graphically in Figure 3.5, where example 'A' suggests that the reserve was not met by only a small volume, in other words this is a minor infraction. Whilst example 'B' suggests that the reserve was not met by almost the entire reserve requirement, signifying a very severe infraction.



	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	3.84	3.69	3.62	3.59	3.54	3.41	2.81	2.14	1.18	0.5
Nov	4.92	3.77	3.74	3.64	3.53	3.2	2.87	2.34	1.42	0.53
Dec	6.43	5.29	4.77	4.18	4.15	4.06	3.55	2.55	1.44	0.74
Jan	12	7.24	6.14	5.31	5.14	5.07	4.43	2.98	2.01	0.71
Feb	13.8	12.7	6.06	5.84	5.6	5.08	4.83	3.35	2.28	1.34
Mar	35	27.8	5.76	5.68	5.41	5.22	4.84	4.07	3.02	1.33
Apr	6.18	5.37	5.33	5.24	5.04	4.68	4.12	2.55	1.79	0.82
May	4.87	4.85	4.78	4.69	4.51	3.84	3.32	2.34	1.47	0.65
Jun	4.38	4.37	4.3	4.2	4.04	3.55	2.92	2.03	1.37	0.59
Jul	3.88	3.87	3.82	3.72	3.56	3.36	2.79	1.73	1.22	0.5
Aug	3.72	3.71	3.65	3.56	3.4	3.1	2.44	1.99	1.07	0.45
Sep	3.64	3.64	3.6	3.54	3.43	3.2	2.77	2.33	1.18	0.43

interpolated reserve requirement @ 89% = 1.56 m^3/s

observed flow at 89% = 1 m^3/s

reserve not met by = 0.56 m^3/s

Figure 5 Example determination of the difference between an observed non-compliant flow and an interpolated reserve requirement, for hypothetical May months.

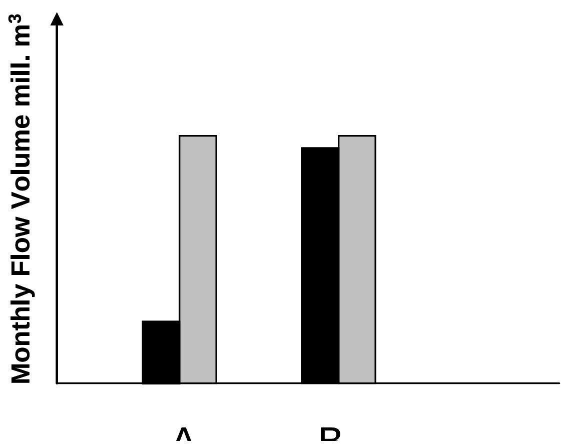


Figure 6: Example volumetric analysis of reserve non-compliance; black columns represent the volume by which the reserve was not met; grey columns are the reserve requirement volumes.

2.5. Results: historical compliance

2.5.1. Luvuvhu River

The approach described in Section 2 was applied using the EWR methodology. The Luvuvhu was done as a desktop Reserve and thus the co-ordinates have been estimated at the downstream-most point of quaternary catchment A91H. The class selected for analysis was a C. The EWR rule curve for A91H is given in Appendix 2. The EWR 1 site is approximately 50 km downstream of the gauge A9H012 (see Appendix 1, Figure 1).

Only one period was assessed for compliance in the case of the Luvuvhu. Although irrigated agriculture started increasing in the 1970s and 80s (see Figure 3), the gauged data only started in 1989 thus constraining the starting date of the assessment as well as the amount of data available. The limited data set meant that all data were analysed as one period. The assessment was based on average monthly data.

Incidence of failure (%) and months in which this occurred

In the last 20 years incidence of failure to meet the EWRs (Figure 7) is evident in all months.

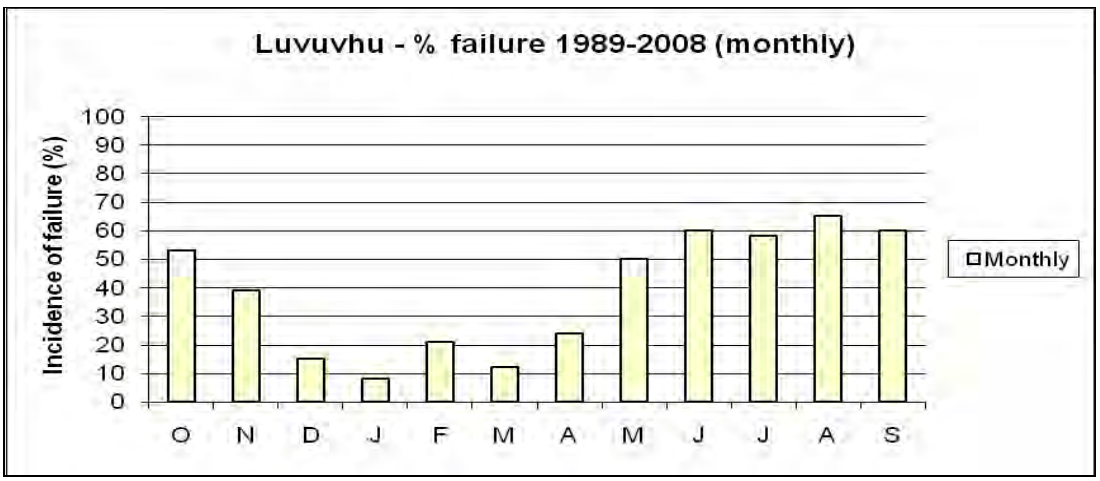


Figure 7 Incidence of failure to meet the ecological Reserve (%) at A91H (based on a desktop estimate) on the Luvuvhu River between 1989 and 2008. Data are based on monthly averages

These results indicate non-compliance between 8 and 65% of the time. Failure is evident in all months but is worst in the dry season, when the ER was met less than 50% of the time. The average incidence of failure across all months is 38%. Since only one period was analysed no comments can be made on whether or not this is improving or worsening. However, the construction of the Nondoni Dam completed is likely to have improved compliance.

Amount of failure (volume)

The amount (as a volume) by which the ER was not met for the last period (i.e. since 2001) is shown in Figure 8. This indicates that there is little consistency as to whether the greatest failure is in the wet or dry season. The period between 2003 and 2006 were dry years.

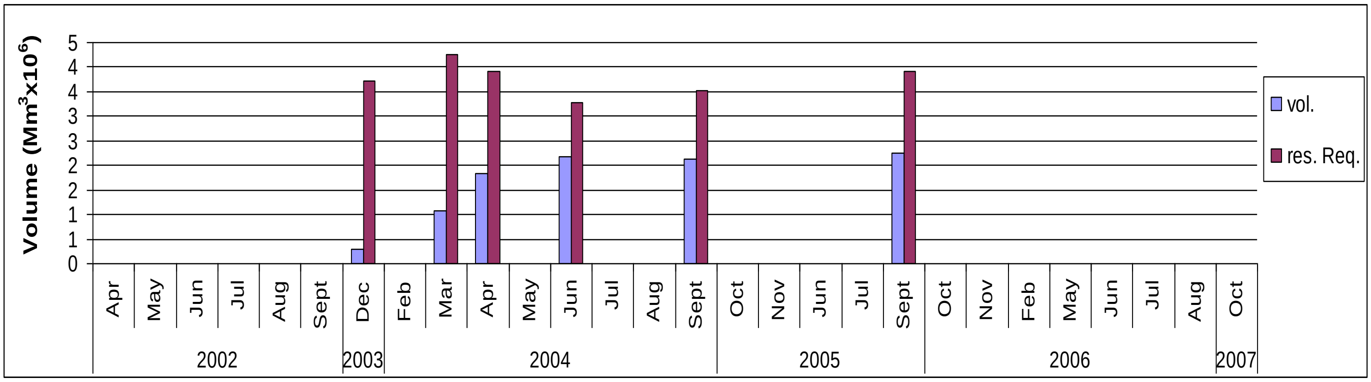


Figure 8: Non-compliance on the Luvuvhu as a volume indicating the amount (as a monthly volume) by which the ER failed for the latest period analysed (see Table 1).

The graph shows the volumetric ER requirements versus the observed failure (i.e. the volume by which the ER failed). Note that the smaller the difference between the two bars, the greater the degree of non-compliance. To assist the reader only the months in which there was non-compliance are indicated.

The possible reasons for the non-compliance are as follows:

- There has been an increase in irrigated agriculture most notably in the 80s and 90s placing pressure on the available resources (see Figure 3).
- The White paper on the Nondoni Dam is very vague in terms of EWRs and did not even make mention of the 1998 IFR determination. Thus it appears that EWRs have not been incorporated into the planning for the sub-catchment. The Nondoni Dam was already fully allocated prior to considerations for the ER so it is hard to see how this could be built in to the operating rules. A preliminary analysis suggests that if Nondoni Dam is operated to deliver the EWR requirements in keeping with the NWA, there would be a possibility of securing the ER some of the time but water is now being allocated temporarily to Giyani (Mr. B. Badenhorst, DWA, pers. comm.). Given the domestic shortages in Giyani and the surrounds, and the lack of viable alternatives, it is unlikely that this water will be 're-called" without compulsory licencing.
- To-date attempts to calculate an EWR have been unsuccessful. The ER determination studies appear to have suffered a number of setbacks due to technical and biophysical issues (D. Louw, pers. comm.).

All of these factors point to the need for integrated planning that takes into account the need to deliver the Reserve (both the ER and the Basic Human Needs Reserve). This is a challenge that will face the new CMA once their catchment management strategy is developed.

2.5.2. Groot Letaba River

The class selected for analysis was a C/D based on the REC from the EWR 4 outputs. The gauge station used was B8H008 and is approximately 9 km upstream of the EWR site (see Appendix 1, Figure 2). The EWR site 4 rule curve is given in Appendix 2.

Two periods were selected for the assessment of compliance. Agriculture was already fairly well established by the 1960s in some quaternary catchments. The first period thus represents a notable increase in irrigated agriculture (1960s and early 1980s) as is illustrated in Figure 3.

1) 1960-1993: Represents a period of established and increasing water resources development without IWRM. Also the gauging started in 1960.

2) 1994-2008: Represents a period when water resources management from the Tzaneen Dam and downstream started in earnest and has continued to today. This includes efforts on the part of the manager from the infrastructure branch and the Groot Letaba Water User Association as well as collaboration between them (Pollard & Du Toit 2009). This period also coincides with the changes in policies regarding water resources (see Section 2.3).

The assessments were based on monthly data for first two periods (1960-1993; 1994-2008), and daily data for the last period (1994-2008).

Incidence of failure (%) and months in which this occurred

Failure to meet the ER is evident in all months in both periods examined except in the January, as well as in December in the most recent period (Figure 9). However the results suggest that there is increased compliance since 1994 in comparison to the preceding period. Indeed the incidence of failure declines from an average of 41% to 22% across all month.

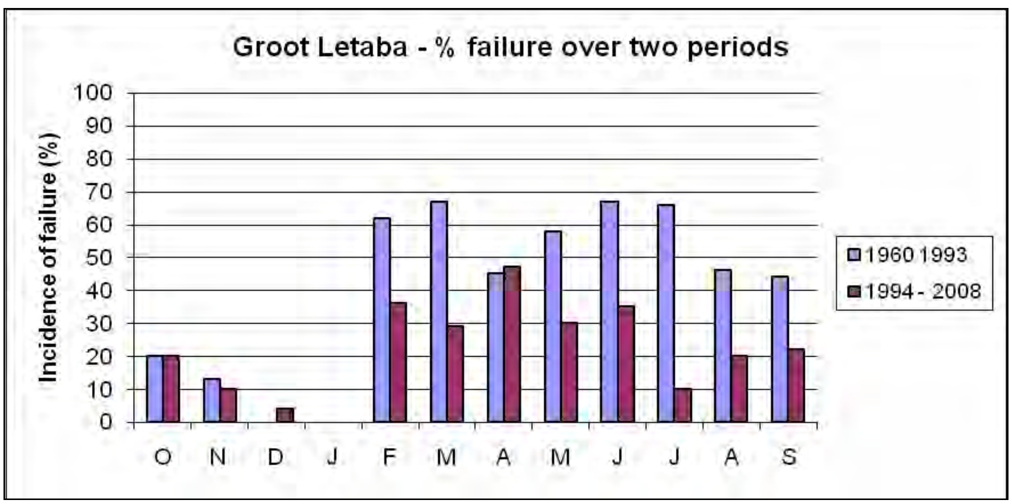


Figure 9. Incidence of failure to meet the ecological Reserve (%) at EWR 4 on the Groot Letaba River over two periods. Data are based on monthly averages.

The worst cases of failure are evident in the dry season (54% and 27% for each period respectively) when compared to the wet season (27% and 17% for each period respectively). However when data for the latest period based on daily averages are examined (Figure 10), the greatest failure occurs in the wet season (57%) as opposed to the dry season average of 40%. This is a function of the amount of data (14 points versus many) and the detail in flows.

It is noted that these results may represent a conservative estimate of non-compliance since they are based on monthly averages.

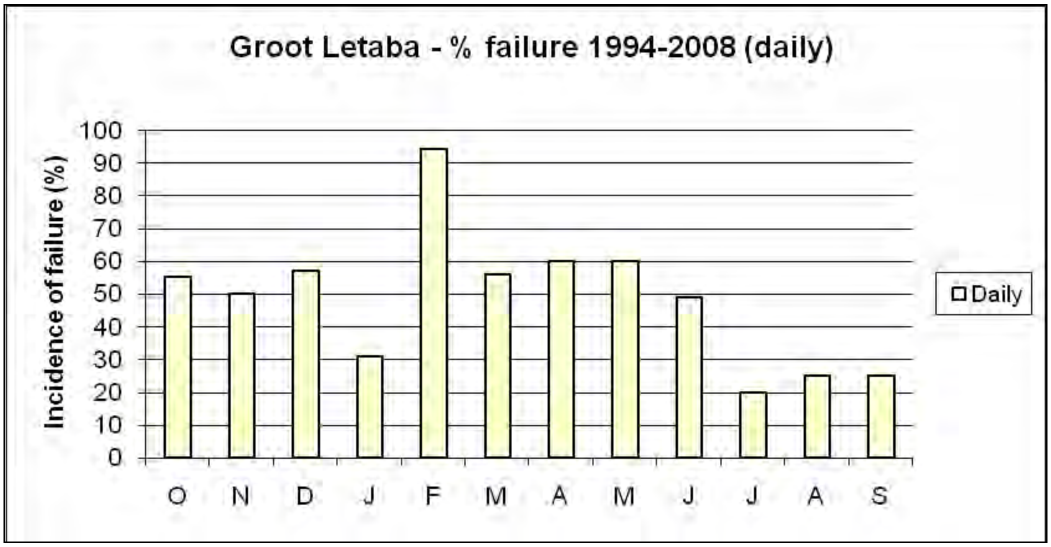


Figure 10 Incidence of failure to meet the ecological Reserve (%) at EWR 4 on the Groot Letaba River for the period 1994 to 2008 based on daily averages.

A more detailed analysis based on daily flow over the last 14 years (since improved WRM), shown in Figure 10 indicates failure of compliance in all months, with an average incidence of failure of 46%. As explained above the greatest failure occurs in the wet season (57%) in contrast to the dry season average of 40%. The month of February shows an extremely high incidence of failure.

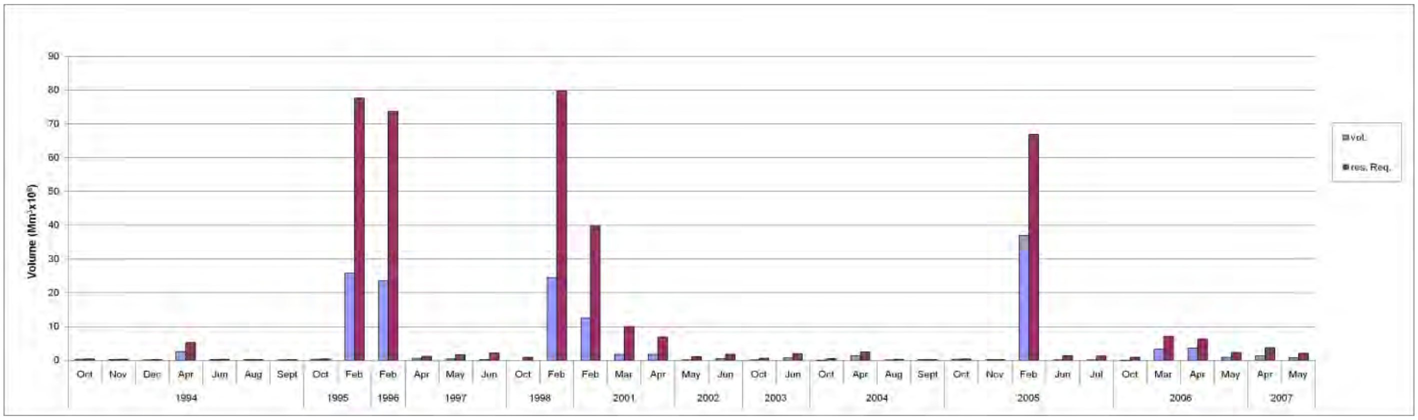


Figure 11 Non-compliance on the Groot Letaba as a volume indicating the amount (as a monthly volume) by which the ER failed for the latest period analysed (see Table 1).

The graph shows the volumetric ER requirements versus the observed failure (i.e. the volume by which the ER failed). Note that the smaller the difference between the two bars, the greater the degree of non-compliance. To assist the reader only the months in which there was non-compliance are indicated.

Amount of failure (volume)

The amount (as a volume) by which the ER was not met for the last period is shown in Figure 11, indicating that the ER fails by relatively small amounts. In general the infringements are very minor volumetrically and the large infringements observed during Februarys are due to the flashy flow regime (high coefficient of variation) of this river system typically during this very wet month. Consequently high flow volumes are experienced (and hence required for the ER) less than 30% of the time (i.e. they do not occur in all years), with the remaining 70% of the time dominated by low flow volumes typical of the other months of the year. It appears that in general the ecological Reserve is met is during the dry season and when there are infringements they are minor (due to very shallow slope of the FDC).

The Letaba has benefited from persistent efforts to improve water resources management since 1994. At that time the water resources manager implemented his own 'rapid response system' for managing flows from the Tzaneen Dam. This involved collaboration with commercial agriculture through the Groot Letaba Water Users Association (GLWUA). When the KNP starting monitoring flows near the western boundary, further measures were taken based on a flow of 0.6 m^3/s. This value was set as an absolute minimum by KNP managers in the face of a dearth of better data for the EWRs (see Pollard and Du Toit 2008). Despite this, there has been a failure to meet the ER albeit by relatively small amounts. However awareness is growing amongst users and in 2009 a new operational system was implemented for testing. This involved a collaborative process between researchers, managers and the GLWUA. All evidence suggests that compliance will improve based on this system.

There has been an increase in compliance and this is undoubtedly due to the aforementioned improved IWRM practices. However for the most part the figure of 0.6 m^3/s was being used as the benchmark ("the Reserve") by the water resources manager in Tzaneen, whilst here we have used the EWR figures which are dynamic values that vary as a function of rainfall. Thus even if the manager and users were attempting to comply, the benchmark being used was outdated.

Some of the constraints to meeting the ER include the following reasons:

- In times of stress when the manager is alerted to problems near the KNP it normally takes around seven days for the effects of releases from Tzaneen Dam to be felt downstream. A more responsive system is currently being developed.
- The increasing demand for urban consumption has placed further demands on the water resources of the catchment and the dam.

2.5.3. Klein / Middle Letaba River

The Middle Letaba river flows into the Klein Letaba which is tributary of the Groot Letaba (see Appendix 1, Figure 3). Their confluence lies below the Groot Letaba EWR site. It has been analysed separately because of the recognised physical, social and institutional differences between the two catchments.

The class selected for analysis was a B based on the REC from the EWR 5 outputs. The EWR site 5 rule curve is given in Appendix 2. The hydrological gauge used was B8H003 which is about 2.5 km downstream of the EWR site. Only one period was examined from 1986 (when gauged data started) to 2008. This is because little integrated management has taken place and constant and increasing pressure places the Klein Letaba in a state of near crisis. For example, in many recent years the level of the middle-Letaba Dam has been 10% or less (see Pollard & Du Toit 2009).

Incidence of failure (%) and months in which this occurred

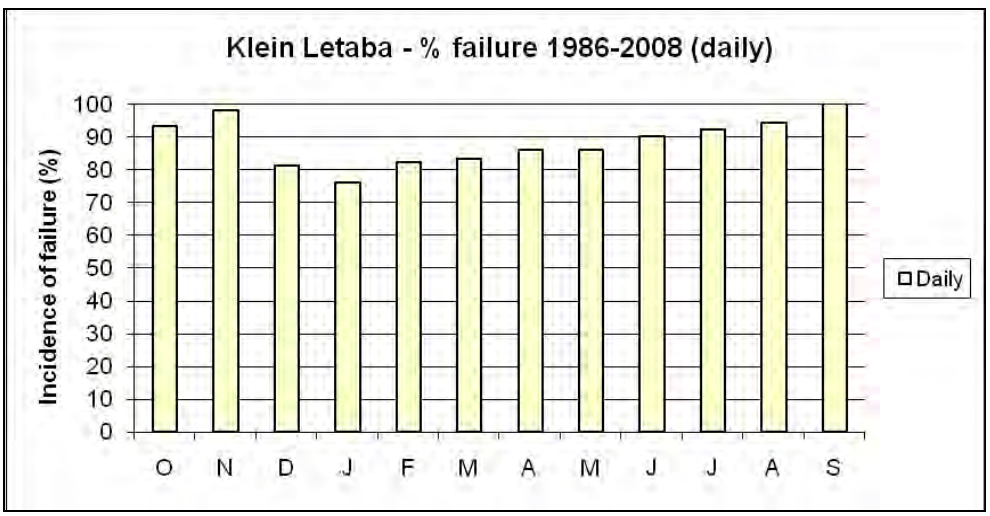


Figure 12 Incidence of failure to meet the ecological Reserve (%) at EWR 5 on the Klein/Middle Letaba River for the period 1986 to 2008 (daily averages)

All months indicate extremely high incidences of failure, with an average of 88%. Failure is evident in all months but is marginally worse in the dry season, when the ER was met less than 10% of the time (Figure 12). Since only one period was analysed no comments can be made on whether or not this is improving or worsening. Given the high degree of almost total failure, the volumetric differences were considered unnecessary.

The possible reasons for the non-compliance are as follows:

- The Klein/ Middle Letaba system is in almost constant water-deficit or nearly so. There are insufficient water resources to meet even a realistic estimate of domestic water requirements. Given that water services are largely focused on meeting the needs of the rural poor in the former Bantustans, this is seen as a priority by the regional office of DWA (see Pollard & Du Toit 2008). For all practical purposes meeting the EWR requirements under the current situation would be extremely difficult.
- Institutional disparity undermines managing the system as a whole. In their analysis Pollard & Du Toit (2008) pointed out that WRM roles are somewhat confused between the National Infrastructure Branch (NIB) and the DWA RO (although this conclusion is contested by the DWA RO). If the NIB manager attempts to institute curtailments these can be overturned by the RO. Moreover, there is little knowledge or understanding of the EWR requirements for this sub-catchment at the DWA RO. Currently there is no monitoring of water use thereby confounding attempts to develop a realistic water balance or to manage the system as a whole.

All of these factors point to the need for integrated planning that takes into account the need to deliver the Reserve (both the ER and the Basic Human Needs Reserve). Moreover it is important to recognise the spirit and intent of the NWA – to ensure sustainability of the water resources. Thus although the EWR might be met at the EWR site below the confluence of the Groot and Klein Letaba Rivers, it is possible that all flows are delivered from the Groot Letaba. Not only may this be contested by water users on the Groot Letaba but it was never the intent of the NWA to allow failure on one sub-system or tributary of a water resource to be compensated for by another tributary. (Nonetheless, at 17% of the MAR the ER requirement is very low in any event – see Pollard & Du Toit 2008). This is a challenge that will face the new CMA once their catchment management strategy is developed. Note also the proposed Nwamitwa Dam on a tributary of the Groot Letaba.

2.5.4. Lower Olifants River

The class selected for analysis was a B based on the REC from the EWR 16 outputs. The EWR site 16 rule curve is given in Appendix 2. The hydrological gauge used was B7H015 which is approximately <u>69 km upstream</u> of the EWR site. Note that the hydrological gauge (B7H015) is a considerable distance from the EWR site and water losses along the section are anticipated (see Appendix 1, Figure 4).

Two periods were selected for the assessment of compliance. Agriculture was already established by the 1960s in some quaternary catchments but nearly doubled in the 1980s (see Figure 2.2). The gauged data started in 1987. The first period thus represents a notable increase in irrigated agriculture and the start date is set by the availability of hydrological data.

1) 1987-2000: Represents a period of established and increasing water resources development without IWRM.
2) 2001-2008: Post 2000 floods and a period in which improvements can be expected given IWRM.

The assessments were based on monthly data for first two periods (1987-2000; 2001-2008), and daily data for the last decade (2001-2008).

Incidence of failure (%) and months in which this occurred

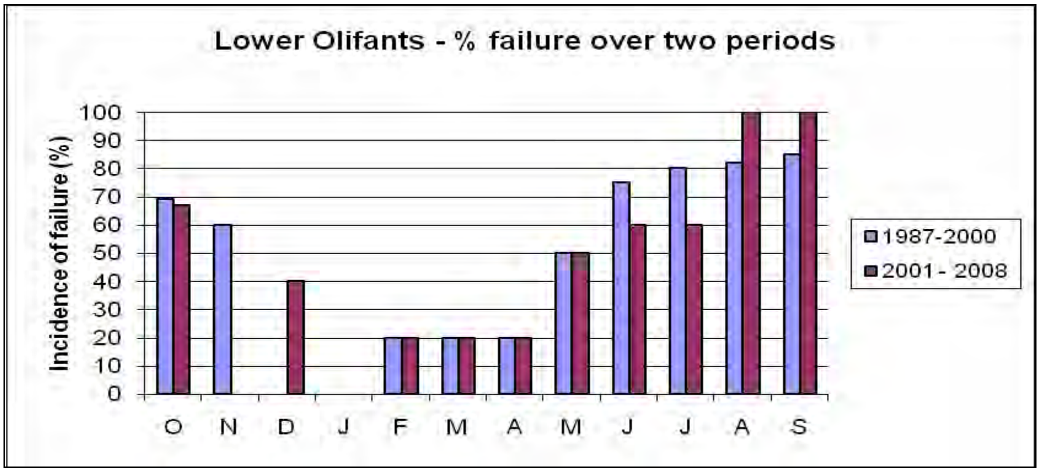


Figure 13 Incidence of failure to meet the ecological Reserve (%) at EWR 16 on the lower Olifants River over two periods. Data are based on monthly averages

Failure to meet the ER is evident in all months in both periods examined except in the Januarys, as well as in December in the first period (Figure 13). The results suggest that there is no improvement in the situation with the overall incidence of failure being fairly similar at an average across all months of 47% and 45% for each period respectively.

The worst cases of failure are evident in the dry season (an average of 67% for each period) when compared to the wet season averages (28% and 25% for each period respectively). However when data for the latest period based on daily averages are examined, the failures in the wet season increase considerably (45%). These results may represent a conservative estimate of non-compliance since they are based on monthly averages.

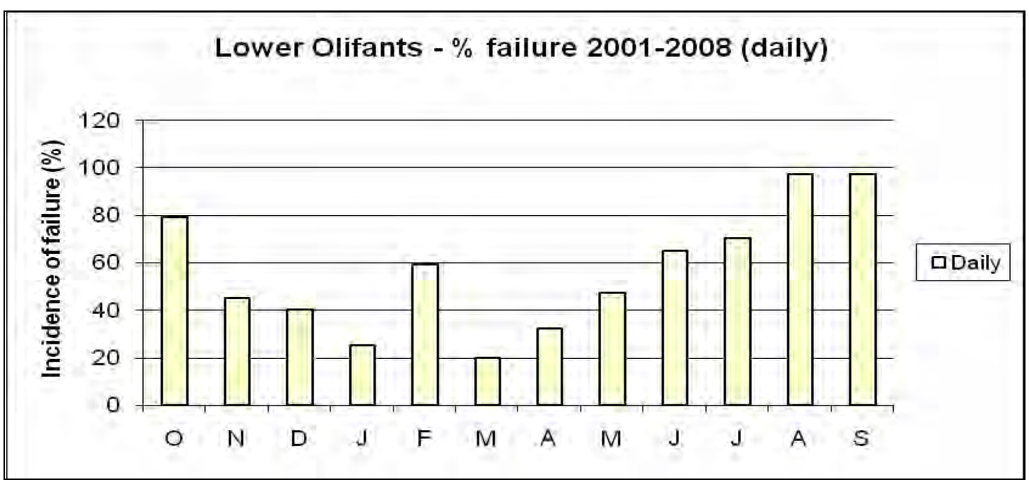


Figure 14 Incidence of failure to meet the ecological Reserve (%) at EWR 16

A more detailed analysis based on daily flow over the last seven years (Figure 14) indicates failure of compliance in all months, with an average incidence of failure of 56%. The greatest failure occurs in the dry season (687%) but that of the wet season is still high at 46%. The dry-season months of August and September indicate a nearly complete failure to meet the ER. Indeed concerns have been raised about the recent flow cessations. For example, the hydrological record indicates that the lower Olifants (B7H015, A01) ceased flowing[6] for a total of 33 days in the two driest months in 2005 (10 days in September and 23 days in October 2005).

Amount of failure (volume)

The amount (as a volume) by which the ER was not met for the last period (i.e. since 2001) is shown in Figure 15. This indicates that in the dry season almost the total amount required by the ER is not met pointing to the seriousness of the situation.

This assessment only deals with the lower Olifants River (lowveld). No quantitative assessment has been done of the section upstream (see Appendix 1, Figure 5). It is suggested that in terms of water quantity, the flows may be compliant up to Flag Boshielo Dam (this is likely to be examined as part of Olifants Reconciliation Study starting in May 2010).

In terms of the section examined, the possible reasons for the non-compliance stem from a severely stressed catchment and the dire need for integrated planning and management. Agricultural and urban demand has increased in the last decade. Overall, the Olifants catchment faces severe water resource constraints since the catchment is in water deficit by an estimated 179 Mm^3/a (with the EWR). It is noted that an inter-basin transfer (IBT) is planned from the Olifants (despite it being in water deficit) into the Letaba. The off-take point will be from the existing pump station about 20 kms downstream of the Flag Boshielo Dam.

Meeting the ER will require compulsory licencing amongst other strategic and management interventions since there is no surplus water in the catchment. Currently, IWRM appears to be weak (Pollard and Du Toit 2011).

Note that all the reserves for the Olifants catchment incorporated both flows, i.e. there was no distinction made for low flows. The implications therefore would be that we would be overestimating the non-compliance certainly for high flow (rain season) months. This overestimation would be less of an issue during winter when the flows are almost exclusively low flows.

[6] Flows $< 0.01\ m^3/s$

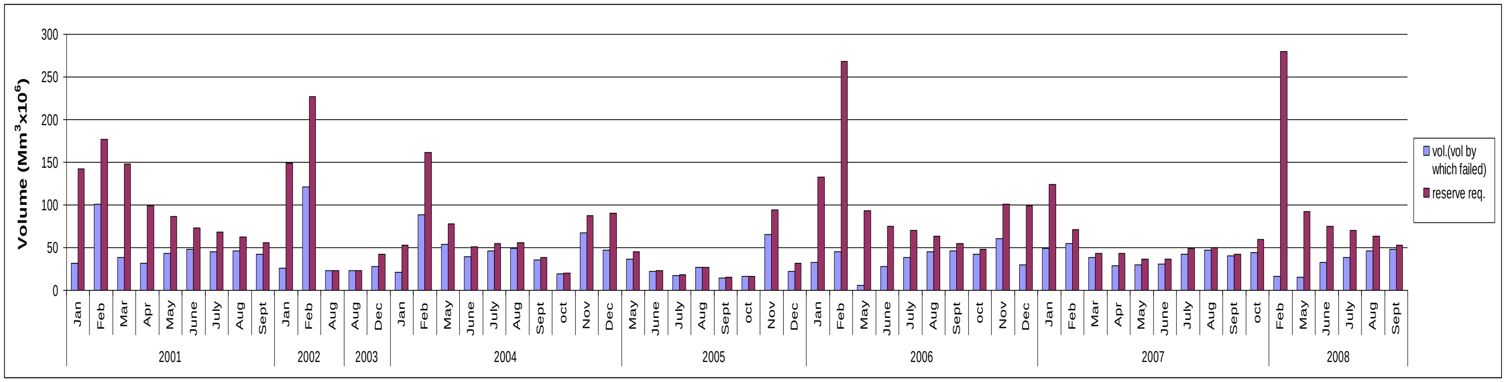


Figure 15 Non-compliance on the lower Olifants as a volume indicating the amount (as a monthly volume) by which the ER failed for the latest period analysed (see Table 1).

The graph shows the volumetric ER requirements versus the observed failure (i.e. the volume by which the ER failed). Note that the smaller the difference between the two bars, the greater the degree of non-compliance. To assist the reader only the months in which there was non-compliance are indicated.

2.5.5. Blyde River (tributary of the Olifants Catchment)

The Blyde River sub-catchment is part of the Olifants River Catchment. The Blyde River analysis was done in addition to that of the Olifants to see if there were any differences in compliance since it is widely-held that the Blyde River ensures flows to the lower Olifants River.

The class selected for analysis was a B based on the REC from the EWR 12 outputs. The EWR site 12 rule curve is given in Appendix 2. The hydrological gauge used was B6H004 which is about 8 km upstream of the EWR site (see Appendix 1, Figure 5). Only one period was examined from 2001 to 2008 (i.e. see Olifants (see Section 2.5.4).

Incidence of failure (%) and months in which this occurred

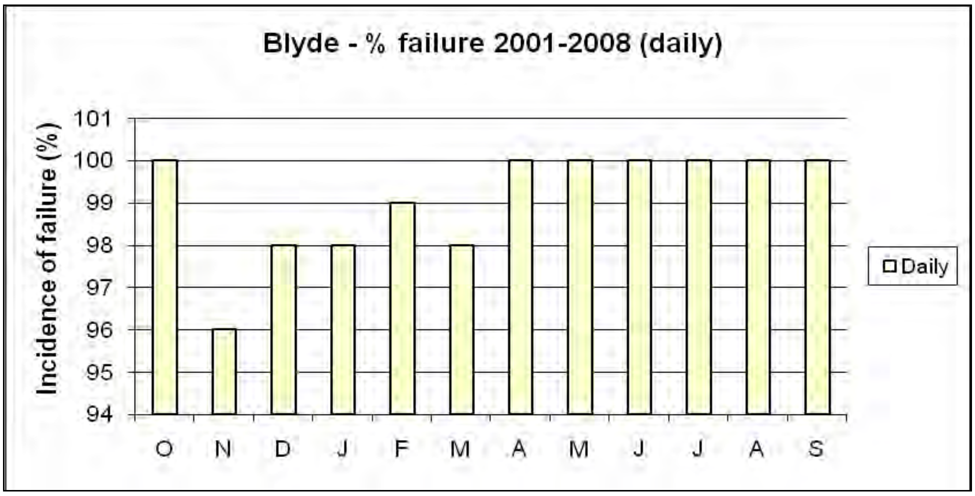


Figure 16 Incidence of failure to meet the ecological Reserve (%) at EWR 12 on the Blyde Letaba River for the period 1986 to 2008 based on daily averages

All months indicate incidences of failure, with an average of 73% across all months (Figure 16). Since only one period was analysed no comments can be made on whether or not this is improving or worsening. Note that the above results were somewhat surprising given the apparently good status of the Blyde.

Amount of failure (volume)

The results for the Blyde (Figure 17) are somewhat unexpected given the proximity of the Blyde Dam and the potential for this to deliver the EWRs. The data and outputs will be checked as part of a current project that examines the water resources of the Olifants River[7]. The possible reasons for the non-compliance are likely to reflect the lack of operating rules that incorporate the ER release and abstraction patterns that compromise this.

[7] Development of a Reconciliation Strategy for the Olifants River Water Supply System

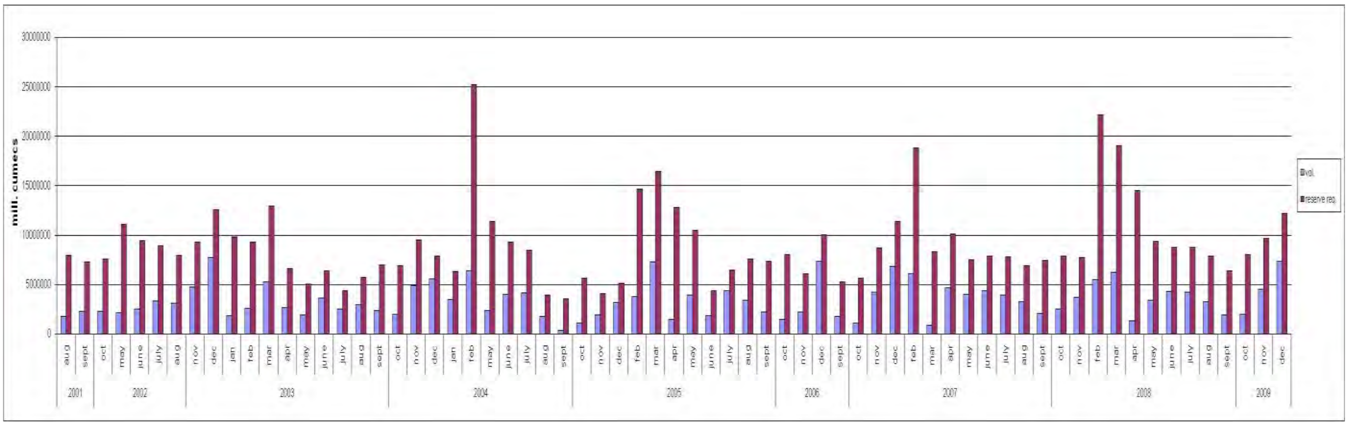


Figure 17 Non-compliance on the Blyde River as a volume indicating the amount (as a monthly volume) by which the ER failed for the latest period analysed (see Table 1).

The graph shows the volumetric ER requirements versus the observed failure (i.e. the volume by which the ER failed). Note that the smaller the difference between the two bars, the greater the degree of non-compliance. To assist the reader only the months in which there was non-compliance are indicated.

2.5.6. Sabie River

The current PES is given as a B. The class selected for analysis was a B, based on the REC from the EWR 3 outputs. The EWR site 3 rule curve is given in Appendix 2. The hydrological gauge used X3H006 is about 22 km upstream of the EWR site. The analysis for the Sabie River was complicated by a major constraint, namely that two different hydrological stations had to be used. The gauge X3H006 (also known as Perry's Bridge) was destroyed by the 2000 floods and so no data is available after that period. This meant that the period of greatest interest – the last seven years – could not be examined. Thus another gauging station, X3H021 (also known as Kruger Gate) had to be used to examine the last period. The hydrological gauge X3H021 is approximately 28 km downstream of the EWR site. The distance to the EWR sites is such that there is abstraction downstream of the EWR site this was not considered ideal. Nonetheless for comparative purposes data from this gauge was examined for two periods: 1994-2000 and 2001-2008. Data from Perry's bridge were examined for two periods: 1960-1993 and 1994-2000. These periods are now described:

<u>Perry's Bridge</u>

i. 1960-1993: The Sabie River catchment experienced a growth in irrigated agriculture from the early 60s until about 1998 (Figure 3). Also in the 1970s people were forcibly moved into the area under Apartheid adding a small increase in demand on the resource through two agricultural schemes.
ii. 1994-2000: This period coincides with policy changes as well as a time when local stakeholders took on managing the Sabie River, mainly in times of scarcity, through the Sabie River Working Group.

<u>Kruger Gate</u>

i. 1994-2000: As above.
ii. 2001-2008: This period coincides with changes in policies which meant that operating rules were developed for the Sand River catchment. At the same time Injaka Dam on the Marite tributary came on line. Both of these factors would theoretically result in improved compliance with the ER.

The assessment was based on monthly data for all three periods, and on daily data for the last period.

Incidence of failure (%) and months in which this occurred

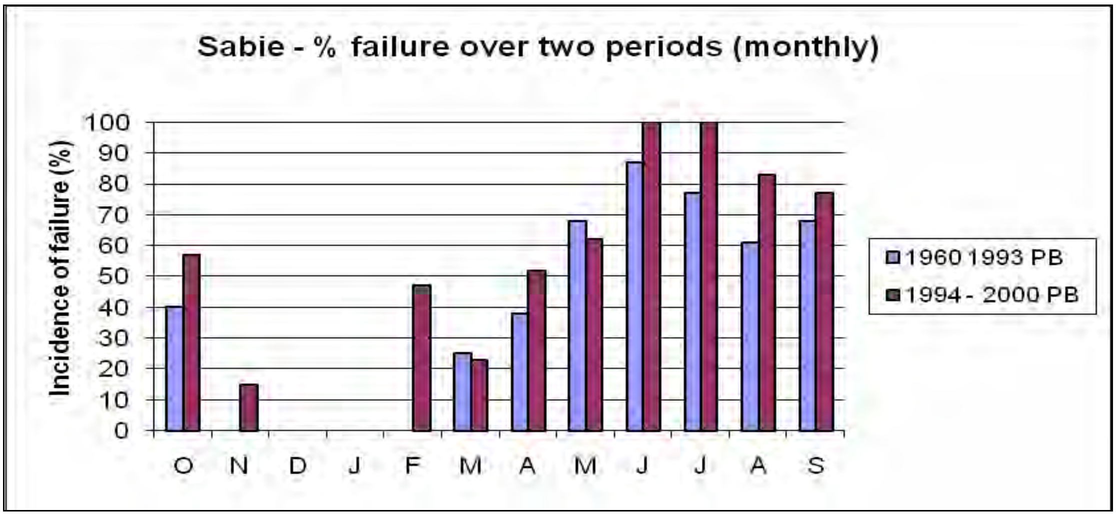


Figure 18 Incidence of failure to meet the ecological Reserve (%) at EWR 3 on the Sabie River over two periods. Note this analysis is based on data from the gauge at Perry's Bridge (see text for details). Data are based on monthly averages

Failure to meet the ER is evident in all months in the two periods examined (Figure 18) with the exception of December and January, and November and February in the 1960-1993 period. The average incidences of failure were 39% and 51% for the two periods respectively. The average dry season failure was higher (72%-84%) than that of the wet season (11% and 24% for each period respectively).

In order to examine patterns between the most recent period and that preceding it, data for the Kruger Gate gauge had to be used (Figure 19).

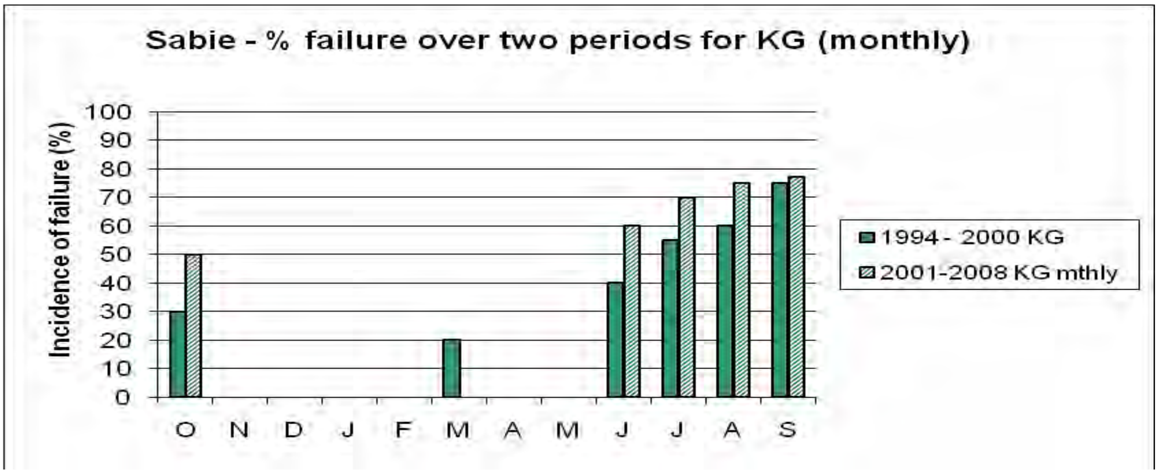


Figure 19 Incidence of failure to meet the ecological Reserve (%) at EWR 3 on the Sabie River over two periods covering 1994 to 2008). Note this analysis is based on data from the gauge at Kruger Gate (see text for details). Data are based on monthly averages

In general the results suggest that non-compliance is persistent in the dry season and potentially worsening over the last seven years despite the completion of Injaka Dam and the operating rules for it.

The average incidences of failure were 23% and 28% for the two periods respectively. Note that these results may represent a conservative estimate of non-compliance since they are based on monthly averages.

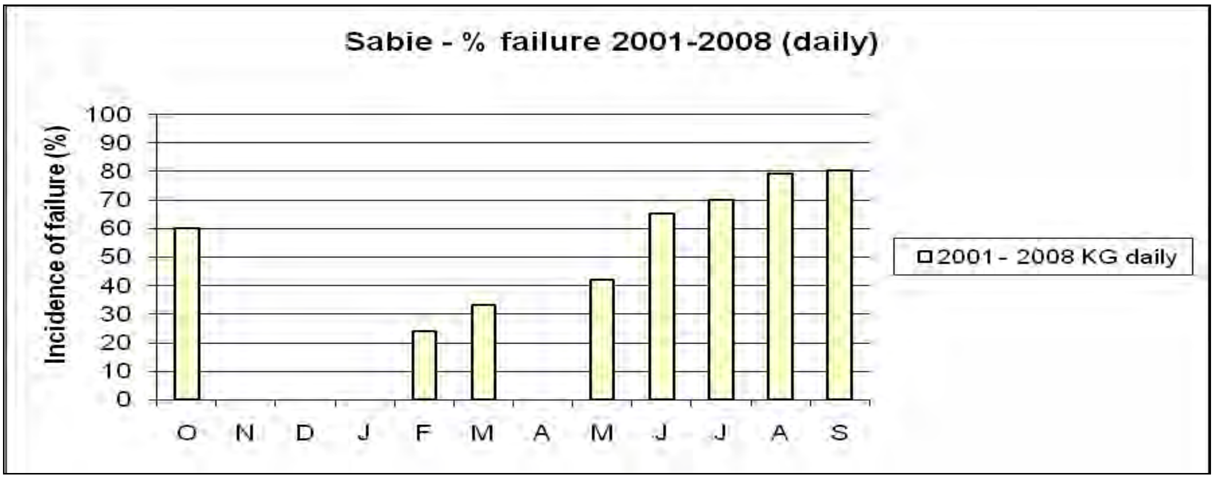


Figure 20 Incidence of failure to meet the ecological Reserve (%) at EWR 4 on the Sabie River for the period 2001-2008 based on daily averages. Note this analysis is based on data from the gauge at Kruger Gate (see text for details).

A more detailed analysis based on daily flow over the last seven years (Figure 20) indicates failure of compliance in eight months, with an average incidence of failure of 38% across all months for the last seven years (from 2001). The greatest failure occurs in the dry season and is evident in all months (average of 67%). The months of August and September display nearly 80% incidence of failure.

Amount of failure (volume)

Figure 21 indicates that the amount by which the ER fails is relatively small. Although more marked in the dry season, the results suggest that mitigatory measures would be easier to implement than in other catchments.

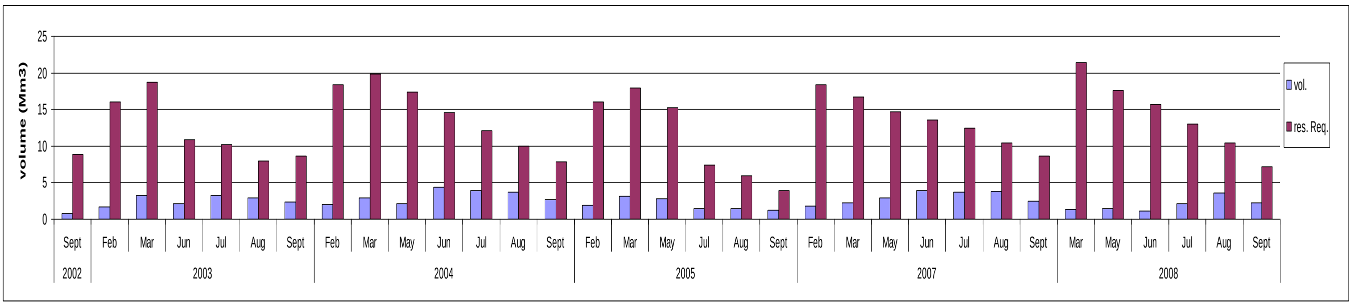


Figure 21 Non-compliance in the Sabie as a volume indicating the amount (as a monthly volume) by which the ER failed for the latest period analysed (see Table 1).

The graph shows the volumetric ER requirements versus the observed failure (i.e. the volume by which the ER failed). Note that the smaller the difference between the two bars, the greater the degree of non-compliance. To assist the reader only the months in which there was non-compliance are indicated.

The possible reasons for the non-compliance are as follows:

- The Injaka White Paper intentions and the operating rules have not been adhered to. This situation may change with the recent DWA project to develop an operational system for the Sabie-Sand catchment.
- Other reasons may include the increasing demand for urban consumption. The lack of co-ordinated water resources management has meant that municipalities are expanding infrastructure with little consideration for the water resources or of the legal requirements to do so.

Finally it must be noted that monitoring the Reserve for compliance will be difficult given that the new EWR site is some distance from the gauge station. Thus data needs to be calibrated to account for the losses or new gauge instrumentation needs to be established at the EWR site.

2.5.7. Sand River

The Sand River is a sub-catchment of the Sabie River (see section 2.5.6). It has been analysed separately because of the recognised biophysical, social and institutional differences between the two catchments. Moreover a more detailed analysis than the other catchments was undertaken given the threats of potential litigation regarding non-compliance (see Pollard & Du Toit et al. 2009). This involved examining compliance based on daily data for two periods as well as the standard analyses based on monthly averages.

The current PES is given as a B. The class selected for analysis was a B, based on the REC from the EWR 8 outputs. The EWR site 8 rule curve is given in Appendix 2. The hydrological gauge X3H008 is approximately 48 km upstream of the EWR site. Three periods were selected for the assessment of compliance. Agriculture was already fairly well established by the 1960s in some quaternary catchments. The first period thus represents a notable increase in irrigated agriculture (1960s and early 1980s) as is illustrated in Figure 3):

1) 1967-1993: This represents a period of increasing water resources development without IWRM as people were forcibly moved into the area under Apartheid.
2) 1994-2000: Agriculture increased markedly in this period (see Figure 3).
3) 2001-2008: This period coincided with changes in policies which meant that operating rules were developed for the Sand River Catchment. At the same time Injaka Dam came on line. Both of these factors would theoretically result in improved compliance with the ER.

As noted, the assessment was based on monthly data for all three periods, and on daily data for the last two.

Incidence of failure (%) and months in which this occurred

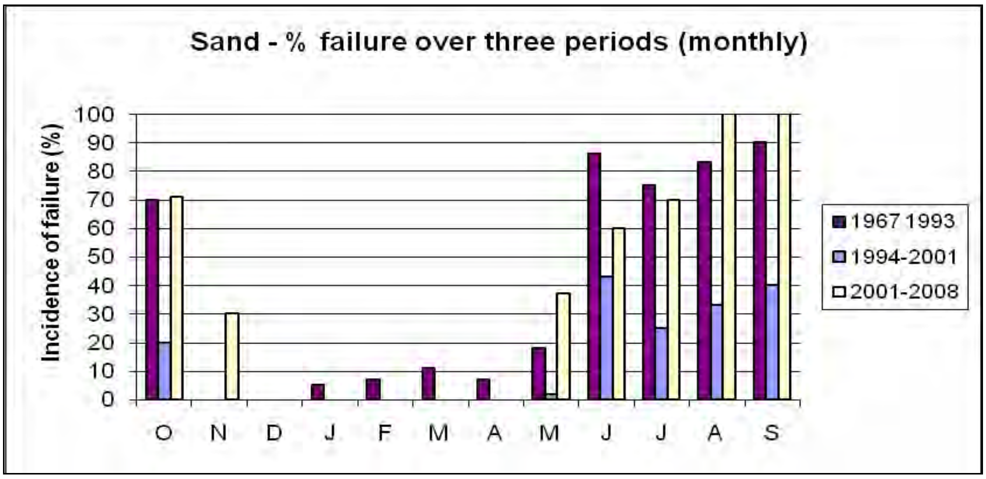


Figure 22 Incidence of failure to meet the ecological Reserve (%) at EWR 8 on the Sand River over three periods. Data are based on monthly averages

Failure to meet the ER is evident in all dry-season months in all periods examined (Figure 22). Wet season failures were only evident in the earliest period between 1967 and 1993, with the exception of November in the last seven years. The average incidences of failure are similar in the first and third periods; 16% and 72% for the wet and dry seasons respectively. The period 1994 to 2000 has a far lower incidence of failure of 3% and 28% for the wet and dry seasons respectively, possibly reflecting the inclusion of extremely high flows from the 2000 floods.

In general the results suggest that there a persistence in non-compliance over the last seven years despite the completion of Injaka Dam and the design of detailed operating rules. These results may represent a conservative estimate of non-compliance since they are based on monthly averages.

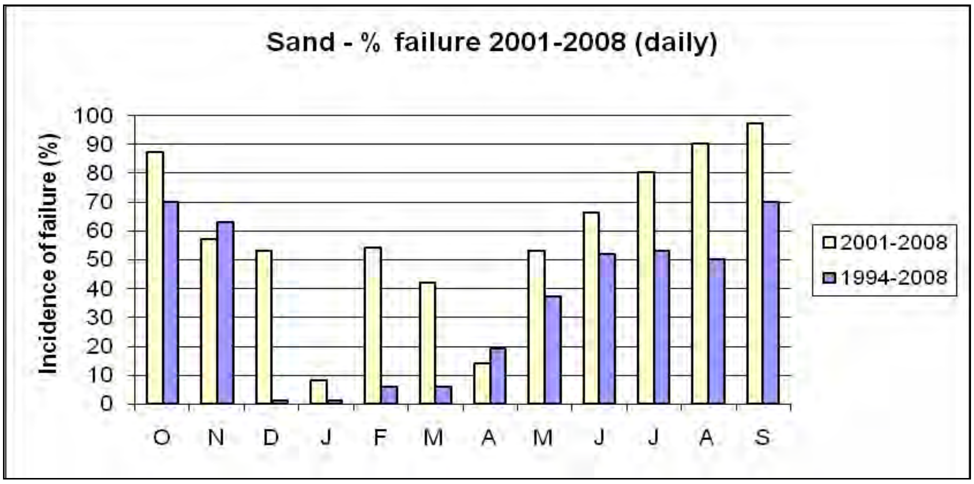


Figure 23 Incidence of failure to meet the ecological Reserve (%) at EWR 8 on the Sand River for the period 1994 to 2008 based on daily averages

A more detailed analysis based on daily flow over the last 14 years (after 1994, Figure 23) indicates failure of compliance in all months, with an average failure incidence of 58% across all months for the last seven years (from 2001), which is worse than 1994-2000 at 37%. As stated above the greatest failure occurs in the dry season (77%) although non-compliance is still evident in the wet-season average of 50%. The months of August, September and October all display over 80% incidence of failure.

Cessation of flow between 1999 and 2009

Concerns over the integrity of the Sand River have also pointed to days of flow cessation (Figure 24). An examination of daily data for the last decade up to October 2009 revealed a total of 108 days of flow cessation (< 0.01 m^3/s). These were always experienced at the end of the dry season (Sept-Nov). The greatest number of days of flow cessation occurred in 2005 and 2006.

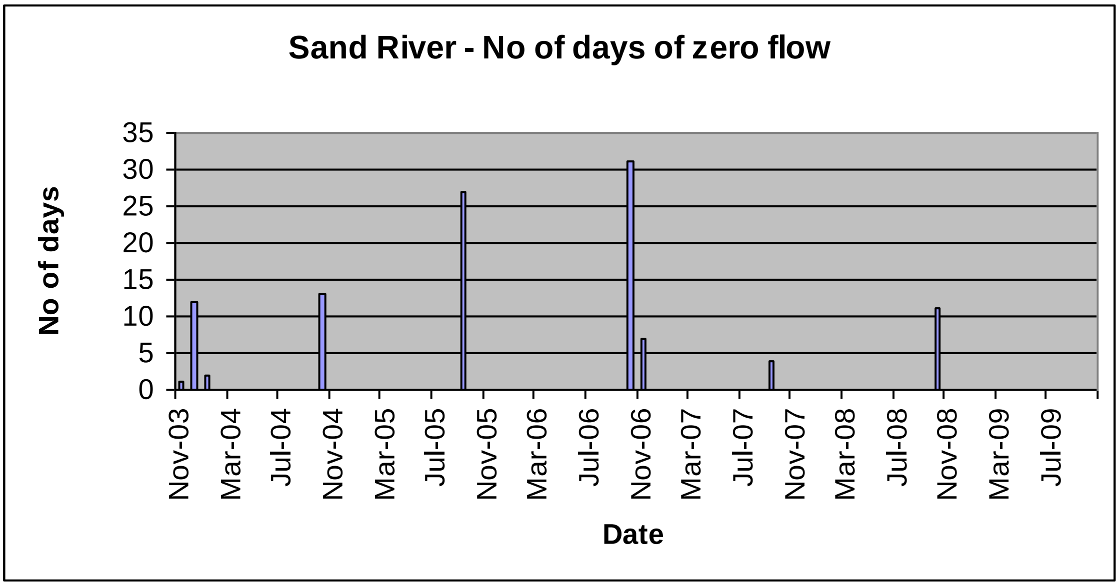


Figure 24 Number of days of flow cessation in the Sand River (x8H001) over the last decade Oct 1999 – Oct 2009

Amount of failure (volume)

The amount by which the ER fails shows a high degree of variability (Figure 25). However, an intra-annual pattern indicates that the dry season months appear to have lower volumetric infringements than summer months whose volumetric infringements appear greater. This requires statistical validation.

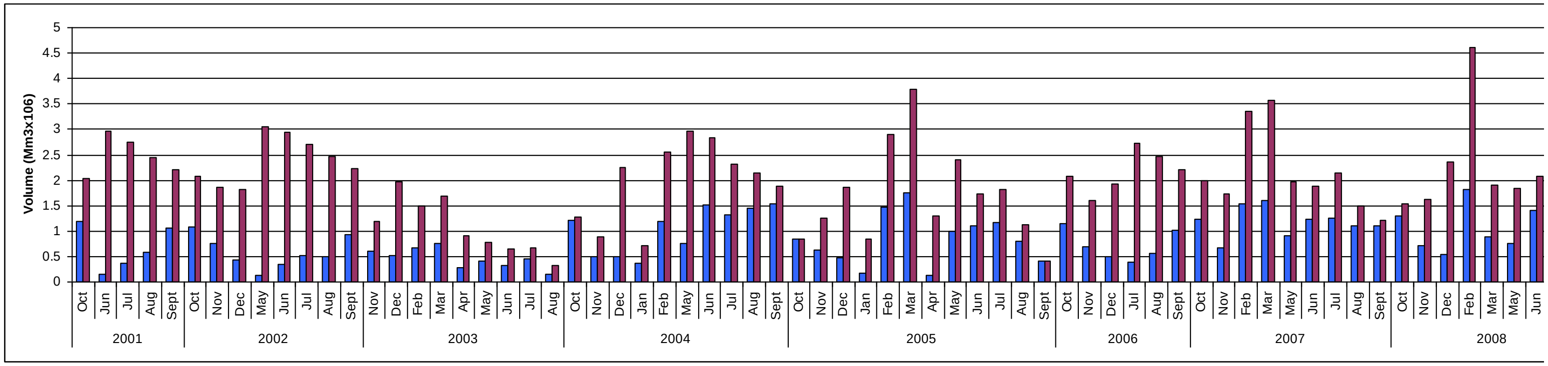


Figure 25 Figure 4.19: Non-compliance on the Sand River as a volume indicating the amount (as a monthly volume) by which the ER failed for the latest period analysed (see Table 1).

The graph shows the volumetric ER requirements versus the observed failure (i.e. the volume by which the ER failed). Note that the smaller the difference between the two bars, the greater the degree of non-compliance. To assist the reader only the months in which there was non-compliance are indicated.

A number of studies have elaborated the reasons for failure in the Sand. The most recent (Agterkamp 2009) (Pollard and Agterkamp in prep) point to poor overall integrated management, weak co-operative governance actions coupled with increasing demands. Firstly, the Injaka White Paper intentions to augment flows of the Sand River through an inter-basin transfer have not been adhered to (see (DWAF 1994). The operating rules that were developed for the Sand River have not been implemented, together with the associated actions needed (Pollard & Agterkamp in prep). Increased demand and un-coordinated abstraction downstream of the irrigation schemes by the municipalities compromise the current resources. The fact that the abstractions are not undertaken as part of an integrated approach that is based on a sound water reconciliation for the Sand River tributaries mean that any free water freed up by improved agricultural efficiencies is likely to be taken up by the municipalities.

Finally it must be noted that monitoring the Reserve for compliance will be difficult given that the new EWR site is some distance from the gauge station after which the Sand River experiences net losses. Thus meeting the ER at the gauge may not necessarily imply compliance at the EWR site. Thus data needs to be calibrated to account for the losses or new gauge instrumentation needs to be established at the EWR site.

2.5.8. Crocodile

The class selected for analysis was a C based on the REC from the EWR 6 outputs. The EWR site 6 rule curve is given in Appendix 2. The hydrological gauge used was X2H016 which is about 6.5 km upstream of the EWR site. It must be noted that the Reserve is a preliminary until classification is undertaken.

Three periods were selected for the assessment of compliance. The first two periods represent notable increases in irrigated agriculture (1960s and early 1980s) as is illustrated in Figure 3:

1) 1960-1983: Represents a period of increasing water resources development
2) 1984-2000: 1980 Kwena Dam constructed- + increased irrigated agriculture
3) 2001-2010: 1999 Piggs Peak Agreement; WRM in earnest; 2002 – IIMA

The assessment were based on monthly data for all periods (1960-1983; 1984-2000), and daily data for the last decade (2001-2008).

The assessment indicates a high degree of non-compliance with the Reserve in the Crocodile River

Incidence of failure (%) and months in which this occurred

In the last 50 years there is increasing incidence of failure to meet the EWRs (Figure 26)

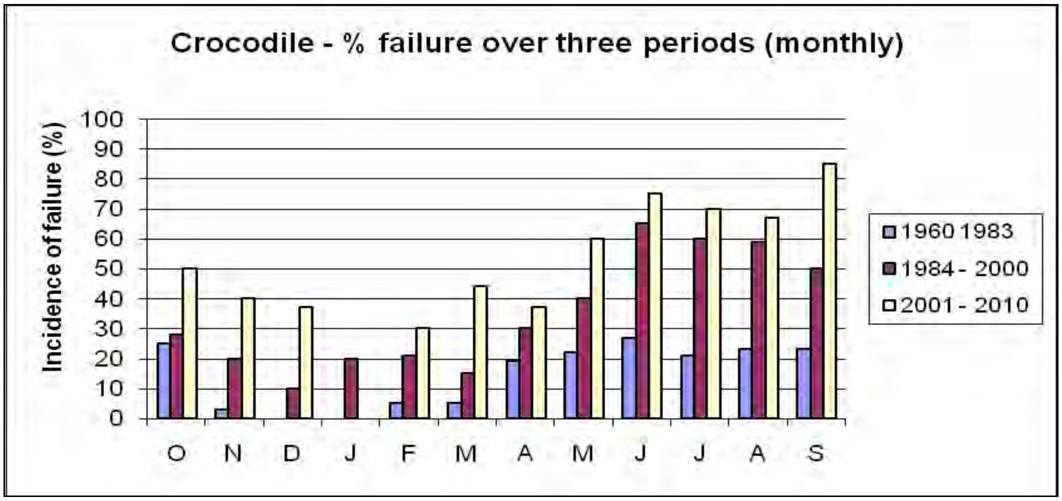


Figure 26 Incidence of failure to meet the ecological Reserve (%) at EWR 5 on the Crocodile River over three periods. Data are based on monthly averages

These results suggest that there is a pattern of increasing non-compliance over the three periods since 1960. The average incidence of failure across all months is 14%, 35% and 46% for each period respectively. In each period failure is evident in every month with the exception of the wet season in the earliest period. Failure is highest in the dry season where it varies between 40 and 80%. The worst cases of failure are evident for the latest period starting in 2001 between June and September (dry season) where there is non-compliance for at least half the time. In this period the ER was only met in January all of the time. Note that these results may represent a conservative estimate of non-compliance since they are based on monthly averages.

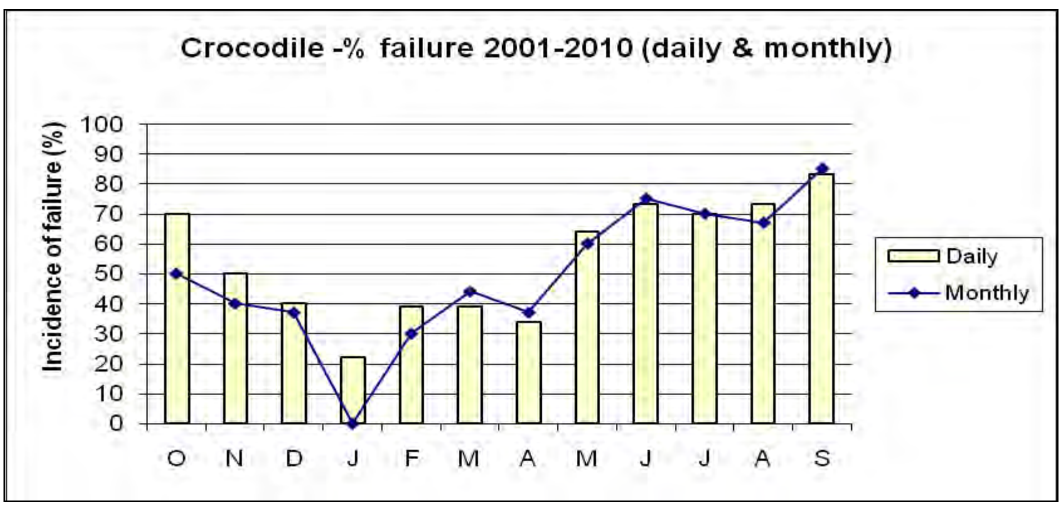


Figure 27 Incidence of failure to meet the ecological Reserve (%) at EWR 5 on the Crocodile River for the period 2001-2010 based on daily averages (monthly shown for comparative purposes)

A more detailed analysis based on daily flow over the last seven years (since the signing of Piggs Peak Agreement and the IIMA, as well as more concerted IWRM) indicates a high degree of non-compliance

(Figure 27). During this period increased or complete compliance with the Reserve is to be expected. However, examination of the data (based on the FDC, not time series) suggests that this is not the case. The % time of failure varied between 30 and 82% most notably in the dry season, but surprisingly in the wet season as well. Failures were recorded in all months when daily data were examined.

Amount of failure (volume)

The amount (as a volume) by which the ER was not met for the last period (i.e. since 2001) is shown in Figure 28. This indicates that in 2002, 2003, 2004 and 2006 almost the entire ER requirement was not met. The period 2003-2006 was a dry one. However once the operating rules started in earnest in 2008 there is some indication of improvement.

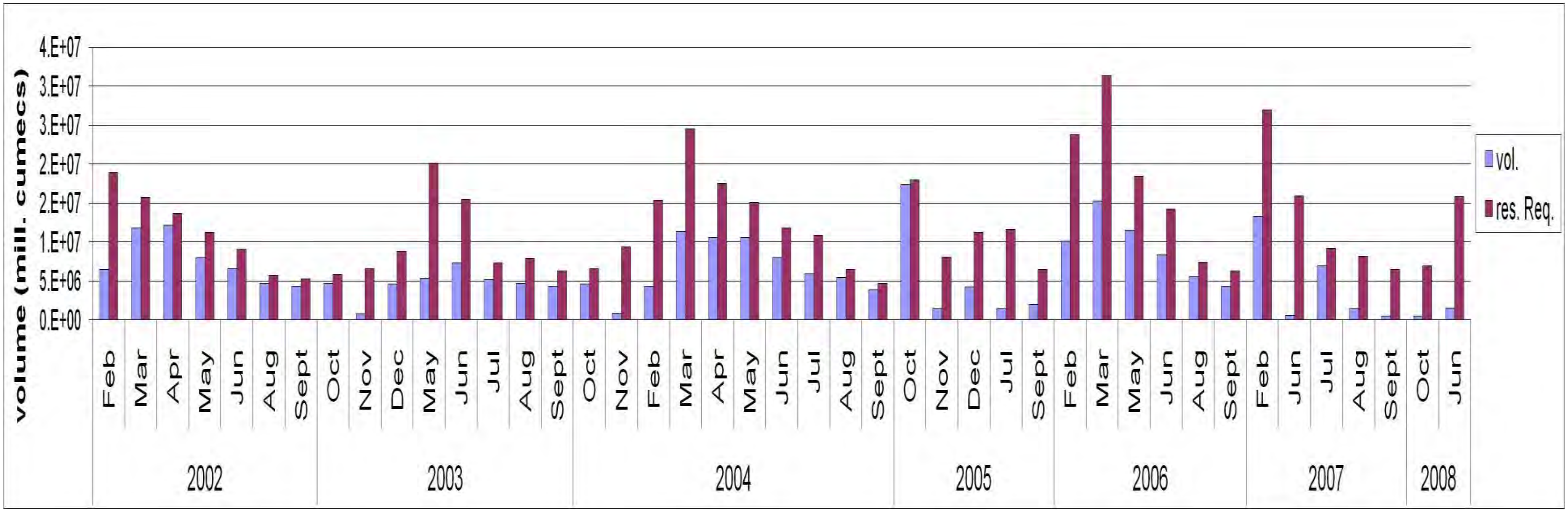


Figure 28 Non-compliance in the Crocodile River as a volume indicating the amount (as a monthly volume) by which the ER failed for the latest period analysed (see Table 1).

The graph shows the volumetric ER requirements versus the observed failure (i.e. the volume by which the ER failed). Note that the smaller the difference between the two bars, the greater the degree of non-compliance. To assist the reader only the months in which there was non-compliance are indicated.

The Crocodile catchment is severely stressed and has experienced a reversal in flow seasonality as a result of the operation of Kwena Dam. The likely reasons for the high levels of non-compliance are as follows:

- There has been an increase in irrigated agriculture as is shown in Figure 3. Moreover the last decade has seen an increasing demand for urban consumption associated with expanding development in the Nelspruit area as well as a demand for high levels of domestic services.
- The current abstraction regimes can reduce flows to near zero on a daily basis during the course of the day. Irrigators have an agreement with Eskom to pump in off-peak times (rates can double causing huge fluctuations)

Improved technical and management systems since 2008, together with greater collaborative efforts between the Inkomati CMA and the irrigators give reason to believe that the situation will improve to some degree in the foreseeable future.

2.5.9. Komati River

The class selected for analysis was a D based on the REC from the EWR K3 outputs. The EWR site K3 rule curve is given in Appendix 2. The hydrological gauge used was X1H003 which is about 3 km upstream of the EWR site.

Three periods were selected for the assessment of compliance. Agriculture was first established around the early 1960s and increased steadily with major increases evident in the selected quaternary catchments in the 1990s (see Figure 3):

1) 1960-1997: Period of established and increasing water resources development for agriculture without IWRM. The start of the hydrological record was 1960. Users were restricted prior to 1996.
2) 1998-2005: The Driekoppies Dam on the Lomati was completed in 1998 and theoretically should have contributed to improved flows. However the construction of Maguga Dam on the main stem of the Komati in Swaziland was underway in the early 2000s and effects clearly evident by 2003 such that prior to the 2006 operating rules (see next period) there were situations of no flow in many places. Maguga started filling in about 2002 and was full for the first time in January 2008.
3) 2006-2008: This represents a period when the combined effects of water resources management from the Driekoppies and Maguga Dams could improve flows (prior to this Driekoppies was being used to meet most of the demands). In 2006 the dam was filling and KOBWA started managing Maguga according to the full operating rules. Thus the ER should be met.

The assessment was based on monthly data for the first two periods. A monthly analysis was not used in the last period because of the short data set. Instead an analysis based on daily data was undertaken for the last period.

Incidence of failure (%) and months in which this occurred

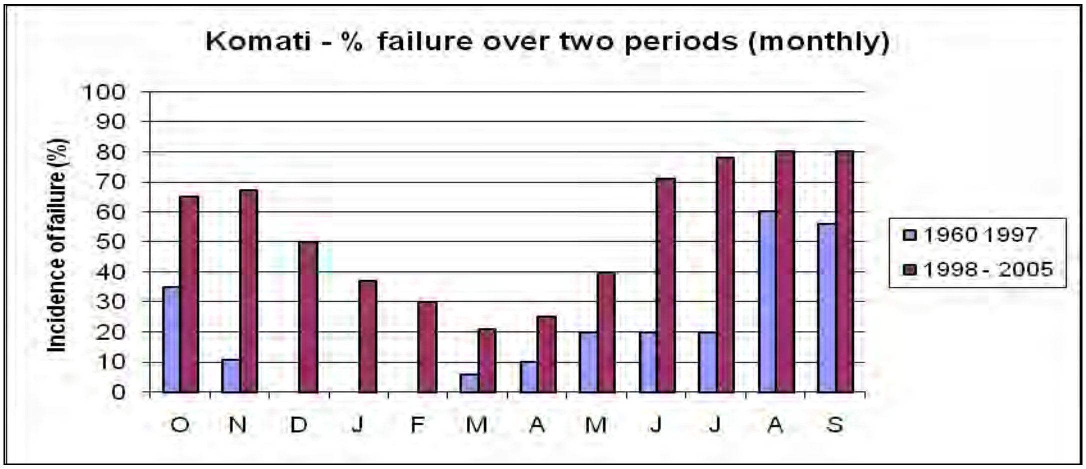


Figure 29 Incidence of failure to meet the ecological Reserve (%) at EWR K3 on the Komati River over two periods. Data are based on monthly averages

Failure to meet the ER is evident in the dry season in the first period (1960-1997) with an average failure of 19% across all months and a dry season average of 35% (Figure 29). In the following period up to 2005, failure is evident in all months with an average failure of 54% across all months, a dry season average of 70% and wet season average of 45%. Note that these results may represent a conservative estimate of non-compliance since they are based on monthly averages.

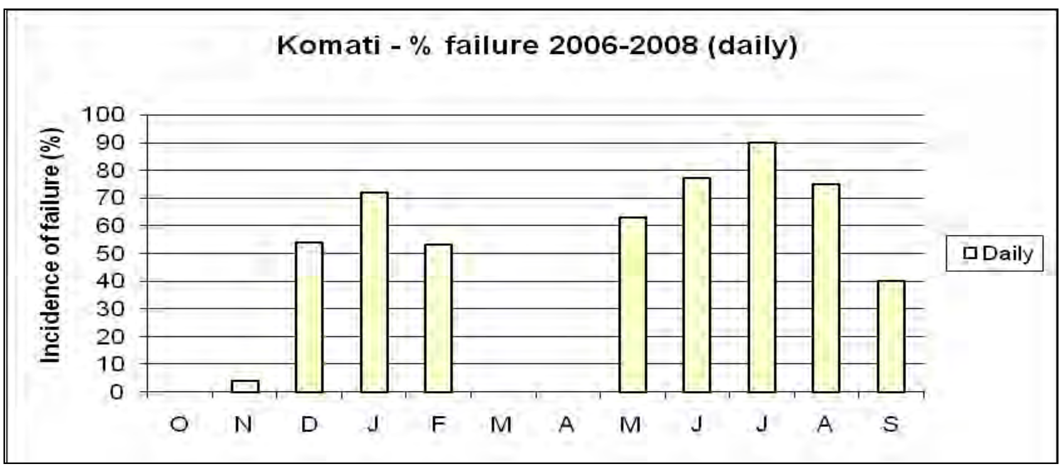


Figure 30 Incidence of failure to meet the ecological Reserve (%) at EWR K3 on the Komati River for the period 2006 to 2008 based on daily averages

During the last period failure in compliance is still evident nine months (Figure 30) with an average incidence of failure of 44% despite the implementation of operating rules. The highest failure occurs in the early part of the dry season (average of 69%) notably in June, July and August. In contrast the wet season average of 31%.

Amount of failure (volume)

The volumes by which there was failure suggest that the severity was worst in 2006 in June and July, and in July in 2007 (Figure 31).

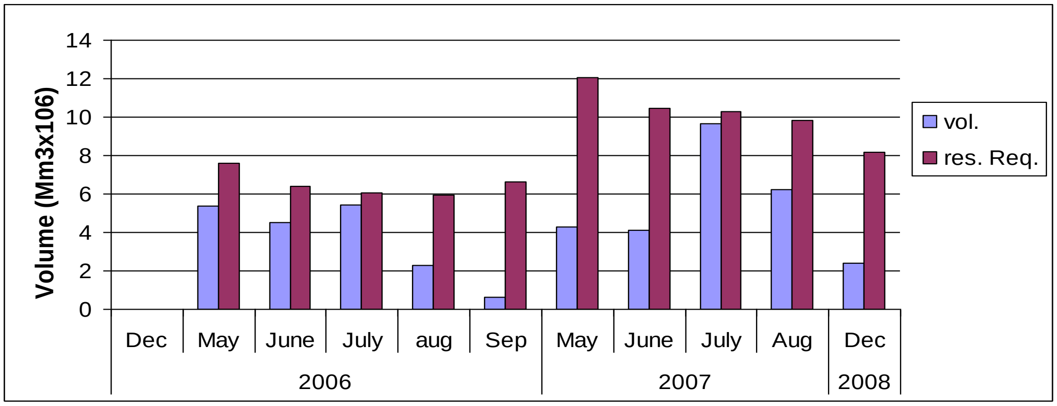


Figure 31 Non-compliance in the Komati River as a volume indicating the amount (as a monthly volume) by which the ER failed for the latest period analysed (see Table 1).

The graph shows the volumetric ER requirements versus the observed failure (i.e. the volume by which the ER failed). Note that the smaller the difference between the two bars, the greater the degree of non-compliance. To assist the reader only the months in which there was non-compliance

The possible reasons for the non-compliance are as follows:

- The high incidences of infringements in the last period probably reflect the fact that the Komati ceased flowing frequently during the construction of Maguga Dam from 2000 onwards.
- In 2006 a new operational system was implemented for the Maguga Dam. As stated, the period prior to this experienced a number of zero flow or near zero-flow situations partially explaining the lack of compliance in the period 1998-2005.
- However, despite improved operational systems there are still considerable evidence of non-compliance and this is concerning. Currently the ER requirements are not part of the operating rules; the dam is only being operated to deliver the international requirement (of 1.1 m^3/s). There are two studies underway that may address this issues: (a) a study underway to examine ER requirements in Swaziland and (b) a study to determine the operating rules for all the weirs.
- Eskom have persuaded irrigators to operate at off-peak times. This will result in highly variable river flow.

There are some signs that infringements may improve. Firstly as the ICMA gears up to better IWRM, the Komati will receive greater attention. Secondly the aforementioned ER study in Swaziland is likely to address integrating of the ER into the operating rules. Thirdly, the Komati River is part of the recent PRIMA project designed to realize that international water sharing agreements are met.

2.5.10. Lomati River

The Lomati is a tributary of the Komati River. It has been analysed separately because of the recognised institutional differences between the two catchments. The class selected for analysis was a D based on the REC from the EWR L1 outputs. The EWR site L1 rule curve is given in Appendix 2. The hydrological gauge used was X1H014 which is at approximately the same location as the EWR site.

As for the Komati, three periods were selected for the assessment of compliance. The same rationale for each period applies and will not be repeated. However the first period starts in 1968 (not 1960) since that is when the hydrological gauge station became operational. The three periods are as follows:

1) 1968-1997
2) 1998-2005
3) 2006-2008

The assessment was based on monthly data for the first two periods. A monthly analysis was not used in the last period because of the short data set. Instead an analysis based on daily data was undertaken for the last period.

Incidence of failure (%) and months in which this occurred

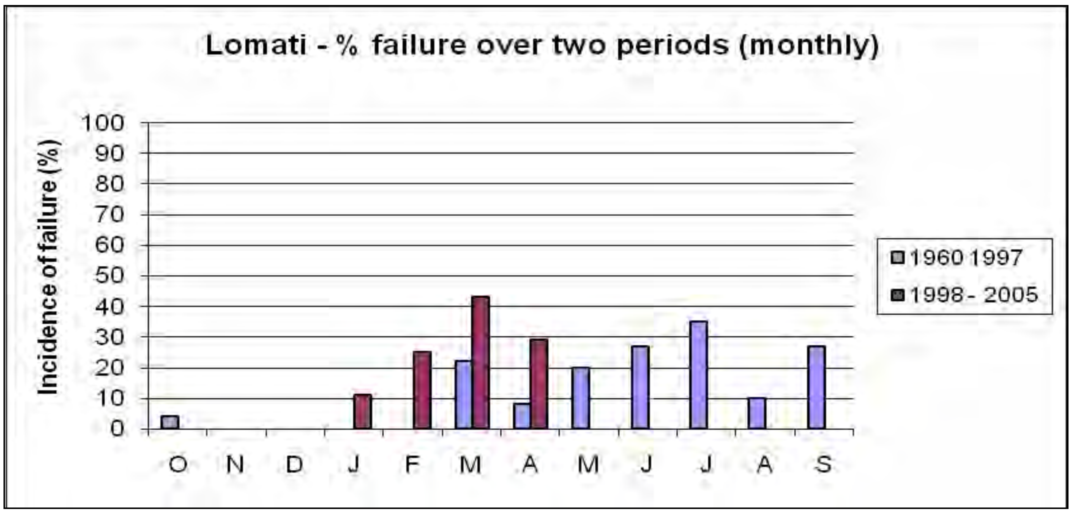


Figure 32 Incidence of failure to meet the ecological Reserve (%) at EWR L1 on the Lomati River over two periods. Data are based on monthly averages

Failure to meet the ER is evident principally in the dry season in the first period (1968-1997) with an average failure of 13% across all months and a dry season average of 24% (Figure 32). In the following period up to 2005, the incidence of failure appears to shift to the wet months with an average failure of 9% across all months and wet season average of 13%. Note that these results may represent a conservative estimate of non-compliance since they are based on monthly averages.

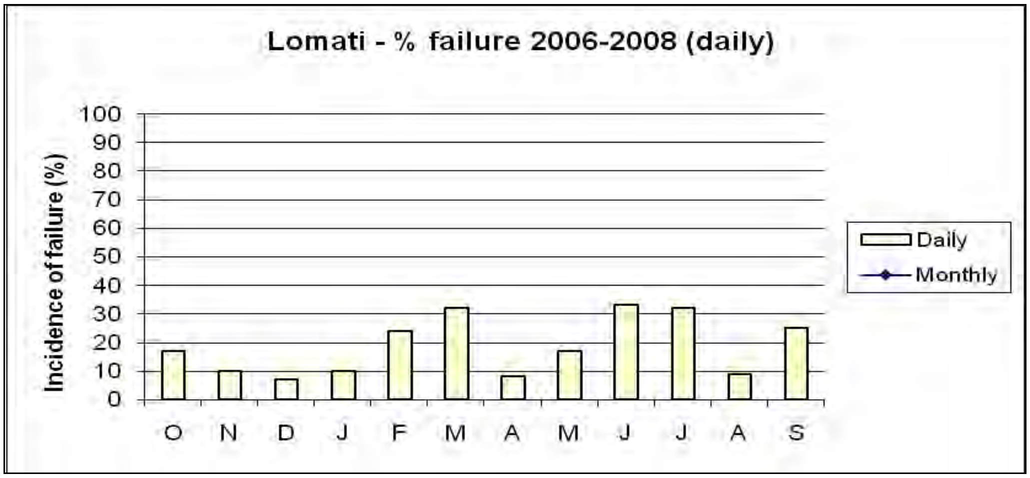


Figure 33 Incidence of failure to meet the ecological Reserve (%) at EWR L1 on the Lomati River for the period 2006 to 2008 based on daily averages

A more detailed analysis based on daily flow over the last three years (after 2006 operating rules, Figure 33) indicates some degree of non-compliance across all months in contrast to the preceding graphs, with an average incidence of failure of 19%. This is despite the implementation of operating rules. The highest failure occurs in the early part of the dry season (average of 23%) notably in June, July and in the last part of the wet season (March). The wet season average of is 17%.

Amount of failure (volume)

The volumes by which there was failure (see Figure 34) suggest that non-compliance is relatively low and could be addressed with judicious management.

Although the situation of non-compliance in the Lomati River is somewhat better than others, there is still infringement of the ER. The possible reasons for the non-compliance may be partly ascribed to the facts that although a new operational system was implemented for the Driekoppies Dam in 2000, this does not include the ecological Reserve.

As with the Komati, there are some signs that infringements may improve as a results of better IWRM via the ICMA and the PRIMA project.

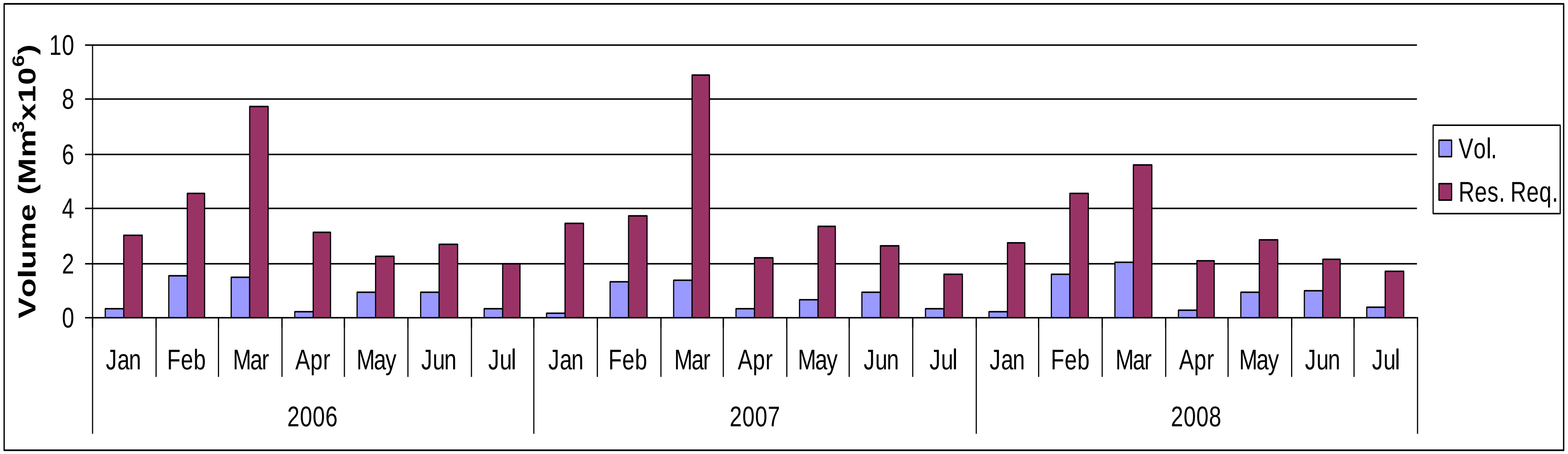


Figure 34 Non-compliance in the Lomati River as a volume indicating the amount (as a monthly volume) by which the ER failed for the latest period analysed (see Table 1).

The graph shows the volumetric ER requirements versus the observed failure (i.e. the volume by which the ER failed). Note that the smaller the difference between the two bars, the greater the degree of non-compliance. To assist the reader only the months in which there was non-compliance are indicated.

2.6. Discussion

This section provides a summary of the results of compliance with the ecological Reserve per WMA. It goes on to highlight some of the constraints in the assessment of compliance as important issues to be examined in the future. Recommendations are also made on principles framing compliance monitoring in the future.

2.6.1. Overview of compliance per WMA

A discussion of the results from Section 2.5 is presented below. In the Letaba/ Luvuvhu WMA there is non-compliance with the ER in all three rivers (Table 8). Results from the Groot Letaba however indicate a steady improvement with the introduction of improved management (IWRM) and stakeholder buy-in over the last decade. Analysis for the period covering the last decade of the volumes by which the ER is infringed are relatively minor (see Figures 8 & 9). The Klein Letaba on the other hand shows high and persistent infringement of the ER with little indication of attempts to mitigate the situation. In the case of the Luvuvhu, it appears that the non-compliance may not necessarily improve despite the completion of the Nondoni Dam. This is because it appears that EWRs have not been incorporated into the dam operations or planning for the sub-catchment

In the Olifants WMA, the ER is not met for an estimated 50% of the time at the lowest EWR site. The results for the Blyde are somewhat unexpected given the proximity of the Blyde Dam and the potential for this to deliver the EWRs. The data and outputs will be checked as part of a new Olifants River reconciliation study. The possible reasons for the non-compliance are likely to reflect the lack of operating rules that incorporate the ER and release and abstraction patterns that compromise this.

The incidence of non-compliance in the Inkomati WMA varies for each sub-catchment. The Crocodile and Sand rivers display the highest incidence of failure – between 55 and 60% when daily data are examined. Both systems are known to be highly stressed. Neither system has improved to-date under the scenario of 'improved policy and IWRM'. However, very recent advances in the management system for the Crocodile River provide optimism for significant improvements in compliance in the near future (see Section 2.5.8 and Section 3). The case of the Sand River appears to be somewhat more complex with improvements relying on multiple factors that are political, infrastructural and institutional in nature (see Section 2.5.7 and Pollard & Agterkamp in prep.). A recent project by DWA to up-date the operating system for the Sabie-Sand Catchment[8] is one step towards the needed improvements. Additionally however, a more integrated strategic approach is needed to address the worsening situation. The results for the Sabie River are somewhat surprising and indicate a need for specific attention to the underlying causes.

[8] A Real-time Operating Decision Support System for The Sabie/Sand River System

Table 8 Summary of results comparing the incidence of failure (%) to meet the ER between two periods for the lowveld rivers. In some cases an additional period was examined and these data are indicated in parenthesis. * data from Perry's Bridge; **data from Kruger Gate (see text for details)

WMA	River	1st period (Development without IWRM)	2nd period (improved policy &/or management)	2nd period (improved policy &/or management)	Worst month	Compliance improving?
		Monthly Data		Daily data		
2	**Luvuvhu**	38.8	as previous	N/A	August	Not known
	Letaba	40.7	21.9	48.5	February	Improving since 1994
	Klein Letaba	see daily	see daily	88.4	September	Not known
4	**Lower Olifants**	46.8	44.8	56.3	August, September	No improvement
	Blyde	N/A	72.9	99.1	April to October	Not known
5	**Sand**	37.7	(13.6) 39.0	58.4	September	Declining
	Sabie	*38.7	**(23.3) 27.7	37.8	August, September	Declining
	Crocodile	14.4	(34.8) 50.0	55.5	September	Declining
	Komati	19.8	(53.7) 37.1	44.0	July	Declining
	Lomati	12.8	(9.0) 0.0	18.7	June, July	Improving

2.6.2. Lessons for the assessment of non-compliance

As noted in the introduction, there are a number of reasons for assessing or tracking compliance with the ecological Reserve. The type of assessment presented herein aims to answer the question: how well are we doing in meeting the obligation to the ecological Reserve? This talks to the concept of *progressive realisation* addressed in Section 4 (and see Pejan et al. 2007). At the final workshop of this project, held on the 13th and 14th May 2010[9], the representative of the Inkomati CMA suggested that this would be a useful tool to track and audit progressive realisation of the ecological Reserve. This could be done every three to five years for example. The purpose would be to audit compliance so as to share the information with stakeholders. Thus it would offer a useful tool for discussion and collaborative engagement regarding actions. Given that the ER is not an absolute value and that different management responses are appropriate depending on the severity of infringements, section 4.3 offers some recommendations in this regard. Prior to this however we turn to some of the lessons that have emerged in the assessment of compliance.

Using monthly versus data daily to assess compliance

At the workshops with various researchers and managers as part of this project, it was evident that the interpretation of infringements based on monthly data varied. To clarify this, Box 2 provides an overview of these interpretations.

In all cases it was noted that the use of average monthly data is likely to provide a conservative estimate of non-compliance (i.e. to underestimate incidences) both in quantity and in the distribution of non-compliance since they are based on monthly averages (see Table 8). Figure 35 provides an example of

[9] Final SRI-hydro workshop held at the Inkomati CMA, Nelspruit

the analysis based on monthly and daily data. In the case of monthly data, five months displayed infringements of the ER in contrast to eight months when daily data were examined. This is because monthly data can obscure daily infringements because the overall monthly average meets the ER requirement.

Box 2

Interpreting the incidence of compliance based on monthly data:

One of the interpretations for monthly data was that a single failure would render the whole month non-compliant. However, if there was a single day failure (for example) in a month, this does not imply that the whole month would be categorised as a "fail". Monthly data are an average of all daily flows for the whole month, so although a failure on a 'day' may occur, if the flows for the majority of days in the month were above failure level then the average would be compliant, unless of course a single days failure was so severe that it brought the average for the month down to a failure level. This is unlikely from one single day, but several/consecutive days could do this.

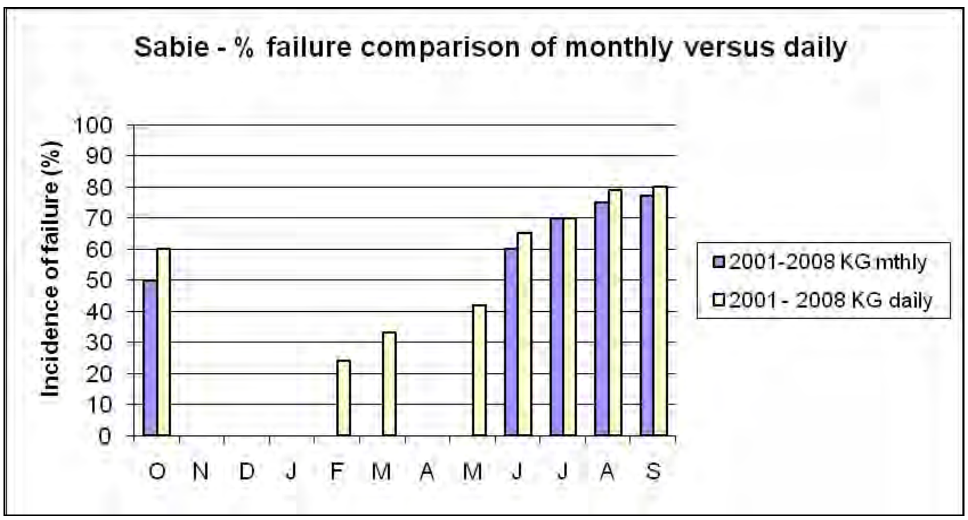


Figure 35 Comparison of determining incidence of failure based on monthly and daily data. Example illustrates EWR 3 on the Sabie River over two periods.

In data-poor environments there are constraints to basing the assessment on FDCs (as opposed to hydrographs for example). In some cases for example, our analyses was limited to a very short period of three to four years such as in the Komati and Lomati Rivers. In such instances, daily data must be used in order to have enough points to construct a reliable FDC; otherwise one may deem a situation to be compliant or non-compliant when in fact it reflects the shape of the curve. The important point here is that <u>FDCs are an indicator</u> rather than being representative of absolute values – a theme that will be addressed in the recommendations. The alternative is to develop a hydrograph of the ER against the observed flows but again, natural flows are needed. The constraints of this are highlighted in Section 4.

2.6.3. Location of gauge versus EWR sites

In a number of cases (see Table 8), the EWR sites are some distance upstream or downstream of the gauge station (see maps in Appendix 1). In both cases the estimate of non-compliance will be inaccurate without some sort of calibration. In a number of rivers assessed in this study such as the Sand, Olifants, Sabie and Luvuvhu, the EWR site is of a sufficient distance downstream of the gauge for flows to be reduced through evapotranspiration, groundwater transmission losses and abstraction. Thus the gauged data is likely to be higher than the actual observed flows at the EWR sites. In other words calibration would have to compensate for the losses experienced between the EWR site and the gauge. For example in order to deliver 2 m^3/s on a certain day at EWR 3 on the Sabie River, observed flows at the gauge X3H021 would need to be higher to compensate for losses and in particular for abstraction to the two bulk infrastructure schemes.

Table 9 Summary of the 'driver' EWR sites on the lowveld rivers and their distance and location relative to the closest DWA gauge station

Catchment	EWR site (driver site)	Closest Gauge station	Distance between EWR and gauge station (km)	Position of EWR site relative to gauge station
Komati	EWR K3	X1H003	<1	/
Lomati	EWR L1	X1H014	3	downstream
Crocodile	EWR6	X2H016	6.5	downstream
Sand	EWR8	X3H008	48	downstream
Sabie pre 2000[10]	EWR 3	X3H006	22	downstream
Sabie post 2000		X3H021	28	upstream
Olifants	EWR16 B73H	B7H015	69	downstream
Blyde	EWR12 B60J	B6H004	8	downstream
Letaba	EWR4	B8H008	9	downstream
Klein Letaba	EWR5	B8H033	2.5	upstream
Luvuvhu	desktop A91H	A9H012	50	downstream

The opposite situation in which the gauge is upstream of the EWR site is also likely to affect accuracy and require calibration. In this study only one gauge was a considerable distance upstream of the EWR site (X3H006 on the Sabie pre-2000). Like the above example, calibration would have to compensate for the losses experienced between the gauge and the EWR site. Using the same example, to deliver 2 m^3/s at an EWR 3 on the Sabie, may require higher flows at the X3H006 gauge. However, calibration is further complicated by inflows from the Marite and Noord-Sand systems just below the gauge and this would also need to be considered.

[10] The gauge X3H006 (also known as Perry's Bridge) was destroyed by the 2000 floods and so no data is available after that period. Thus another gauging station, X3H021 (also known as Kruger Gate) had to be used to examine compliance over the last period.

Examination of data from the Sabie illustrates the point further. A comparison of estimates of compliance based on these two different gauge stations is shown in Figure 36. The upstream gauge (X3H006) indicates a greater degree of non-compliance (incidence of failure) than data for the same period based on the downstream gauge (X3H021). This may partly reflect the aforementioned factor; the inputs from two river systems just below X3H006 are not accounted for. Equally, the data for the downstream gauge have also not been calibrated for losses and were they to be considered, non-compliance based on this gauge (X3H021) would be likely to be higher.

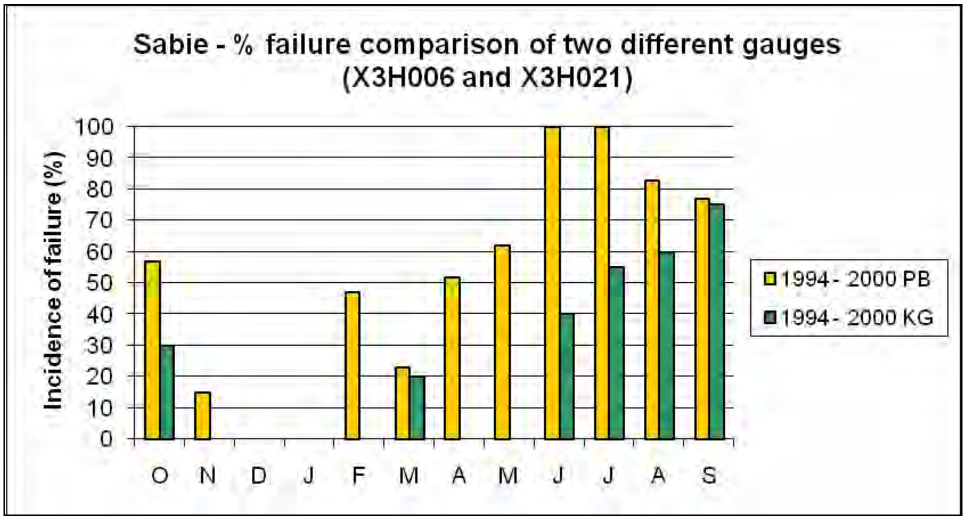


Figure 36 Comparison of determining incidence of failure based on different gauging stations. Example illustrates EWR 3 on the Sabie River over two periods.

Although some argue that these calibrations could be incorporated into the monitoring, it would appear to be an unsatisfactory. A far more accurate and elegant solution would be to ensure that the EWR sites are situated where monitoring can be facilitated – either via a current gauge or through inexpensive instrumentation in support of monitoring.

2.7. Recommendations – Linking the operation and monitoring of the ecological Reserve to management actions

A central question for the team towards the later part of this work was this: *Can real-time compliance monitoring based on daily data be undertaken?* We would suggest that our work throughout this project repeatedly demonstrated that determining and monitoring the ER as an absolute value, such as a daily Reserve (albeit dynamic on an intra-seasonal and inter-annual basis) is not tenable (see Section 4 for further discussions). This thinking is not new. Indeed the Kruger National Park has persistently attempted to improve upon monitoring for management over the last seven to eight years (see Biggs and Rogers 2003) . The core of their approach – which is adaptive in nature – is that of Thresholds of Potential Concern (TPC). A detailed description of these is beyond the scope of this project and readers are referred to the literature for further detail. The essence is that there are different levels of concern related to the status of a resource in question (e.g. river flow) and hence different management actions linked to each. In general, the concerns increase from 'taking note', to the most severe, which may involve contacting government representatives for example. The severity of the worry level is given via an indicator or TPC which is collaboratively determined. The important principle therefore is that there is an envelope of *levels of concern* – supported by clear rationale – and each linked to different management actions. This approach is now being tested in the Crocodile and Letaba Rivers. An example of this is given in Figure 37 for the Letaba River. Here the ER is set according to a drought severity index. Thereafter different flow levels are associated with different thresholds of concern which are linked to different management actions.

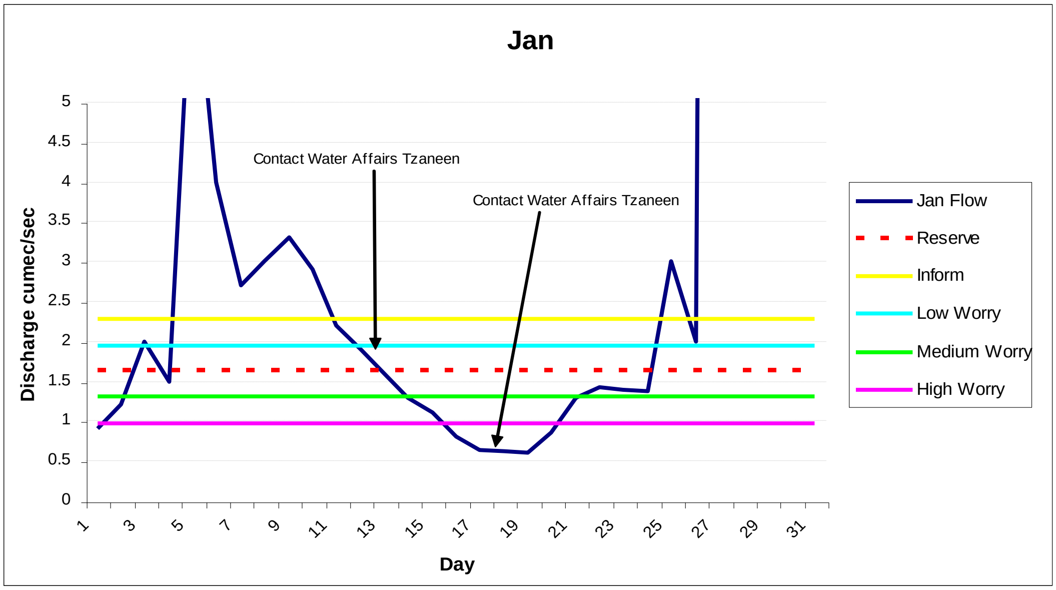


Figure 37: An example of the management system being developed for the Letaba River indicating levels of concern associated with different flows in January (drought severity of 60%)
(source C. McLoughlin, SanParks, pers. comm.)

In recognition of the complexities of real-time monitoring and management it was generally agreed by the team and wider group at the May 2010 workshop, that the ER will be need to be represented by a minimum flow for each month in much the same way as is being done in the Letaba River. Adding worry levels or TPCs as shown above (and in the same way as is done for other ecosystem components in the KNP) provides a model for linking monitoring to action. Moreover such data, and a visual representation thereof, also provides a powerful tool with which to share and discuss with stakeholders. Thus the central principle should be that there is a minimum flow and associated levels of concern that need to be tracked and linked to clear management actions. The data presented in this report offers a useful benchmark from which to initiate such monitoring measures.

SECTION C A comparison of Reserve implementation using natural and gauged flows for the Crocodile and Letaba Rivers

By Stephen Mallory

3. Modeling the Reserve with natural and gauged flows

3.1. Introduction

As noted in the introduction, the ecological Reserve is defined, at least in South Africa, as a function of the natural flow. While this is a useful method to describe the ecological flow requirements, it creates problems with real-time implementation of the Reserve simply because the natural flow in a system is not known at any point in time. In order to estimate the natural flow, and hence the ecological flow requirements, real-time hydrological models are required which need to be provided with accurate daily rainfall recorded over the catchment in question.

A serious short-coming in models which are currently attempting to implement the Reserve in real-time is the lack of real-time rainfall data to drive the hydrological model. This problem was document by Hughes et al. 2008. The South African Weather Services have closed down most of their real-time rainfall stations and while they are developing radar and satellite techniques for recording rainfall, these techniques are not yet accurate enough for use in hydrological models.

An alternative to the use of a hydrological model is to use a flow gauge located in an undeveloped catchment and extrapolate this recorded flow to other points in the catchment. The short-coming of this approach is that there are very few undeveloped gauged catchments in the areas where catchment managers wish to implement the Reserve. Also, extrapolation does not necessarily result in accurate estimates of natural flow at locations with significantly different rainfall.

The other problem emerging from the attempted implementation of real-time water use management systems is that water users, especially irrigators, would like to know in advance how much water will be available to them over the next growing season so that they can decide what area of crops to cultivate. Existing water resources models can give estimates of available water in the short-term but cannot indicate how much water will be required for the Reserve, simply because the future flow is not known.

Possible solutions to the problem of estimating real-time natural flows and hence estimating real-time ecological flows have been addressed in this project. During the first Phase, the methodology was described and software developed to facilitate both testing and actual implementation of the methodology. During the second Phase, the methodology was been tested, and this report present the outcome of these tests.

It must be stressed, however, that the methodologies developed as part of this project are but one many possible approaches and that each methodology has its strengths and weaknesses. As part of this study, a brief review of the currently available reserve implementation methodologies has been carried out and suggestions made as to which methodologies are applicable under which circumstances.

3.2. Brief review of Reserve implementation methodologies

Hughes, in his report to the Water Research Commission (Hughes et al. 2007), uses the natural flow as a mechanism to trigger operational decision relating to meeting the Ecological Water Requirements. The decisions relate to either releasing water from a dam to supplement flows from incremental catchment downstream of the dam, or restricting water use if there are no dams with which to manage releases into the river. In some complex catchments, a combination of restrictions and releases is also possible.

The decisions made are based on the natural flow at some key point in the catchment that is relevant to ecological Reserves site in question. Typically this would be the natural flow at the site but in pilot studies conducted subsequent to the WRC studies (DWAF 2009), the natural flow into dams was also used as the decision making criterion. Whether this methodology is successful or not is difficult to judge at this point in time and it is suggested that monitoring will be required over several years in order to ascertain this.

Using the natural flow as a decision making criteria is logical in one sense in that the ecological water requirement is already defined as a function of the natural flow. However, several practical limitations need to be overcome when applying this technique. If the catchment is being operated on a monthly time step, it is only possible to estimate the natural flow after the event, by obtaining monthly rainfall data and carrying out a simulation using a calibrated hydrology model. Even then, these estimates are not always accurate due to poor spatial representivity of the rainfall data and to limitations in the hydrological model. Hughes attempts to overcome the timing problem by using recent rainfall data to predict (based on historical records) what is likely to happen in the remainder of the month. Nevertheless, the variation between the predicted runoff and the actual runoff can be large resulting in over or under estimation of the ecological Reserve requirements.

3.2.1. Berg River Dam

The recently completed Berg River Dam, located in the upper reaches of the Berg River near Cape Town, has a complex ecological flow releases rule which is designed to release water for both base flow and flood requirements of the ecological Reserve. This is reported to the first dam in South Africa which is operated to meet ecological flood requirements. The operating rule is based largely on the inflow into the dam and can be applied successfully in this case because this inflow is very close to natural. The release is then estimated from a database of recorded flood events. The dam operator matches the current inflow flood event to a similar event in the database and selects a matching release pattern. The other factor which contributes to the success of this methodology is that the ecological flow to be met is monitored just downstream of the dam, and hence floods generated from the incremental catchment between the dam and the EWR monitoring site as well as the lag time of releases from the dam become irrelevant.

3.2.2. Sabie River catchment

A complex river management model was developed for the Sabie River catchment by the DWAF and their consultants (DWAF 2003). The basis of this model was to utilize the recorded flow at a gauge to estimate the Reserve requirements at other points in the catchments. While the flow at the selected gauge is not natural, the main impact on the flow at the gauge is exotic forestry, which while it does reduce the runoff significantly, the pattern of flow remains close the natural pattern. Through calibration, the relationship between the so-called reference flow at the indicator gauge and the ecological water requirements at the EWR sites located in the Kruger National Park.

3.3. General Approach

A possible solution to the problem of estimating natural flow (and hence the ecological Reserve) is to utilize gauged flows as a basis for Reserve implementation rather than natural flow.

Since the Reserve is defined as a function of natural flow, the use of gauged flow will require an adjustment of the gauged flow to natural flow which entails estimating water use during the time interval under consideration and adding this onto the observed flow. Expressing this mathematically:

Eq. 3 $\text{Natural flow}_t = \text{Observed flow}_t + \Sigma \text{Wateruse}_t$

Where t refers to a time interval rather than a point in time. The time interval will generally be monthly or daily, depending on the sophistication of the catchment management model.

If there are a significant number of dams in a catchment, the change in storage of these dams will also cause the observed flow to deviate from natural. For example, if large unseasonal releases are made from a dam, the observed flow could even be greater than natural, while during the first summer rains floods are stored and hence the observed flow is much less than natural.

Hence, including this in equation 3:

Eq. 4 $\text{Natural flow}_t = \text{Observed flow}_t + \Sigma \text{Wateruse}_t + \Delta \text{Storage}$

The advantages of applying this concept to estimate natural flows is that there is a relatively good network of real-time gauges flows in South Africa, especially in the developed catchments where Reserve implementation is urgently required. The use of gauged flows does away with the need for complex hydrological models. Hence the uncertainty relating to hydrological modeling is effectively removed from the equation. Furthermore, rainfall data, which is becoming a huge stumbling block in Reserve implementation, is not required

Estimating water use in real-time can become a complicated process depending on the temporal scale at which the catchment is operated. Essentially what is required is a detailed knowledge of the water use drivers within a catchment and this must be at a temporal scale appropriate to the temporal scale at which the catchment is operated. Water use information is becoming increasingly more reliable and accessible through the DWAF's Water Allocation and Registration Management System (WARMS). Also, detailed studies have been undertaken by DWAF in all of their highly stressed catchments and hence water use information is generally available, even if not in real-time. Since no or very few new water use licences are being issued in these stressed catchments, the water use situation is also static which makes this proposed approach stable and sustainable.

The proposed methodology was investigated in a phased manor. Firstly a theoretical modeling exercise to compare the estimates made using gauged flows with estimates made using known natural flows over a historical period. The uncertainty relating to these two approaches will also be evaluated. It is hypothesized that the uncertainty in hydrological modeling is at least as great if not greater than the uncertainty relating to water use, and hence the use of gauged flows as an indicator of the ecological Reserve is as good as if not better than attempts to estimate natural flow in real-time.

The objectives of this component were:

To test real-time on a real operation system.

This required the use of a water resource model to convert recorded daily flow at gauges in a catchment to natural flow based on estimates of water use. Real-time models have already been set up for the Crocodile and Letaba catchments incorporating a real-time hydrology model. The water use in the catchment is well understood and detailed water resources models are available to assist with the assessment of natural flow based on observed or gauged flow. A comparative analysis is therefore suggested to compare the two approaches of determining the ecological flow requirement. It will be possible by monitoring the flows to determine after a period of say 1 year which method was most successful in estimating Reserve requirements. Details of this proposed real-time modeling are as follows:

The overall approach which compares the EWR based on natural flows (the current approach) to that based on observed flow, is summarised as follows

Approach 1 *Estimate the natural flow using a hydrological model.*

In the case of the Crocodile River catchment, a real-time model has been set up using the NAM hydrology model which uses daily satellite rainfall data. The maintenance and operation of this model has recently been handed over to The Inkomati Catchment Management Agency.

In the Letaba catchment, the intention is to utilize the Hughes Real-time model that was set up for the Department of Water Affairs' RDM office in order to implement the ecological Reserve. This model also uses satellite rainfall data to drive a modified Pitman hydrology model. While the NAM model generated daily flow, the Pitman model is really a monthly model. Some features have been added by Hughes to disaggregate the hydrology produced in the 10 day time intervals.

Approach 2 *Estimate the natural flow using estimates of water use over the selected time period*

The methodologies used to estimate water use in real-time (described in this report) have already mostly been incorporated into the Water Resources Modelling Platform (WReMP) which is a monthly time-step water resources modeling tool. This model will then be used to estimate water use on either a daily or monthly basis.

The results from the two approaches will be compared and conclusions drawn as to which offers the best solution to real-time implementation of the ecological Reserve.

3.3.1. Obtaining observed flow

The Department of Water Affairs operates numerous flow gauges throughout South Africa. A few of these gauges are fitted with real-time technology which transmits information to the DWA website. Flow at these real-time gauges can therefore be obtained with a time lag of only a few hours. The catchments selected for study both have real-time gauges at the downstream end of the catchments, without which this study would not be possible.

3.3.2. Estimating water use

General methodology

There are two main issues regarding the estimation of water use within a catchment. The first is simply obtaining an estimate of average use (usually expressed as a mean annual average use) and secondly the disaggregation of this estimate into monthly or daily estimates. If the ecological Reserve is to be applied and monitored on a monthly basis, then the annual estimate will need to be disaggregated into monthly volumes while daily disaggregation will be required if more detailed monitoring becomes a pre-requisite of EWR implementation.

Domestic and industrial use

Water use estimates for industrial water use are readily available from the WARMS database and are generally considered to be reliable because most industrial users have registered their water use and have the expertise to calculate their water requirements reasonably accurately. Domestic water use becomes a problem when considering small towns, villages or rural communities, where water use is not monitored. The water use of the larger towns can generally be obtained from the WARMS database and records of actual water use can usually be obtained from the larger municipalities or the water services providers.

The problem of disaggregating annual water use estimates of domestic water users is fairly straightforward and can be estimated from water use records where these are available. The general trend in towns and cities is to observe somewhat lower water demands in winter than in summer due to garden irrigation, which is greater in summer than in winter. Industrial water use mostly remains constant throughout the year, although some industries may have peculiar patterns due to the specific nature of their operation. A good example is the sugar mill located on the lower Komati River catchment which shuts down for maintenance for about 2 months every year, during which time the water use is very limited.

Irrigation

By far the biggest challenge in estimating water use within a catchment, whether this is based on annual average use or daily use, is that of the irrigation sector. Irrigation water use is rarely monitored and engineers and water resource modelers need to resort to estimates based on the factors influencing the irrigation water requirements. The factors are:

- The type of crop grown
- The cropping pattern (winter, summer, or double cropping)
- The evapotranspiration rate which dictates the water requirement of the crop on any day
- The rainfall, which affects the soil moisture and hence the need to irrigate.

This complex requirement pattern has fortunately been studied in a lot of detail by many researchers and there are now a wide range of models that can be used to estimate the amount of water that should be applied to a crop to target optimal growth. While the intention is to utilize such models to estimate crop water requirements on a day to day basis as part of this project, the short-comings are:

- Regardless of the theoretical crops requirement, restrictions are often placed on the actual supply due to the limited water resource.
- Accurate determination of the crop water requirement requires the use of a potentiometer which measures the soil moisture. While an increasing number of irrigators are utilizing this technology, there are still many irrigators who irrigate constantly regardless of soil moisture.
- Some irrigators have constructed off-channel storage and will continue abstracting from the river regardless of the crop requirement. This water will then be stored for later use. Even if information on the operation of these off-channel schemes was known (mostly it is not), it would not be practical to model each and every off-channel scheme individually and some simplifying assumptions need to be made to take into account off channel storage practices.

Streamflow reduction due to afforestation

It is a well established fact that afforestation in South African conditions will result in a reduction in runoff. The reason for this is largely due to the increased rooting depth of trees over the grassland they replace and that trees planted commercially in South Africa (Pine, Eucalyptus, Wattle) grow throughout the year while the natural vegetation generally become dormant during the dry winter months, using very little water during this time. The two impacts results in increased transpiration of water sourced from the soil profile, hence decreasing interflow and groundwater recharge to rivers. A secondary and less pronounced effect is the increased interception of forests over grassland. Typical rainfall interception estimates are 1.5 to 2 mm for natural vegetation in South Africa while this increases to 5 to 7 mm if grassland is replaced by exotic forests.

Methodologies to estimate streamflow reduction in South Africa are mostly based on natural flow, with afforestation using a greater proportion of the natural flow during low-flow periods than during high flow periods. A typical example is given below in which streamflow reduction estimates for Eucalyptus, Pine and Wattle are shown as duration curves relative to the natural flow. This shows that Pine will typically reduce floods by 50% and low-flow by 100% within the catchment that they occupy. This is assuming 100% cover of the catchment which never happens in practice due to many areas being unsuitable for afforestation, for example, insufficient soil depth, excessive slope, etc. Legislation now also forbids the planting of exotic trees within riparian zones.

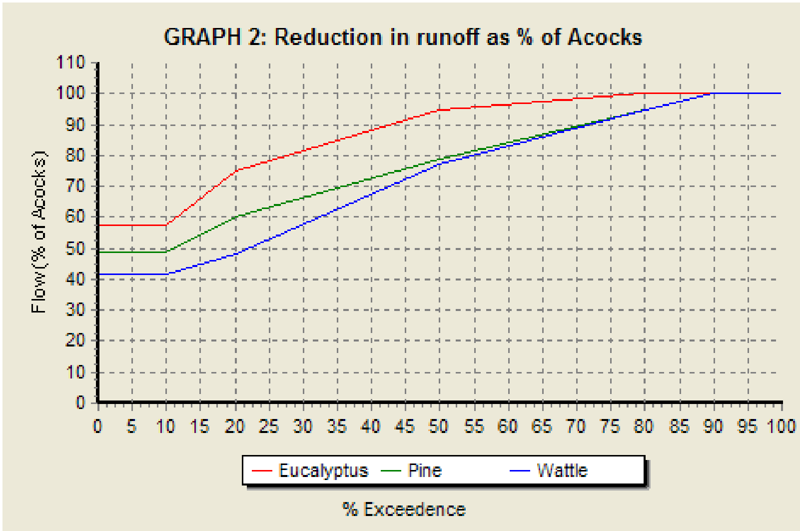


Figure 38 Typical streamflow reduction to afforestation

Relationships such as those shown in Figure 38 are available for all areas in South Africa where there is currently afforestation. With the aid of a water resources model, it is therefore possible to estimate the streamflow reduction within any area provided a record of the natural flow is available. The short-coming of applying this technique to estimating streamflow reduction in real-time is that the natural flow is not necessarily being determined at a sufficiently refined scale to utilize directly for streamflow reduction estimates. In the case of the Letaba River catchment, the Hughes Real-time model has been calibrated to estimate natural flows only at the EWR site (Letaba Ranch) while the proposed methodology to estimate natural flow in real time which is proposed (and is being tested in an associated project) also only determines that at a key gauge site.

The approach taken to resolve this problem is to assume that the estimated natural flow is indicative of rainfall throughout the catchment, hence if a high natural flow is estimated at the lower end of the Crocodile catchment (Tenbosch), the high natural flow must have occurred throughout the catchment in order to achieve this condition. Hence the estimated natural flow is expressed as a point on the natural flow duration curve for the EWR6 site and the assumption made that this same percentile applies at all other sub-catchments within the catchment. It is then possible to estimate streamflow reduction on this basis.

A complication that needs to be overcome in estimating the SFR based on the natural flow is that the natural flow itself is dependant on the SFR. This inter-dependancy is resolved numerically through an iterative solution. It was found through trial and error than after only 4 or 5 iterations the used algorithm solves simultaneously for SFR and natural flow.

Impoundments

As indicated in Equation 2, the change is storage over the time interval under consideration needs to be taken into account when estimating the natural flow if the observed flow is to be used as the prime indicator. The water level in the larger dams operated by DWA is recorded on a daily basis and this information is published on their website on a weekly basis. It is therefore possible to obtain a reasonably accurate estimate of the change in storage within a catchment over a weekly time period.

The methodology used was to use the weekly change in storage and disaggregate this into a daily flow by assuming the change in storage was uniform over the 7 days making up the week. Alternatively, if a monthly EWR is being estimated then the change in storage over the past month is used. This does necessitate maintaining a record of the change in storage within the catchment. The system has been set up to keep track of the storage in the following dams in the Crocodile (east) catchment:

- Kwena
- Witklip
- Klipkoppie
- Longmere
- Primkop

3.3.3. Transfers In

Many catchments in South Africa receive water from other catchments, a notable example being the Vaal River catchment which receives water from the Thukela River, Lesotho, the upper Usuthu and the Komati River. Observed flows within the Vaal System will therefore be influenced by these transfers. In order to estimate natural flow these additional flows must be subtracted from the observed flow. Hence equation 4 becomes:

Eq. 5 $$\text{Natural flow}_t = \text{Observed flow}_t + \Sigma\text{Wateruse}_t + \Delta\text{Storage} - \Sigma\text{Transfers in}$$

3.4. Methodology

The actual implementation of real-time naturalization is not as simple as equation 5 might imply. Firstly, accurate observed flow is required and this must be collected diligently. Then estimating water use by the irrigation sector also presents a challenge since this can vary depending on rainfall. While rainfall is not crucial to this real-time naturalisation process (as it is in the case of a hydrology model) it does improve estimates of irrigation requirements.

3.4.1. Real-time Natural flow Estimation Modelling techniques

In order to address the challenges of real-time natural flow estimation, several adaptations to an existing water resources model (Mallory et al. 2010) were made, as described in the following sections.

Real time Rainfall

The main change entailed adapting an irrigation model to accept rainfall as a parameter passed to the irrigation procedure in run time rather than utilising a rainfall time series, which typically covers the period 1920 to 2004. While this may seem to be a trivial change, it does imply the collection of rainfall for the entire catchment, preferably at a quaternary resolution. For the purposed of this study, rainfall was obtained from the NOAA[11] website and adjusted in order to match the mean annual precipitation of the catchments in which the rainfall is located. More rigorous adjustment techniques have been developed for monthly rainfall (Sawunyama 2009) and this is an aspect that requires further attention.

Restrictions

In both the Letaba and Crocodile River catchments, the irrigation boards limit the water use of their members during droughts. Hence to obtain a realistic estimate of the actual water use this needs to be taken into account. Failure to do so will result in an over-estimation of the natural flow and hence the ecological Reserve.

A record of the restriction imposed by the irrigation board in both the Letaba and Crocodile River catchments was obtained from the Groot Letaba Irrigation Board (Venter 2009) and the Crocodile Irrigation Board (Putter 2009). Decisions to impose restrictions are made on a weekly basis in both these catchments and it was therefore necessary to aggregate this weekly data into monthly data for the purpose of this pilot study.

3.5. Pilot Application of Real-time naturalization

3.5.1. The Groot Letaba catchment

Catchment overview

The Groot Letaba catchment is located in the Limpopo province just north east of Polokwane, stretching from Haenertsburg and Duiwelskloof via Tzaneen to the western boundary of the Kruger National Park. The rainfall is high by South African standards, with rainfall in the mountainous areas in the West in excess of 1 800 mm/annum in places. Towards the east the rainfall reduces down to only 500 mm/annum.

[11] ftp://ftp.cpc.ncep.noaa.gov/fews/newalgo_est

The catchment as a whole is well developed in terms of irrigation while there is also a significant amount of domestic water use (see Table 10). The hydrology of the Groot Letaba River catchment is summarised in Table 11.

Table 10 Water use in the Groot Letaba River catchment

Water use sector	Water use/Stream flow reduction (million m^3/annum)
Irrigation	160
Domestic	33
Industrial and mining	3
Afforestation	31

Table 11 Summary of the hydrology of the Groot Letaba River catchment

Sub catchment	Natural MAR (million m^3/annum)
B81A	48.5
B81B	156.9
B81C	28.2
B81D	94.3
B81E	34.5
B81F	20.2
B81G	23.1
B81H	7.5
B81J	5.9
Total	**419.1**

The water requirements of the Groot Letaba system cannot be fully met all the time and restrictions are frequently applied to all sectors, especially the irrigation sector. While DWA do recommend restrictions to users and have on occasions applied these through the gazetting of restrictions, the Groot Letaba Irrigation Board regulate themselves and impose restrictions on their users. It is interesting to note that in recent times these restrictions were harsher than those recommended by DWA.

Methodology specific to the Groot Letaba River catchment

The intention with the pilot testing of this real-time naturalisation technique was to compare the natural flow obtained, in real-time, by different methods. While comparison of models or methods may not be scientific, the reality is that natural flow is a concept and not something that can be measured in a developed catchment. It can only be calculated and there will always be some inaccuracy or uncertainty in this calculation. Hence comparison with existing techniques or data sources is the only way to test a new technique.

One of the reasons that the Groot Letaba River catchment was chosen as a pilot catchment is that there is an existing process in the Groot Letaba River to implement the ecological Reserve. This process was initiated by DWA as part of the study referred to as the Development of a Framework to Operationalise the Reserve (DWA 2009) and has been continued by SANPARKS (McLoughlin 2009). One of the outcomes of this study was a near real-time hydrological model which uses satellite rainfall data to drive a hydrology model, produce natural flow, and can hence indicate the action required within the catchment to meet the Reserve. These actions usually entail releases from the Tzaneen Dam but can also entail applying restriction to users.

The importance of this near real-time model is that it generates natural flow and hence provides a comparative data set for this real-time naturalisaton methodology. Hence the methodology followed in the Letaba catchment was as follows:

Method A: Hughes Real-time model

- Obtain the Hughes Real-time model setup for Letaba
- Run this model as far back in time as possible, the limitation being the length of the satellite data record.

Method B: Real-time naturalization model

- Get observed flow at B8H008 (Letaba Ranch)
- Obtain data on all anthropogenic influences over the same period as the Hughes Real-time model (or far back into the past as possible). This includes:
  - Water use
  - Change is storage
  - Streamflow reduction
  - Evaporation losses
- Estimate natural flow based on a monthly time step (observe flow plus the above influences)

The natural flows generated from these two methods were then compared.

3.5.2. The Crocodile River Catchment

Catchment overview

The Crocodile River catchment is located on the north-eastern side of South Africa and drains into Mozambique. This catchment has relatively high rainfall compared to the rest of South Africa, with rainfall in excess of 1 100 mm/annum in the mountainous area west of Nelspruit while the catchments in the lower reaches of the Crocodile River catchment experience rainfall of about 600 mm/annum. The catchment as a whole is highly developed in terms of irrigation while there is also a significant amount of domestic water use (see Table 12). The hydrology of the Crocodile River catchment is summarised in Table 13.

Table 12 Water use in the Crocodile River catchment

Water use sector	Water use/Stream flow reduction (million m^3/annum)
Irrigation	482
Domestic	52
Industrial	22
Afforestation	158

Table 13 Summary of the hydrology of the Crocodile River catchment

Sub catchment	Natural MAR (million m^3/annum)
X21 (Elands River)	467
X22 (Middle Crocodile)	362
X23 (Kaap River)	204
X24 (Lower Crocodile)	107
Total	**1 140**

As indicated in section 3.2.2, the water requirements of the Crocodile River cannot be met all the time. Irrigators are therefore restricted frequently. While the ICMA keep track of the water situation in this catchment with the aid of a sophisticated real-time model (Cai et al. 2010) and can enforce restrictions, the irrigation board are currently imposing restrictions on their users which are often in excess of the restrictions recommended by the ICMA. This has a direct and very significant impact on the actual water use within the catchment at any point in time.

Methodology specific to the Crocodile River

The Crocodile Real-time model was supposed to have the capability of generating natural flow with the NAM hydrological model. However, the NAM model could not be calibrated successfully. Hence there is no other source of real-time hydrology to compare against. An alternative strategy was adopted in which all data required for real-time naturalisation was collected as far back as possible and a simulation, referred to in this report as a *batch run*, was carried out over this period. The reason this is referred to as a batch run is because the intention was (and still is) for the catchment operator to determine the real-time natural flow on a daily or weekly basis and not determine this many years later, which would defeat the purpose of the exercise. Hence it was necessary to develop a separate procedure within the Crocodile water resources model to carry out this batch run.

While there are unfortunately limitations on how far back in time this batch run could go, the natural flow generated does overlap with the hydrology produced by the Inkomati Water Availability Assessment Study (DWA 2009). Hence some comparison of naturalisation methodologies is possible.

The data collected for this Batch Run is summarised in Table 14.

Table 14 Summary of data available in the Crocodile River catchment

Data	Period	Frequency	Source
Rainfall	Jan 2001 to July 2010	Daily	NOAH website
Storage	1980 to June 2010	Weekly	DWA
Observed flow	October 2003 to June 2003	Monthly and daily	DWA
Restrictions	Jan 2003 to June 2003	Weekly	Crocodile Main Irrigation Board

The storage, observed flow and restriction data sets are listed as monthly time series in Appendix B. Note that the data was obtained as daily or weekly frequencies while the observe flow is also available at a daily time step. It is therefore possible to generate real-time natural flow at a weekly time step using this data.

3.6. Results

3.6.1. Results: Groot Letaba catchment

The natural flow determined in the Groot Letaba River (approximately at the lower EWR site, referred to as EWR4) using the real-time naturalisation technique is show in Figure 39. The flow has been plotted with the Observed flow and the natural flow from derived from the Hughes Real-time model (Hughes et al. 2008; DWA 2009).

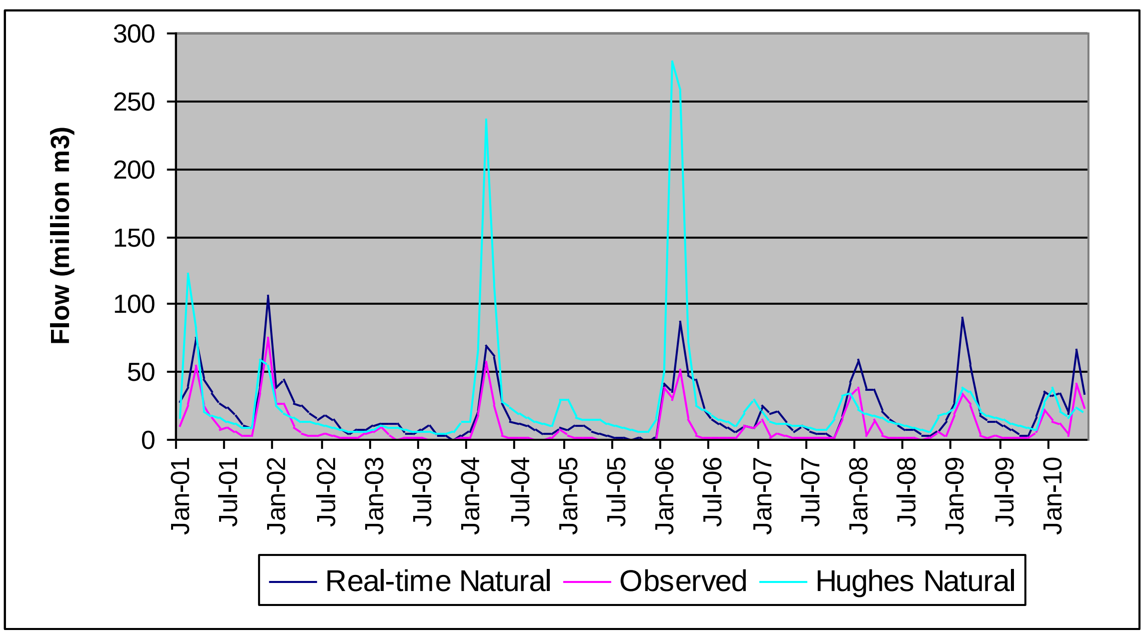


Figure 39 Natural flow estimated using the Real-time model (Letaba catchment)

Based on visual inspection, the Hughes Natural and real-time natural flows (derived as part of this study) are similar and track the pattern of the observed flow well enough to be plausible. The exceptions are:

- the Hughes natural flow seems to overestimate the floods in 2004 and 2006. It could be argued that the Hughes' model is correct and that the observed flow at this time was an underestimate, but careful analysis of the daily observed record during these time periods shows no evidence on inaccurate gauging, and
- The Real-time naturalisation gives suspiciously low natural flow during the extreme drought in 2005. This very low flow stems from the 90% restriction applied to irrigators during this period. If irrigators really only used 10% of their allocation during this time and the observed flow was close to zero, then it follows that the natural flow during this period could indeed have been very low. It is possible, even likely, that while a 10% restriction was announced, some irrigators used more than they should have during this period, resulting in an underestimation of the natural flow. It is also possible that there were high losses during this period which the real-time naturalisation has not catered for.

Table 15 Summary of the anthropogenic influences on the Letaba River catchment over the period January 2001 to June 2010

Naturalisation parameter	**Average annual volume (million m^3/annum)**
Irrigation water use	76.7
Streamflow reduction due to afforestation	N/A
Other water use (domestic/industrial)	42.5
Transfers into the catchment	0.0
Change in storage	0.0
Evaporation	12.1
TOTAL	**131.3**

Note that while there are large areas of afforestation upstream of the Tzaneen Dam (see Table 15), which result in a large reduction in runoff, this is mostly upstream of the Tzaneen Dam and hence it impact is already captured in the change of storage of this dam.

Another source of comparison is the natural flow derived from the WR2005 study (Middleton and Bailey 2008). Although this data overlaps the Hughes and Real-time naturalisation dataset for only a shorter period of about 5 years, this does provide another important comparison (see Figure 40).

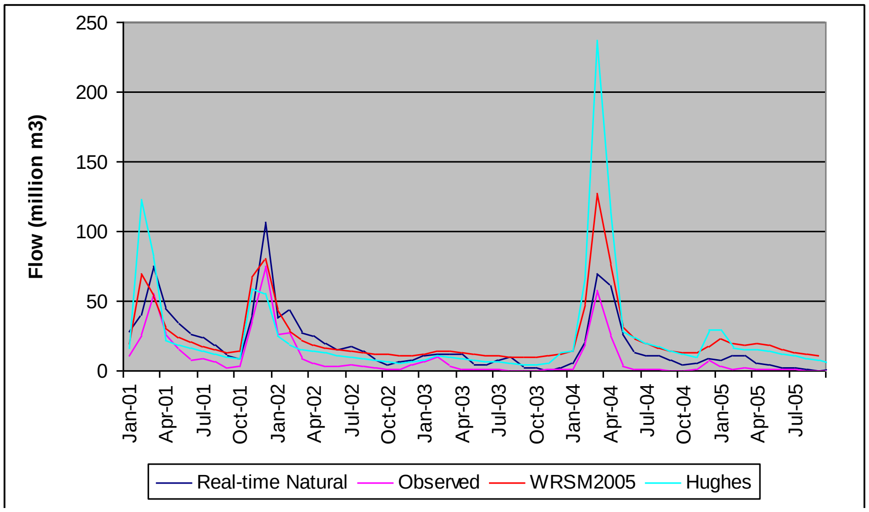


Figure 40 Natural flow estimated using the Real-time model, including WRSM2005 natural flows (Letaba catchment)

Including the WR2005 (Middleton and Bailey 2008) as a comparative dataset reinforces the conclusion that the real-time naturalisation process is sound. The WR2005 dataset does however seem to indicate higher natural flow during the winter low-flow periods than the real-time or Hughes methods. This was investigated in more detail by comparing the simulated and observed flows obtained from the WRSM2005 model (see Figure 41).

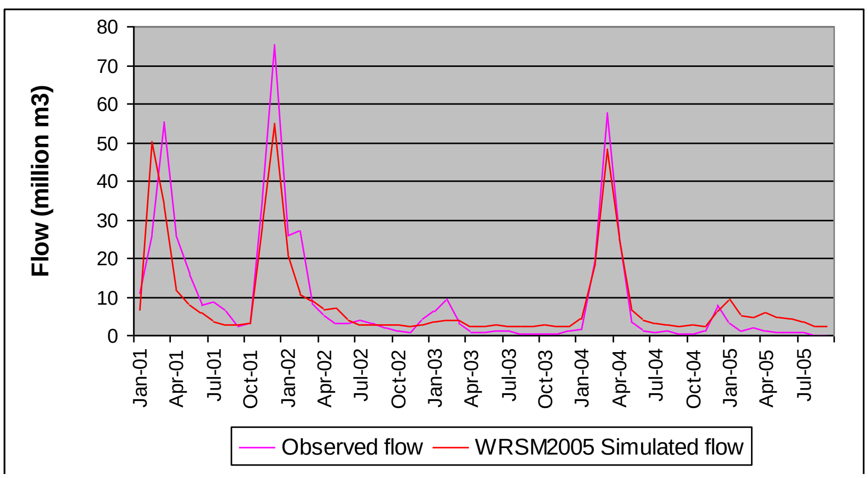


Figure 41 Comparison WRSM2000 Simulated flow and Observed flow

It is clear from Figure 41 that the WRSM2000 model is over-estimating the low flow during the severe drought of 2003 and 2005. This is probably due to an underestimate of the actual water use during this period and/or elevated losses. The result of this is the WRSM2000 natural flow will be an over-estimate of the natural flow, especially during low-flow periods.

3.6.2. Crocodile catchment

The natural flow determined in the Crocodile River catchment (approximately at the lowest EWR site) using the real-time naturalisation technique is show in Figures 42-44. The flow has been plotted with the Observed flow and the natural flow from derived from the Inkomati Water Availability Assessment (DWA 2009).

The natural flow is, as expected in this catchment, always greater than the observed flow, the difference between natural and observed being the water use and change in storage within the catchment. This water use and change in storage is summarised in the Table 16 while the monthly times series were given in Deliverable 3.

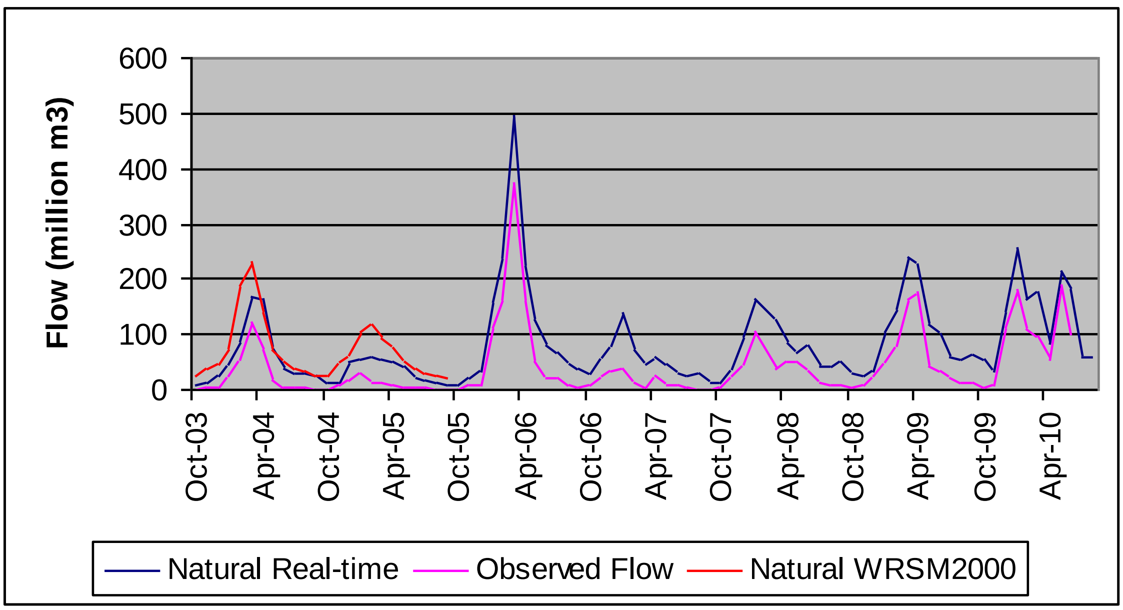


Figure 42 Natural flow estimated using the Real-time model

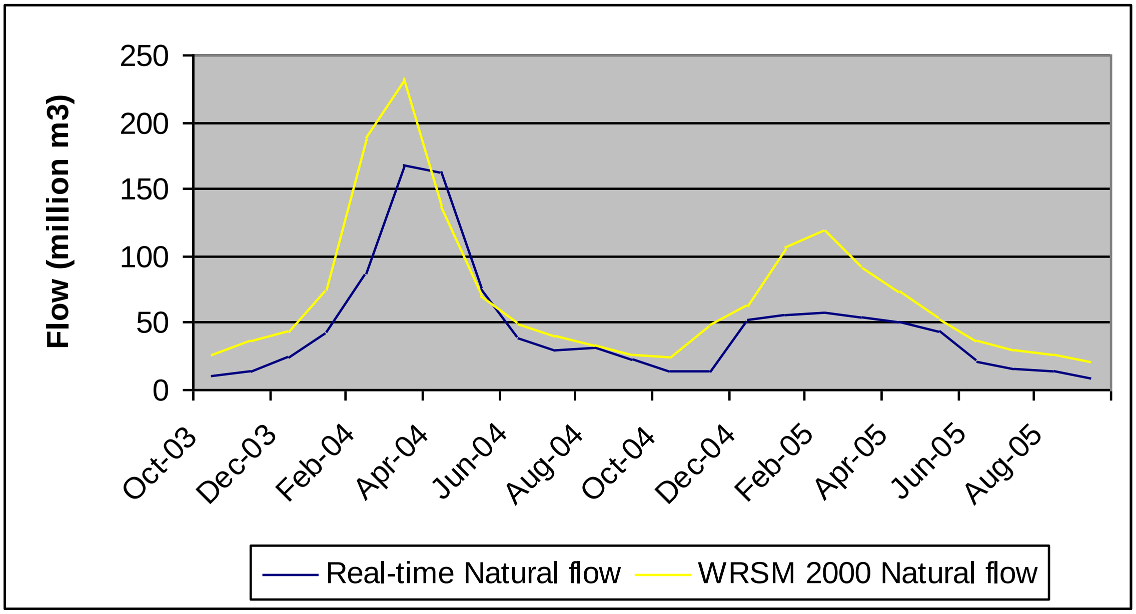


Figure 43 Comparison between Real-time naturalisation and WRSM2000

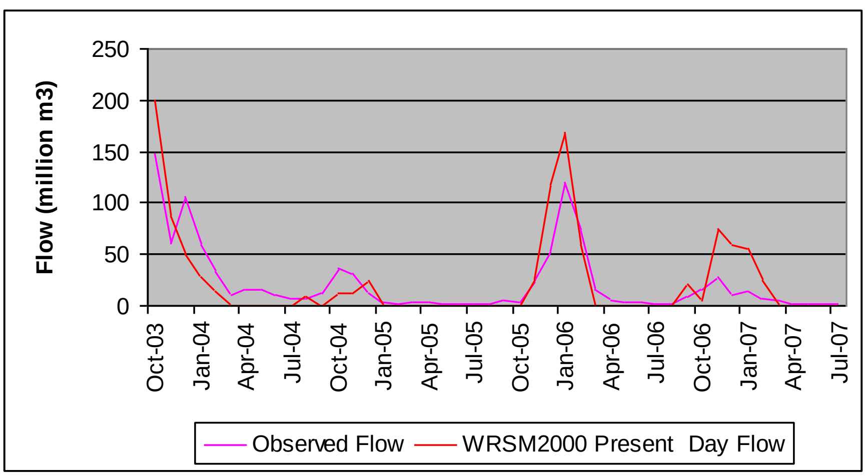


Figure 44 Comparison WRSM2000 Simulated flow and Observed flow

Table 16 Summary of the anthropogenic influences on the Crocodile River catchment over the period October 2003 to June 2010

Naturalisation parameter	**Average annual volume (million m^3/annum)**
Irrigation water use	254
Streamflow reduction due to afforestation	158
Other water use (domestic/industrial)	65
Transfers into the catchment	13
Change in storage	14
Evaporation	10
TOTAL	**482**

3.7. Implementation of the Real-time naturalization

The proposed methodology to estimate the EWR on a monthly or real-time basis needs to be tested over as long a time interval as possible to ascertain if it produces plausible and consistent results. From equation 4, the observed flow and change in storage are reasonably easy to obtain, while water use during a time interval, and especially streamflow reduction, are not easy to estimate since some components of this use are a function of rainfall, while others (SFR) are a function of the natural flow itself.

The approach taken to implement this methodology was therefore to develop the necessary algorithms to function as a procedure within a larger water resources model which already has most of the tools and algorithms available for solving this type of problem. The obvious choice of model is the Water Resources Modelling Platform (WReMP) (Mallory et al. 2007) since this is already set up and being operated in the Crocodile River catchment, and the following section describes the implementation methodologies for this catchment.

The interface that has been developed to assist the catchment operators to estimate the ecological Reserve is shown in Figure 45. It allows for two time intervals, namely, monthly or daily, with the monthly being the default time interval. The user may toggle between these time intervals with the following provisos:

- **Monthly time interval**: enter the observed flow (in million m^3) as the sum of flow recorded at the gauge over the previous month (m^3).

- **Daily time interval:** A daily time interval is used a proxy for an instantaneous estimate of the EWR. The observed flow must be provided in m^3/s, and while initial tests were carried out using the latest recorded flow available on the DWA website, due to the rapid daily fluctuations of this flow it was decided to rather use the flow rate averaged over the day. These rapid, often diurnal fluctuations are thought to be due to abstractions for irrigation.

The model takes note of the time interval selected and makes the following assumptions:

- **Change in storage:** The model stores the storage in the five larger reservoirs in the system, namely, Kwena, Witklip, Klipkoppie, Longmere and Primkop dams. If the monthly time interval is selected the change in storage between current and 4 weeks ago is taken change in storage. If the daily time interval is selected, then the time change in storage is assumed to be one seventh of the change in volume over the last week, i.e.

Eq. 6 $$\Delta S = (\Sigma Storage_t - \Sigma Storage_{t-1})/7$$

This change in storage is expressed in m^3/s to be consistent with the units used

- **Irrigation:** This is generally assumed to vary with rainfall and hence an irrigation model is often used by water resource modelers to estimate the irrigation requirements based on, inter-alia, rainfall during the time period under consideration. The WReMP has its own irrigation model which is based on the standard methodologies used widely in Southern Africa.

Two important parameters relating to estimating the natural flow is the rainfall[1] threshold above which it is assumed that rainfall contributes to soil moisture and hence is available for crops. The assumption is made is that irrigators will not irrigate as much since part of the water requirement for the crop is met by rainfall. In the case of daily estimates of this threshold this is simply the interception loss which is approximately 2 mm. In the case of monthly estimates a widely accepted figure is 25 mm (DWAF 2009).

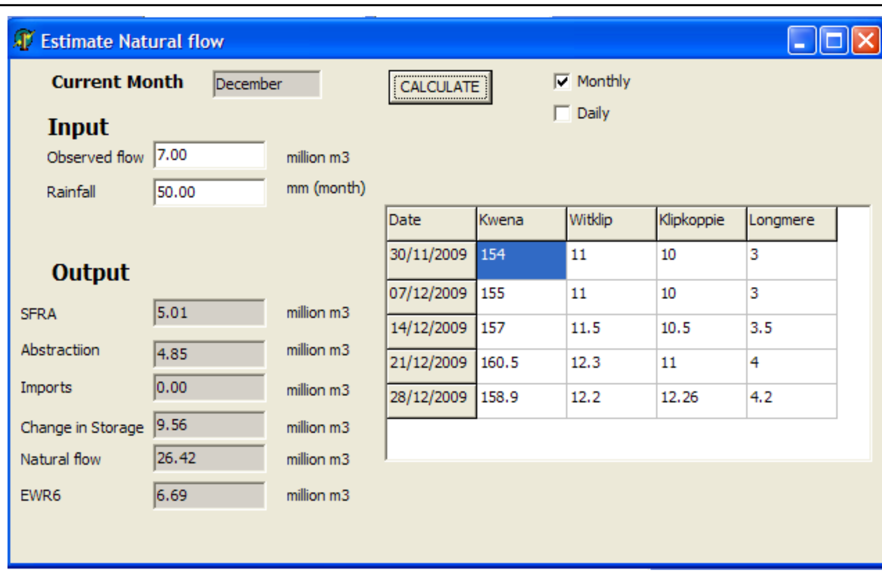


Figure 45 Application to estimate Natural flow from observed flow from the WReMP model (Mallory, 2007).

3.8. Future prediction of the ecological flow requirement

A further component of the study was to make predictions of the ecological flow requirements into the future. The methodology used is an extension of the methodology used for the Crocodile Real-time model which already incorporates a stochastic hydrological model that utilises the observed monthly correlation of flows from one month to the next. This correlation is strong in the Crocodile catchment and hence good predictions of flow can be made through the winter months. While the methodology, as applied to the Crocodile Real-time model is geared towards predicting the range of possible water levels in the Kwena Dam, the methodology was extended to predict the range of possible natural flows at the outlet of the catchment, i.e. at the Tenbosch weir. From this probability distribution of flows it follows that the probability distraction of the EWR can also be determined. An example of the application of this methodology is shown if Figure 46 and 47.

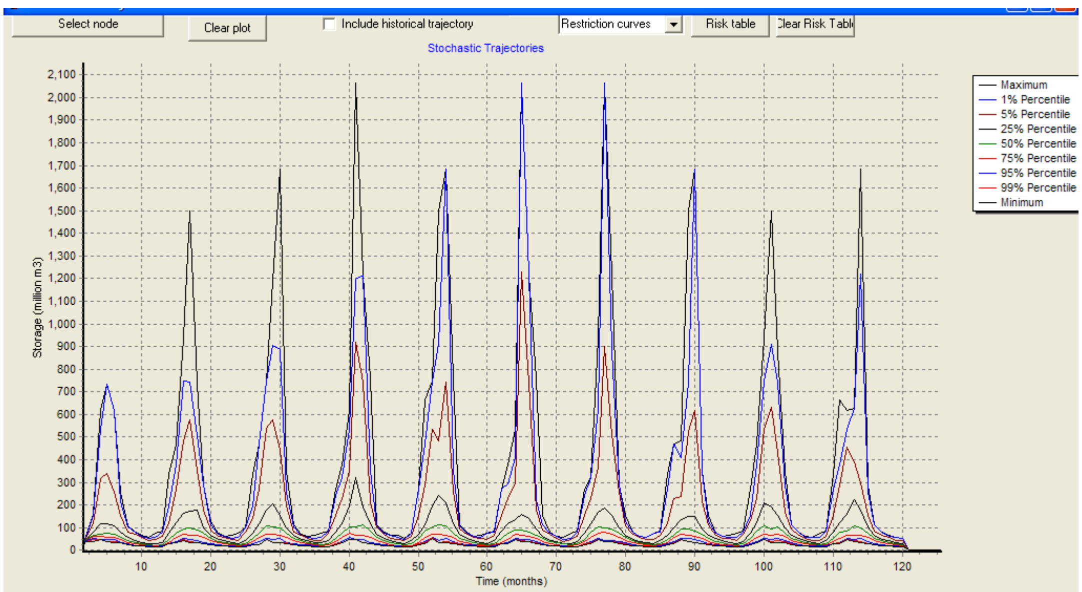


Figure 46 Probabilistic plot of natural flows at the EWR6 site

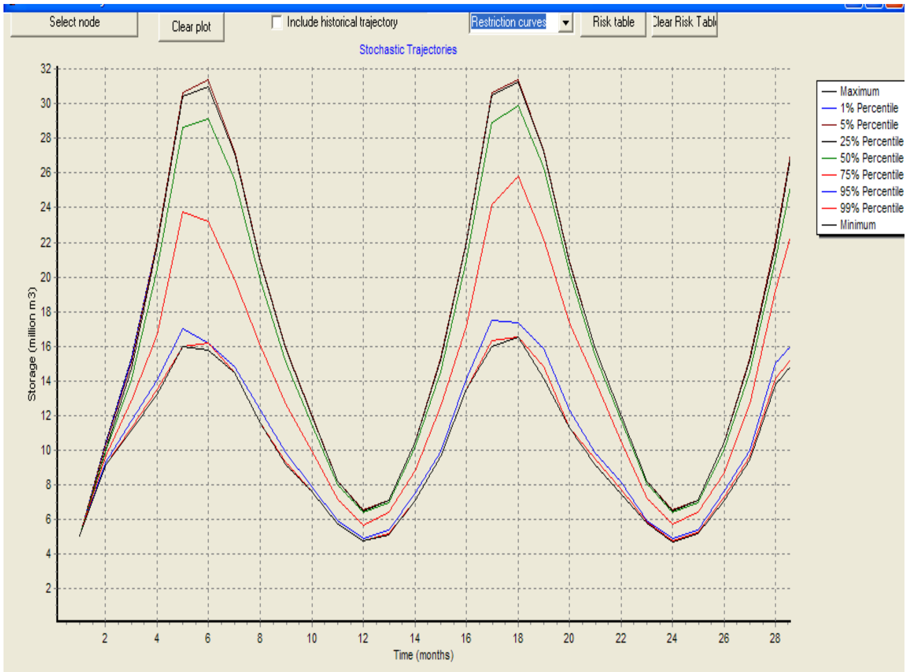


Figure 47 Probabilistic plot of EWR at the EWR6 site

3.8.1. Uncertainty analysis

It is important when conceptualizing and developing new techniques which deviate from the accepted norm to compare results, preferably with observed data, but if this is not possible, then at least compare existing and new methodologies. Natural flow is somewhat of an academic concept and cannot really be measured as such, hence comparison of modeled results and an analysis of the uncertainty surrounding the results is the next best option.

There are several criteria to consider in order to carry out a meaningful comparison. These are:

- Reasonable estimates of the historic water use must be available, or information such as crop areas and types grown in the past must be available from which the irrigation water use can be estimated.
- Accurate observed flow must be available.
- A reliable hydrological model must be available to generate natural flows.
- The period over which the comparison is carried out should be as long as possible.

The Crocodile River catchment is being used as a pilot catchment to test this methodology. The main reason for this is that there is already a real-time implementation model set up for the Crocodile catchment and there should be an immediate benefit to the Kruger National Park if these methodologies prove successful. Unfortunately the Crocodile River is not ideal in term of the criteria listed above for the following reasons:

- Irrigation activities increased dramatically from the early 90s until approximately 2003. With the publication of the DWAF's Internal Strategic Perspective (DWAF 2004), it was finally acknowledged that the Crocodile River was over-allocated and the regional office ceased issuing new water use licences except under very strict conditions. Hence while the current water use is reasonably well documented and thought to be within about 10% of the actual water use, there is uncertainty as to how much irrigation took place during the nineties.
- There are two years of missing observed flow due to the large floods in 2000 which damaged or destroyed many flow gauges.

The period selected for comparison is from October 2002 to September 2004, since this is the only period during which there is relatively high confidence in the water use estimates as well as the observed flow data. Although the record is too short to make definite conclusion, it does give an indication of whether the proposed methodology is at least producing plausible results.

Various comparisons of the observed and modeled data were carried out in order to assess the validity of the proposed methodology as well and the range of error. Figure 48 is simply a plot of the observed and modeled flow, average over the three years of analysis (2002 to 2004). The differences are clearly quite large absolute terms in the months of December and February.

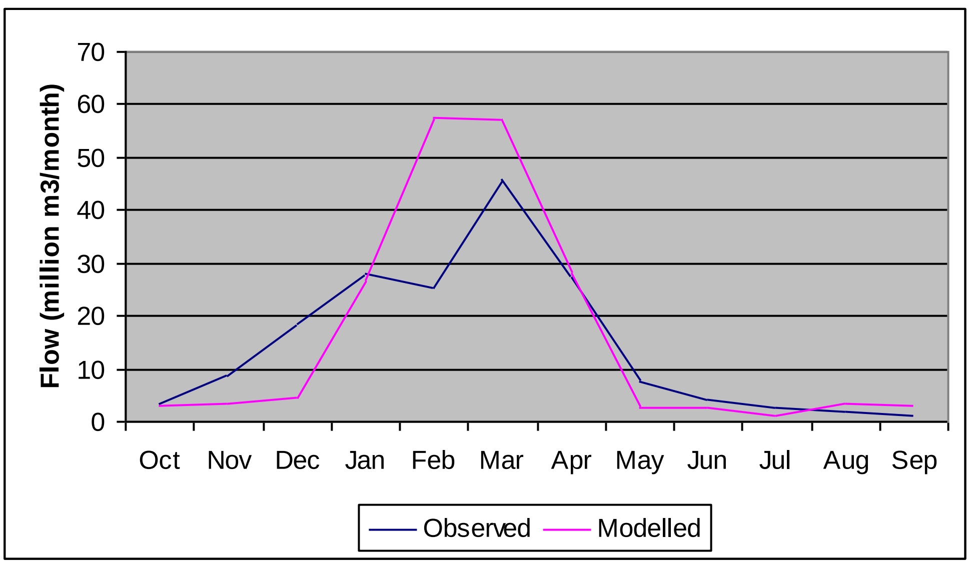


Figure 48 Observed and modeled flow for the period October 2002 to September 2004 for the Crocodile River close to EWR6

Of more importance for real-time Reserve implementation is the error between the natural flow derived from a hydrology and that estimated from the observed flow coupled with estimates of water use within the catchment at that point in time. From a theoretical point of view the latter approach should be more accurate because a hydrology model is calibrated to obtain a good fit based on long term averages and could therefore be quite inaccurate on any particular day. Flow estimates on a particular day can, on the other hand, take into account actual observed conditions, such rainfall (which influence the irrigation requirement) and change in storage in reservoirs.

In order to test this hypothesis, the following error analysis was carried out:

- **Error analysis 1:** Assuming the modeled natural flow to be correct, how does the natural flow calculated from the observed flow differ from this? A monthly time step was used in this analysis since daily natural hydrology is not available.

Figure 49 indicates the range of error in each month based on the above assumption. Large errors can be expected but where there is a trend of always over or underestimating the natural flow in any month, this is cause for concern. For example, the month of June, July and August are problematical, with February also a cause for concern.

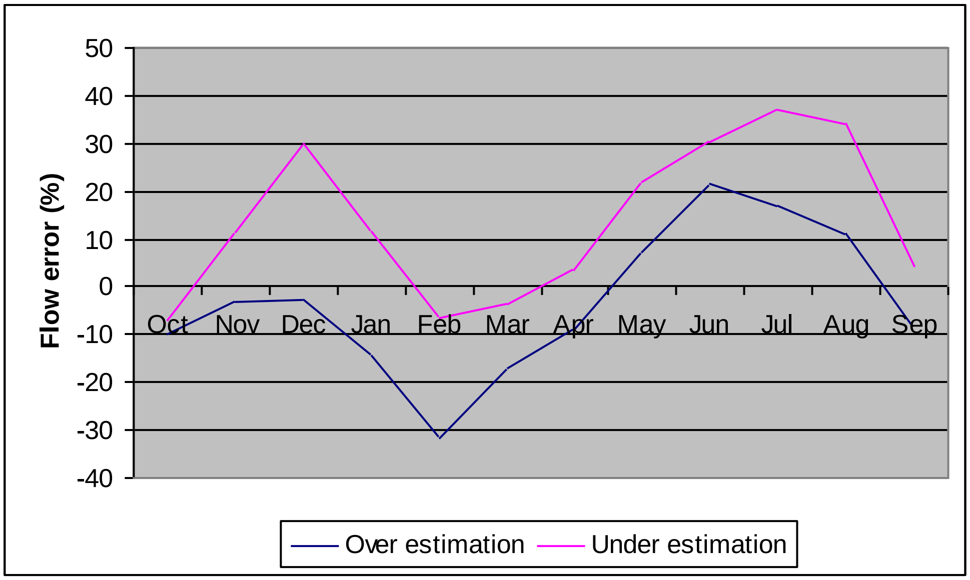


Figure 49 Monthly error bands for the Crocodile River close to EWR6

- **Error analysis 2:** While Figure 49 indicates large difference between the modeled natural flow and the proposed month to month (or day to day) calculation based on observed flows, the question that must be asked is does the error lie with the modeled flow or the new methodology, or a subtle combination of both.

In order to get some perspective of the error range of the modeled flow, the simulation used to determine this was obtained from the hydrologists that carried out this study. These simulations were carried out using the WRSM2000 model which was set up for the Inkomati Water Availability Assessment Study (DWAF 2009). Figure 50 plots the monthly observed flows and the WRSM2000 simulated flow over the same period.

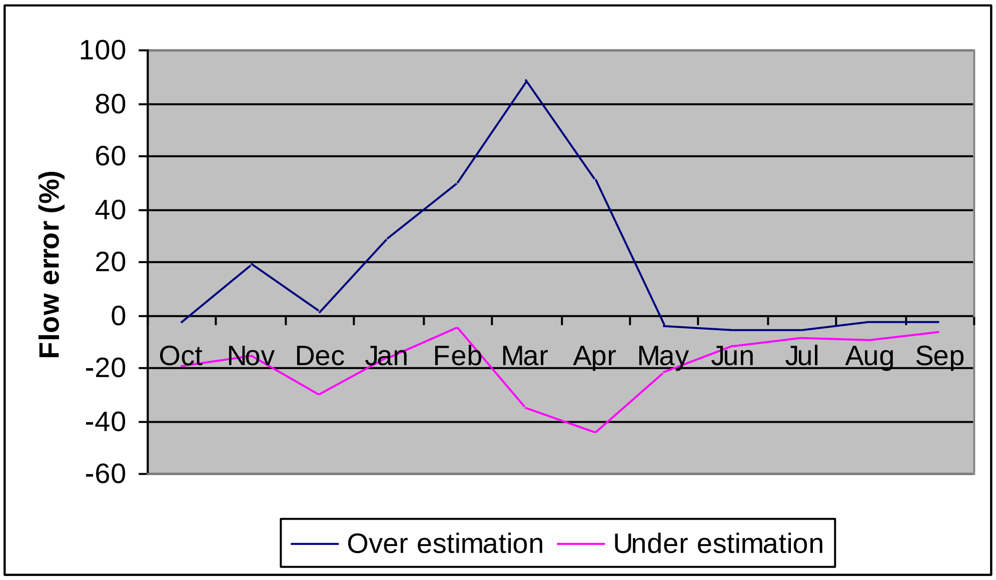


Figure 50 Error in modeled flow based on WRSM2000 simulation for the Crocodile River close to EWR6

The interesting observation that can be made from Figure 50 is that the error or discrepancy between modeled and observed data based on the WRSM2000 simulation is even greater than the error between the two natural flow methodologies. It is therefore not correct to assume that the modeled natural flow is necessarily correct. The large error in February, March and April (the months in which floods occur) is probably due to the inability of the flow gauge at Tenbosch (gauge X2H016 close to EWR6) to record floods accurately.

The final step in comparing methodologies and the range of errors, is to compare the errors inherent in the WRSM2000 model and the error between the two natural flow methodologies (see Figure 51). The conclusion drawn from this uncertainty analysis is that the WRSM2000 model has even greater errors when comparing observed versus modeled flows than the range of errors when comparing the two natural flow estimation methodologies. There is clearly a great deal of uncertainty and large scope for error regardless of which methodology on pursues.

The large errors in the WRSM200 simulation can be attributed to inaccurate gauging of floods, while the large errors in the Mallory method in June, July and August are thought to be due inaccurate estimates of the distribution of the crop requirements throughout the year. This will need be investigated in more detail to see if this discrepancy or error can be reduced.

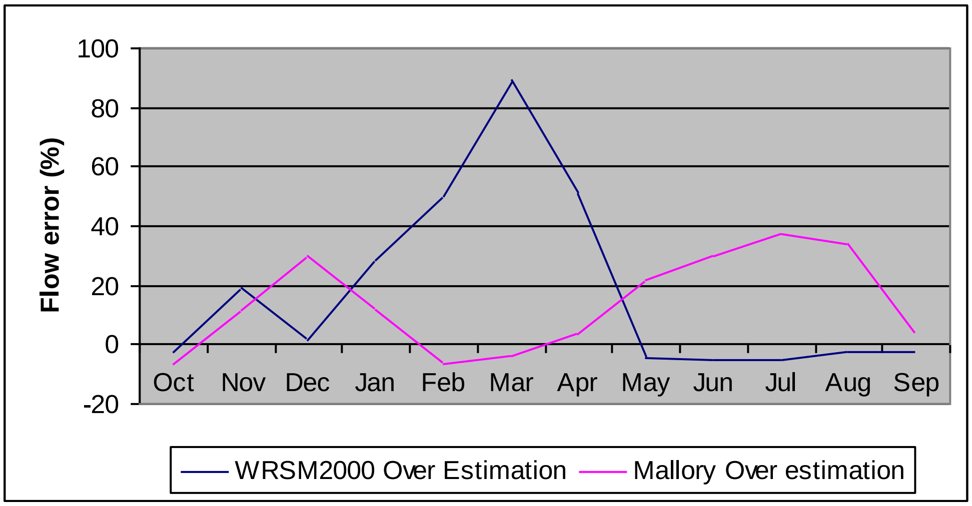


Figure 51 Comparison of maximum monthly errors for the Crocodile River close to EWR6

3.9. Conclusions and recommendations

A comparison of natural flows generated within the Crocodile and Letaba catchments (both complex and highly developed catchments) using a process referred to in this report as Real-time naturalisation, show that the methodology produces realistic and plausible estimates of natural flow. Hence this approach should be acceptable as an ecological Reserve implementation tool to determine natural flows in real-time. While it is generally not acceptable to compare results of different models as a method to verify a model or modelling approach, natural flow is a concept that cannot be measured or observed in developed catchments, hence comparative analysis is the only tool available to verify new naturalisation techniques.

The comparison of natural flow generated using different techniques does seem to suggest that WRSM2000 is overestimating the natural flow during periods of exceptionally low flow while the Real-time naturalisation technique is possibly under-estimating the natural flow during the same period. The reason for the WRSM2000 over-estimation probably lies in the calibration procedures which are weighted heavily towards matching observed and simulated mean annual runoff and standard deviation rather than low flow. No doubt better low-flow calibration could be obtained with WR2000 if required. The suspected under-estimate of the natural flow (during extreme droughts) using the Real-time naturalisation technique is possibly due to underestimating the actual water use during these low-flow periods. During these droughts the irrigation boards in both the Letaba and Crocodile river catchment imposed heavy restrictions on their users but is not clear to what extent their members actually complied with these restrictions. The other possible cause of under-estimation during droughts is the increased natural losses during these periods. In both the Groot Letaba and the Crocodile River there is anecdotal evidence of large river losses during severe droughts. In the case of the Groot Letaba these losses are thought to be into the river alluvium due to a low ground-water table while in the Crocodile River these losses are probably elevated evapotranspiration losses due to higher than normal temperature coupled with low rainfall during these periods. These losses can be unnaturally enhanced due to releases from the Kwena Dam.

The ability of the Real-time naturalisation technique to estimate natural flow has been demonstrated in this report. However, the limitations of this methodology must be noted and the technique should not be attempted if the conditions for its application are not met.

These conditions are:

- Accurate and reliable (i.e. always available) real-time gauged flow.
- A good knowledge of water use in the catchment.
- A good knowledge of stream flow reduction activities in the catchment
- A continuous record of the storage in the significant impoundments within the catchment.

It is suggested that Real-time naturalisation could replace the currently accepted methods of estimating natural flows, the reason being that real-time naturalisation allows intense scrutinisation of every water use data during every time interval, while the currently accepted modelling techniques at best look at long-term trends of changing water use. So while models such as WRSM2000 may provide reliable natural flow (if properly calibrated) *on average* over the period of simulation, Real-time naturalisation will provide estimates that are accurate at every time step, and hence must result in better long-term estimates as well, provided that Real-time naturalisation is continued for a long enough period into the future.

Based on the above conclusions, the following recommendations can be made:

- Implementation of real-time monitoring of water use will greatly improve the accuracy of natural flow estimates and hence estimates of Reserve requirements.
- There is a need to distinguish between irrigators that are part of an irrigation board and are responding to the call for restrictions during droughts and those that are not.
- The inclusion of water loss routines in the Real-time naturalisation procedure should improve estimates of natural flow, especially during periods of exceptionally low flow.
- Testing of the Real-time naturalisation procedure should be carried out at finer time increments. The minimum time step possible is daily while weekly is probably a more practical time step.
- Real-time naturalisation produces natural flow only for a gauged catchment. A technique to disaggregate this natural flow to sub-catchments (e.g. quaternary catchments) comprising the gauged catchment would be useful.
- The implementation of Real-time naturalisation needs to be tested over an extended period in order to ascertain if this technique could replace the current practice of periodic updating of hydrology, e.g. the WR2005 project (Middleton and Bailey 2008). Catchment Management Agencies should be well positioned to carry out Real-time naturalisation within their catchments since they will have the local knowledge to do this well, while hydrology carried out on a national scale (e.g. WR 2005) is not necessarily carried out by those with expert local knowledge.

The uncertainty analysis carried out indicates that the range of uncertainty appears to be less utilizing the methodology proposed here although more work is required in order to reduce the uncertainty and hence the range of error. Hence there appears to be some merit in utilizing observed flow as an indicator of the ecological Reserve requirements and it is recommended that the methodology be continued to be piloted in the Crocodile and Groot Letaba catchments.

Section D: Overall discussion and recommendations

4. Overall discussion and recommendations

4.1. Introduction

A central question for meeting the commitment to sustainability as outlined in the NWA (1998) is to understand if the Reserve is being met or, in other words, is there compliance with this aspect of the National Water Act? A central issue in seeking answers to this is being clear on what is meant by, and what constitutes compliance. For the lowveld rivers where concerns about their integrity are increasing, it is critical to evaluate whether or not the Reserve is being met for each of the catchments and whether or not the operationalisation (projections for the ER for management purposes) is tenable. This question has raised a number of additional and critical issues for assessments of Reserve compliance. This includes understanding firstly, how the Reserve is represented formally as an approved Reserve, and secondly, how this gets 'translated' into an operational tool for implementation and monitoring. Thirdly, if there are transgressions, what are the actions that can be taken to mitigate these? Fourthly, if all other measures fail and litigation is considered, is the Reserve legally defensible? This discussion seeks to elaborate these concepts as a contribution to the discourse on Reserve compliance.

In seeking to do this, each of the aforementioned issues has been addressed as the work has progressed. It is important to note that the focus of this study was on the ecological component of the Reserve in this work which is briefly described below.

That the NWA views water resources as a resource of diverse goods and services (rather than simply a source of water) is evident in the classification system comprising three permissible classes. Each of these – in effect a negotiated desired state – delivers a different complement of ecosystem services and each has attached risks and tradeoffs. Associated with each class is a recommended ecological category (REC) and a Reserve which is a composite description of a dynamic hydrological, geomorphological, physico-chemical, and biological state. The Reserve refers to <u>both</u> <u>the quantity and quality</u> of the water. Moreover the quantity is described by three characteristics, namely magnitude, duration and timing. The quality issues are captured by the setting of standards in the Resource Quality Objectives (RQOs). RQOs are set based on the classification for a particular significant resource and are ultimately linked to monitoring programmes.

Once a management class has been selected by stakeholders – an expression of a negotiated desired state – it forms the basis of planning. All Reserve determinations done ahead of resource classification are considered 'preliminary Reserve determinations'. There are four levels of RDM determination (desktop, rapid, intermediate and comprehensive[12]) that are required for different circumstances that reflect the degree of use, the sensitivity and importance of the catchment, and the potential impact of the proposed water use.

[12]Comprehensive Reserve determination is required in the case of (a) compulsory licensing; (b) water use allocation planning; (c) large impacts; (d) sensitive/ stressed catchments (DWAF 2003).

What does Reserve implementation refer to?
With regard to terminology, it is important to define what is meant by key terms such as implementation, Reserve determination and operationalisation. In this report we consider implementation of the ER as the umbrella concept comprising a wide range of important strategic actions. It includes ensuring that the concept is captured in policy, that there has been institutional and strategic realignment and that the Reserve can be determined. Thus it includes both the determination and operationalisation. In discussions on compliance it is important to distinguish the macro-planning process (which includes Reserve determination) from operationalisation in which we include operational planning (e.g. projecting ER requirements for a pre-defined management period), monitoring, regulation, enforcement, reflection and learning.

What is needed to meet the ER and what does this mean for compliance?

As we noted in the introduction, there is little guidance as to what constitutes compliance, other than a simplistic one that states 'anything below the Reserve'. We will go on to discuss why this is possibly not meaningful or appropriate in the short- to medium-term. We also posed the question: Is any flow that is less than the specified Reserve flow to be designated as non-compliance (100% assurance)? The implications were highlighted using an example of 98% assurance (7 days a year or less than once a month the flow is less than the Reserve)? Conceptually one may consider any failure to be non-compliant but when the practicalities of overhauling an entire water resources management system[13] are considered (see Pollard & Du Toit 2009), many would be reticent to deem the above case as one of non-compliance and hence a transgression of the law. Lags are an inherent component of such transformation (Pollard & Du Toit 2011) and also require a legal interpretation (Pejan et al. 2011). The important issue at hand is whether or not there is demonstrable effort and progress towards meeting the intentions of the NWA including the Reserve. Pollard & Du Toit (2011) have provided details of the key management actions required to meet the Reserve. Appreciably this takes time requiring strategic, operational and administrative re-orientation many aspects of which are inter-dependent. In summary these are:

- determination of the Ecological Reserve (which will include international obligations)
- implementation or operationalisation
- water resource protection measures
- financial planning
- stakeholder participation
- compliance monitoring, enforcement
- co-operative governance.

It might be more useful to note the failures (timing, duration and so on) and examine underlying causes so as to improve the system. The issue of litigation is one that may require additional thinking (see below)

Again it is worth stressing that the **Reserve is not a fixed daily value** (as the IFR was) – it is a variable value that is contingent on the prevailing climatic conditions. If the methods and technical expertise to derive these are not available or are sub-standard, this **throws into question the derived Reserve values** (i.e. they may be an over- or under-estimate). By implication, the accuracy

[13] This involves taking an integrated, catchment-wide orientation that brings all stakeholders on board into a process of negotiating water-sharing and protection arrangements and needs to be captured in a strategic planning through a catchment management strategy. The strategy then has to be operationalised.

of compliance assessment is called into question. This implies that we have to have a high level of confidence in order to deem 'any flow less than the Reserve as non-compliant'.
Bearing these constraints in mind let us turn to the issue of compliance. Two additional considerations regarding the definition of non-compliance must be addressed. The first is apparent when one looks at the catchment as a whole. Currently, one or two sites 'drive' the system, particularly in terms of establishing the operating rules for a water resource. These are generally (but not always) the most downstream site. Whilst the Reserve may be met at the EWR site, this does little to indicate if the EWR is met at all sites. The Letaba Catchment is a case in point where the Reserve is almost exclusively delivered by the main stem whilst the major tributaries experience severely reduced flows. The intention of the Act was to maintain water-resource health from a catchment perspective and not to simply ensure the delivery of water at one site. This re-affirms that the EWR must be delivered at all of the sites but currently a number of constraints have been pointed out in this regard.

Secondly, the EWRs – and hence compliance – **comprise a number of components** including magnitude, duration and frequency as well as water quality parameters (see Box 1). Thus whilst the quantity of water may be acceptable, the timing (including duration and frequency of freshes) may not meet the requirements of the Reserve. Equally the flows may be met but the water quality may be problematic. This again is an issue that requires addressing since currently, monitoring and management defaults to a simpler system.

It was noted previously (Section 2) that a central question that emerged for the team towards the later part of this work was this: *Can real-time compliance monitoring based on daily data be undertaken?* We would suggest that our work repeatedly demonstrated that determining and monitoring the ER as an absolute value, such as a daily Reserve (albeit dynamic on an intra-seasonal and inter-annual basis) is not tenable currently. Firstly the uncertainties associated with the data sourcing, analysis and representation that has been demonstrated in this work would make providing any assessment of compliance of a very high confidence (as suggested by absolute values) as exceedingly difficult. Moreover, as has been noted, the initial ecological Reserve for any river is a working hypothesis that needs to be monitored to check that it is delivering some desired state (such as the management class). Insisting on absolute values under such circumstances would be hard to defend. Rather we would suggest, once the constraints of determining the ER are taken into account and their operationalisation is conceptualised and framed against realistic management actions, then tracking against trends becomes more appropriate and meaningful. This is not to suggest that there will not be instances in which specific data are needed and tracked. However, in many instances tracking against trends is in keeping with the spirit and intent of the NWA [constitution?] which seeks progressive realisation and if used judiciously is a powerful tool on which to base stakeholder discussions and participatory processes.

We also noted in Section 2 that given the complexities of realtime monitoring and management the ER will be need to be represented by a minimum flow for each month in much the same way as is being done in the Letaba River (and now in the Crocodile). Adding worry levels or TPCs as shown Figure 37 (by the KNP) provides a model for linking monitoring to action. A visual representation of such data for discussion with stakeholders offers a powerful tool. The central principle should be that there is a minimum flow and associated levels of concern that need to be tracked and linked to clear management actions. The data presented in this report offers a useful benchmark from which to initiate such monitoring measures.

4.2. Moving from Reserve determination to operation

We highlighted in Section 1 the importance of understanding how the Reserve is represented formally as part of a Reserve determination study and the lack of support given to water resource managers to 'translate' this into an operational tool for implementation and monitoring.

The first step in Reserve implementation comprises determining the ecological Reserve for a particular sub-catchment as part of a Reserve determination study. The outputs from this then need to be developed into an operational tool that is utilisable for management purposes. Currently there is no clear, concerted approach to doing this so that water resources managers are supported to integrate the ER needs into water resources planning and operation. However, DWA have been developing a framework to operationalise the Reserve for several years but the final reports have not yet been made available to the broader public or researchers. Research from the SRI (Pollard & Du Toit 2011) demonstrates the difficulties that managers are facing. In one catchment for example, the water resources manager simply defaulted to interpreting the ER as a minimum flow (thinking it was the IFR which it was not). In the face of enormous management challenges it is simply not tenable to insist that it is their task alone to 'make sense' of the ER outputs and then to operationalise this. Although there are some initiatives that are starting to address this, some fundamental problems still constrain this. These will now be discussed.

Also as noted, in order to (a) monitor Reserve compliance and (b) to provide a reasonable prediction of future ER requirements (say over the next year) in order to advise and possibly restrict other users one needs to be able to calculate the ER in real-time. There are a number of constraints to this which have already been discussed at some length in Section 1 and 3. The important point is that water resources managers need to be given guidance and support to do this.

In addition to the fact that currently our monitoring of the ER is only possible for a period over which we have reliable estimates of natural flow, which in most cases is up to September 2005, (i.e. real time natural flows are not available), another constraint relates to the infrastructure for monitoring.

It is essential to remember that the intention of the NWA is to maintain water-resource health from a catchment perspective and not to simply ensure the delivery of water at one site. Thus the Reserve determination methodology selects a number of sites (representative of zones within the catchment) and not simply one site. However it is becoming clear that the challenges of operationalising the ER mean that generally one EWR site is selected for management purposes. This site, often the most downstream, then drives water resources management for the catchment. Thus the de facto situation is that one EWR site will be used for management purposes. The implications are that in the worst case scenario, the full ER requirements will be met by one portion of the river whilst the others continue to degrade. However it is noted that in principle other sites are checked especially problematic sites, and operating rules must be developed for all sites. In reality this may not have happened for some sites as yet.

Two examples here are illustrative. In the Letaba system all the ER requirements at the EWR site within the Kruger National Park (EWR 6[14]) are currently being furnished by the Groot Letaba system

[14] This is not the EWR site that drives the system nor that is monitored. The EWR site used for management purposes (EWR 4) is located further upstream prior to the confluence of the Klein Letaba River. For all intents and purposes then the Groot Letaba River

whilst inputs from the Middle and Klein Letaba system are not even being considered. In terms of the Klein Letaba, interviews from the SRI indicate the view that the system is so severely degraded and poorly managed that meeting the EWR is highly unlikely in the foreseeable future. This raises a range of questions regarding firstly the intentions of the NWA as well as the 'justice' (and hence justifiability) of expecting water users on one tributary of the system alone to change water use practices to meet the ER.

A second case is that of the Sand River. Here the EWR site (EWR 8) is located just before the border with the Sabie River (Figure 52). Two issues emerge from research over the past three years. Firstly, unlike the Letaba River case study, the operating rules are based on meeting flows in both tributaries of the Sand River (i.e. EWR 6 and 7). These rules took into account the Injaka White Paper (DWAF 1994) plans which outlined intentions for an inter-basin transfer to the southernmost tributary of the Sand River (near EWR 6). However, there has been no such IBT into the Mutlumuvi implying that the ER will have to be met by some other – as yet unknown – means. (Why the Injaka White Paper has not been honoured is still a subject of ongoing enquiry). Secondly and highlighting what was discussed in the case of the Letaba, there is no way to monitor the flows at sites on the two tributaries since there are no gauging stations – an issue that will be further discussed below. Again the implication however, is that the ecological Reserve at EWR 8 could be met from one tributary alone whilst degradation continues on the other.

As noted, the intention of the NWA was to ensure sustainability of the nations' water resources. To do this, managers (and others) need to be able to monitor compliance against some benchmark, in this case the ecological Reserve. Thus even if we overcome the problems associated with determining the ER in real-time, we need to be able to monitor to deliver flows at all the sites. And to monitor these. However, an obvious question that arises is how can monitoring – in real time – be undertaken without gauging systems? Currently, at ungauged EWR sites this is not possible. Appreciably, water quality is even less likely to be monitored.

Another issue relates to the distance between the "driver" sites and the closest gauging stations. Research from the SRI indicates (Table 17) that in some lowveld rivers these distances are such that they may throw into question the reliability of results in terms of monitoring for compliance. It is hard to see how monitoring could take place in rivers such as the Sand, Sabie, Olifants and Luvuvhu where distances exceed 20 km without calibration which needs to take into account a number of factors. In all cases except maybe the Sabie, the river reaches in question are sand-bed sections that are prone to sub-surface interactions and losses. These interactions are still poorly understood in lowveld rivers. Moreover, evaporative influences and seasonal differences are likely to further complicate calibration. Further complications are added when considering water use (let alone landuses that influence the water quality component) between the EWR and gauging sites. In the Sabie River for example, two major abstraction points lie between EWR 3 and X3H021[15]. These issues, each of which add uncertainty, will all seriously constrain trying to "prove' non-compliance especially in cases where litigation is considered.

[15] This will be determined in the new Sabie-Sand Real time project

Table 17 Summary of the 'driver' EWR sites on the lowveld rivers and their distance and location relative to the closest DWA gauge station (data from (Pollard & Du Toit 2011)

Catchment	EWR site (driver site)	Co-ord.	Closest Gauge station	Co-ord	Distance between EWR and gauge station (km)	Position of EWR site relative to gauge station
Komati	EWR K3	25° 40'01.1"S 31o 48'04.8"E	X1H003	25 40 56.1 31 46 54.8	<1	/
Lomati	EWR L1	25° 38'58.0"S: 31o 37'23.5"E	X1H014	25 40 25.9 31 34 31.0	3	downstream
Crocodile	EWR6		X2H016	25 21 49.9 31 57 20.6	6.5	downstream
Sand	EWR8		X3H008	24 46 12.1 31 23 19.0	48	downstream
Sabie pre 2000[7]	EWR 3		X3H006	25 01 50.3 31 07 35.2	22	downstream
Sabie post 2000			X3H021	24 58 06.5 31 30 55.5	28	upstream
Olifants	EWR16 B73H	24°3'4.2"S; 31°43'56.3"E	B7H015	24 03 58.6 31 14 34.4	69	downstream
Blyde	EWR12 B60J	24°24'31"S; 30°49'35"E.	B6H004	24 27 33.5 30 49 38.5	8	downstream
Letaba	EWR4	23 40 39.1;S 31 05 55.1 E	B8H008	23 39 31.6 31 02 59.2	9	downstream
Klein Letaba	EWR5	23 15 02.9; S 30 29 44.6 E	B8H033	23 14 26.7 30 28 32.2	2.5	upstream
Luvuvhu	desktop A91H		A9H012	22 46 06.5 30 53 21.6	50	downstream

NB. The gauge X3H006 (also known as Perry's Bridge) was destroyed by the 2000 floods and so no data is available after that period. Thus another gauging station, X3H021 (also known as Kruger Gate) had to be used to examine compliance over the last period.

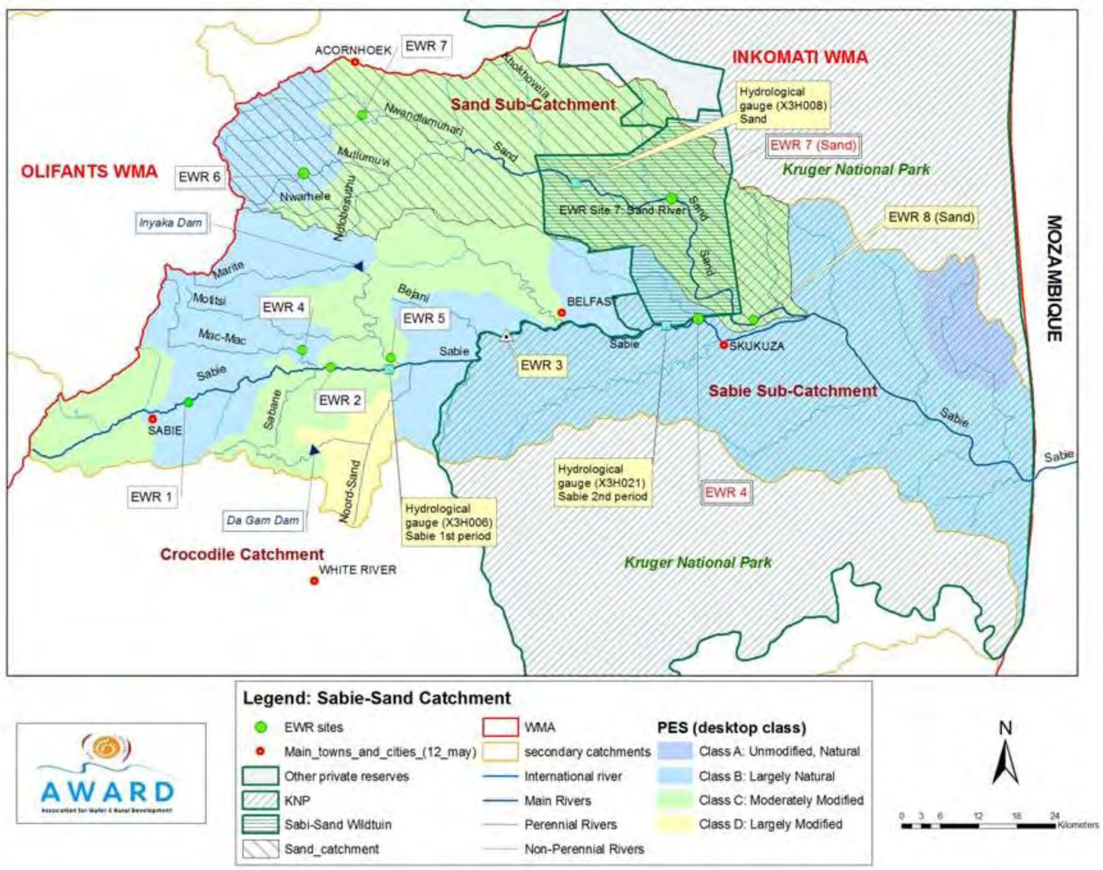


Figure 52 Sabie-Sand Catchment showing the location of the EWR sites

4.3. Legal interpretations

If there are transgressions with Respect to meeting the ecological Reserve, there are a number of likely management actions. The first is to find the source of the transgression and to discuss these with the transgressor(s) so as to firstly make them aware of the problem and secondly take remedial action. This is fairly commonplace in some lowveld catchments. For example in the Letaba catchment the water resources manager initiates discussions with the GLWUA who in turn undertake internal regulatory action (see (Pollard and Du Toit 2009).

However in some cases transgressions may be addressed through legal means if mitigatory actions are considered to be failing. This raises the question: Is the Reserve defensible legally? There are two aspects to such a question, both of which raise many further questions and potential issues.

Firstly, can non-compliance be shown (i.e. past reasonable doubt)?

> *Secondly can government be shown to not be working towards progressive realisation of the ecological Reserve?* (see Pejan et al. 2011) and Pejan and Snyman (2011) for a broader description of this term).

These questions are not necessarily mutually exclusive, and often non-compliance must be measured within the government's legal obligations around progressive realization.

The first question, whether there is non-compliance, would require a court to understand difficult technical concepts discussed above, such as measuring flows (magnitude, timing, duration), gauging, modeling, calibration and other natural resource management actions. It may also require courts to filter through competing claims, i.e. disagreements between experts on whether there is non-compliance. To date courts in South Africa have not adequately demonstrated that they are ready for such a challenge, and no complicated cases around water resource management have yet to be raised in courts (Kidd 2006; Pejan and Snyman 2011).

The second question stems from the government's constitutional obligation to take reasonable steps to ensure sustainability and equity. In other words, because there is a transformation in practice from the pre-NWA era, the constitution recognizes that changes related to socio-economic and environmental rights cannot happen overnight, but must instead be evaluated with the context of reasonableness. This obligation is mainly entrenched in the environmental right under Section 24 of the Constitution. Because the Ecological Reserve is the key tool to ensure sustainability and equity of water resources it is subject to the legal obligation of progressive realization that emanates from Section 24 (Pejan and Snyman 2011). The implications of progressive realization are many. First, just because a potential transgression may be determined to be non-compliant with the delivering or operationalising the Ecological Reserve (see question 1), the government may still be able to show that they are taking reasonable actions and are thus compliant with their obligations to progressive realize sustainable water resources. Second, there is no clear way to legally evaluate progressive realization. The Constitutional Court has presented a reasonability test; however, this test is quite general and may not lend itself to evaluating progress with delivering and operationalising the Ecological Reserve (Pejan et al. 2011).

The Sand River catchment is a case in point (see Box 3). Despite what may at first seem as fairly straightforward questions to the academic or manager well-versed in the field, both of these are fairly complicated issues to unpack from a legal perspective. Indeed the depth and breadth of this is beyond the scope of this paper and will be examined in detail as part of the second phase of the SRI programme. Here we outline some of the major issues for consideration.

Box 3
Potential litigation in the Sand River Catchment

To date the operating rules have not been implemented and the Sabie-Sand Wildtuin is now considering legal action against various government departments for the failure to progressively realise these. If anything, flows appear to have worsened (Pollard et al. in prep). A strong part of their argument points to the fact that government has done little towards progressive realisation

4.4. Conclusion: On progressive realizations

The Ecological Reserve is the tool designed to establish and track the commitment to sustainability and equity. The integrated workings of both water resource protection measures (also known as RDM) with the authorisation of water use (known as Source Directed controls or SDC), together with other associated strategies, ensure that this commitment can be met (NWRS (DWAF 2004); (DWAF 2007); (Pollard et al. 2007). This overall process, to be captured in the various regionalised Catchment Management Strategies, is still underway. Thus as Pollard and Du Toit (2009) point out, lags are an inherent part of the process of reform and change in a complex environment and are to be anticipated. Setting the Reserve today will not mean that it is met tomorrow. However it is important to consider which of these lags is unacceptable and what makes certain delays unacceptable. This is a hard question to answer given that there is little experience upon which to base the new approach to WRM and given the various constraints of skills and funding. Here various discourses might eventually be brought to bear including legal discourse that looks at progressive realisation and reasonability tests against which to make considered judgments (Du Toit and Pollard 2009). Moreover, the issue of lags requires further examination given that these may vary, reflecting lags in procedures, sequence, and in the development of capacity, skill and social capital (to co-manage and collaborate) (Pejan et al. 2011). As with the Letaba, Luvhuvhu and Sabie Sand catchments, there do appear to be a number of questionable and problematic lags that lead one to conclude that the Reserve is poorly realised and that progressive realisation is not being achieved.

Finally, readers are referred to a report in which regulators, water users, operations and maintenance staff, researchers and other stakeholders explored possible reasons for non-compliance (Pollard & Du Toit 2011). Major issues included a lack of integration between water-resources and water supply– in particular municipalities and in some areas mining – are highly problematic; a poor understanding of the Ecological Reserve and an inability to use the information on the approved Reserve, the lack of clear local leadership, unlawful uses of water, and a dearth of legal and regulatory skills to manage the situation, unclear roles and responsibility, and the lack of feedbacks. Transformation toward collective stakeholder understanding through a shared, catchment-based vision and management strategy is sought and should be provided by the catchment management strategies and plans. IWRM is still largely a concept rather than a practicality in the area, except in the new Incomati CMA where it is emerging through the development of the Incomati Catchment Management Strategy.

5. References

Abban, B, Shand, M,J, Kamish, W, Makhabane, M, van Zyl, B and Tente, T (2009). Decision support system for the Berg River Dam and Supplement Scheme. Paper presented at the International Conference on Implementing Environmental Water Allocations, Port Elisabeth, South Africa.

Agterkamp, J. W. 2009. Allocating contested water: A case study on the (non-) compliance with Environmental Water Allocations in the Sand sub-catchment, South Africa. Wageningen University, Wageningen.

Biggs, H., and K. H. Rogers. 2003. An adaptive system to link science, monitoring and management in practice. Pages 59-80 *in* J. T. d. Toit, K. H. Rogers, and H. C. Biggs, editors. The Kruger Experience. Ecology and Management of Savanna Heterogeneity. Island Press, Washington DC.

Du Toit, D., and S. Pollard. 2009a. Crocodile River Catchment: Contextual profile on factors that constrain or enable compliance with environmental flows. . DRAFT Report. Project K5/1711.

Du Toit, D., and S. Pollard. 2009b. Luvuvhu River Catchment: Contextual profile on factors that constrain or enable compliance with environmental flows. . DRAFT Report. Project K5/1711.

DWAF. 1994. Report on the proposed Sabie river Government Water Scheme (First Phase: Injaka Dam and Bosbokrand transfer pipeline). DWAF, Pretoria.

Gordon, N. D., T. M. McMahon, and B. Finlayson. 2004. Stream hydrology: An introduction for ecologists. 2nd Ed. Wiley & Sons, Chichester.

Pejan, R., A. Norberg, D. d. Toit, and S. Pollard. 2007. The development of a framework for understanding human rights-based approaches and integrating them into water resources management in South Africa. WRC Report No.1512/1/07, Water Research Commission (WRC), Pretoria.

Pollard, S., and J. W. Agterkamp. in prep. Constraints to meeting the Reserve in the Sand River Catchment.

Pollard, S., and D. du Toit. 2008. The Letaba Catchment: Factors that enable or constrain compliance with Environmental Water Requirements. Draft Report. WRC report for the Shared Rivers Initiative.

Pollard, S., and D. du Toit. 2009a. Drawing Environmental Water Allocations into the World of Realpolitik: Emerging Experiences on Achieving Compliance with Policy in the lowveld Rivers, South Africa. Implementing Environmental Flow Allocations, Port Elizabeth, South Africa.

Pollard, S., and D. du Toit. 2009b. The Sabie-Sand Catchment: Contextual profile on factors that constrain or enable compliance with environmental flows. . DRAFT Report. Project K5/1711.

Pollard, S., and D. du Toit. 2011. Towards the sustainability of freshwater systems in South Africa: An exploration of factors that enable and constrain meeting the ecological Reserve within the context of Integrated Water Resources Management in the catchments of the lowveld. Report to WRC, K8/1711. Sept. 2010.

Pollard, S. and S. Mallory. in prep. Constraints to determining compliance with the Reserve: A position paper. Report prepared for the WRC for the SRI. (Del. 5). unpubl.

Sawunyama, T. and D. A. Hughes. 2008. Application of satellite-derived rainfall estimates to extend water resource simulation modelling in South Africa. Water SA **34**:9.

Smits, S., S. Pollard, D. du Toit, P. Moriarty and J. Butterworth. 2004. Modelling scenarios for water resources management in the Sand River Catchment, South Africa. NRI, Chatham.

WRC. 2008. Water Resources of South Africa. Report to the Water Research Commission, Pretoria.

Appendices

Appendix 1- Maps of EWR sites

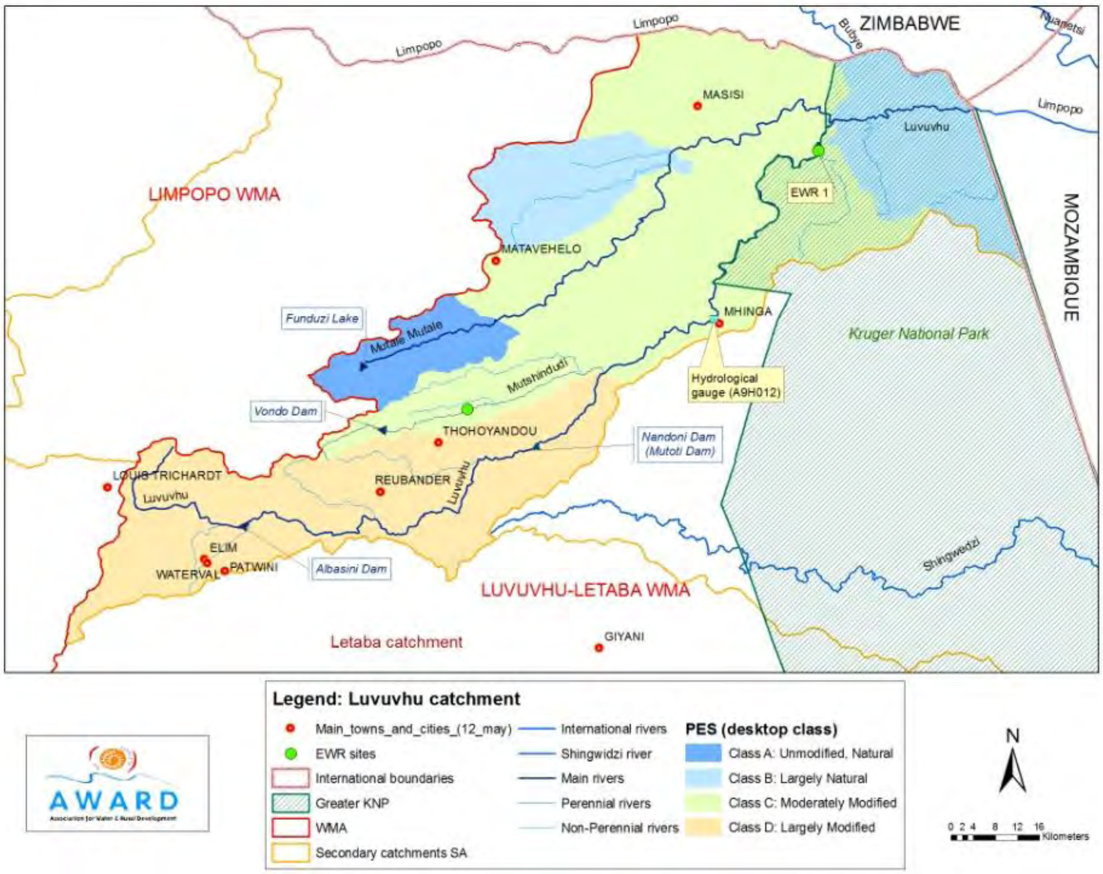


Figure 1: Luvuvhu Catchment showing EWR sites and corresponding gauging stations

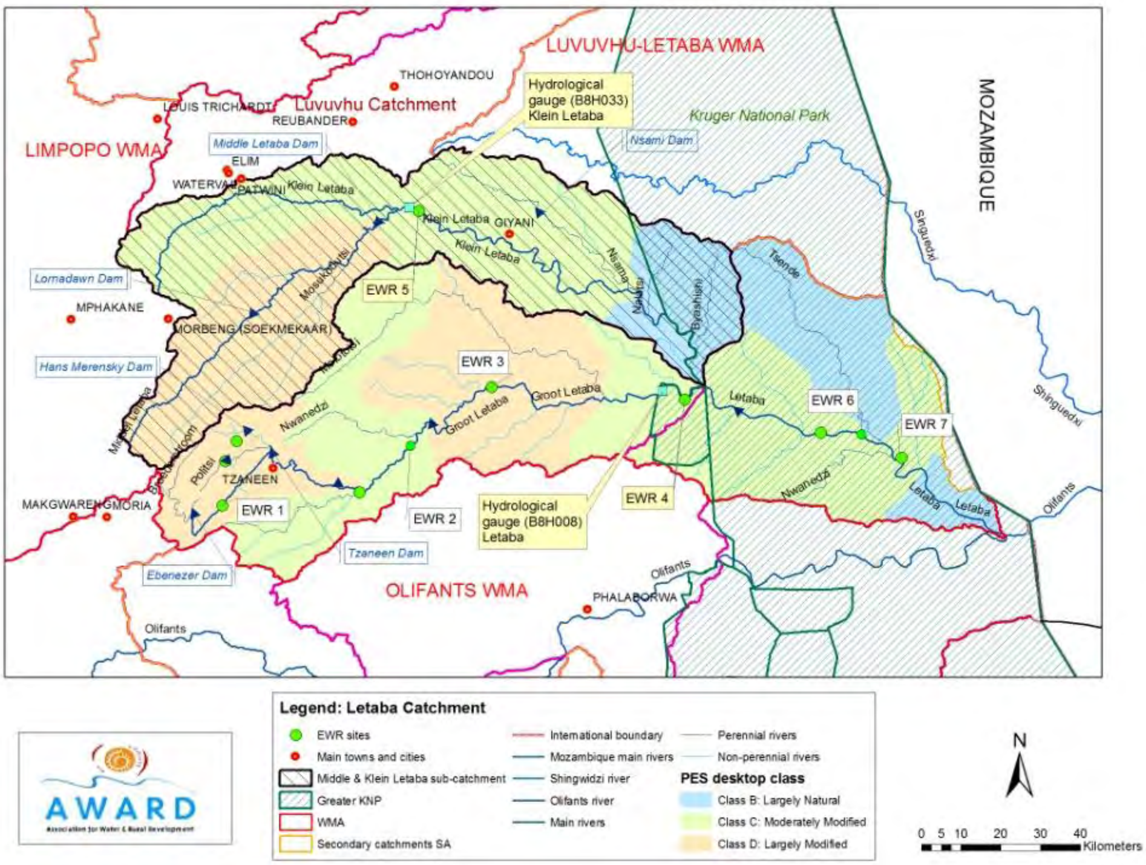


Figure 2: Letaba Catchment showing EWR sites and corresponding gauging stations

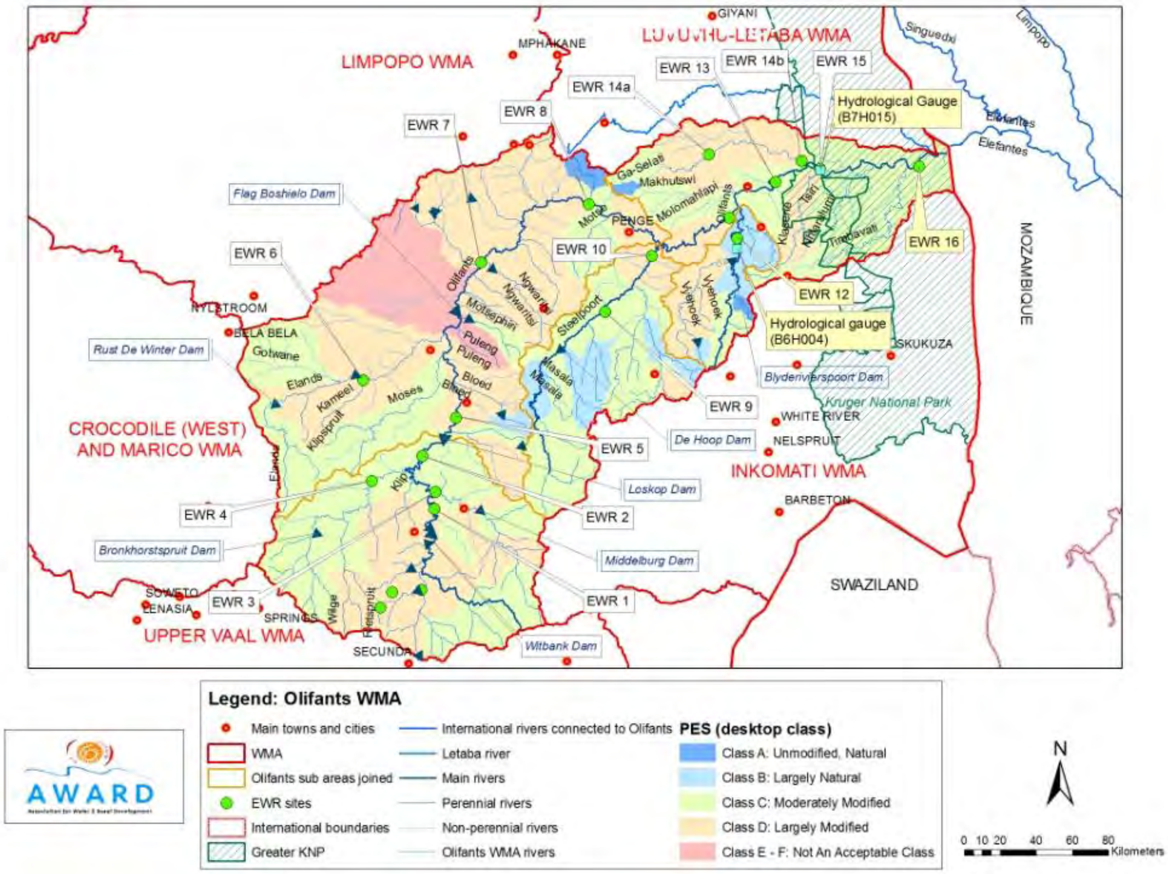


Figure 3: Olifants Catchment showing EWR sites and corresponding gauging stations

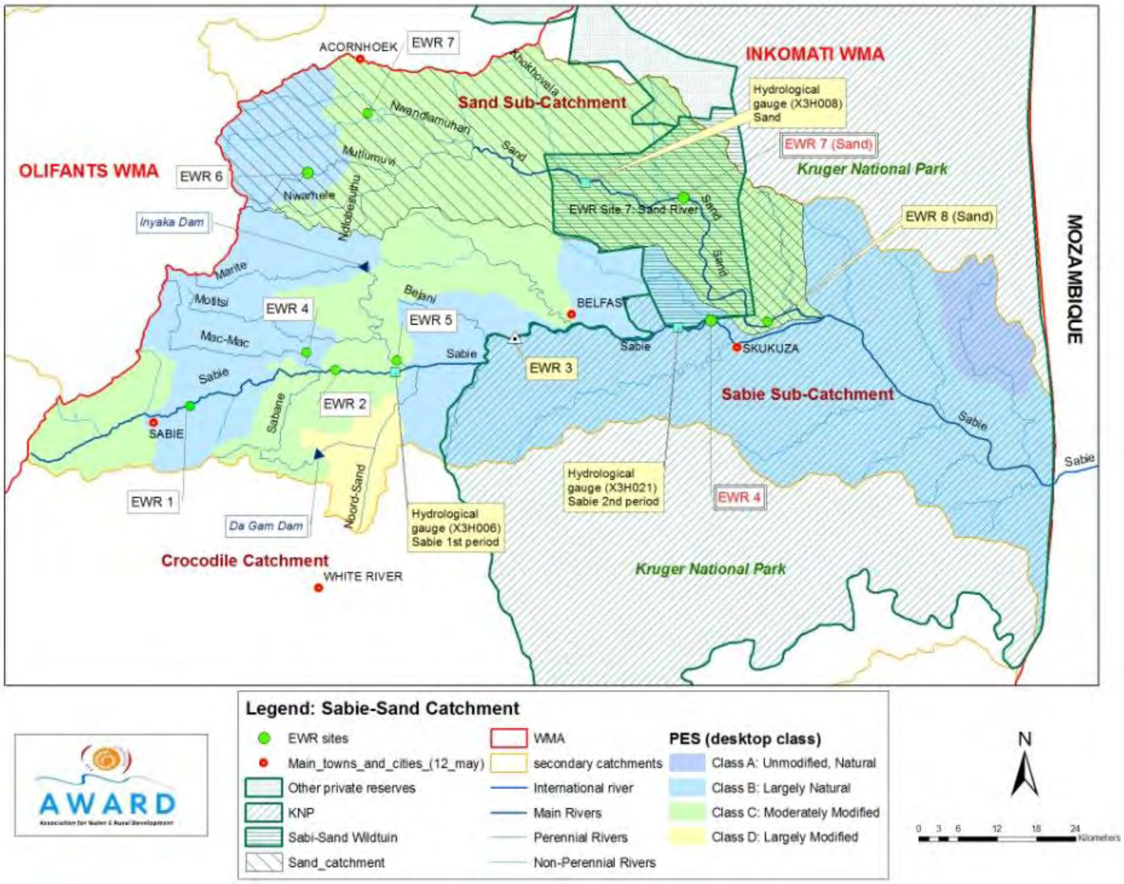


Figure 4: Sabie-Sand Catchment showing EWR sites and corresponding gauging stations

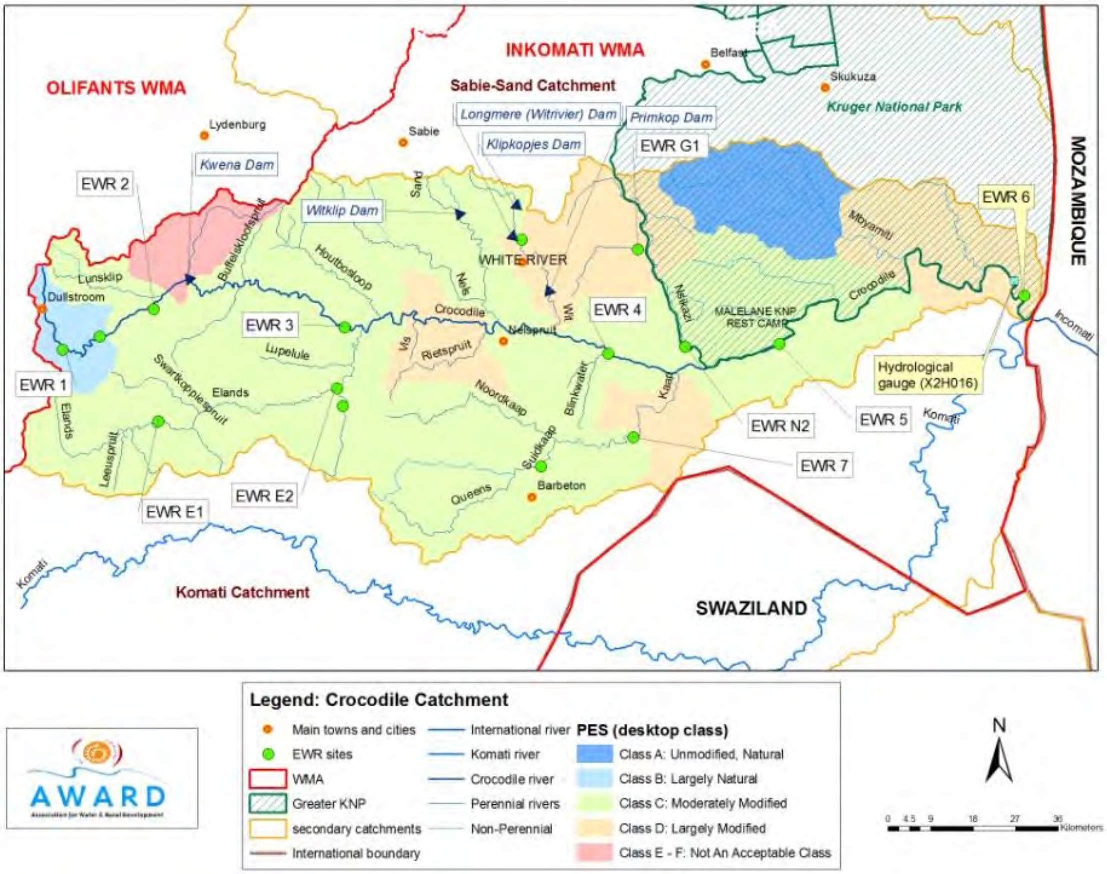


Figure 5: Crocodile Catchment showing EWR sites and corresponding gauging stations

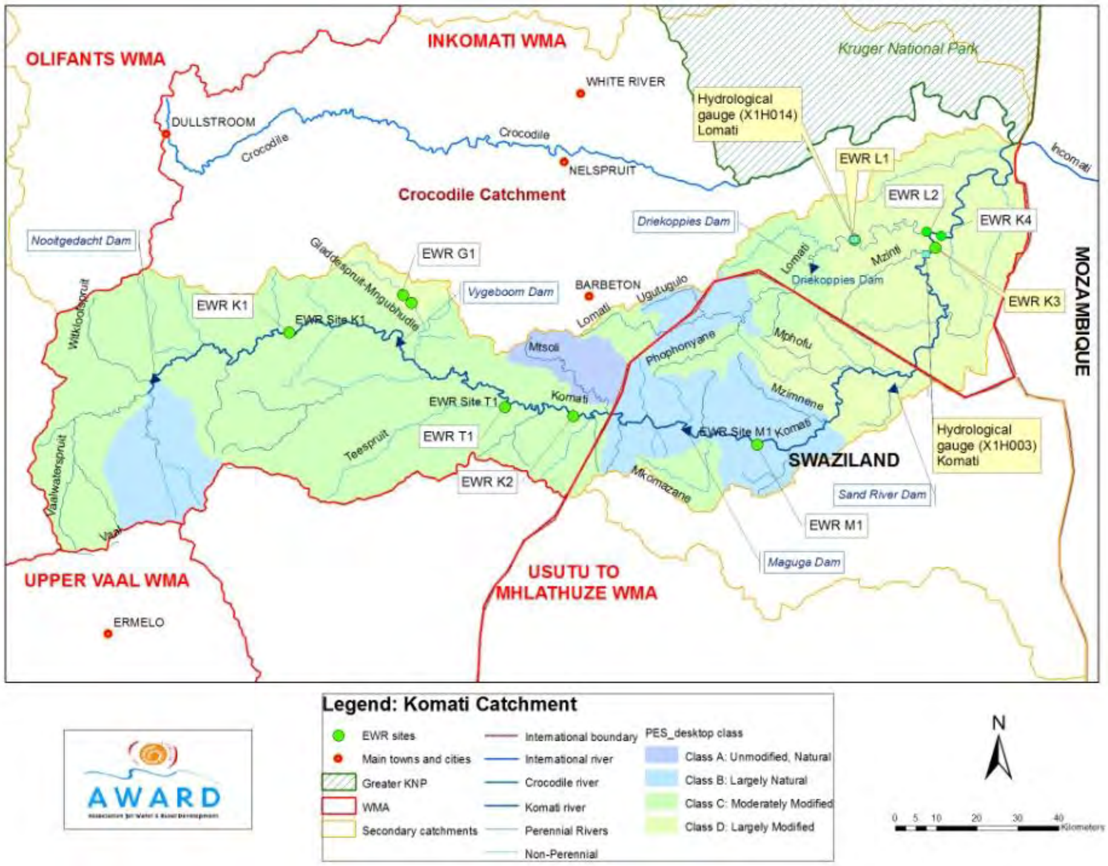


Figure 6: Komati Catchment showing EWR sites and corresponding gauging stations

Appendix 2
Rule curves (natural and ecological Reserve) for rivers under examination

1. Luvuvhu A91H

```
Summary of Reserve requirements for : A91H
Desktop Reserve Model Version 2, Dated: 9/29/2007
Dominant Rule Region               : 17 (E.Escarp)
Total Catchment Area (km^2)        :     2547.612
Total Natural MAR (Mill. m^3)      :      355.363
Ecological Reserve Category        : C

Annual IFR requirements: Mill. m^3 (% MAR)
Total maintenance     =       82.066 ( 23.09)
High flow maintenance =       29.516 (  8.31)
Low flow maintenance  =       52.550 ( 14.79)
Low flow drought      =       27.567 (  7.76)
Long-term mean        =       90.452 ( 25.45)
```

Monthly Table of IFR requirements (m^3 / s)

Month	Natural Flow Mean	Natural Flow St.Dev.	Lowflow Maint.	Lowflow Drought	Highflow Maint.	Total Maint.
Oct	3.580	1.612	1.109	0.602	0.055	1.165
Nov	5.136	3.900	1.176	0.636	0.264	1.440
Dec	9.114	7.374	1.302	0.696	0.806	2.109
Jan	19.898	29.153	1.757	0.917	1.649	3.407
Feb	29.935	34.861	2.410	1.242	5.844	8.254
Mar	26.095	31.910	2.343	1.203	1.649	3.992
Apr	15.958	20.195	2.188	1.129	1.369	3.557
May	7.846	4.341	1.888	0.981	0.000	1.888
Jun	6.232	2.922	1.795	0.938	0.000	1.795
Jul	4.912	1.939	1.527	0.805	0.000	1.527
Aug	4.141	1.417	1.336	0.712	0.000	1.336
Sep	3.728	1.206	1.227	0.661	0.000	1.227

Monthly Rule Curves
Data given in m^3/s mean monthly flow

Month	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
EWR without high flows										
Oct	1.541	1.537	1.524	1.498	1.448	1.360	1.218	1.019	0.789	0.628
Nov	1.630	1.623	1.606	1.573	1.513	1.413	1.260	1.055	0.824	0.664
Dec	1.805	1.797	1.777	1.739	1.670	1.557	1.386	1.158	0.903	0.726
Jan	2.430	2.414	2.381	2.320	2.216	2.054	1.822	1.522	1.190	0.959
Feb	3.340	3.324	3.287	3.215	3.085	2.870	2.547	2.115	1.634	1.300
Mar	3.247	3.233	3.199	3.131	3.007	2.800	2.486	2.064	1.589	1.260
Apr	3.039	3.031	3.004	2.951	2.850	2.670	2.383	1.977	1.510	1.184
May	2.622	2.617	2.597	2.555	2.472	2.323	2.079	1.728	1.317	1.028
Jun	2.493	2.489	2.471	2.433	2.357	2.218	1.988	1.654	1.260	0.983
Jul	2.130	2.128	2.116	2.089	2.033	1.926	1.740	1.455	1.102	0.844
Aug	1.857	1.854	1.841	1.812	1.756	1.654	1.485	1.239	0.950	0.746
Sep	1.705	1.701	1.689	1.662	1.609	1.514	1.359	1.136	0.875	0.691
EWR with high flows										
Oct	1.607	1.602	1.589	1.561	1.508	1.414	1.263	1.051	0.806	0.636
Nov	1.943	1.935	1.913	1.871	1.793	1.664	1.467	1.202	0.905	0.698
Dec	2.763	2.748	2.713	2.645	2.522	2.318	2.012	1.604	1.147	0.831
Jan	5.732	5.241	4.806	4.397	3.645	3.326	2.869	2.275	1.620	1.164
Feb	14.926	13.292	11.888	10.637	8.257	7.507	6.380	4.874	3.194	2.030
Mar	6.517	6.048	5.629	5.230	4.473	4.117	3.577	2.850	2.033	1.466
Apr	4.668	4.653	4.606	4.512	4.331	4.011	3.499	2.777	1.944	1.363
May	2.622	2.617	2.597	2.555	2.472	2.323	2.079	1.728	1.317	1.028
Jun	2.493	2.489	2.471	2.433	2.357	2.218	1.988	1.654	1.260	0.983
Jul	2.130	2.128	2.116	2.089	2.033	1.926	1.740	1.455	1.102	0.844
Aug	1.857	1.854	1.841	1.812	1.756	1.654	1.485	1.239	0.950	0.746
Sep	1.705	1.701	1.689	1.662	1.609	1.514	1.359	1.136	0.875	0.691
Natural flows										
Oct	5.37	4.36	4.07	3.52	3.35	3.14	2.81	2.57	2.05	1.64
Nov	10.10	6.17	5.41	4.88	4.18	3.68	3.06	2.65	2.30	1.66
Dec	22.52	14.71	10.52	7.43	5.87	5.22	4.40	3.76	3.05	1.76
Jan	39.31	24.96	20.97	14.17	9.94	8.73	5.78	4.76	4.06	1.82
Feb	74.72	50.27	41.87	24.66	15.87	12.07	6.80	5.35	4.17	2.17
Mar	58.80	44.58	28.60	21.04	13.84	11.71	6.63	4.98	4.18	2.95
Apr	32.69	19.02	15.51	11.19	9.34	8.66	6.76	5.11	3.77	3.07
May	13.38	10.92	9.71	8.25	6.99	6.18	5.34	3.96	3.50	2.58
Jun	9.96	8.26	7.61	6.49	5.83	5.21	4.42	3.78	3.03	2.31
Jul	7.30	6.41	5.88	5.10	4.85	4.36	3.63	3.20	2.56	1.88
Aug	5.99	5.45	4.84	4.45	4.21	3.61	3.22	2.86	2.30	1.89
Sep	5.19	4.75	4.26	4.05	3.75	3.25	3.05	2.55	2.27	1.90

2. Groot Letaba EWR4

EWR 4: Letaba Ranch on the Groot Letaba River
Recommended Ecological Category: C/D

	EWR4- Final Rule Tab (m3/s)									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	98%
October	0.469	0.370	0.369	0.357	0.333	0.307	0.229	0.190	0.096	0.060
November	2.667	1.339	0.776	0.655	0.543	0.527	0.345	0.215	0.131	0.092
December	2.953	2.953	2.938	1.855	1.592	1.349	1.162	0.804	0.174	0.068
January	4.138	4.034	3.773	3.146	2.746	1.627	0.898	0.796	0.248	0.087
February	32.961	30.796	27.311	9.151	5.244	3.056	1.811	0.964	0.270	0.096
March	12.129	12.107	10.716	7.952	5.441	3.008	2.084	0.966	0.397	0.114
April	3.057	3.057	3.046	2.843	2.663	2.363	1.494	0.886	0.199	0.091
May	1.092	1.092	1.090	1.037	0.942	0.855	0.654	0.368	0.193	0.074
June	0.907	0.907	0.905	0.857	0.781	0.655	0.347	0.251	0.123	0.066
July	0.604	0.604	0.604	0.577	0.531	0.413	0.278	0.206	0.105	0.062
August	0.454	0.352	0.352	0.338	0.311	0.271	0.203	0.134	0.079	0.057
September	0.378	0.238	0.176	0.173	0.166	0.150	0.121	0.095	0.062	0.054

Natural Duration curves										
% Points										
Month	**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**99%**
Oct	5.414	4.813	4.473	4.085	3.644	3.454	3.118	2.916	2.52	2.255
Nov	8.218	6.435	5.494	5.058	4.861	4.275	3.619	3.256	2.847	2.353
Dec	23.406	12.843	10.23	9.129	6.851	5.6	5.037	4.536	3.506	2.811
Jan	63.747	29.727	21.636	15.3	11.081	8.397	7	6.485	5.388	3.405
Feb	129.568	64.802	42.08	19.267	15.522	11.83	9.073	6.643	5.861	3.695
Mar	86.533	49.993	28.976	18.937	13.478	9.991	7.721	6.705	5.149	3.693
Apr	28.846	23.167	18.854	13.792	11.034	8.904	7.616	6.782	5.139	3.854
May	12.242	10.536	9.692	8.755	8.177	7.389	6.422	5.541	4.547	3.297
Jun	8.557	8.098	7.674	7.423	6.848	6.107	5.59	5.042	4.495	3.009
Jul	6.847	6.564	6.284	5.88	5.615	5.018	4.716	4.439	3.771	2.621
Aug	5.944	5.507	5.249	4.925	4.708	4.514	4.062	3.853	3.304	2.468
Sep	5.455	4.88	4.649	4.471	4.24	3.908	3.619	3.372	2.913	2

3. Klein Letaba EWR5

EWR 5: Klein Letaba River

Recommended Ecological Category: C

	ERW5-Final Rule Tab (m3/s)									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	98%
Oct	0.242	0.239	0.233	0.220	0.205	0.163	0.110	0.057	0.026	0.009
Nov	1.021	0.902	0.835	0.743	0.658	0.496	0.263	0.178	0.094	0.037
Dec	0.814	0.797	0.755	0.697	0.594	0.389	0.231	0.152	0.073	0.038
Jan	1.171	0.992	0.822	0.627	0.472	0.323	0.209	0.109	0.066	0.055
Feb	2.916	2.574	2.030	1.489	1.057	0.814	0.622	0.307	0.172	0.082
Mar	3.552	1.887	1.024	0.810	0.724	0.606	0.456	0.329	0.157	0.055
Apr	0.923	0.715	0.607	0.547	0.504	0.456	0.365	0.303	0.123	0.063
May	0.376	0.372	0.357	0.344	0.282	0.249	0.157	0.096	0.032	0.013
Jun	0.336	0.331	0.319	0.306	0.267	0.216	0.136	0.073	0.031	0.012
Jul	0.305	0.304	0.296	0.288	0.258	0.228	0.175	0.105	0.057	0.011
Aug	0.242	0.239	0.230	0.221	0.177	0.156	0.097	0.062	0.027	0.009
Sep	0.215	0.213	0.203	0.194	0.168	0.135	0.098	0.057	0.022	0.006

Natural Duration curves										
% Points										
Month	**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**99%**
Oct	1.027	0.84	0.732	0.631	0.575	0.482	0.429	0.381	0.34	0.291
Nov	2.222	1.454	1.227	1.019	0.806	0.687	0.567	0.459	0.37	0.278
Dec	5.97	3.935	2.311	1.983	1.251	0.974	0.833	0.653	0.403	0.284
Jan	21.278	8.774	5.992	3.517	2.576	2.031	1.236	0.9	0.586	0.399
Feb	28.303	12.368	6.473	4.514	2.906	1.906	1.236	0.984	0.682	0.355
Mar	12.291	5.309	3.047	2.042	1.647	1.281	1.083	0.743	0.653	0.538
Apr	2.944	2.23	1.879	1.508	1.2	1.069	0.891	0.671	0.575	0.482
May	1.691	1.449	1.213	1.128	0.989	0.859	0.713	0.586	0.5	0.411
Jun	1.508	1.211	0.984	0.953	0.849	0.779	0.679	0.563	0.455	0.378
Jul	1.243	1.034	0.889	0.799	0.739	0.694	0.609	0.534	0.422	0.343
Aug	1.064	0.892	0.803	0.702	0.668	0.616	0.553	0.47	0.399	0.34
Sep	0.984	0.81	0.718	0.667	0.61	0.559	0.49	0.428	0.374	0.336

4. Olifants B73H (data was converted to m^3s)

Table 1: Summary of IFR Estimate for Quaternary Catchment Area: B73H cumulative up to site IFR 16 (24°3'4.2"S; 31°43'56.3"E)

Total Runoff: Cumulative up to IFR site 16:
(24°3'4.2"S; 31°43'56.3"E) in Catchment B73H

Annual Flows	(Mill.	cu. m or index values):	
MAR	=	######	
S.Dev.	=	######	
CV	=	0.633	
Q75	=	48.050	
Q75/MMF	=	0.293	
BFI Index	= Index	0.481	
CV(JJA+JFM)	=	1.461	
IFR Management Class = B			
Total IFR	=	425.73	(21.63 %MAR)
Maint. Lowflow	=	361.02	(18.34 %MAR)
Drought Lowflow	=	95.014	(4.83 %MAR)
Maint. Highflow	=	64.716	(3.29 %MAR)
Monthly Distributions		(Mill.	cu. m.)
Distribution Type:		Olifants	

Month	**Natural Flows**			**Modified Flows**	**(IFR)**		
				Low Flows		**High Flows**	**Total Flows**
	Mean	**SD**	**CV**	**Maint.**	**Drought**	**Maint.**	**Maint.**
Oct	64.267	78.188	1.217	18.749	5.357	1.089	19.838
Nov	188.32	191.84	1.019	26.698	7.258	8.129	34.827
Dec	239.23	208.02	0.870	31.605	8.303	6.604	38.210
Jan	355.57	357.07	1.004	42.855	10.981	6.962	49.817
Feb	383.89	475.49	1.239	48.384	12.096	32.798	81.182
Mar	283.76	326.21	1.150	45.533	11.517	6.757	52.290
Apr	154.03	132.13	0.858	33.437	8.554	2.377	35.814
May	92.431	47.008	0.509	29.463	7.767	0.000	29.463
Jun	66.123	24.198	0.366	24.365	6.480	0.000	24.365
Jul	53.591	17.095	0.319	21.963	5.893	0.000	21.963
Aug	44.999	13.819	0.307	19.820	5.625	0.000	19.820
Sep	41.801	17.267	0.413	18.144	5.184	0.000	18.144

Table 2: Summary of IFR Rule Curves for Quaternary Catchment Area: B73H cumulative up to the IFR site 16 (24°29'47.4"S; 30°23'56.4"E)

Total Runoff: Cumulative up to IFR site 16(24°29'47.4"S; 30°23'56.4"E) in Catchment B73H
Regional Type: Olifants
EMC = B
Data are given in m^3 * 10^6 monthly flow volume

Month			% Points							
	10%	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**99%**
Oct	23.582	23.409	23.017	22.206	20.695	18.205	14.692	10.646	7.187	5.579
Nov	40.773	40.530	40.024	39.022	37.146	33.870	28.660	21.421	13.352	8.275
Dec	44.964	44.697	44.139	43.037	40.971	37.365	31.630	23.660	14.778	9.189
Jan	64.694	62.593	60.442	57.885	54.356	48.296	40.902	30.627	19.174	11.968
Feb	121.47	112.64	104.73	97.086	88.705	74.551	62.602	45.998	27.490	15.845
Mar	67.494	65.426	63.278	60.679	57.033	50.767	42.978	32.154	20.090	12.499
Apr	42.526	42.204	41.474	39.964	37.150	32.514	25.971	18.438	11.997	9.002
May	35.182	34.921	34.327	33.100	30.813	27.046	21.729	15.607	10.373	7.939
Jun	29.095	28.880	28.390	27.378	25.491	22.384	17.997	12.947	8.629	6.622
Jul	26.277	26.033	25.593	24.683	22.987	20.192	16.248	11.707	7.825	6.020
Aug	23.670	23.498	23.108	22.300	20.794	18.315	14.815	10.785	7.340	5.738
Sep	21.669	21.512	21.155	20.417	19.042	16.777	13.579	9.898	6.751	5.287
Natural Duration curves										
	10%	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**99%**
Oct	95.687	75.272	57.072	52.561	46.020	38.079	33.506	30.282	27.285	22.073
Nov	446.27	316.35	192.52	130.54	120.11	91.413	75.530	62.768	48.513	29.201
Dec	450.56	335.76	296.05	239.15	159.93	147.61	124.75	88.415	70.606	42.498
Jan	908.19	600.11	356.91	240.29	222.51	179.15	136.12	114.53	93.009	68.742
Feb	991.26	697.84	366.43	234.37	196.61	133.19	117.05	103.27	83.863	71.204
Mar	549.37	420.1	339.07	236.98	156.62	115.23	100.73	83.904	79.990	57.196
Apr	243.68	217.75	165.07	131.53	115.31	104.2	88.106	73.686	57.278	50.645
May	139.3	125.25	######	87.354	80.330	76.076	66.816	55.538	47.473	44.599

Jun	100.64	87.20	75.829	65.910	62.027	57.464	49.378	44.949	39.233	36.647
Jul	78.929	69.834	60.832	55.311	49.419	47.277	45.032	39.346	33.310	31.055
Aug	63.633	55.043	50.964	46.196	41.633	38.800	36.761	33.877	30.128	27.491
Sep	77.786	50.068	43.414	39.923	38.223	35.381	32.435	28.840	26.481	23.227

5. Blyde (data was converted to m^3s)

Table 1: Summary of IFR Estimate for Quaternary Catchment Area: B60J cumulative up to site 24°24'31"S; 30°49'35"E.

Total Runoff:	B60J at IFR site 12(24°24'31"S;	30049'35"E.)	
Annual Flows	(Mill.	cu. m or index values):	
MAR	=	383.7	
S.Dev.	=	332.55	
CV	=	0.867	
Q75	=	13.155	
Q75/MMF	=	0.411	
BFI Index	=	0.568	
CV(JJA+JFM)	Index =	1.654	
IFR Management Class = B			
Total IFR	=	132.33	(34.49 %MAR)
Maint. Lowflow	=	107.27	(27.96 %MAR)
Drought Lowflow	=	33.130	(8.63 %MAR)
Maint. Highflow	=	25.058	(6.53 %MAR)
Monthly Distributions		(Mill.	cu. m.)
Distribution Type:		E.Escarp	

Month	**Natural Flows**			**Modified Flows (IFR)**			
				Low Flows		**High Flows**	**Total Flows**
	Mean	**SD**	**CV**	**Maint.**	**Drought**	**Maint.**	**Maint.**
Oct	12.111	3.697	0.305	5.625	2.143	1.229	6.853
Nov	18.942	10.224	0.540	5.962	2.074	2.395	8.357
Dec	32.152	51.930	1.615	7.232	2.411	3.826	11.058
Jan	52.610	69.414	1.319	10.178	2.946	4.261	14.439
Feb	78.912	113.1	1.433	13.790	3.871	7.904	21.694
Mar	69.638	99.392	1.427	14.463	4.018	3.764	18.227
Apr	38.518	48.771	1.266	11.923	3.370	1.680	13.603

May	22.696	8.628	0.380	9.642	2.946	0.000	9.642
Jun	17.813	5.121	0.287	8.035	2.592	0.000	8.035
Jul	15.061	3.772	0.250	7.500	2.411	0.000	7.500
Aug	12.878	3.143	0.244	6.696	2.277	0.000	6.696
Sep	12.372	6.839	0.553	6.221	2.074	0.000	6.221

Table 2: Summary of IFR Rule Curve for Quaternary catchment Area: B60J cumulative up to the site (24°24'31"S; 30°49'35"E).

Total Runoff: B60J at IFR site 12 (24°24'31"S; 30°49'35"E)
Regional Type: E. Escarp
EMC = B
Data are given in m^3 * 10^6 monthly flow volume

Month	% Points								
	10%	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**99%**
Oct	8.065	8.046	7.980	7.842	7.570	7.073	6.239	5.010	3.527	2.450
Nov	9.742	9.707	9.612	9.420	9.053	8.393	7.311	5.745	3.886	2.545
Dec	12.823	12.768	12.634	12.365	11.855	10.950	9.480	7.372	4.889	3.104
Jan	20.432	19.263	18.194	17.123	15.897	13.824	11.896	9.179	6.023	3.769
Feb	31.819	29.718	27.828	26.011	24.028	20.654	17.773	13.640	8.771	5.270
Mar	24.582	23.556	22.569	21.526	20.235	17.998	15.577	12.073	7.914	4.913
Apr	16.077	16.037	15.893	15.594	15.008	13.932	12.130	9.471	6.266	3.936
May	11.517	11.502	11.414	11.226	10.849	10.141	8.928	7.102	4.863	3.223
Jun	9.598	9.590	9.522	9.376	9.078	8.510	7.527	6.031	4.181	2.820
Jul	8.958	8.958	8.902	8.778	8.518	8.010	7.108	5.705	3.939	2.628
Aug	7.999	7.993	7.937	7.818	7.574	7.111	6.307	5.085	3.575	2.463
Sep	7.431	7.422	7.367	7.250	7.014	6.571	5.813	4.671	3.272	2.247

Natural Duration curves										
	10%	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**99%**
Oct	16.960	15.306	13.462	12.020	11.363	10.250	9.985	9.317	8.554	7.568
Nov	31.238	24.263	19.917	18.380	16.017	14.904	13.250	11.575	9.572	8.501
Dec	47.711	35.574	29.023	25.875	22.578	20.893	18.730	16.303	15.020	11.088
Jan	142.316	58.915	39.845	30.390	27.507	24.316	21.772	20.229	17.638	13.632
Feb	223.490	144.36	58.607	44.891	29.987	25.302	22.112	19.907	18.380	15.243
Mar	153.965	100.44	75.101	38.499	31.334	24.815	22.928	21.391	19.091	14.649
Apr	71.433	41.965	30.623	28.631	26.765	22.334	20.914	19.801	18.465	14.829
May	29.934	25.652	24.444	22.705	21.211	19.122	17.596	16.812	16.112	12.858
Jun	21.772	19.960	19.250	17.967	17.087	15.858	15.158	13.928	13.133	11.236
Jul	18.932	16.886	16.313	15.412	14.511	13.674	13.155	11.596	11.448	9.794
Aug	18.147	14.925	13.780	13.027	12.519	11.883	11.384	10.621	9.763	8.544
Sep	15.858	14.119	12.805	11.575	11.024	10.579	10.049	9.328	8.862	7.431

6. Sabie EWR3 AB

Desktop	Version	2,	Printed	on	2008/07/31					
Summary	of	IFR	rule	curves	for	:	SB3	Natural	Flows	
Determination	based	on	defined	BBM	Table	with	site	specific	assurance	rules.
Regional	Type	:	E.Escarp	ERC	=	A/B				
Data	are	given	in	m^3/s	mean	monthly	flow			
	%	Points								
Month	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	3.23	3.223	3.199	3.148	3.048	2.864	2.557	2.103	1.556	1.144
Nov	6.082	6.06	6.001	5.88	5.65	5.236	4.558	3.575	2.409	1.539
Dec	7.104	7.073	6.999	6.851	6.569	6.07	5.259	4.096	2.725	1.706
Jan	10.172	9.664	9.19	8.7	8.118	7.132	6.15	4.766	3.159	1.971
Feb	20.234	18.756	17.44	16.198	14.88	12.642	10.847	8.273	5.241	2.984
Mar	11.597	11.217	10.834	10.402	9.828	8.828	7.636	5.911	3.863	2.334
Apr	8.289	8.269	8.196	8.044	7.745	7.198	6.281	4.928	3.296	2.069
May	6.92	6.911	6.857	6.742	6.511	6.078	5.335	4.217	2.847	1.808
Jun	6.115	6.11	6.066	5.971	5.777	5.409	4.77	3.798	2.597	1.683
Jul	4.881	4.881	4.851	4.784	4.643	4.37	3.883	3.127	2.175	1.444
Aug	3.974	3.971	3.944	3.886	3.768	3.544	3.156	2.566	1.835	1.28
Sep	3.443	3.439	3.415	3.365	3.264	3.074	2.748	2.258	1.657	1.202
Reserve	flows	without	High	Flows						
Oct	3.23	3.223	3.199	3.148	3.048	2.864	2.557	2.103	1.556	1.144
Nov	4.017	4.004	3.968	3.897	3.759	3.512	3.106	2.52	1.823	1.303
Dec	5.105	5.085	5.035	4.935	4.746	4.411	3.866	3.084	2.163	1.478
Jan	6.624	6.588	6.514	6.37	6.102	5.638	4.898	3.855	2.644	1.748
Feb	9.366	9.326	9.229	9.035	8.666	8.013	6.951	5.429	3.635	2.3
Mar	8.966	8.933	8.844	8.664	8.319	7.7	6.685	5.215	3.471	2.169
Apr	8.289	8.269	8.196	8.044	7.745	7.198	6.281	4.928	3.296	2.069
May	6.92	6.911	6.857	6.742	6.511	6.078	5.335	4.217	2.847	1.808
Jun	6.115	6.11	6.066	5.971	5.777	5.409	4.77	3.798	2.597	1.683
Jul	4.881	4.881	4.851	4.784	4.643	4.37	3.883	3.127	2.175	1.444
Aug	3.974	3.971	3.944	3.886	3.768	3.544	3.156	2.566	1.835	1.28
Sep	3.443	3.439	3.415	3.365	3.264	3.074	2.748	2.258	1.657	1.202
Natural	Duration	curves								
Oct	8.86	7.624	6.814	5.761	5.111	4.723	4.488	4.178	3.711	3.088
Nov	18.808	14.742	11.802	10.093	9.086	8.221	7.272	5.76	4.911	3.746
Dec	33.923	25.989	21.229	16.726	13.922	12.291	10.275	9.491	7.706	5.066
Jan	55.88	37.817	26.202	23.749	19.71	17.111	13.702	11.645	10.447	8.18
Feb	82.507	64.559	41.46	31.754	23.177	20.747	16.923	13.368	10.074	7.647
Mar	66.439	45.318	34.009	28.054	20.968	16.599	14.501	11.787	10.122	6.776
Apr	32.28	25.035	20.359	17.535	14.271	13.499	12.222	11.084	9.63	6.227
May	15.17	13.355	12.444	11.391	10.783	9.849	8.703	8.18	7.396	5.115
Jun	11.682	10.073	9.525	9.136	8.6	8.194	7.353	6.632	6.03	4.568
Jul	9.58	8.162	7.646	7.042	6.735	6.452	6.022	5.451	5.052	4.036
Aug	7.553	7.105	6.254	6	5.679	5.417	5.01	4.749	4.238	3.435
Sep	7.612	7.06	5.741	5.409	5.235	4.842	4.552	4.209	3.866	3.14

7. Sand EWR8

Desktop	Version	2,	Printed	on	2008/08/01					
Summary	of	IFR	rule	curves	for	:	SB8	Natural	Flows	
Determination	based	on	defined	BBM	Table	with	site	specific	assurance	rules.
Regional	Type	:	E.Escarp	ERC	=	B				
Data	are	given	in	m^3/s	mean	monthly	flow			
	%	Points								
Month	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	0.8	0.794	0.782	0.759	0.716	0.642	0.524	0.357	0.163	0.02
Nov	1.315	1.306	1.288	1.253	1.187	1.073	0.89	0.634	0.335	0.115
Dec	1.514	1.501	1.472	1.414	1.307	1.129	0.876	0.576	0.304	0.155
Jan	2.171	2.051	1.936	1.81	1.58	1.384	1.097	0.75	0.433	0.258
Feb	7.677	6.844	6.135	4.551	3.509	3.038	2.381	2.03	1.13	0.622
Mar	2.889	2.772	2.652	2.512	2.249	1.985	1.586	1.089	0.624	0.368
Apr	1.757	1.747	1.719	1.66	1.548	1.359	1.082	0.748	0.442	0.273
May	1.28	1.27	1.248	1.202	1.118	0.979	0.781	0.546	0.333	0.217
Jun	1.19	1.181	1.159	1.116	1.034	0.901	0.71	0.483	0.278	0.166
Jul	1.044	1.037	1.023	0.996	0.946	0.858	0.718	0.521	0.292	0.123
Aug	0.934	0.927	0.914	0.889	0.842	0.759	0.629	0.444	0.23	0.072
Sep	0.865	0.859	0.847	0.823	0.777	0.699	0.573	0.397	0.192	0.041
Reserve	flows	without	High	Flows						
Oct	0.8	0.794	0.782	0.759	0.716	0.642	0.524	0.357	0.163	0.02
Nov	0.898	0.892	0.879	0.855	0.809	0.73	0.605	0.428	0.223	0.071
Dec	1.109	1.1	1.079	1.037	0.958	0.828	0.643	0.423	0.225	0.115
Jan	1.461	1.452	1.429	1.379	1.286	1.127	0.896	0.616	0.36	0.22
Feb	2.355	2.347	2.315	2.244	2.103	1.855	1.479	1.011	0.574	0.332
Mar	2.179	2.172	2.143	2.078	1.949	1.722	1.378	0.951	0.55	0.33
Apr	1.757	1.747	1.719	1.66	1.548	1.359	1.082	0.748	0.442	0.273
May	1.28	1.27	1.248	1.202	1.118	0.979	0.781	0.546	0.333	0.217
Jun	1.19	1.181	1.159	1.116	1.034	0.901	0.71	0.483	0.278	0.166
Jul	1.044	1.037	1.023	0.996	0.946	0.858	0.718	0.521	0.292	0.123
Aug	0.934	0.927	0.914	0.889	0.842	0.759	0.629	0.444	0.23	0.072
Sep	0.865	0.859	0.847	0.823	0.777	0.699	0.573	0.397	0.192	0.041
Natural	Duration	curves								
Oct	1.62	1.456	1.299	1.18	1.012	0.915	0.866	0.818	0.694	0.459
Nov	3.549	2.859	1.971	1.686	1.447	1.289	1.165	0.93	0.806	0.521
Dec	10.45	5.462	3.573	2.655	2.363	1.695	1.441	1.31	0.967	0.635
Jan	18.089	9.558	5.395	3.655	3.3	2.729	2.173	1.77	1.37	0.829
Feb	38.538	16.286	9.077	4.551	3.509	3.038	2.381	2.03	1.674	0.798
Mar	26.43	10.57	7.486	4.958	2.987	2.714	2.195	1.792	1.512	0.691
Apr	9.267	5.127	3.573	2.998	2.5	2.215	1.941	1.779	1.535	0.795
May	3.177	2.815	2.52	2.184	1.923	1.729	1.602	1.497	1.262	0.683
Jun	2.442	2.23	2.091	1.806	1.663	1.505	1.381	1.292	1.111	0.648
Jul	2.046	1.807	1.676	1.52	1.404	1.296	1.18	1.079	0.978	0.609
Aug	1.759	1.557	1.411	1.333	1.213	1.113	1.045	0.96	0.833	0.538
Sep	1.601	1.489	1.35	1.223	1.115	1.026	0.941	0.876	0.772	0.494

8. Crocodile EWR 6

Desktop	Version	2,	Printed	on	2008/08/01					
Summary	of	IFR	rule	curves	for	:	SB8	Natural	Flows	
Determination	based	on	defined	BBM	Table	with	site	specific	assurance	rules.
Regional	Type	:	E.Escarp	ERC	=	B				
Data	are	given	in	m^3/s	mean	monthly	flow			
	%	Points								
Month	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	0.8	0.794	0.782	0.759	0.716	0.642	0.524	0.357	0.163	0.02
Nov	1.315	1.306	1.288	1.253	1.187	1.073	0.89	0.634	0.335	0.115
Dec	1.514	1.501	1.472	1.414	1.307	1.129	0.876	0.576	0.304	0.155
Jan	2.171	2.051	1.936	1.81	1.58	1.384	1.097	0.75	0.433	0.258
Feb	7.677	6.844	6.135	4.551	3.509	3.038	2.381	2.03	1.13	0.622
Mar	2.889	2.772	2.652	2.512	2.249	1.985	1.586	1.089	0.624	0.368
Apr	1.757	1.747	1.719	1.66	1.548	1.359	1.082	0.748	0.442	0.273
May	1.28	1.27	1.248	1.202	1.118	0.979	0.781	0.546	0.333	0.217
Jun	1.19	1.181	1.159	1.116	1.034	0.901	0.71	0.483	0.278	0.166
Jul	1.044	1.037	1.023	0.996	0.946	0.858	0.718	0.521	0.292	0.123
Aug	0.934	0.927	0.914	0.889	0.842	0.759	0.629	0.444	0.23	0.072
Sep	0.865	0.859	0.847	0.823	0.777	0.699	0.573	0.397	0.192	0.041
Reserve	flows	without	High	Flows						
Oct	0.8	0.794	0.782	0.759	0.716	0.642	0.524	0.357	0.163	0.02
Nov	0.898	0.892	0.879	0.855	0.809	0.73	0.605	0.428	0.223	0.071
Dec	1.109	1.1	1.079	1.037	0.958	0.828	0.643	0.423	0.225	0.115
Jan	1.461	1.452	1.429	1.379	1.286	1.127	0.896	0.616	0.36	0.22
Feb	2.355	2.347	2.315	2.244	2.103	1.855	1.479	1.011	0.574	0.332
Mar	2.179	2.172	2.143	2.078	1.949	1.722	1.378	0.951	0.55	0.33
Apr	1.757	1.747	1.719	1.66	1.548	1.359	1.082	0.748	0.442	0.273
May	1.28	1.27	1.248	1.202	1.118	0.979	0.781	0.546	0.333	0.217
Jun	1.19	1.181	1.159	1.116	1.034	0.901	0.71	0.483	0.278	0.166
Jul	1.044	1.037	1.023	0.996	0.946	0.858	0.718	0.521	0.292	0.123
Aug	0.934	0.927	0.914	0.889	0.842	0.759	0.629	0.444	0.23	0.072
Sep	0.865	0.859	0.847	0.823	0.777	0.699	0.573	0.397	0.192	0.041
Natural	Duration	curves								
Oct	1.62	1.456	1.299	1.18	1.012	0.915	0.866	0.818	0.694	0.459
Nov	3.549	2.859	1.971	1.686	1.447	1.289	1.165	0.93	0.806	0.521
Dec	10.45	5.462	3.573	2.655	2.363	1.695	1.441	1.31	0.967	0.635
Jan	18.089	9.558	5.395	3.655	3.3	2.729	2.173	1.77	1.37	0.829
Feb	38.538	16.286	9.077	4.551	3.509	3.038	2.381	2.03	1.674	0.798
Mar	26.43	10.57	7.486	4.958	2.987	2.714	2.195	1.792	1.512	0.691
Apr	9.267	5.127	3.573	2.998	2.5	2.215	1.941	1.779	1.535	0.795
May	3.177	2.815	2.52	2.184	1.923	1.729	1.602	1.497	1.262	0.683
Jun	2.442	2.23	2.091	1.806	1.663	1.505	1.381	1.292	1.111	0.648
Jul	2.046	1.807	1.676	1.52	1.404	1.296	1.18	1.079	0.978	0.609
Aug	1.759	1.557	1.411	1.333	1.213	1.113	1.045	0.96	0.833	0.538
Sep	1.601	1.489	1.35	1.223	1.115	1.026	0.941	0.876	0.772	0.494

9. Komati EWR 3

KOMATI RIVER: RU D, SITE K3

Table B3.3. EWR rule table for REC: D

Desktop Version 2, Printed on 28/11/2004
Summary of EWR rule curves for : EWR K3 Monthly Nat EWR K3
Determination based on defined BBM Table with site specific assurance rules.
Regional Type : E.Escarp REC = D
Data are given in m^3/s mean monthly flow
This EWR rule table can be used in combination with the natural duration curves below for
implementation.

	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	3.84	3.69	3.62	3.59	3.54	3.41	2.81	2.14	1.18	0.50
Nov	4.92	3.77	3.74	3.64	3.53	3.20	2.87	2.34	1.42	0.53
Dec	6.43	5.29	4.77	4.18	4.15	4.06	3.55	2.55	1.44	0.74
Jan	12.02	7.24	6.14	5.31	5.14	5.07	4.43	2.98	2.01	0.71
Feb	13.84	12.65	6.06	5.84	5.60	5.08	4.83	3.35	2.28	1.34
Mar	34.99	27.78	5.76	5.68	5.41	5.22	4.84	4.07	3.02	1.33
Apr	6.18	5.37	5.33	5.24	5.04	4.68	4.12	2.55	1.79	0.82
May	4.87	4.85	4.78	4.69	4.51	3.84	3.32	2.34	1.47	0.65
Jun	4.38	4.37	4.30	4.20	4.04	3.55	2.92	2.03	1.37	0.59
Jul	3.88	3.87	3.82	3.72	3.56	3.36	2.79	1.73	1.22	0.50
Aug	3.72	3.71	3.65	3.56	3.40	3.10	2.44	1.99	1.07	0.45
Sep	3.64	3.64	3.60	3.54	3.43	3.20	2.77	2.33	1.18	0.43

Natural Duration curves

	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	22.435	17.992	13.430	11.264	10.140	8.643	7.941	7.269	6.261	4.954
Nov	59.313	39.063	29.444	23.677	19.564	17.940	16.574	14.788	9.306	6.327
Dec	86.526	69.598	57.400	40.961	33.942	29.204	25.258	21.244	16.805	7.228
Jan	132.098	92.047	73.723	60.357	46.924	35.850	31.829	27.225	22.555	18.399
Feb	246.532	134.970	76.120	55.915	44.267	34.487	31.130	26.939	23.822	19.610
Mar	129.600	71.024	52.737	39.397	31.892	29.794	26.449	22.185	17.955	15.252
Apr	60.544	38.873	32.971	29.672	27.832	25.829	23.681	19.267	15.694	12.018
May	29.686	24.854	22.390	21.050	20.288	18.160	16.566	14.303	12.593	8.695
Jun	23.472	19.583	16.682	15.961	15.251	13.978	12.647	11.134	9.468	6.501
Jul	18.705	14.755	13.381	11.884	11.126	10.559	9.468	8.580	7.389	5.190
Aug	14.397	12.254	10.977	9.845	9.353	8.531	7.796	7.247	6.470	4.887
Sep	15.448	11.335	9.857	9.182	8.850	7.982	7.438	6.686	5.826	5.150

10. Lomati EWR 1

LOMATI RIVER, RU M, SITE L1

Table B3.6. EWR rule table for REC: C/D

Desktop Version 2, Printed on 31/01/2005
Summary of EWR rule curves for : EWR L1 Monthly Nat EWR L1
Determination based on defined BBM Table with site specific assurance rules.
Regional Type : E.Escarp REC = C/D
Data are given in m^3/s mean monthly flow
This EWR rule table can be used in combination with the natural duration curves below for implementation.

	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	0.54	0.54	0.54	0.53	0.51	0.48	0.44	0.36	0.27	0.21
Nov	1.05	1.05	1.03	1.01	0.97	0.89	0.80	0.63	0.43	0.28
Dec	1.29	1.28	1.27	1.23	1.20	1.11	0.97	0.76	0.53	0.35
Jan	2.34	2.20	2.03	1.91	1.78	1.53	1.32	1.00	0.67	0.41
Feb	3.12	2.97	2.73	2.59	2.32	2.08	1.82	1.42	0.90	0.52
Mar	5.08	4.76	4.15	3.55	3.04	2.75	2.36	1.95	1.20	0.63
Apr	1.56	1.56	1.54	1.51	1.46	1.36	1.18	0.93	0.62	0.39
May	1.31	1.31	1.30	1.28	1.24	1.15	1.01	0.80	0.54	0.34
Jun	1.12	1.11	1.11	1.09	1.06	0.99	0.87	0.70	0.48	0.31
Jul	0.82	0.82	0.82	0.81	0.78	0.74	0.66	0.54	0.38	0.27
Aug	0.60	0.60	0.59	0.59	0.57	0.54	0.49	0.41	0.31	0.23
Sep	0.68	0.67	0.67	0.66	0.64	0.60	0.54	0.44	0.32	0.23

Natural Duration curves

	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	7.217	5.276	4.529	3.573	3.300	3.073	2.740	2.457	2.244	1.941
Nov	14.900	11.497	8.985	7.419	6.235	5.000	4.441	3.526	2.967	2.056
Dec	24.313	18.436	14.053	11.932	10.013	8.707	7.542	5.996	4.559	2.561
Jan	37.563	26.225	18.067	15.401	13.004	10.842	9.349	8.408	6.392	3.547
Feb	68.477	38.389	23.103	16.700	13.174	11.020	9.950	8.213	7.081	4.696
Mar	42.413	28.286	16.850	14.953	11.063	9.595	8.218	7.587	5.974	3.771
Apr	19.128	15.448	12.542	10.829	9.340	8.657	7.596	6.860	5.058	3.326
May	10.443	8.225	7.538	7.198	6.948	6.481	5.746	5.029	4.066	2.475
Jun	8.117	6.759	6.096	5.876	5.382	5.177	4.853	4.120	3.472	2.114
Jul	6.026	5.119	4.869	4.566	4.275	4.085	3.681	3.136	2.733	1.803
Aug	5.037	4.506	4.002	3.749	3.663	3.353	3.084	2.737	2.393	1.773
Sep	4.815	4.101	3.731	3.414	3.167	3.052	2.685	2.527	2.218	1.624

Appendix 2: Observed flow and storage in the Crocodile River catchment

Year	Month	Observed Flov	Storage (% of FSC)		Restrictions
		Tenbosch wei	Kwena Dam	Witklip Dam	(% of full demand supplied
2003	Oct	1.17	41.08	30.70	23.01
2003	Nov	5.79	34.90	23.65	23.83
2003	Dec	4.19	33.17	22.04	20.91
2004	Jan	24.9	29.31	18.84	52.68
2004	Feb	53	29.73	19.81	75.86
2004	Mar	120	37.74	28.34	100.00
2004	Apr	73.4	57.80	42.20	100.00
2004	May	14.8	68.07	51.46	48.39
2004	Jun	5.85	69.36	53.91	40.00
2004	Jul	3.48	68.97	55.89	40.00
2004	Aug	3.19	67.15	58.07	36.84
2004	Sep	1.99	64.46	57.13	37.82
2004	Oct	2	57.99	52.04	33.75
2004	Nov	8.56	52.05	42.72	47.42
2004	Dec	15.1	48.28	40.22	64.84
2005	Jan	28.1	45.09	42.26	73.23
2005	Feb	11.1	48.91	41.14	78.13
2005	Mar	13.2	50.00	37.74	100.00
2005	Apr	6.87	49.95	39.35	65.33
2005	May	4.53	52.41	40.30	39.84
2005	Jun	2.55	50.86	37.96	24.17
2005	Jul	2.16	47.43	35.67	20.00
2005	Aug	1.06	43.03	32.71	21.77
2005	Sep	0.89	38.44	28.75	17.00
2005	Oct	0.557	35.52	21.67	12.29
2005	Nov	6.59	34.93	15.88	30.85
2005	Dec	6.99	34.48	13.57	33.06
2006	Jan	113	34.05	14.97	83.55
2006	Feb	165	56.95	20.60	100.00
2006	Mar	375	98.05	31.09	100.00
2006	Apr	160	101.29	53.23	100.00
2006	May	51.7	100.77	70.84	100.00
2006	Jun	19.2	100.50	76.36	95.00
2006	Jul	18.9	100.28	80.27	70.00
2006	Aug	8.74	100.25	82.42	58.39
2006	Sep	4.43	97.57	82.99	58.00
2006	Oct	9.25	93.07	78.89	66.52
2006	Nov	26.9	90.53	73.23	70.00
2006	Dec	34.8	95.59	75.05	81.81
2007	Jan	39.4	99.06	80.64	100.00
2007	Feb	13.6	98.25	85.52	100.00
2007	Mar	4.26	94.16	82.21	75.48
2007	Apr	25.1	96.99	72.35	85.00
2007	May	6.96	93.44	69.78	57.03
2007	Jun	8.09	89.08	66.82	39.67
2007	Jul	4.94	85.29	62.42	35.00
2007	Aug	1.91	85.30	58.54	35.00
2007	Sep	1.99	78.70	51.00	39.67
2007	Oct	6.03	71.05	42.75	54.54
2007	Nov	25	66.84	40.41	60.97
2007	Dec	48.1	67.50	47.19	58.00
2008	Jan	104	79.83	57.69	58.00
2008	Feb	37	100.03	87.74	58.00
2008	Mar	52.2	100.32	100.80	58.00
2008	Apr	50.6	100.28	100.93	58.00
2008	May	31.9	100.23	100.35	58.00
2008	Jun	14.3	100.19	100.24	61.20
2008	Jul	10.2	100.07	100.24	39.44
2008	Aug	6.73	97.78	98.67	38.58
2008	Sep	6.03	92.96	92.49	49.17
2008	Oct	6.44	86.76	82.18	52.14
2008	Nov	25.6	81.59	71.12	53.00
2008	Dec	49.3	88.18	71.66	92.58
2009	Jan	79.4	91.92	73.99	100.00
2009	Feb	164	97.11	88.68	100.00
2009	Mar	177	102.15	102.23	100.00
2009	Apr	43.8	100.84	100.43	100.00
2009	May	32.2	100.63	100.31	100.00
2009	Jun	19.8	100.48	100.34	100.00
2009	Jul	11	100.41	100.28	65.03
2009	Aug	13.2	99.13	100.39	75.99
2009	Sep	6.01	96.73	99.54	61.84
2009	Oct	7.24	92.41	93.79	67.80
2009	Nov	113	87.30	86.73	67.80
2009	Dec	182	95.12	96.99	67.80
2010	Jan	108	100.62	100.56	100.00
2010	Feb	96.1	101.14	101.10	100.00
2010	Mar	54.2	100.62	100.47	100.00
2010	Apr	190	100.47	100.47	100.00
2010	May	95.2	100.92	100.71	100.00
			100.00	100.00	100.00
			100.00	100.00	100.00