WATER RESOURCES PLANNING WITH RECOGNITION OF ALIEN VEGETATION ERADICATION

EJ Larsen[1], C Marais[2], AHM Görgens[1]

[1] Ninham Shand Consulting Engineers, PO Box 1347, Cape Town, 8000

[2] Working for Water, Private Bag X4390, Cape Town 8000

ABSTRACT

The approach to water resources planning in South Africa has usually been to increase supplies as soon as the demand exceeds the yields of the existing water supply schemes, and has mostly focused on surface water augmentation options such as dams and river diversions. In recent years, the scarcity of surface water resources and an increasing awareness of the importance of setting aside the riverine environmental reserve has lead to a greater emphasis on alternatives to traditional surface water augmentation options, particularly water demand management. Awareness of the significance of water use by alien invasive plants in certain catchments has also grown. The need to include this as a specific land use with its associated water demand in water resource studies in such catchments has been identified, and a draft methodology for doing so was presented at SANCIAHS 1999.

This paper demonstrates the application of the aforementioned methodology to a case study for the town of George. Currently water supply for the town is obtained from the Garden Route Dam on the Swart River. The catchment of the Swart River contains invasive alien plants, with the level of invasion upstream of the dam estimated to be 48% in 1999. The two adjacent catchments also contain alien invasive plants. The level of infestation in 1999 in the Malgas River was 9% and the Kaaimans River was 60%.

These adjacent rivers are likely to be developed for future water supplies, and sample water resource augmentation options, for example two dams and a river diversion, are put forward and modeled in this paper. An estimate of the riverine environmental reserve was made and included in the modeling exercise. In addition, the clearing of alien vegetation in the three catchments is included as a separate augmentation option. The costs of the sample augmentation options and the clearing options are estimated and compared as unit costs. The sensitivity of the resulting costs to various factors, for example the assumed rate of increase in water demand, the costs of clearing, etc were also tested.

The results show that clearing alien invasive plants results in increased yields of existing and future sample augmentation schemes. This delays the date at which augmentation is required by a significant number of years. Clearing schemes were seen to have competitive unit costs compared with traditional augmentation options such as dams. The study confirmed that the Unit Reference Value (in Rand/m^3 of water yield) is reduced by clearing starting immediately and this is particularly advantageous in catchments where the levels of infestation are high.

WATER RESOURCES PLANNING WITH RECOGNITION OF ALIEN VEGETATION ERADICATION

1. INTRODUCTION

This study demonstrates the application of a methodology to include the effect of invasive alien plants on the planning of water resources augmentation schemes. This was done by means of a case study in which the water resource augmentation options in the catchments of the Kaaimans, Swart and Malgas Rivers were investigated in terms of three scenarios, namely:

- "No interference" (i.e. no clearing takes place)
- "Clear 1999" (i.e. clear all three catchments starting in 1999)
- "Clear 2009" (i.e. clear all three catchments after a ten year delay, starting in 2009)

An estimate of the riverine environmental reserve was also included in order to comply with current legislative requirements.

The first task was to conceptualise sample water resource augmentation schemes in the catchments and to define the study area. This was done by making use of potential augmentation schemes put forward in past studies. The following sample schemes were used in this study:

- Existing Garden Route Dam
- Raising of the Garden Route Dam with fuse gates
- Refurbishment of the existing Swart River Dam on the Swart River
- Sample dam and pumpstation combination on the Kaaimans River
- Sample dam on the Malgas River.

A map showing the location of these sample schemes and the extent of the study area is given as Figure 1.1.

The study was undertaken for Working for Water, and full results can be found in the final report of the study (Larsen et al, 2001). In order to meet the space requirements for this paper, only the results of the "Clear 1999" scenario, and a selection of results for one potential augmentation option are reported.

2 MAPPING OF ALIEN PLANT INFESTATIONS

The next task was to map the levels of infestation of alien plants in the catchments. This was done on 1:50 000 topographical sheets according to a standard methodology (Le Maitre et al, 1994). Six different species were mapped and their distribution in the year 1999 is shown in Figure 1.1. The main plant species present are Pinus Radiata, Hakea Sericea and Acacia Mearnsii. Other species present to a lesser extent are Acacia Saligna, Acacia Melanoxyl and various species of Eucalyptus. The densities of the species are given in Table 2.1. Overall, the Kaaimans River catchment is the most densely infested at 60% overall density, followed by the Swart River catchment at 48%. The Malgas River catchment is lightly infested at 9%.

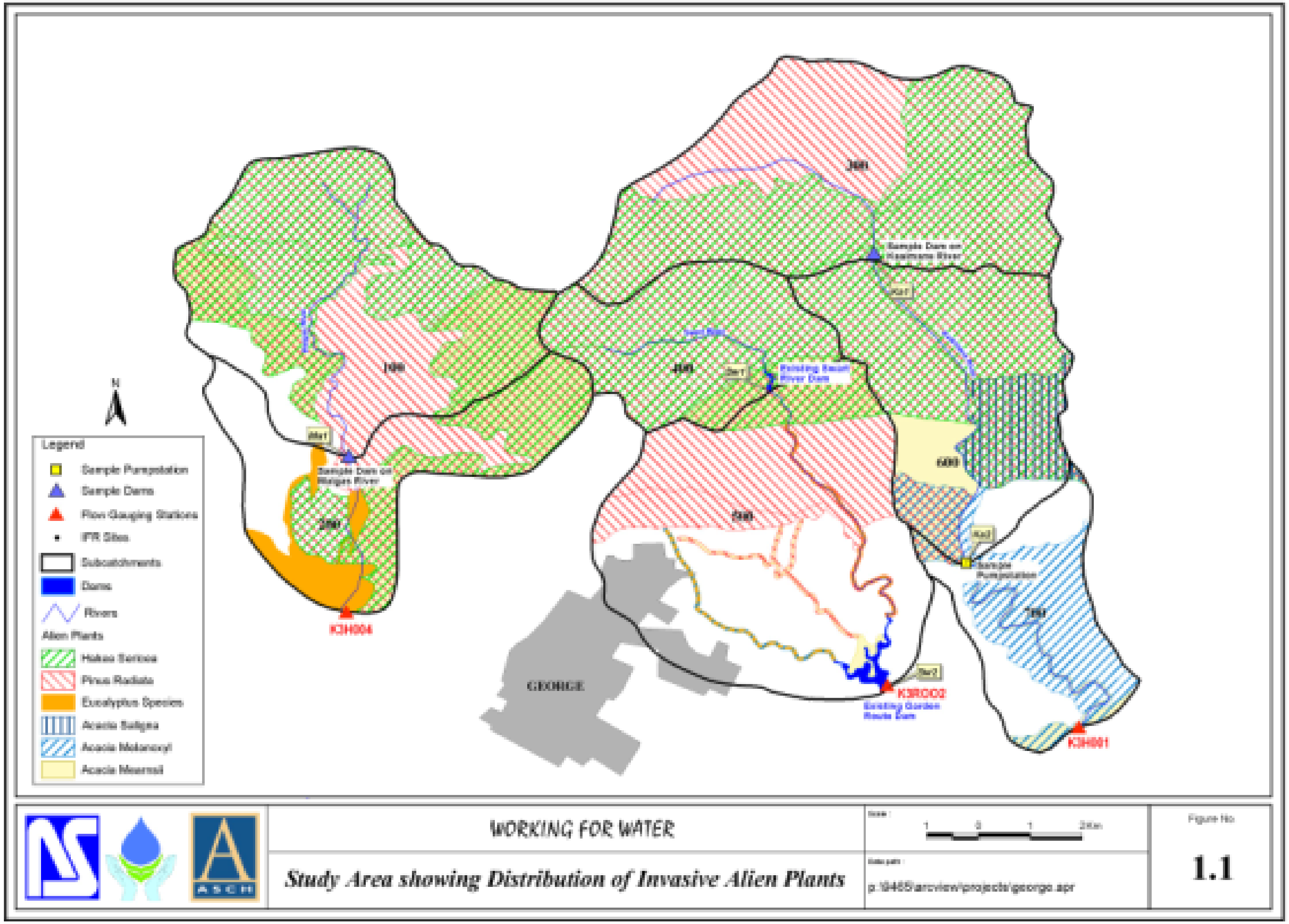
Legend
Sample Pumpstation
Sample Dams
Flow Gauging Stations
IFR Sites
Subcatchments
Dams
Rivers
Alien Plants
Hakea Sericea
Pinus Radiata
Eucalyptus Species
Acacia Saligna
Acacia Melanoxyl
Acacia Mearnsii
K3H004
K3R002
K3H001
GEORGE
100
200
300
400
500
600
700
WORKING FOR WATER
Study Area showing Distribution of Invasive Alien Plants
p:\9465\arcview\projects\george.apr
Figure No.
1.1

TABLE 2.1 : Extent of Invading Alien Plants in the Catchment in 1999

Density Classes									Total =	8069	3521,20	43,6%
Catchment	Total Area	Genus	0-0,1%	0,1-1%	1-5%	5-25%	25-50%	50-75%	75-100%	Area	R1 (ha)	R1 (%)
Swart River	2145	Tot. Dense	-	-	125	318	556	930	217	2145	1030,65	48,0%
		Pinus	-	-	478	212	575	647	190	2101	832,21	39,6%
		Hakea	-	125	662	410	-	-	-	1197	82,01	6,9%
		Acacia	-	125	206	32	-	79	-	442	61,00	13,8%
		Eucalyptus	-	-	-	59	-	-	-	59	8,86	15,0%
Kaaimans	3809	Tot. Dense	23	-	-	273	1624	-	1889	3809	2302,78	60,5%
		Pinus	-	-	126	1311	1437	-	765	3639	1408,44	38,7%
		Hakea	-	-	313	1769	468	656	-	3206	860,44	26,8%
		Acacia	23	313	127	273	-	-	-	736	46,36	6,3%
		Eucalyptus	-	-	-	-	-	-	-	-	-	-
Malgas	2115	Tot. Dense	-	490	494	1130	-	2	-	2115	187,77	8,9%
		Pinus	-	490	1363	260	-	-	-	2113	82,36	3,9%
		Hakea	-	500	1130	-	-	-	-	1629	36,39	2,2%
		Acacia	-	566	145	-	2	-	-	713	7,81	1,1%
		Eucalyptus	-	-	-	2	-	-	-	2	0,25	15,0%

3 MODELLING THE EXTENT OF ALIEN PLANT INVASIONS

The 1999 levels of infestation of invasive alien plants were used as a basis to estimate the historical spread of the alien plants over time. This information was used as one of the inputs to the calibration of the catchment model.

Projections of the possible future spread of invasive alien plants in the three catchments were made for each of the three scenarios. Figure 3.1 illustrates the effect of clearing the Swart River catchment for the three clearing scenarios. Graphs for the other catchments can be found in the study report (Larsen et al, 2001). This information was used to generate long term monthly flow sequences representing all the alien vegetation demands, for input to the system model.

The methodology for the spread model is fully described elsewhere (Larsen et al, 2001) and (Marais, 2000).

4 DETERMINING THE STREAMFLOW REDUCTION CAUSED BY INVASIVE ALIEN PLANTS

Streamflow reduction by invasive alien plants is an area of focus for South African researchers in the water field at present, and methodologies are being updated and refined on an ongoing basis. At the time this study was undertaken, the latest available streamflow reduction models developed were used (Le Maitre et al, 2001).

The models are based on the biomass of the vegetation, which is determined initially using separate age-biomass models for each type of vegetation, namely tall trees, medium trees and tall shrubs. The equations are as follows:

Tall tree biomass (t/ha) = $300/(1 + e^{3.67947} \times \text{Age in years}^{-1.4109})$, $r^2 = 0{,}96$, $n = 9$, $P < 0{,}01$

Medium tree biomass (t/ha) = $96{,}0732 * \log_{10}(\text{Age in years}) - 4{,}8081$, $r^2 = 0{,}98$, $n = 4$, $P = 0{,}01$

Tall shrub biomass (t/ha) = $76/(1+e^{3{,}18628} \times \text{Age in years}^{-1{,}25973})$, $r^2 = 0{,}68$, $n = 12$, $P < 0{,}01$

A proportional flow reduction model is used for the relationship between biomass and flow reductions. Low flows and annual flows are adjusted separately, and there are separate cases for vegetation occurring in upland or riparian sites. The equations are as follows:

Long lag curves (mostly used for upland situations):

Annual flow reduction (%) = $115/(1 + e^{14,2216} \times \text{biomass (t/ha)}^{-2,9194})$, $r^2 = 0,83$, $n = 34$, $P < 0,01$

Low flow reduction (%) = $122/(1+e^{10,0252} \times \text{biomass}^{-2,0927})$, $r^2 = 0,68$, $n = 34$, $P < 0,01$

Short lag curves (mostly used for riverine situations):

Annual flow reduction (%) = $103/(1+e^{2,2958} \times e^{\text{Biomass[t/ha]}*-0,02388})$, $r^2 = 0,86$, $n = 13$, $P < 0,01$

Low flow reduction (%) = $102/(1+e^{1,9677} \times e^{\text{Biomass[t/ha]}*-0,02474})$, $r^2 = 0,68$, $n = 10$, $P < 0,01$

In all cases, an average vegetation age of 8 years was used. The flow reduction factors used for the vegetation types occurring in the study area are listed below:

- upland tall trees : average = 33,27%, low flow = 42,82%
- riparian tall trees : average 58,70%, low flow = 56,12%
- upland tall shrubs: average = 1,56%, low flow = 5,74%

5 CALIBRATION OF THE HYDROLOGICAL MODEL AND GENERATION OF FLOW SEQUENCES

Three flow gauges were calibrated using the Pitman monthly rainfall-runoff model, inclusive of the flow reductions estimated by the above long and short lag curves. These gauges were as follows, and their locations are shown on Figure 1.1:

- K3H004 on the Malgas River,
- K3H001 on the Kaaimans River,
- K3R002 at the Garden Route Dam on the Swart River.

Long term monthly naturalised flows were produced for the period 1920 to 1997 for each sample dam site, using the calibrated model, for input into the system model. The spatial distribution of available long term rainfall records is far from optimal. The quality of the available streamflow information, which was used for the catchment model calibration, is quite variable. These two concerns have induced a fairly conservative approach to the catchment modelling.

6 DETERMINATION OF THE ENVIRONMENTAL RESERVE

The Environmental Reserve for each of the three rivers was determined, by Southern Waters Ecological Research and Consulting CC, according to the legislated procedure (DWAF, 1999). Long term monthly IFR flow sequences were prepared as input into the system model, using the prescribed software. This software applies the maintenance and drought flow IFR according to dry and wet periods experienced in the region as a whole, to produce an estimate of the long term IFR.

The long term IFR requirements for the Kaaimans River were high (46% of natural MAR) because it is a Class A river, which signifies a highly sensitive system. The upper reach of the Swart River is classified as a Class B/C which is a sensitive to moderately sensitive system with an IFR of 20% of the natural MAR. The reach downstream of the Garden Route Dam is classified as a Class D, which indicates a resilient system, and the IFR is 14% of the natural MAR. The Malgas River was classified as a Class C, or moderately sensitive system, and the IFR was determined to be 26% of the natural MAR.

A summary of the results of the reserve determination for each river is given in Table 6.1 below.

TABLE 6.1: Results of the Environmental Reserve Determination

Site	Ka1	Ka2	Ma1	Sw1	Sw2
River	Kaaimans River		Malgas River	Swart River	
Located downstream of:	Sample dam site	Sample pumpstation site	Sample dam site	Swart River Dam	Garden Route Dam
Present Ecological Status (PES)	Class A		Class C	Class B/C	Class D
Future Ecological Management Class	Class A (Highly sensitive systems: No human induced hazards)		Class C (Moderately sensitive systems: Moderate risk allowed)	Class B/C (B only :Sensitive systems: Small risk allowed)	Class D (Resilient systems: large risk allowed)
Natural MAR (million m^3/a)	6.79	11.70	11.75	3.33	12.34
Total IFR (including allowance for droughts) (million m^3/a)	3.13	5.44	3.05	0.67	1.74
IFR as a % of Natural MAR	46%	46%	26%	20%	14%

The results of the reserve determination are adequate for this level of study, but should be viewed as having low confidence. The reason for this is because model defaults were used throughout the determination, and proper calibration of the model used in this study is still necessary. This would form part of a comprehensive reserve determination, which is required for any future work on water resource developments in the area.

7 YIELD ANALYSIS

The system model (WRYM) was set up and used to determine the historical firm yield for the proposed augmentation schemes for the three scenarios. The yield results were generally found to be considerably lower than the yields reported on in the source reports used to conceptualise the sample schemes. This was attributed to the introduction of the Environmental Reserve, as no previous studies had included this requirement. The Kaaimans schemes were particularly affected, because this river has the highest conservation value possible, and therefore the IFR forms a substantial portion of the flow. The introduction of the Environmental Reserve has made the sample schemes on the Kaaimans River unviable.

To illustrate the nature of the results, those for the Malgas catchment are given in Table 7.1 below, and the yield variations over time compared to the potential water demand are shown in Figure 7.1.

TABLE 7.1 : Summary of Results of Hydrological and Yield Analyses for the Garden Route Dam plus Malgas Dam

a) Constant values for all scenarios

Description	Swart River (Existing Garden Route Dam)	Malgas River (sample dam)
MAP	960 mm	980 mm
Total area upstream of existing/ proposed development	35.152 km^2	21.750 km^2
"Invadable" area	21.452 km^2	21.149 km^2
IFR	1.74 million m^3/a	3.05 million m^3/a
Afforested area in Catchment	6.684 km^2	0.595 km^2
Afforestation demand in Catchment	1.15 million m^3/a (172 mm)	0.13 million m^3/a (218 mm)
Naturalised MAR	12.34 million m^3/a	11.75 million m^3 /a

b) Varying results for the three clearing scenarios

SCENARIO	YEAR	*ALIEN VEGETATION (Malgas Catchment only)*				YIELD		
		AREA	LEVEL OF INFESTATION	TOTAL DEMAND		Combined system yield	Garden Route Dam only	Malgas Dam only
	UNIT	km^2	%	m^3 x 10^6/a	Mm/a	m^3 x 10^6/a		
No development	Natural	0	0%	0	0	n/a		
No interference	1999	1 880	9%	0.25	133	12.0	5.8	6.2
	2006	6 180	29%	1.84	136	11.5	5.7	5.8
	2015	12 110	57%	1.63	135	10.5	5.3	5.2
	2039	17 940	85%	2.43	135	9.8	5.3	4.5
Clear starting 1999	1999	1.880	9%	0.25	133	12.0	5.8	6.2
	2007	0.878	4%	0.11	125	12.7	6.4	6.3
	2014	0.304	1%	0.03	22	12.7	6.4	6.3
	2025	0.100	0%	0.00	0	12.8	6.4	6.4
	2039	0.079	0%	0.00	0	12.8	6.4	6.4
Clear starting 2009	1999	1 880	9%	0.25	133	12.0	5.8	6.2
	2006	6 180	29%	1.84	136	11.5	5.7	5.8
	2009	7.660	36%	1.03	134	11.2	5.6	5.6
	2017	0.646	3%	0.08	124	12.7	6.4	6.3
	2021	0.347	2%	0.03	86	12.8	6.4	6.4
	2029	0.314	1%	0.03	96	12.8	6.4	6.4

With reference to Table 7.1, if the alien vegetation is allowed to spread unchecked in both catchments, the combined yield will gradually decrease to 9.8 million m^3/a in the year 2039 when condensed infestation in both catchments is estimated to reach approximately 87% (assumed to be the equivalent of 100% infested).

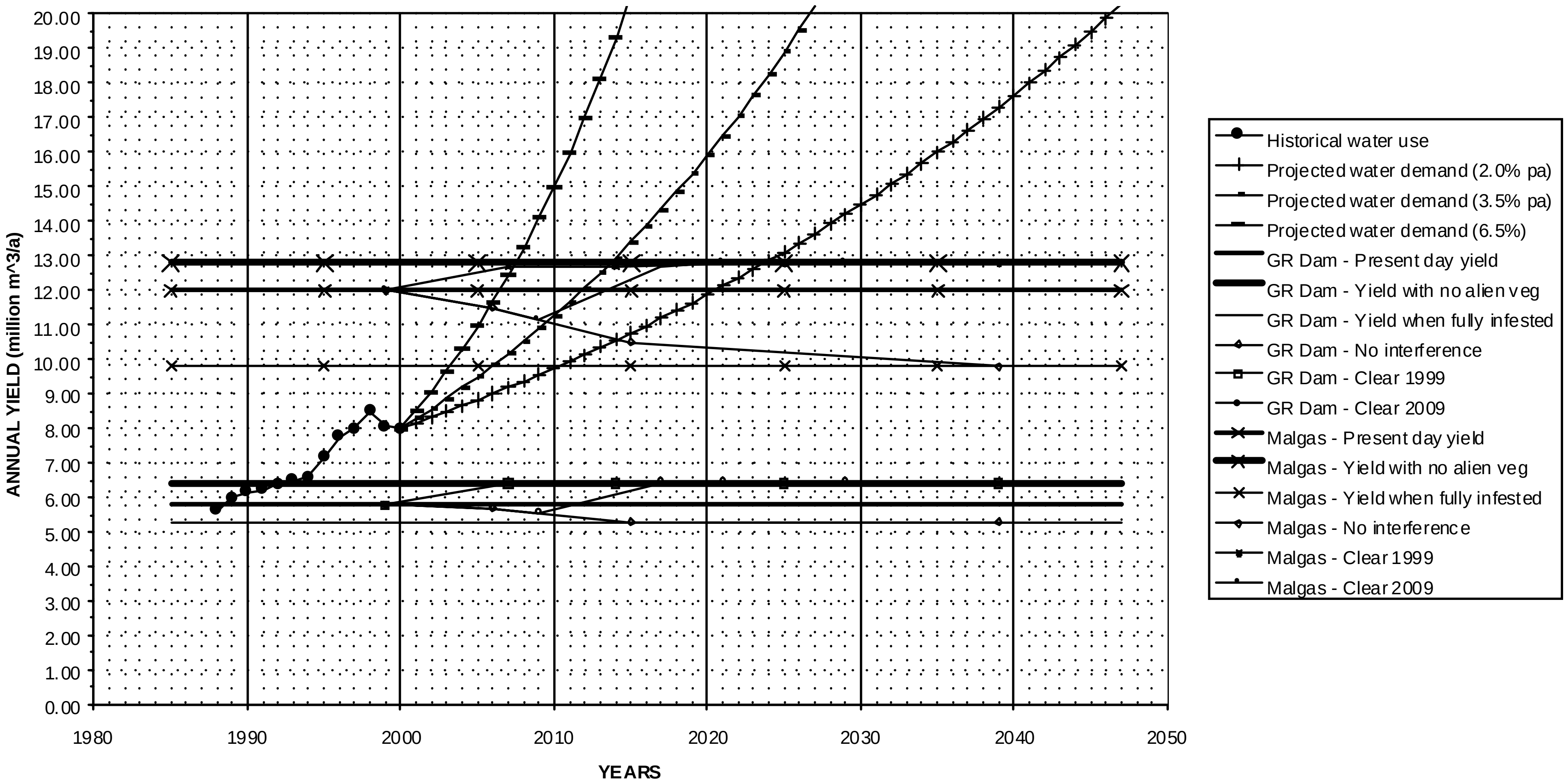

Figure 7.1: Results of Reduction in Streamflow and Yield for the Malgas Dam

However, if clearing of alien vegetation is commenced immediately, the infestation in the Malgas catchment will be reduced from current levels of 9% to 1% by the year 2014, with a corresponding increase in system yield from 12.0 to 12.7 million m^3/a. If clearing continues after that date, the levels of infestation would be reduced to 0% by the year 2039, giving a further incremental increase in system yield of 0.1 million m^3/a. The estimated yield from the combined system once all alien vegetation in the catchment has been cleared is 12.8 million m^3/a, which is 0.8 million m^3/a more than present levels.

The overall gain in system yield from clearing all alien vegetation in both catchments, compared to the yield at full infestation is 3.0 million m^3/a. This is a significant saving, and equates to 52% of the estimated yield from the existing Garden Route Dam at current levels of infestation.

With reference to Figure 7.1, the additional yield provided by the Malgas Dam if no clearing is undertaken will be adequate for the “high growth” scenario until the year 2005, the “medium growth” scenario until the year 2009, and the “low growth” scenario until the year 2014. If the “clear 1999” scenario is adopted, this will delay the need for augmentation from the abovementioned dates by 2 years, 4 years and 9 years respectively for the three growth rates.

If clearing is delayed until the year 2009, the “high growth” scenario will be met until the year 2005. The "medium growth" scenario will be as discussed for the “no clearing” option discussed above. Adequate water will however be available for the “low growth” scenario until the year 2023.

8 FINANCIAL ANALYSIS

Estimates of capital and ongoing operating and maintenance costs were determined for each sample augmentation option using 1999 prices. Costs of clearing invasive alien plants were also determined and included in the total costs for the clearing scenarios. Unit reference values (URVs) were used to compare the cost of each augmentation option against the others. The URV is defined as the unit cost per m^3 of water that would result in the discounted costs of an augmentation scheme being equal to the discounted income from selling the water provided by that scheme. It is a very specific and limited term, which is useful for comparing augmentation schemes against each other. However it cannot be used for other, more general purposes which are beyond the scope of this paper, for example to determine the true cost or value of the water itself.

The URV was derived by determining the NPV of capital and maintenance costs by discounting the costs over 49 years, and dividing this by the NPV of the actual volume of water supplied by each proposed new water resource scheme. The base case scenario was set at a 6% discount rate and a 3.5% p.a. growth in water demand. The results of the financial analyses are given in Table 8.1 below :

TABLE 8.1: Unit Reference Values (R/m^3) for Base Case Scenarios

Scheme	Scenario	Existing Garden Route Dam	Raise Garden Route Dam by 2.5 m	Kaaimans Dam and pumpstation	Malgas Dam
Unit Reference Values (R/m^3)	No interference	N/a	0.37	1.51	0.51
	Clear 1999: New scheme plus clearing	N/a	0.36 (-3%)	1.26 (-17%)	0.50 (-2%)
	Clear 1999: Clearing only	0.38	0.36 (-3%)	0.67 (-56%)	0.45 (-12%)

The "clear 1999" scenario reduces URVs by between 2% and 17% of the “no interference” scenario when considering the effect of the new dam and the clearing process. If the effect of the clearing process only is considered, these marginal URVs are between 3% and 56% lower than those of the “no interference” scenario. This indicates that a cost saving results from the clearing effort in all cases when clearing commences immediately, and therefore that clearing of alien vegetation in catchments with significant levels of invasion is economically worthwhile, if future water resource developments are planned there.

9 SENSITIVITY ANALYSES

A range of sensitivity analyses was conduced to determine the robustness of the URVs. A list of the sensitivity analyses conducted is given below in order from the most to the least sensitive. The upper and lower percentage differences in URVs when compared to the base case values are given in brackets :

- Discount rates used in net present value calculations (- 64% to + 64%)
- Cost of clearing alien vegetation (- 18% to + 20%)
- Growth in water demand (- 10% to + 14%)
- Efficiency of clearing alien vegetation (- 1% to + 13%)
- Rate of spread of alien vegetation (- 4% to + 2%)

The choice of discount rate was the most significant of these, with the URV showing significant variation (up to 64%) in both directions. The effect on the URV of all the others is considerably smaller. The cost of clearing is the next most significant with variations of the order of 20%, followed by the growth in water demand with variations of the order of 10 - 15%.

The town of George has an urgent need to either reduce water demand or to augment supplies. This results in the new water supply made available by any of the sample schemes being accessed in a very short space of time, and makes this particular case study comparatively insensitive to the variation in growth in water demand. This is not usually the case, and it could be expected that this factor should show more significance in another case study, and should not be under-rated.

More efficient clearing of alien vegetation did not show much sensitivity, whereas less efficient clearing varied the URV between 0% and 13%. A faster rate of spread of alien vegetation did not show much sensitivity either, whereas a slower rate of spread reduced URVs by less than 5%.

10 CONCLUSION

The study confirmed that the URV (in Rand/m^3 of water yield) is reduced by clearing starting immediately, and this is particularly advantageous in catchments where the levels of infestation are high. Once a water resource augmentation scheme is in place, the marginal URV of clearing the catchment upstream of the dam is equal to or less than the URV of that scheme if no clearing is undertaken.

Calculation of the URV is extremely sensitive to the discount rate chosen, and to a lesser extent to the cost of clearing and the growth in water demand. Less sensitive factors are the efficiency of clearing and the rate of spread of invasive alien plants.

This study highlighted the limitations of the URV for use in the wider context of economic analyses of the value of water, and indicates an area of research need, particularly with regard to discounting of natural resources.

ACKNOWLEDGEMENTS

Louise Stafford (CNC staff) for help with mapping of 1999 levels of infestation

Harold Basson, George Municipality for providing data

Brian van Wilgen, David Le Maitre, Arthur Chapman and David Scott of the CSIR for the information regarding streamflow reduction modeling for alien plants.

REFERENCES

Department of Water Affairs and Forestry, South Africa. 1999. Resource Directed Measures or Protection of Water Resources. Volume 2: Integrated Manual, Version 1.0.

Department of Water Affairs and Forestry, South Africa. 1999. Resource Directed Measures for Protection of Water Resources. Volume 3: River Ecosystems, Version 1.0.

Larsen, EJ and Marais, C. 2001. The Effect of alien Vegetation on Water Resources Planning for the Town of George. A study undertaken for Working for Water by ASCH Consulting Engineers and Ninham Shand.

Le Maitre, D and Görgens, A. 2001 (in prep). Impact of Invasive Alien Vegetation on Dam Yields . Report to the Water Research Commission by the CSIR and Ninham Shand.

Le Maitre, D.C., Versfeld. 1994. Field Manual For Mapping Populations Of Invasive Plants For Use With The Catchment Management System. Version 1.1 Unpublished. Report, CSIR Division Of Forest Science And Technology.

Marais, C. 2000. Developing an Ecological Catchment Management Model to Generate Expected Cost Streams for the Economic Assessment of Invading Alien Plant Control Programmes for Fynbos Catchments. Paper read at The Water Institute of Southern Africa, Biennial Conference and Exhibition, Sun City 28 May – 1 June 2000.

Van Wilgen, BW, Larsen, EJ, Marais, C, Görgens, AHM, Willems, T and Little, PR. 1999. The Importance of Alien Plant Invasions for Water Resource Planning in the Fynbos Catchment Areas of the Western and Eastern Cape. Paper presented at the Ninth South African National Hydrology Symposium: 29 – 30 November 1999.