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

WP10197

Extent of Invasive Alien Plants and the Impact of Removal on the Water Resources of the Olifants River Catchment

Original

FINAL REPORT

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Glossary of Terms

Acid Mine Drainage
Decanting water from defunct mines that has become polluted and acidic.

Allocatable Water
Water that is available to allocate for consumptive use.

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

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

Integrated Water Resources Management (IWRM) Objectives
The objectives and priorities for water resource management, for a given time frame, that have been agreed by the parties as those which will best support the agreed socio economic development plans for the basin.

Internal Strategic Perspectives
DWA status quo and strategy development reports for large catchment systems outlining the current situation and how these systems will be managed until Catchment Management Strategies are written under CMAs.

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

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

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

Resource Classification
A process of determining the management class of water resources (typically rivers) by achieving a balance between the beneficial use of the resources and the needs of the ecological Reserve.

List of Abbreviations & Acronyms

ARC	Agricultural Research Council
DWA	Department of Water Affairs
IAP	Invasive Alien Plants
IWRMP	Integrated Water Resources Management Plan
OWAAS	Olifants Water Availability Assessment Study
SFR	Streamflow Reduction
WMA	Water Management Area
WRSM	Water Resource Simulation Model
WRYM	Water Resource Yield Model
WSAM	Water Situation Assessment Model

EXECUTIVE SUMMARY

Alien vegetation, especially large invasive trees such as eucalyptus, pines and wattles, is known to reduce streamflow to less than that which would occur under naturally vegetated conditions. This is due to the additional biomass and water use attributed to alien species. One of the options to consider in finding solutions to the water shortages within the Olifants River catchment is the removal of Invasive Alien Plants (IAPs), thus increasing the runoff from the catchment and the yield of the dams. Hence, an assessment of the streamflow reduction due to invasive alien plants (IAP) has been carried out as part of the Olifants Reconciliation Strategy Study. This report documents the results of this analysis.

While previous water resource studies have assessed the impact of IAPs on the water resource, this Reconciliation Strategy (i) makes use of new information on the extent of IAPs provided by the Agricultural Research Council (ARC), and (ii) provides an evaluation of the various models and methods used by Working for Water and other researchers in estimating streamflow reduction due to IAPs within the Olifants River catchment. It is concluded that the Working for Water assessment for the Blue Ridge mine water trade greatly over-estimates water use by IAPs (see also Appendix A). This was primarily because the extent of riparian invasion, and consequent high levels of water use, is over-estimated.

It would also appear that the ARC areal estimates of invasion are greatly over-estimated in the catchment of the de Hoop Dam, probably also for Loskop and Witbank Dams, and quite probably far from accurate in other quaternaries. Given that actual area of invasion is the first and foremost parameter in estimating water use, and given that errors and uncertainties in these estimates are greater than uncertainties in the application of different water use models, it is recommended that a specific study be undertaken to verify existing figures. This could be undertaken by experts at desktop level, over a few days, using existing areal and satellite imagery.

The methodology used in this assessment of the Olifants River catchment is derived from the research carried out by the University of KwaZulu-Natal which culminated in the so-called Gush tables. These tables are also applicable to upland alien vegetation. Riparian IAPs will use much more water than upland IAPs due to increased access to water. Models used by Working for Water indicate streamflow reduction varying from 200 to 500 mm/a depending on which model was used. For the purposes of this Olifants assessment, the streamflow reduction due to riparian IAPs was set at 300 mm/a and assumed to vary from month to month with the evapo-transpiration rate.

From a water resource management perspective the real problem with IAPs is not streamflow reduction per se, *but the extent to which these invasions are reducing the* ***available yield from dams****. This yield impact was assessed using a simplified yield model - and the results of this analysis are summarised in* ***Table E1*** *below. However it must be cautioned that errors in estimates of actual invaded area will be carried over into both errors in estimates of both streamflow reduction and available yield from dams.*

Table E1: *Summary of streamflow and yield reduction due to IAPs*

Catchment	Streamflow Reduction (million m^3/a)		Reduction in yield (million m^3/a)
	Upland	Riparian	
Bronkhorstspruit	1.0	0.2	0.8
Middelburg	0.9	0.1	0.3
Witbank	7.4	0.2	2.1
Loskop	20.0	1.4	6.8
Rust De Winter	1.2	0.5	0.7
Renoster	0.5	0.0	1.1
Flag Boshielo	4.1	1.2	3.2
B51-B52	0.8	0.0	
B71	1.5	0.0	
De Hoop	10.5	0.4	0.0
B41-B42	5.0	0.0	
Orighstad	0.0	0.0	
Blyde	7.6	0.3	6.0
B72	1.2	0.0	
B73	0.0	0.0	
TOTAL	**61.7**	**4.3**	**21.4**

Recommendations from this study are:

(i) *The use of improved methodologies to estimate water use by Invasive Alien Plants will give better estimates of actual water use (SFR) and of the utilisable yield of dams.*

(ii) *Past estimates of water use by IAPs appear to over-estimate this impact, primarily due to over-estimates of the impact of Invasive Alien Plant within the riparian zone. These have been corrected.*

(iii) *Base data for actual areas of invader plants must be improved. A specific study for the Olifants River Catchment, commencing with the catchment area above the de Hoop dam should be initiated. This can be undertaken by experts at desk-top level in a matter of days.*

(iv) *Best current estimates on areas of invasion suggest insignificant invasion in the catchment of de Hoop Dam and a reduction of previously calculated impact to zero.*

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1. INTRODUCTION

This assessment of the impact of Invasive Alien Plants (IAPs) on the water resources of the Olifants River catchment forms part of the Olifants Reconciliation Strategy Study. One of the options to consider in finding solutions to the water shortages within the Olifants River catchment is the removal of IAPs, which will increase the runoff from the catchment and thus increase the yield of the dams. The primary objective of this report is to document the results of an analysis of the streamflow reduction (and reduction in yield) due to IAPs within the Olifants River catchment.

Alien vegetation, especially large invasive trees such as eucalyptus, pines and wattles, is known to reduce streamflow to less than that which would occur under naturally vegetated conditions. This is due to the additional biomass and water use attributed to alien species. In areas in which grassland dominates under natural conditions, the evergreen nature of trees is also an important factor since the trees continue to use water through winter while grassland become dormant and use very little or no water during winter. A considerable amount of research has been carried out in South Africa into streamflow reduction. This has for the most part been undertaken on commercial afforestation, but much of the research is also applicable to invasive alien vegetation. While this research has consistently shown that replacing indigenous grassland with large exotic trees results in a reduction in the natural streamflow, various models (and modellers) provide a wide range of estimates of the magnitude of this reduction.

At the onset of this evaluation of the impact of invasive alien vegetation on the water resources of the Olifants River catchment, the large disparity in results, using different methods to calculate this impact, became apparent. A scientifically defensible conclusion could not be obtained without first analysing the wide range of results and determining which of the many methods being used are applicable within the Olifants River catchment. The secondary objective of this report is therefore to present the results of an analysis of the different techniques, as well as the technique used in this Olifants Reconciliation Strategy to evaluate the streamflow reduction in the Olifants River catchment due to IAPs.

Additional to differences resulting from analytical methods are the very large differences in estimates of the areal extent of IAPs. The extent of invasion (area) is the most important determinant of impact and it is clear that this most urgently requires re-assessment. While this report reviews methodologies and introduces an improved approach, the application of a revised and improved methodology will only have real meaning when applied to accurate data on invasions.

2. EXTENT OF ALIEN VEGETATION IN THE OLIFANTS RIVER CATCHMENT

This study makes use; *inter alia*, of the most recent estimates of the extent of IAPs in the catchment, determined by the Agricultural Research Council (ARC, 2009). However, these estimates differ significantly from previous estimates. In order to provide a perspective of how the estimates have changed over the last few years, the areas of IAPs published in other reports are summarised below.

Table 2.1: Areas of IAPs from Various Studies

Catchment	Area of IAPs (km^2)		
	Versfeld (1998)	WAAS Studies	ARC (2009)
Bronkhorstspruit Dam	6	12	42
Middelburg Dam	0.4	9	40
Witbank Dam	1	97	228
Loskop Dam	18	91	601
Rust de Winter Dam	4	4	60
Mkombo Dam	74	42	71
Flag Boshielo Dam	213	204	498
De Hoop Dam	9	8	301
Remainder of B41/B42	285	256	181
Remainder of B51/B52	851	665	169
Blyde River Dam	301	293	169
B71	192	167	77
B72	6	6	189
B73	30	19	0
TOTAL	**1 990**	**1873**	**2 626**

These differences provide very real cause for concern as calculations of water use by IAPs are first and foremost determined by the extent of the invasions, with species, age and vigour, and position in the landscape co-determining factors. Of greatest concern is the huge discrepancy observed for de Hoop Dam (assumed over-estimated by ARC), along with Witbank and Loskop Dams (also over-estimated?), and for the Remainder of B51/B52 (possibly underestimated?). This puts ALL estimates of invaded area into question. This is further discussed in Section 4.

The authors of the NIAPS (ARC, 2009) study indicated that their estimates of IAP areas are applicable at large scales, such as WMA scale, while detailed surveys are required if the impact is required at quaternary (or finer) scale.

3. EXISTING METHODS OF ESTIMATING STREAMFLOW REDUCTION DUE TO IAPS

There are numerous methods for estimating the streamflow reduction (SFR) due to IAPs. These are summarised here briefly so as to provide context for the method used in the Olifants River catchment.

3.1. BIOMASS MODEL

The Biomass model developed by Le Maitre (Le Maitre et al, 1996) estimates SFR from the knowledge of forestry water use linked to the biomass of the invasive plants relative to the biomass of the indigenous plants displaced by the IAPs. The model was developed from data collected as part of long-term studies which compared streamflow from natural fynbos catchments in the Western Cape with catchments afforested with pines. The biomass model is a simple view of vegetation water and does not take the complexity of this process fully into account.

The advantage of this method is that it deals with three categories of IAPs, namely: tall shrubs, medium trees and tall trees, with an equation for each of these three categories. However, the model is based on data collected in only one region that is not representative of the whole country.

3.2. WRSM 2000

The WRSM 2000 Pitman model (Middleton and Bailey, 2008) uses the Biomass Model of Le Maitre (Le Maitre et al, 1996), but allows for both riparian and upland alien vegetation. However, it is not clear <u>how</u> the WRSM2000 distinguishes between these two categories. A known shortcoming of WRSM 2000, with respect to IAPs, is that they are modelled as only having access to water from the quaternary catchment in which they are located, while in reality, IAPs located on the main stem of a river will have access to water from upstream catchments as well. This is an important shortcoming which results in the under-estimation of the SFR attributable to riparian IAPs. This problem only becomes apparent in higher order rivers and is probably not significant in headwater catchments. A review of the SFR due to IAPs estimated using the WRSM 2000 model indicated that this model under-estimates SFR due to riparian IAPs, at least when compared to other estimates.

3.3. ACRU

The *ACRU* Model (Smithers and Schulze, 1995) has not been used specifically to model IAPs, but has been used extensively (Gush *et. al*, 2002; Jewitt *et. al*, 2009) to model the SFR due to afforestation. The results of this research are largely applicable to IAPs which are not located in the riparian zone and consist of medium and tall trees. However, the forestry simulations assumed a fixed rotation period while IAPs reach maturity and could remain in place indefinitely resulting in higher SFR that afforestation. The Gush data therefore represents the lower limit of SFR due to IAPs.

3.4. MODELS ESTIMATING AFFORESTATION IMPACTS (SCOTT-SMITH, 1997)

A basket of models has been developed over time to estimate the impact of afforestation on water resources, and by extension the impact of Invasive Alien Plants. These models were based on research covering a number of different forestry species (primarily pines, eucalypts and wattles) and several experimental catchments but did not distinguish between upland (non-riparian) and riparian SFR since the entire catchments, including the riparian zones were afforested in these experiments.

4. METHODOLOGY

4.1. INTRODUCTION

Crucial factors that need to be considered when estimating streamflow reduction due to IAPs are (i) The areal extent of the invasion, and (ii) whether the infested area is riparian or not. Vegetation within a riparian zone, whether alien or not, often has access to more water than vegetation that is growing upslope. If a river is perennial, the riparian vegetation will take up as much water as it requires, and will never be limited by soil moisture, as is the case with non-riparian vegetation. It must be borne in mind, however, that access to water is not the only limitation to vegetation growth, with potential evapo-transpiration (ET) being one of the other major limiting factors. Non-riparian (or upland) IAPs generally rely on rainfall to sustain their growth, which in South Africa is usually a very limiting factor. There are however known cases of IAPs utilising shallow groundwater which provides additional motivation to carry out detailed analysis in cases where the impact of IAPs on small catchments needs to be evaluated.

4.2. UPLAND IAPS

A lot of research has been done in South Africa over many years into SFR due to exotic forests. Most of this research did not focus specifically on whether the forestry was riparian or not, but the Department of Water Affairs (DWA) policy has for many years prohibited afforestation in riparian zones because of the recognised high impact this has on streamflow, so estimates of SFR carried out for afforestation should not result in estimates that deviate much from that of upland alien vegetation. Where some research catchments were planted through the riparian zone these were used also by the research to separate out and determine riparian effects. These methods, the latest of which is referred to as the Streamflow Reduction Assessment Tool, developed by the University of Kwazulu-Natal (Jewitt, *et. al*, 2009), all have one fundamental hydrological principle in common: the streamflow after the clear felling of an exotic forest (or IAPs) can never exceed the streamflow that originally occurred under natural conditions over the long-term. Short-term increase in runoff before the natural vegetation re-generates is however possible but is not relevant from a water resources point of view. In other words; by removing upland alien vegetation, the mean natural flow from that area is assumed to be reinstated, but no more than that. While this may appear to be an obvious argument, there are numerous examples of this fundamental principle being ignored. See **Appendix A** for these examples.

4.3. RIPARIAN IAPS

Unlike upland IAPs that rely on rainfall, vegetation within a river's riparian zone has access to a lot more water, usually the river flow itself, but also soil moisture and inter-flow which feeds the river laterally. The water use by riparian vegetation has also been the topic of much research in South Africa, although much of this research has considered water use generally, and not SFR *per se*. The difference here is that SFR considers the <u>difference</u> in water use, that is, how much <u>more</u> water is being used by the IAPs, as opposed to the indigenous riparian vegetation. Considering that indigenous vegetation in riparian zones also use more water than upland vegetation, the impact of riparian IAPs on SFR can be over-stated (Dye and Jarmain, 2004).

South African forest hydrologists have for many years worked on the premise that riparian forestry has an SFR that is approximately twice that of upland vegetation (Versfeld, 2010). This was based on analyses of catchments that had been 100% afforested, with the riparian zone later cleared as a partial treatment (Smith and Bosch 1989, Scott et al, 2000). The publication by Cullis *et al* (Cullis *et al*, 2007) assumed a factor of three, that is, that riparian IAPs reduce runoff by three times as much as upland vegetation. These multipliers came about from research carried out in viable forestry areas (areas of high rainfall) and are not necessarily applicable in lower rainfall areas. This is because water use by riparian vegetation is a function of the evapo-transpiration rate and access to water. Hence, IAPs along the banks of the Orange River will have a very high water use while the SFR by upland IAPs in this same climatic region will be very low, simply because there is no runoff to reduce. Similarly, IAPs in Lesotho will have lower water usage due to the lower evapo-transpiration rate in this high-altitude region, while upland IAPs would have significant SFR due to the high rainfall, and hence high levels of available soil moisture in these catchments. The principle that we derive here is that Riparian SFR can generally not be <u>directly</u> related to upland water use and upland SFR, and must be considered as a separate entity. There are however exceptions, such as ephemeral headwater catchments in which the SFR due to upland and riparian IAPs are closely linked.

4.4. APPLYING FUNDAMENTAL HYDROLOGICAL PRINCIPLES IN SETTING AN UPPER LIMIT TO SFR DUE TO IAPS

As discussed in Section 4.2, it is clearly stated that there is an upper limit to SFR by upland IAPs, this being the natural runoff from the catchment; this means that, the streamflow can never be increased to above the natural flow by removing alien vegetation, at least in terms of the long-term mean. The other principle (section 4.3) is that the SFR caused by riparian alien vegetation is generally not directly related to the SFR of upland vegetation. The upper limit of SFR due to riparian vegetation, taking several case studies into account (see **Appendix A**) appears to be in the order of 500 mm/a, although it is usually less than this, in the 200 to 300 mm/a range, and could be less still where natural vegetation has a high evapo-transpiration rate, as per Dye and Jarmain (2004).

4.5. APPLICATION OF THE SFR ASSESSMENT TOOL TO THE ESTIMATION OF SFR DUE TO IAPS

While Sections 4.1 to 4.3 set an absolute limit to the SFR due to IAPs, this is not the best estimate of the SFR. It is suggested that upland IAPs should have an SFR only slightly higher than commercial afforestation (i.e. usually in the range 50-100 mm/a in forestry catchments, depending on rainfall, soil depth and species). Therefore, using the SFR models that have been developed (Jewitt, 2006; Mallory, 2006), would provide a better estimate of the upland SFR than simply applying the maximum possible SFR. The method proposed by Mallory is to express the SFR as a dimensionless duration curve of SFR, an example of which is given in **Figure 4.1**. The advantage of this is that it allows the use of SFR relationships determined using the ACRU Model to be applied within models using different hydrology. This is important since most water resource models use monthly Pitman hydrology and not *ACRU* daily hydrology, and in many cases the differences between these hydrology datasets is large.

This method was developed for DWA's sub-directorate: Streamflow Reduction and has been applied to numerous projects. The method allows SFR for Pine, Wattle and Eucalyptus to be differentiated and knowledge of the invading species therefore improves estimates. In the case of the Olifants River catchment the dominant species of IAPs is the Black Wattle (*Acacia mearnsii*), thus areas of upland IAPs have been modelled as Wattle throughout.

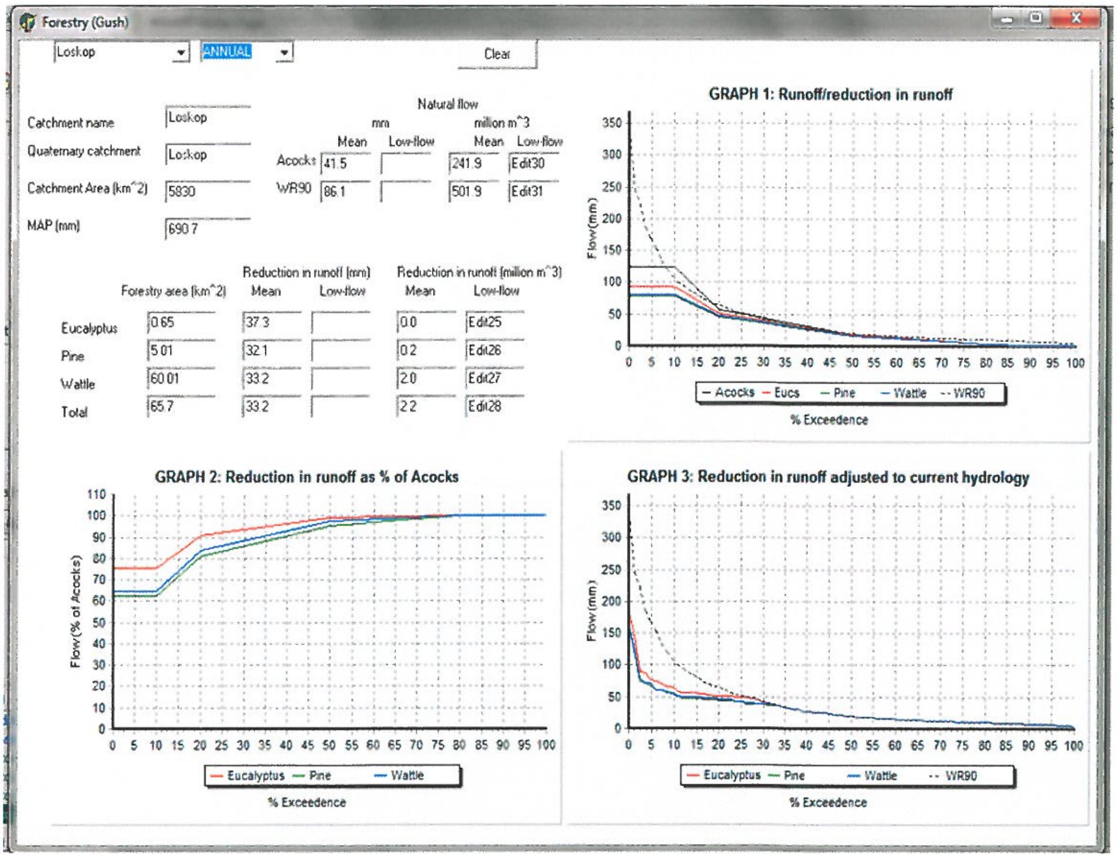

Figure 4.1: Example of process to apply ACRU derived SFR relationship to Pitman monthly hydrology

This above methodology does not allow for riparian IAPs. The assumption made in the Olifants River catchment is that riparian IAPs will reduce the runoff by 300 mm/a on the area invaded. This is consistent with estimates from various other studies (see **Appendix A).** This SFR is, however, not uniformly distributed throughout the year but assumed to be a function of the evapo-transpiration potential of the quaternary catchment in which the IAPs are located. **Figure 4.2** shows a typical distribution of evapo-transpiration in the Olifants River catchment.

The upper limit to riparian SFR is in the order of 500 mm/a. This would be in catchments where the indigenous vegetation is either partly deciduous, regularly burned grassland, and or has not been able to colonise the river wetlands and banks as successfully as the invader species. It must also be noted that this is a maximum estimate and that no stand of invasives is continuously at its peak evaporative stage. Invader trees tend, more than indigenous vegetation, to reach a period of peak vigour and then to become more and more moribund until some natural event (e.g. fire) renews the cycle. As is shown when modelling plantation water use, life-cycling of the vegetation significantly reduces overall water use.

Further to this the Olifants catchment cannot all be classified as "hot and dry" although rainfall is for the most part low (500 mm/a) and potential evaporation rates are high relative to rainfall. This marked difference between Mean Annual Precipitation and Mean Annual Evaporation is less extreme in the upper reaches of the catchment.

Most important is our knowledge of how much of the riparian invaded area is an area with permanent access to water, and how many trees have only semi-permanent access. As shown by Doody and Benyon (2011) this is a very critical factor. The assumption that all trees within a riparian zone are fully riparian with permanent access to water, is one that must be treated with caution. We believe that an estimate of water use by riparian vegetation (largely black wattle) in the Olifants Catchment, at 300 mm/a, cannot, given these considerations, be considered conservative.

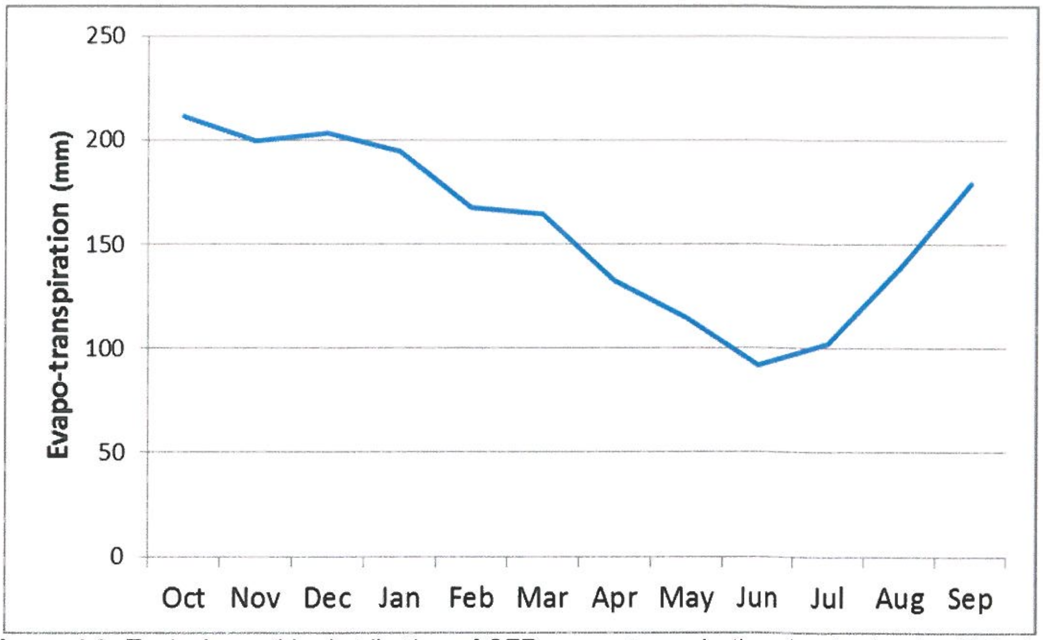

Figure 4.2: Typical monthly distribution of SFR evapo-transpiration due to riparian IAPs in the Olifants River catchment

4.6. WATER RESOURCE MODELLING TO DETERMINE THE IMPACT OF THE SFR ON THE YIELDS OF THE DAM

A very detailed Water Resource Yield Model (WRYM) setup is available from the Olifants Water Availability Assessment Study (OWAAS) (DWA, 2010). This setup includes SFR due to alien vegetation and afforestation, but the two land-use entities (upland and riparian) have been lumped into a single file (at each hydrological node), thus it is difficult to distinguish between SFR due to afforestation and that of alien vegetation. Also, due to the complexity of this model, any changes made to the SFR due to IAPs would be very time consuming. In order to overcome this problem, a preliminary scoping exercise was carried out to assess the impact of IAPs in terms of SFR and in terms of reduction in yield using a simplified model consisting of the major dams and the remaining undeveloped catchments downstream of these major dams.

A systems diagram of this simplified system is shown in **Figure 4.3**.

SFR within this simplified model was modelled in two ways. Upland IAPs were modelled as a Stream Flow Reduction (SFR), which implies that the SFR is abstracted from the natural flow, thereby gaining access to water before any other users. SFR due to riparian IAPs was modelled as a water user, as IAPs have access to the total flow in the river, but should the river flow be less than the IAPs' demand, the actual abstraction due to the riparian IAPs is limited by the available flow. The current models (WRSM 2000 and WRYM) do not model riparian IAPs in this way and it is suggested that these models be updated to model riparian SFR in this more rigorous manner.

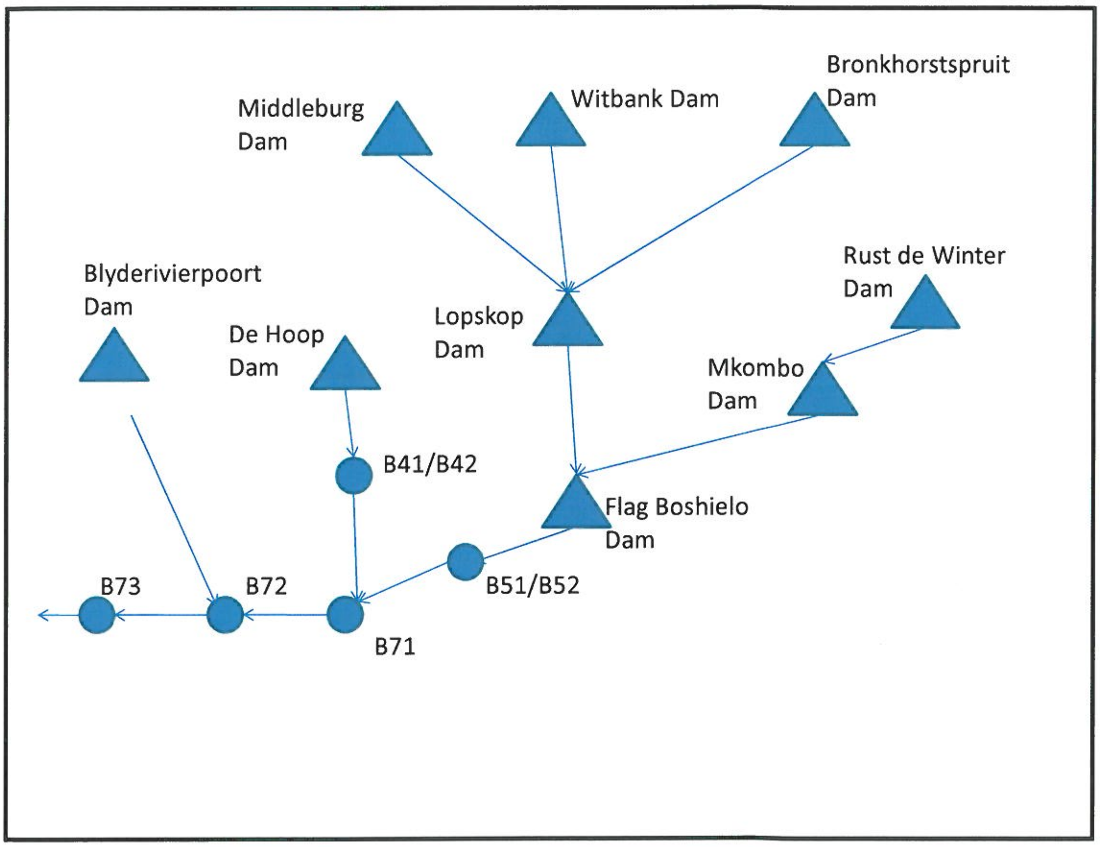

Figure 4.3: Simplified systems diagram of the major dams in the Olifants River catchment

5. RESULTS

5.1. STREAMFLOW REDUCTION (SFR)

Estimates of SFR due to IAPs, based on the areas of invasion by catchment indicated in **Table 2.1** and the methodology described in Section 4, are shown in **Table 5.1**.

Table 5.1: Streamflow Reduction due to IAPs based on areas provided by the ARC (2009)

Catchment	Streamflow Reduction (Million m^3/a)		
	Upland	Riparian	Total
Bronkhorstspruit	1.0	0.2	1.2
Middelburg	0.9	0.1	1.0
Witbank	7.4	0.2	7.6
Loskop	20.0	1.4	21.4
Rust De Winter	1.2	0.5	1.7
Renoster	0.5	0.0	0.5
Flag Boshielo	4.1	1.2	5.3
B51-B52	0.8	0.0	0.8
B71	1.5	0.0	1.5
De Hoop	10.5	0.4	10.9
B41-B42	5.0	0.0	5.0
Orighstad	0.0	0.0	0.0
Blyde	7.6	0.3	7.9
B72	1.2	0.0	1.2
B73	0.0	0.0	0.0
TOTAL	61.7	4.3	66.0

The reduction in yield is always less than the reduction in streamflow, the reason being that not all streamflow is utilisable as yield. Where streamflow is being stored in a dam to create utilisable yield, the impact due to SFR is much greater than where there is no storage. Due to the significant storage in the upper Olifants River catchment, the impact of the SFR is relatively large when expressed as a percentage of the SFR. See **Table 5.2**.

As noted above, the concern with this calculation remains the accuracy of the ARC area estimates, which often differ significantly from other estimates, and in some catchments from our understanding of the situation in those catchments. A key requirement is to confirm the actual area of invasive alien plants - both upland and riparian.

Table 5.2: Impact of IAPs on the yield of the Olifants System

Sub-catchment	Yield (million m^3/a)			% Change in yield
	Without IAPs	With IAPs	Impact	
Bronkhorstspruit	23.3	22.5	0.8	3.4
Middelburg	24.5	24.2	0.3	1.2
Witbank	57.5	55.4	2.1	3.7
Loskop	158.7	151.9	6.8	4.3
Rust de Winter	14.5	13.8	0.7	4.8
Mkombo	14.6	13.5	1.1	7.5
Flag Boshielo	67.1	63.9	3.2	4.8
De Hoop	109.2	98.8	10.4	9.5
Blyde River	178.5	172.5	6	3.4
TOTAL	**647.9**	**616.5**	**31.4**	**4.8**

The OWAAS study (DWA, 2010) did not indicate the extent to which IAPs reduce the yield of the system, quantifying only the SFR, while the Integrated Water Resources Management Plan (IWRMP) (DWA, 2009) estimated the impact of IAPs on the yield of the Loskop System to be 8.6 million m^3/a, which is similar to this latest estimate of 10.0 million m^3/a (cumulative impact). Note that for the Loskop System the total SFR due to IAPs in the Witbank and Loskop Dam catchments is much higher at a cumulative 31.2 million m^3/a.

The study carried out by Cullis *et al* in 2007 estimated the reduction in yield in the Olifants River catchment to be 69 million m^3/a., where the estimate from the Olifants Reconciliation Study is 31.4 million m^3/a. The reason for the "Cullis" reduction in yield being so much higher than the estimate of this Olifants Reconciliation Strategy can be explained primarily by the fact that much larger areas of riparian IAPs were assumed by Cullis. This again highlights the need for detailed mapping in critical catchments.

6. CONCLUSIONS AND RECOMMENDATIONS

The impact of IAPs on SFR, and impact on yield, has been assessed within the Olifants Water Management Area (WMA). This assessment used the latest estimates of the areal extent of IAPs produced by the ARC (ARC, 2009). The IAP areas published by the ARC are for the most part much higher than previous estimates, although a very much lower value for the "Remainder of B51/B52" reduces the total overall difference (see **Table 2.1**). One specific area of uncertainty is the De Hoop Dam catchment. Previous work on IAPs indicated very few IAPs in the De Hoop Dam catchment (total of 8 - 9 km^2), while the ARC estimate this infested area at 300 km^2. Discussions with water resource practitioners, who know the area well, and an examination of Google Earth images, suggest that the original estimates are far more likely to be in line with reality. This puts **all** the ARC estimates for **all** quaternaries into question. The importance of water resource issues and decisions in this catchment is such that we must recommend that IAP data for the entire Olifants system should be re-examined. In the interim the recommended way forward for de Hoop Dam has been to assume no significant IAPs upstream of the dam site. This results in an amended yield reduction estimate as given in **Table 6.1**.

Table 6.1: Impact of IAPs on the Yield of the Olifants System

Sub-catchment	Yield			% Change in yield
	Without IAPs	With IAPs	Impact	
Bronkhorstspruit	23.3	22.5	0.8	3.4
Middelburg	24.5	24.2	0.3	1.2
Witbank	57.5	55.4	2.1	3.7
Loskop	158.7	151.9	6.8	4.3
Rust de Winter	14.5	13.8	0.7	4.8
Mkombo	14.6	13.5	1.1	7.5
Flag Boshielo	67.1	63.9	3.2	4.8
De Hoop	109.2	109.2	0.0	0.0
Blyde River	178.5	172.5	6.0	3.4
TOTAL	**647.9**	**616.5**	**21.4**	**3.3**

The methodology used to estimate the SFR due to IAPs in this study entails the use of flow duration curves of SFR provided by the University of KwaZulu-Natal (Jewitt *et al*, 2009). This method is widely accepted amongst forest hydrologists and has been used in numerous water resources studies. The results appear to be similar to those derived from the WRSM 2000 Model (for upland IAPs), but SFR due to riparian IAPs is somewhat higher in this study than that estimated from WRSM 2000. It is acknowledged, however, that more work into SFR due to riparian IAPs is required and that the methods used in this (and other studies) are not particularly robust. The developers of WRSM 2000 have been informed of their model's shortcoming and it is understood that they are improving this model specifically to deal with riparian IAPs better.

Should the estimated SFR from this study be accepted, the estimates will be disaggregated down to quaternary scale and incorporated into the WRYM setup.

7. REFERENCES

Agricultural Research Council, 2009. *National Alien Invasive Plant Survey.*

Cullis JDS, Görgens AHM, Marais C (2007). *A strategic study of the impact of invasive alien plants in the high rainfall catchments and riparian zones of South Africa on total surface water yield. Water SA Vol. 33 No. 1*

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

Department of Water Affairs, 2010. *Assessment of Water Availability within the Olifants WMA by means of Water Resources Related Models. Water Resources Yield Model Analysis. Report no. P WMA 04/000/00/5507.*

Dye, P.J. and Jarmain, C., 2004. *Water use by black wattle (Acacia mearnsii): implications for the link between removal of invading trees and catchment streamflow response. South African Journal of Science 100, January/February 2004 p 40-44.*

Gush MB, Scott DF, Jewitt GPW, Schulze E, Hallowes LA, Görgens AHM (2002). *Estimation of Streamflow Reduction Resulting from Commercial Afforestation in South Africa. Water Research Commission, Report no. TT 173/02. Pretoria, South Africa.*

Jewitt GPW, Lorentz SA, Gush MB, Thornton-Dibb S, Kongo V, Wiles L, Blight J, Stuart-Hill SI, Versfeld D, Tomlinson K (2009). *Methods and Guidelines for the Licensing of SFRAs with Particular Reference to Low Flows. Water Research Commission Report No. 1428/1/09. Pretoria, South Africa.*

Le Maitre D, Van Wilgen BW, Chapman RA and McKelly DH (1996) *Invasive plants in the Western Cape, South Africa: Modelling the consequences of a lack of management. J. Appl. Ecol. 33 161-172.*

Le Maitre D and Görgens A. (2001) *Potential impacts of invasive alien plants on reservoir yields in South Africa. Proc. 10th S. Afr. National. Hydrology. Symposium, September 2001, Pietermaritzburg, South Africa.*

Mallory, 2006. *Reduction in runoff due to forestry – a proposed alternative interpretation of the Gush Tables for licencing purposes. Unpublished notes prepared for the Department of Water Affairs and Forestry.*

Pitman WV, Kakebeeke JP, Bailey AK (2006). *Water Resources Simulation Model for Windows: Users Guide.* Compiled for the Water Research Commission

Marais, C (2003). *Cluff Mine Invading Alien Plant Water Resource Model.*

Scott, DF, and Smith, RE, 1997. *Preliminary empirical models to predict reductions in total and low flows resulting from afforestation. Water SA, 23: 135-140.*

Smithers, J.C., and Schulze, R.E,, 1995. *ACRU Hydrological Modelling System: User manual Version 3.00. Water Research Commission, Pretoria, report TT70/95.*

Versfeld DB, Le Maitre DC and Chapman RA (1998) *Alien Invading Plants and Water Resources in South Africa: A Preliminary Assessment. WRC Report No. TT 99/98.* Water Research Commission, Pretoria, South Africa.

Versfeld DB. *Personal Communication (2010).*

APPENDIX A

ESTIMATES OF SFR IN THE UPPER OLIFANTS RIVER CATCHMENT DUE TO IAPs USING VARIOUS MODELS AND EQUATIONS

A1. ALIEN INVASIVE PLANTS AND WATER RESOURCE IMPACT ASSESSMENT

The WRC study completed in 1998 by Versfeld, Le Maitre and Chapman (Versfeld *et. al*, 1998), used two models to estimate SFR due to IAPs, the biomass model of Le Maitre (1996) and the Scott curves (1997). However, the Versfeld report does not publish the results independently for the two zones (riparian and upland) so it is not possible to ascertain the SFR relating to riparian and upland IAPs, respectively, from this study.

The SFR for IAPs averaged over the whole country is given as 190 mm/a. This is considerably more than for forestry but this is to be expected due to the riparian component relating to IAPs.

The most useful outcome of the report by Versfeld *et al*, is that the data was provided to DWAF at quaternary scale and incorporated into the Water Situation Assessment Model (WSAM). This data set has been used here to assess the SFR due to IAPs in the Olifants River catchment for comparison purposes.

A2. THE BLUE RIDGE MINE WATER TRADE

A mine located downstream of the Loskop Dam, referred to as the Blue Ridge Mine, applied for a water use licence based on the removal of 2 500 ha IAPs. The impact of removing these IAPs on streamflow was originally assessed by Marais in 2003. See **Table A 1**.

Table A 1: Extent of invasions in the B20, B12 & B11 tertiary catchments

Catchment	River	Total Area of Catchment (ha)	Area Invaded (ha)	Condensed Area (ha)
B20	Wilge	152 840	4 324	1 766
B20	Wilge	282 792	3 405	552
B12	Klein Olifants	239 086	318	87
B11	Upper Olifants	471 537	458	94
B32a	Olifants	Part of Catchment	292	174
		1 146 255	**8 797**	**2 790**

Marais suggested in his report to DWAF dated 2003 (Marais, 2003) that the estimated 2 790 ha is mostly riparian and removing 2 500 ha of this vegetation completely (with necessary follow up maintenance to prevent re-growth) will increase the runoff by approximately 13.36 million m^3/a. Expressing this in mm runoff results in an increase in runoff of 534 mm/a, or 5 344 m^3/ha.

Based on the above analysis, the Blue Ridge Mine paid for the removal of approximately 2 500 ha of alien vegetation and then in 2009 applied for a water use licence. In support of this application, Marais submitted calculations of SFR based on several different methods. These are summarised in **Table A2** so as to give an indication of the wide range of possible estimates derived from the different approaches.

Table A 2: Streamflow Reduction in the Olifants River Catchment

Method	SFR Total	SFR Total	SFR Riparian	SFR Upland
	(million m^3/a)	mm/a		
Le Maitre	3.8	214		
Gush	1.0	56		
Jewitt	1.7	97		
DWAF 1	1.6	90		
DWAF 2	1.1	60		
Dye and Jarmain	7.5	424		244
Cullis et al	1.1	115	300	100
Everson	2.2			
Gorgens & van Wilgen	5.4	274	548	

The areas of alien vegetation actually removed are indicated in **Table A 3**. What is immediately obvious is that only a small percentage of the area proved to be riparian, and this has a huge impact on the actual SFR.

Table A 3: Areas of Alien Vegetation actually removed

Quaternary Catchment	Condensed Area (ha)	Riparian (ha)
B12D	337.1	17.44
B12E	784.1	39.0
B20D	187.4	7.5
B20F	91.6	39.7
B20G	87.8	48.4
B20H	284.1	55.2
B32B	513.9	91.9
TOTAL	2 286.0	299.0
Area excluding B32B	1 772.1	207.2

The area of alien vegetation removed that pertains to the Blue Ridge Mine excludes the B32B catchment and hence all the analyses that follow are based on the areas of 1 772 and 207 ha respectively. Given that only a small percentage of the area of IAPs removed were actually riparian (207 ha) Marais' original estimate of gaining 13.2 million m^3/a is a very optimistic one, with the more likely figure being in the order of 2.4 million m^3/a. This is made up of 207 ha riparian at 3000 $m^3/ha/a$ = 621 000 m^3/a, and 1772 ha of upland vegetation using 1 000 m^3/ha = 1 772 000 m^3, with a total of 2 393 000 m^3 SFR over the whole area.

This brings us back to our core argument, that the key to an accurate assessment of water use by invasives is an accurate assessment of the extent of the invasion (both upland and riparian).

A3. SFR ESTIMATES

Marais' estimated SFR based on several different methodologies is summarised in **Table A 2** while the SFR per quaternary catchment, as calculated by Marais using the Le Maitre bio-mass curves, is given in **Table A 4.**

Table A 4: SFR based on Le Maitre

Quarternary Catchment	Stream Flow Reduction (million m^3/a)
B12D	720 068
B12E	1 674 623
B20D	400 191
B20F	195 589
B20G	187 580
B20H	606 782
B32B	1 097 656
TOTAL	**4 882 490**
Area excluding B32B	3 784 834

Table A 5: Upper Limit of SFR due to Riparian Vegetation

Quaternary catchment	Riparian vegetation (ha)	Assumed SFR (mm)	Maximum SFR (million m^3/a)
B12D	17.44	500	0.09
B12E	39.0	500	0.20
B20D	7.5	500	0.04
B20F	39.7	500	0.20
B20G	48.4	500	0.24
B20H	55.2	500	0.28
TOTAL			**1.04**

Table A 6: All IAPs: Upper limit on SFR (million m^3/a)

Quaternary catchment	SFR due to		Total
	Upland	Riparian	
B12D	0.18	0.09	0.26
B12E	0.37	0.20	0.57
B20D	0.08	0.04	0.12
B20F	0.02	0.20	0.22
B20G	0.02	0.24	0.26
B20H	0.09	0.28	0.37
TOTAL	**0.76**	**1.04**	**1.80**

Hence, the maximum possible streamflow reduction due to IAPs in the Blue Ridge mine catchment is 1.8 million m^3/a. This is substantially less than the 13.4 million m^3/a on which the clearing of the IAPs was originally motivated.