

Options for meeting the ecological Reserve for a raised Clanwilliam Dam

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Abstract

A recent evaluation of the potential raising of Clanwilliam Dam included an assessment of whether the operation of the dam would meet the flow quality and quantity requirements for the protection of the downstream river and its estuary, taking Olifants/Doring River basin-level considerations into account.

The implications of meeting the ecological Reserve of the Olifants River downstream of Clanwilliam Dam to Bulshoek Weir, downstream of Bulshoek Weir to the confluence with the Doring River, and at the estuary, were assessed in terms of the impact on system yield. Some adjustments were made to the ecological Reserve to maximise the yield from a raised Clanwilliam Dam, in return for protection of the vitally important Doring River. Irrigation releases from Clanwilliam Dam were also restructured so that they met the ecological Reserve requirement for small floods of short duration to promote spawning in Clanwilliam yellowfish (*Labeobarbus capensis*). The assessments presented demonstrate that small adjustments in the requirements that form the ecological Reserve can greatly enhance the possibility, and reduce the costs, of successful implementation.

Keywords: Clanwilliam Dam raising, Clanwilliam yellowfish, ecological Reserve, ecological condition, environmental flows, water management tradeoffs

Introduction

The South African National Water Act (NWA, 1998) provides for the protection of water resources through the apportioning of an agreed amount of the water available in a system to maintain the natural environment in some pre-agreed condition. To fulfill its purpose, this water needs to be of an appropriate volume and quality, and be available at the appropriate time of the year, and is known as the ecological Reserve. To arrive at the ecological Reserve, the environmental flows (EFs) for the maintenance of affected rivers, estuaries, wetlands and ground-water are first determined for a range of future conditions. These are then assessed against other requirements in the basin, such as provision of water for off-stream use, as part of a consultative process to decide on acceptable future conditions for the various ecosystems (Dollar et al., 2010). The agreed future condition and the EFs for maintaining such become the ecological Reserve.

The Department of Water Affairs (DWA) is responsible for implementing the ecological Reserve for all significant water resources in South Africa, gradually over time. Importantly, however, new bulk infrastructure or any changes to existing bulk infrastructure, requires implementation of the ecological Reserve as part and parcel of the process. This is the case in the Olifants-Doring Basin, where concerns about the integrity of the Clanwilliam Dam necessitate remedial work on the wall, and opened the possibility of increasing its yield at the same time by raising the dam wall, which would trigger the need for releases to meet the ecological Reserve for the downstream river and its estuary.

This paper is a synthesis of a number of studies, relevant to the issue of Reserve releases from Clanwilliam Dam, including the assessment of the EFs for the Olifants River (Brown et al., 2006a; b) and estuary (Taljaard et al., 2006), a basin-level scenario assessment (Brown et al., 2006c), and a feasibility study for the raising of Clanwilliam Dam (De Wet, 2007).

The main ecological, social and economic considerations relevant to the basin are introduced, and a description of the water resource situation and extant infrastructure is provided for background. The circumstances leading to, and consequences of, various tradeoffs for the ecosystem, with regard to the implementation of the ecological Reserve are discussed in the context of off-stream water demands and potential future bulk water developments in the Olifants-Doring Basin, and specifically the potential raising of Clanwilliam Dam on the Olifants River upstream of its confluence with its main tributary, the Doring River.

The study area

The Olifants-Doring Basin is located on the west coast of South Africa. The Olifants River rises in the Agter Witzenberg Mountains to the north of Ceres. Most of the surface flows originate in the Cederberg Mountains, located along the eastern flank of its middle reaches. The main stem of the river is approximately 250 km long, initially flowing through a steep gorge, but eventually widening and flattening into a wide floodplain and a major estuary at the coast. Its major tributary, the Doring River, also rises in the Agter Witzenberg Mountains, but flows down the opposite side of the Cederberg Mountains.

The total natural mean annual runoff (MAR) of the Olifants River is approximately $1\,055 \times 10^6 \text{ m}^3/\text{a}$, but this has been significantly reduced by abstractions, mainly for irrigation (Sparks and Cullis, 2007), and current inflows to the estuary are approximately $718.4 \times 10^6 \text{ m}^3/\text{a}$. Water resources are not

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evenly distributed over the basin. Precipitation varies from up to 1 500 mm/a in the Cederberg Mountains in the southwest, to less than 100 mm/a in the northern coastal areas, and the mean annual potential evaporation is more than an order of magnitude higher than the rainfall over most of the area. The summer months, November to February, are warm and dry, and climate variation is extreme. The Olifants River is naturally perennial but flows in the Doring River are naturally seasonal, with the flow in the river ceasing for several days to several months each year.

Accurate daily flow data are not available for the Olifants River, or for any of its tributaries, upstream of Clanwilliam Dam, due to a paucity of functioning gauging weirs. Flow modelling indicated that present-day flows throughout the basin are generally lower than naturalised flows, with summer low flows considerably reduced relative to the natural levels, such that in the Olifants River upstream of Clanwilliam Dam surface flow now ceases in the summer months.

The quality of water in the upper and middle Olifants River is good but downstream of the confluence with the Doring River nitrification and salinities become a problem, particularly during March and April.

The study area falls within the Greater Cederberg Biodiversity Corridor, a biodiversity conservation project aimed at conserving critical habitat types in the region (Low et al., 2004). The Olifants and Doring River system has also been highlighted as a 'hotspot' of freshwater fish diversity in South Africa (Skelton et al., 1995) because it contains 8 endemic fish species that occur in no other river systems, as well as several other indigenous fish species. All of these are endangered, mainly as a result of agricultural activities, flow alterations and the impact of introduced species, such as bass and carp. In addition, the Doring River, and some of the tributaries, are virtually unspoiled by human impacts and have a very high ecological importance and sensitivity.

The Olifants River Estuary, located approximately 250 km north-west of Cape Town, is 1 of only 3 permanently open estuaries on the west coast of South Africa, together with the Berg and Orange River estuaries. Based on its size, zonal-type rarity, habitat diversity and biodiversity, it is considered to be the second most important system in South Africa (Turpie et al., 2002). The estuary also plays an important role in bird migration and the conservation of waterbirds (Taljaard et al., 2006).

Agriculture is the chief economic activity in the basin and it contributes approximately 45% of the economic output of the basin (Shippey and Van der Berg, 2004). Citrus farming in the area is important nationally (Kempthorne et al., 2007), as is wine making. Other economic sectors are mainly those serving the agricultural sector, although tourism is also important. The population is mostly rural and dispersed over a large area, with some concentration in small towns such as Citrusdal, Clanwilliam and Vredendal.

The area has high poverty levels and extreme dependence on agriculture and subsistence activities. Resource-poor farmers have limited access to good quality agricultural land and have been historically sidelined in terms of access to water (Kempthorne et al., 2007). The communities at Ebenhaeser (in the estuary) and Papendorp are particularly vulnerable to poverty, with approximately 3 500 people almost solely dependent on the river for their subsistence activities of fishing and irrigated agriculture. The estuary is also a nursery for various line-fish that underpin the West Coast fisheries. Thus, the cost of degrading the estuary would be high in terms of negative effects on livelihoods (Kempthorne et al., 2007).

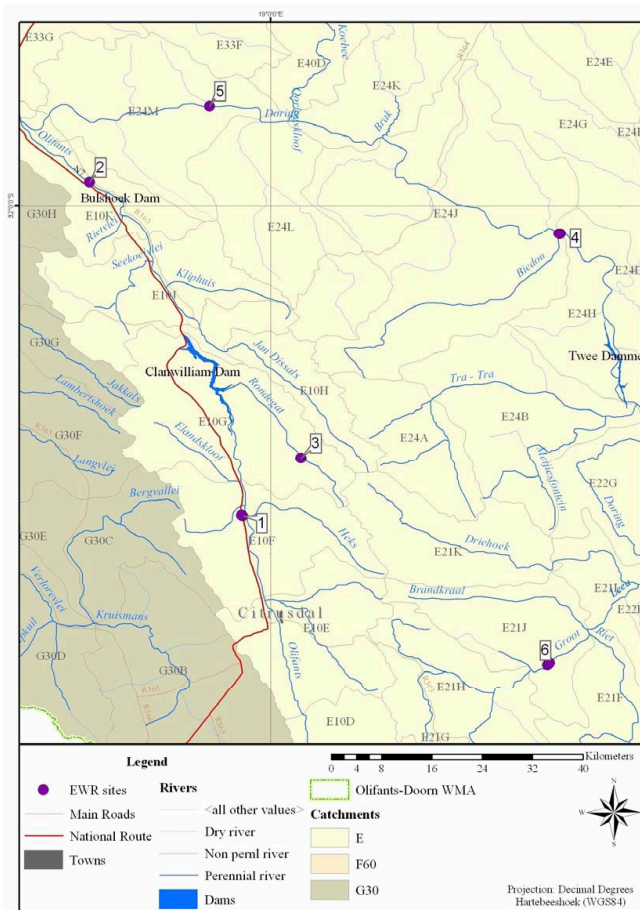


Figure 1
Map of the EF sites in the Olifants-Doring basin

Various small towns, and some other users, receive water from the river, but the bulk of the water is used for irrigation. Irrigation-related infrastructure in the basin consists of run-of-river abstraction and diversions of the river into irrigation canals. There are also numerous farm dams in the upper parts of the basin. In the middle and lower reaches, the Olifants River Government Water Scheme comprises Clanwilliam Dam, Bulshoek Weir and a 186 km long irrigation canal system.

Clanwilliam Dam is a 43-m high mass gravity concrete structure with a centrally situated overspill section, with 13 crest gates. The maximum discharge capacity of the 2 bottom outlet pipes is approximately 10 m³/s (Bester et al., 2006). The Bulshoek Weir is a gated stone-masonry gravity structure. Water is diverted into one canal system at Clanwilliam Dam (live storage 122 x 10⁶ m³) and is also released into the river to flow to Bulshoek Weir (live storage 5.7 x 10⁶ m³), approximately 30 km downstream, where it is diverted into another canal system. The Jan Dissels River also joins the Olifants River between Clanwilliam Dam and Bulshoek Weir. The total irrigated area dependent on Clanwilliam Dam and Bulshoek Weir is more than 140 km² at an estimated 1:5 year assurance of supply. During drought years when Clanwilliam Dam does not fill, restrictions are placed on the irrigation water users. There is a need for an improved assurance of supply for irrigated agriculture and for growth, and a need to allocate additional water to resource-poor farmers in the area.

No ecological Reserve releases are currently made from either Clanwilliam Dam or Bulshoek Weir. In dry periods, leakage from the Bulshoek Weir into the downstream river is also pumped back into the canals.

Table 1 Location and condition of the river EF site					
EF site	River	Location	Natural MAR (Mm ³ /a)	Present day MAR (Mm ³ /a)	Ecological condition
1	Olifants	Adjacent to the N7 downstream of the confluence with the Hex River	332	275	D
2	Olifants	Downstream of Bulshoek Weir, just downstream of Cascade Pools	519	Not known	E
3	Rondegat	Upstream of the Algeria staff accommodation, on the road between Algeria and Clanwilliam	7.7	7.3	B
4	Doring	Immediately upstream of the confluence with the Biedou River	420	320	B
5	Doring	At Ou Drif	511	401	B
6	Groot	Upstream of the Mount Cedar bridge	138	104	B/C

Table 2 Ecological condition categories (from Kleynhans, 1996)	
Category	Description
A	Unmodified, natural
B	Largely natural with few modifications. A small change in natural habitats and biota may have taken place but the ecosystem functions are essentially unchanged.
C	Moderately modified. A loss and change of natural habitat and biota have occurred but the basic ecosystem functions are still predominantly unchanged.
D	Largely modified. A large loss of natural habitat, biota and basic ecosystem functions has occurred.
E	The loss of natural habitat, biota and basic ecosystem functions is extensive.
F	Critically modified. An almost complete loss of natural habitat, biota and ecosystem functioning. In the worst cases, the changes are irreversible.

The EF studies

The riverine and the estuarine EFs were determined using standard DWA methodologies, and included a socio-economic assessment of a series of basin-wide flow scenarios (Brown et al., 2006a; Taljaard, 2006). The following is summarised from Brown et al. (2006a):

River EFs

The EF determination for the river focused on 6 sites (Fig. 1). The location of sites for the river EF was intended to provide information for the rivers upstream of the confluence of the Olifants and Doring Rivers, as it was expected that, for the lower Olifants River, the EF for the estuary would be greater than that for the river. Although it would have been extremely useful, it was not possible to locate an EF site on the Olifants River between Clanwilliam Dam and Bulshoek Weir because the riparian and instream vegetation had been severely burnt just before the study, and would not have yielded the sorts of information needed for the EF determination. When information was needed for either the lower Olifants River or the reach between Clanwilliam Dam and Bulshoek Weir, it was extrapolated from the nearest, relevant EF site.

The DRIFT methodology was used for the riverine ecological assessments (King et al., 2003). This approach allows for the generation of scenarios of different river condition linked with their EFs (Brown and Joubert, 2003), which assisted in the evaluation of a series of basin-wide water-resource developments. Essentially, sites on the more heavily-populated and cultivated Olifants River were in a poorer condition than those on the Doring River or on the tributaries (Table 1). Site 1 on the Olifants River upstream of Clanwilliam Dam was in a D category (Table 2), mainly as a result of excessively low summer flows (cessation of flow at times), cultivation of the floodplains

and riparian zones and high numbers of bass. Site 2, downstream of Bulshoek Weir was in an E category, resulting from loss of floods and low flows, reduced sediment supply, encroachment of reeds and palmiet (*Prionium palmitum*), and cultivation of flood terraces, which have completely and, to all intents and purposes, irreversibly, changed the character of the river. Sites 3 to 5 were in a B category, i.e., largely natural, and Site 6 was in a B/C, mainly because there were some water quality issues, but the habitat was in excellent condition. The EF requirements for maintaining the sites in their current condition were correspondingly lower for the sites in poorer condition (Table 3).

Table 3 The EFs for the study sites, excluding $\geq 1:2$ year return period floods			
Site	Target condition	Mm ³ /a	%nMAR
EF Site 1	Maintain present condition (D)	88	26%
EF Site 2	Maintain present condition (E)	48.3	9%
	Improve to a D category	± 194	38%
EF Site 3	Maintain present condition (B)	3	38%
EF Site 4	Maintain present condition (B/C)	145	34%
EF Site 5	Maintain present condition (B)	175	33%
EF Site 6	Maintain present condition (B/C)	47	34%

In terms of DWA policy, Site 2 should be restored to at least a D category, which would require an additional low-flow of $146 \times 10^6 \text{ m}^3/\text{a}$. This would, however, severely impact on economic activity, as it would reduce amount of water available for off-stream use. There was unanimous agreement from the ecologists that the attainment of a D category at EF Site 2 was unrealistic, and a 'residual flow' was instead recommended, to maintain the riparian and instream vegetation in the reach and keep the reach in an E category.

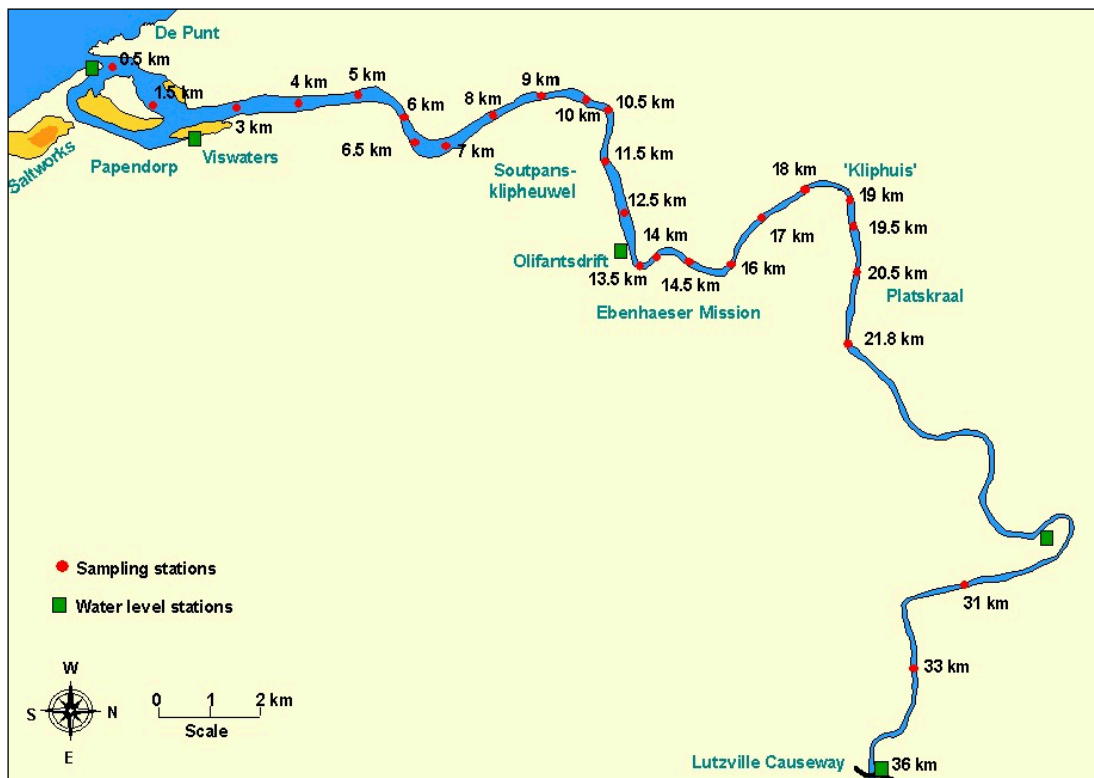


Figure 2
Map showing
extent of the
Olifants Estuary

Estuarine EF

The Olifants River Estuary is permanently open to the sea and the tidal influence extends some 36 km upstream (Fig. 2). The productivity of the estuary is, thus, particularly sensitive to decreases in river flows, flood frequencies and water quality. The estuary itself is still relatively undeveloped, but its condition is affected by a reduction in the volume and variability of freshwater inflows. The present daily flow to the estuary is about 66% of natural, but much of the reduction in flows is concentrated in the dry summer months, when flows are extremely low ($<1 \text{ m}^3/\text{s}$) and of a poor quality as they are strongly influenced by return flow from irrigation along the river.

The present (2005) ecological condition of the estuary is a C category, but this is on a negative trajectory (Taljaard et al.,

2006). Also, given its local, regional and national importance, Department of Environmental Affairs policy dictates that the condition of the estuary should be improved to a B category. Thus, EFs were determined for maintaining the estuary in a C category, i.e., stabilising the negative trajectory (Table 4), and for improving the condition to a B category, which would require an additional $203.3 \times 10^6 \text{ m}^3/\text{a}$ over and above present day flows into the estuary ($800.3 \times 10^6 \text{ m}^3/\text{a}$ in total; Taljaard et al., 2006).

Basin-level EF assessment of water-resource development options

The basin-level EF assessment considered a suite of scenarios, which approximated the effect that future bulk water resource developments would have on river flows and inflows to the

Table 4
Summary of the flow distribution of the EF for the Olifants Estuary to maintain an Ecological Category C (Taljaard et al., 2006)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99%ile	42.17	28.76	21.52	37.04	24.33	7.43	95.80	153.56	471.91	470.40	210.01	149.81
90%ile	23.61	7.85	7.27	3.66	3.84	4.07	9.43	66.69	112.14	150.96	116.78	65.34
80%ile	11.33	3.96	2.33	1.62	1.80	2.11	4.34	17.92	72.07	78.37	81.56	40.07
70%ile	7.85	2.16	1.64	1.53	1.46	1.73	2.24	8.84	44.03	53.49	52.19	30.07
60%ile	5.44	1.67	1.52	1.53	1.45	1.39	1.79	4.84	21.61	38.99	33.68	20.61
50%ile	4.36	1.42	1.52	1.53	1.41	1.32	1.23	2.33	14.39	22.60	27.35	13.96
40%ile	3.17	1.36	1.52	1.53	1.41	1.32	1.15	1.65	9.02	12.62	17.14	12.10
30%ile	2.00	1.36	1.52	1.53	1.41	1.32	1.15	0.90	5.01	8.22	11.91	8.78
20%ile	1.70	1.36	1.52	1.53	1.41	1.32	1.15	0.52	2.19	5.28	8.21	5.68
10%ile	1.43	1.36	1.52	1.24	0.95	0.70	0.80	0.43	0.84	2.91	3.92	3.28
1%ile	1.20	1.19	0.89	0.88	0.40	0.22	0.00	0.04	0.32	0.49	0.84	1.59

estuary. These were done with a network-based, monthly time-step Water Resource Yield Model (McKenzie and Van Rooyen, 1999) and covered as wide a range as possible of differences in volume and distribution of flows, and included different combinations of increasing the capacity of the existing dam (Clanwilliam) on the Olifants River by different amounts, options for dams on the Doring River, and increased abstraction in the headwaters of the Groot River (Table 5).

The anticipated future condition at each of the EF sites and the estuary, resulting from implementation of each scenario, was determined, and a socio-economic assessment, which considered the value of ecosystem goods, services and attributes and sectoral benefits of the off-stream use of water, was done.

The scenarios indicated opportunities for generating additional yield with relatively low environmental impact provided cognisance was taken of the dichotomy brought about by human utilisation of the area. The scenario that offered the most economically- and ecologically-balanced configuration (Scenario 5), comprised the following:

- Raise Clanwilliam Dam by 15 m
- Allow limited additional water resource development in the headwaters of the Groot River
- Protect the Doring River (i.e., no in-channel dams or diversion weirs) and key tributaries on both the Olifants and Doring Rivers, to ensure the variability of flow in the main stems, and to provide refuges and source areas
- Maintain the present condition of the rivers at Sites 1, 3, 4, 5 and 6
- Maintain the present

Scenario	Variant	Schemes				Target ecological condition for EF Sites				Key flows (MCM/a)							
		Dam capacity in MCM				Olifants (O)				Doring (D)				Olifants (O)			
		Farm dams in Kouebokkeveld				EF Site 1				EF Site 2				EF Site 3			
		Groot				D/s Bulshoek				D/s Rondegat trib				D/s U/s Biedou			
		Brandewyn				D/s Clanwilliam Dam				D/s Oudrif				D/s Groot trib			
		Melkbosrug				D/s Hex				D/s Doring Confluence				D/s Extrapolated			
		Additional Clanwilliam Dam capacity				None				None				None			
Natural	0*																
Present Day	1*																
Maximise supply from the Olifants River	2*																
	5*																
	6																
Dam upper reaches of the Doring	7																
	13																
	14																
	15																
Dam lower reaches of the Doring	16																
	17*																
	17B																
Maximise supply from the system	10*																
	11																

² Numbers are not sequential, as some scenarios were discarded early on in the process as they did not differ significantly from other scenarios, and others were added.

condition of Site 2, i.e., an E category. This effectively meant non-compliance to a Category D in the reach between Bulshoek Weir and the confluence with the Doring River (in return no in-channel dams or weirs in the Doring River).

- Maintain the present condition of the estuary, i.e. a C category.

Under the favoured section, the impacts on estuarine fisheries and nursery value were lowest, and the impacts on the livelihoods of small-scale fishers of Ebenhaeser, many of whom do not benefit from agriculture, were negligible. The scenario was further supported by the fact that dams in the Doring River had been repeatedly rejected as economically and ecologically unviable. They would also impact heavily on the estuary as the Doring River supplies much of the flow that supports the estuary (e.g. PGWC, 2003).

On the basis of the outcome of the basin-level EF assessment, the Director-General of the Department of Water Affairs and Forestry (now DWA) approved and officially signed-off a configuration of Preliminary Reserves for the basin that is in alignment with Scenario 5.

The Clanwilliam Dam raising feasibility study

The need for remedial work on Clanwilliam Dam provided a potential opportunity to raise the full supply level of the dam, and a feasibility study was undertaken to assess the technical, environmental, social, economic and financial viability of raising the dam wall by 5 m, 10 m and 15 m.

Other bulk water options for increasing supply volumes for irrigation were also evaluated to ensure that DWA was aware of the full range of alternatives and implications and would thus be able to make an informed decision. As the social development needs in the region are extremely important, the study focused on opportunities for resource-poor farmers presented by the dam raising.

The options analysis re-evaluated many of the options considered in the basin-level EF assessment, but with a greater focus on technical, economic and financial feasibility of each. Fifteen surface water (and 11 groundwater) development options were evaluated in terms their capital to yield ratio; their environmental impacts (barrier/sediment, inundation and downstream effects); and their beneficiaries (cost, agricultural impact, benefits to users and resource-poor farmer opportunities).

Of the surface water options, the results mirrored those of the basin-level EF assessment in that the most favourable were the development of farm dams in the uppermost parts of the basin; the raising of Clanwilliam Dam, or a combination of the two (West and Luger, 2005). There was also broad support for the raising of Clanwilliam Dam from key stakeholders in the basin (West et al., 2007).

The current capacity of the Clanwilliam Dam is about 30% of the present day inflow to the impoundment and the proposed raising of the dam could increase the storage up to 100% of the present day inflow. If Clanwilliam Dam is raised then the dam will absorb more of the winter streamflows before it spills and as a result the spillage over the dam will be reduced and delayed.

EF releases: temperature

The current release structure at Clanwilliam Dam is a 'bottom-release outlet', where water can only be released from the bottom of the dam. Thermal stratification in the impoundment means that water drawn off from a low level in the Dam during the spring and summer months is significantly colder (12 to 14°C) than the temperature in the downstream river (18 to 24°C). This has serious implications for the Clanwilliam yellowfish (*Labeobarbus capensis*), which spawn downstream of the dam in the summer in response to small increases in discharge, but which will not spawn at temperatures below 18°C (Cambray et al., 1997; King et al., 1998). Hence, the temperature of water released from the bottom of the dam to cue spawning would render it ineffectual. The fish have managed to survive and spawn downstream of Clanwilliam Dam, because the size of the current impoundment is small relative to the MAR of the river, which means that the dam usually spills in late winter/early spring. However, increasing the height of the dam, and the attendant change in dam design, would mean that spillage from the dam would be considerably reduced, and spawning seriously affected.

Thus, a 'multilevel outlet works' with releases at various levels (and therefore different temperatures, salinity, etc.) was investigated using the 2-dimensional CE-QUAL-W2, laterally averaged, hydrodynamic and water quality simulation model (Kamish and Rossouw, 2006). The temperatures of the releases, with and without the multi-level outlet structure, are depicted in Fig. 3, which shows that it would be possible to meet the downstream temperature requirements in the summer using a multi-level offtake, provided the impoundment was full

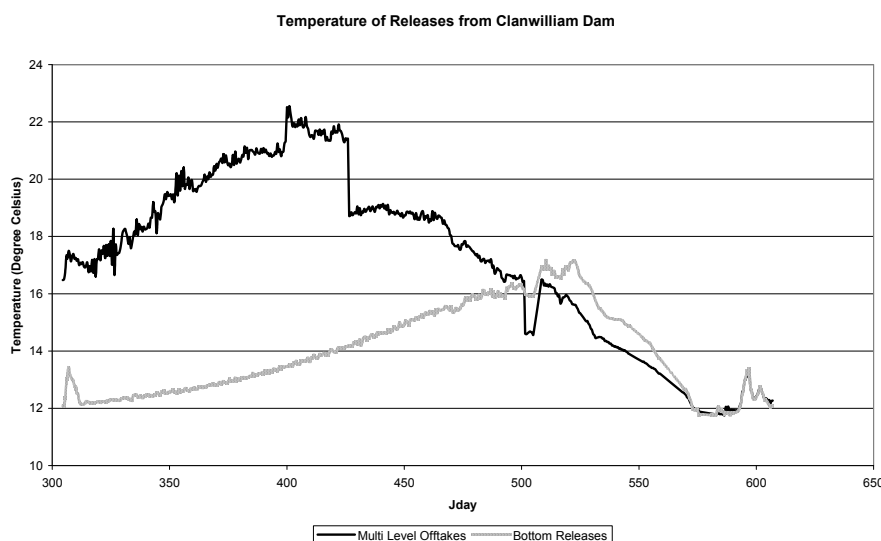


Figure 3
Temperature of dam releases made from the bottom releases and from the multi-level outlet structure, for a 15 m raising (Julian day 300 = 27 October 1994)

on 1 November, so that highest outlet could be used to make releases in early November.

On the basis of these results, a multi-level outlet structure was included in the proposed design, and costing, of the raised Clanwilliam Dam (Van der Berg and Killick, 2007).

EF releases: hydrology and yield modelling

The Water Resource Yield Model that was used in the basin-level EF assessment of water resource development options was updated for use in the feasibility study (Sparks and Cullis, 2007). This entailed, *inter alia*, changes to some of the off-stream demand and land-use data and some changes to the modelled hydrology (Table 6).

Scenarios were analysed to determine the historical yields of the system for the existing dam and for 3 different dam raisings of 5, 10 and 15 m. The scenarios also determined the influence on yield of making releases from Clanwilliam Dam to meet the EFs downstream of the Bulshoek Weir and at the estuary. Much of the focus of this was on meeting the requirements for maintaining a C category in the estuary (Table 4) and an E category at EF Site 2 (Table 7).

For the estuary, the Doring River, which contributes about 50% of the natural winter flow entering the estuary (Table 6), was used to supply the flood requirements and the bulk of the wet season low-flows. This was particularly valuable for Clanwilliam Dam, as it obviated the need to create a large outlet structure to release flood flows for the estuary (Sparks and Cullis, 2007). In the summer, a minimum inflow to the estuary of 1.5 m³/s was maintained. Historically the summer inflows to the estuary have been in the order of 2 m³/s, decreasing to 0.8 to 1 m³/s in severe droughts. The shortfall in the low-flows at the head of the estuary during times of drought was supplied by releases from either Clanwilliam Dam or the Bulshoek Weir.

For EF Site 2, the wet season flows were supplied by spillage, and inflow from the surrounding catchment. In the summer the low-flows were supplied by releases from either Clanwilliam Dam or the Bulshoek Weir.

Off-channel yields were determined for 4 scenarios, namely:

- No EF releases
- Releases from Bulshoek/Clanwilliam to meet 1.5 m³/s summer low-flows into the estuary
- Releases from Bulshoek/Clanwilliam to meet the 'maintenance' EF summer low-flows at Site 2 (Table 7)
- Releases to meet the full EF requirements at Site 2 (Table 7; Sparks and Cullis, 2007).

For each, the historic firm yield (HFY, i.e., never failed) and the yield at a 1:10 year assurance of supply was calculated. In the past, leakage from the Bulshoek Weir (which has since been repaired), and

Keypoint	Natural flow (Mm ³ /a)	Cumulative present day streamflow (Mm ³ /a)	% of natural
EF Site 1	320.3	270.1	84%
Inflow to Clanwilliam Dam	410.3	355.7	87%
Doring River	515.4	405.8	79%
Estuary	1 055.2	718.4	68%

high transmission losses between Clanwilliam and Bulshoek, meant that the supply failed more frequently than once in 10 years. If Clanwilliam Dam is raised, the increased storage will allow for a carry-over from year to year which will be used in drought years (Sparks and Cullis, 2007), thus reducing the number of failures.

The resultant yields for each of the 4 scenarios are shown in (Sparks and Cullis, 2007). If Clanwilliam Dam is not raised, and no EF releases are made, the 1:10 assurance yield is 174

Table 7							
Details of the EF for maintaining an E category at EF Site 2							
Desktop Version 2, Generated on 11/08/2006 (version 2)							
Total runoff: Quaternaries E10K							
Annual Flows (Mill. cu. m or index values):							
MAR		= 519.676					
S.Dev.		= 238.570					
CV		= 0.459					
Q75		= 2.246					
Q75/MMF		= 0.052					
BFI Index		= 0.314					
CV(JJA+JFM) Index		= 2.369					
Ecological Category = E							
Total IFR		= 48.377 (9.31 %MAR)					
Maint. Lowflow		= 17.782 (3.42 %MAR)					
Drought Lowflow		= 17.782 (3.42 %MAR)					
Maint. Highflow		= 30.596 (5.89 %MAR)					
Monthly distributions (Mill. cu. m.)							
Distribution type: Western Cape (wet)							
Month	Natural Flows			Modified Flows (IFR)			
				Low flows		High Flows	Total Flows
	Mean	SD	CV	Maint.	Drought	Maint.	Maint.
Oct	39.933	15.648	0.392	2.458	2.458	0.000	2.458
Nov	15.864	8.903	0.561	0.529	0.529	0.000	0.529
Dec	4.857	4.538	0.934	0.546	0.546	0.000	0.546
Jan	1.532	2.372	1.548	0.546	0.546	0.000	0.546
Feb	1.335	2.386	1.787	0.493	0.493	0.000	0.493
Mar	2.115	3.377	1.596	0.546	0.546	0.000	0.546
Apr	9.449	15.047	1.592	0.529	0.529	0.000	0.529
May	35.829	43.659	1.219	2.458	2.458	3.060	5.518
Jun	94.724	89.304	0.943	2.379	2.379	3.060	5.439
Jul	114.464	72.595	0.634	2.458	2.458	12.238	14.697
Aug	118.849	71.102	0.598	2.458	2.458	12.238	14.697
Sep	80.724	35.294	0.437	2.379	2.379	0.000	2.379

Table 8 Yield analysis results						
Scenario		Assurance of supply	Total yield ($\times 10^6$ m ³ /a)			
			Dam raising			
			0 m	5 m	10 m	15 m
a	No EF releases	1:10	175	219	248	275
		HFY	149	184	213	227
b	1.5 m ³ /s at the estuary in drought years	HFY	133	169	199	214
c	Low-flows at EF Site 2	1:10	161	196	225	254
		HFY	128	165	192	206
d	Full EF at Site 2	1:10	154	183	207	239
		HFY	124	157	172	187

$\times 10^6$ m³/a, and the HFY is 149×10^6 m³/a. This increases to 275×10^6 m³/a, with a HFY of 227×10^6 m³/a, if the dam is raised by 15 m. If a flow of 1.5 m³/s into the estuary is maintained through releases from Clanwilliam Dam during drought years, and the dam is not raised, then HFY for the system is reduced by about 16×10^6 m³/a to 133×10^6 m³/a. If the low-flow requirements at EF Site 2 are met and Clanwilliam Dam is raised by 5, 10 or 15 m the Dam capacity increases to 184, 264 and 362×10^6 m³/a, respectively, resulting in HFYs of 165, 192 and 206×10^6 m³/a, respectively. Yields are lower if the full EF at Site 2 is met through releases from Clanwilliam Dam.

On the basis of these results, it was decided that if the dam is not raised and only dam safety work is undertaken then Scenario b, 1.5 m³/s at the estuary in drought years, should be implemented. Making these releases from Clanwilliam Dam would affect the HFY, but would not negatively affect yield at a 1:10 assurance of supply and thus the economic costs of implementing the Reserve would be limited. The remainder of the flows will be provided by the Doring River, and spills from Clanwilliam Dam and Bulshoek. This would necessitate a moratorium on bulk water resource developments in the Doring River.

If the dam is raised, Scenario c, releases from Bulshoek/Clanwilliam to meet the 'maintenance' EF summer low-flows at Site 2 and 1.5 m³/s at the estuary in drought years, was recommended for implementation. The remainder of the EF at Site 2 would be met by flow from the Jan Dissels River and spills at Clanwilliam Dam (Table 9).

Operationalising the Reserve

The assessments undertaken as part of the Clanwilliam Dam raising feasibility study were used to evaluate various approaches to implementing EFs in the basin and in so doing contribute to operationalising the ecological Reserve (DWAf, 1998).

Table 9 summarises the proposed approach, which was signed off by DWA, for operationalising the ecological Reserve for the Olifants River and its estuary, based on the notion of maximising the yield from the Olifants River.

Discussion

The agricultural sector relies heavily on the water resources of the Olifants-Doring Basin, and is responsible for 95% of water use in the area. It also contributes approximately 45% of the economic output of the basin (Shippey and Van der Berg, 2004) and is the major source of jobs. The areas that are most suitable for agriculture and most extensively cultivated often experience shortages in meeting water demands, and there is a need for an improved assurance of supply for irrigated agriculture as well as the need to allocate water to resource-poor farmers in these areas.

In this setting, despite the clear and urgent need to provide some protection to the aquatic ecosystems that form the resource base on which the basin depends, the introduction of onerous EFs could have significant negative implications for the agricultural sector and for the socio-economic wellbeing of the

basin as a whole, which could have knock-on negative impacts on the natural environment. Thus, there is an excellent chance that unnecessarily onerous EFs would do more harm than good.

There are, however, some options in the Olifants/Doring Basin for generating additional yield with relatively low environmental impact, presenting a rare opportunity to achieve a true balance between development and protection of the aquatic environment (Brown et al., 2006a). Of the scenarios considered, Scenario 5 offered the most economically- and ecologically-balanced configuration, based on maximising yield from the Clanwilliam Dam (possibly augmented by some off-channel farm dams in the upper reaches of the Doring River). Scenario 5 comprised raising Clanwilliam Dam by up to 15 m and meeting the full requirements for the recommended ecological Reserve at 5 of the 8 EF river sites, and at the estuary. The 3 sites where the full EFs would not

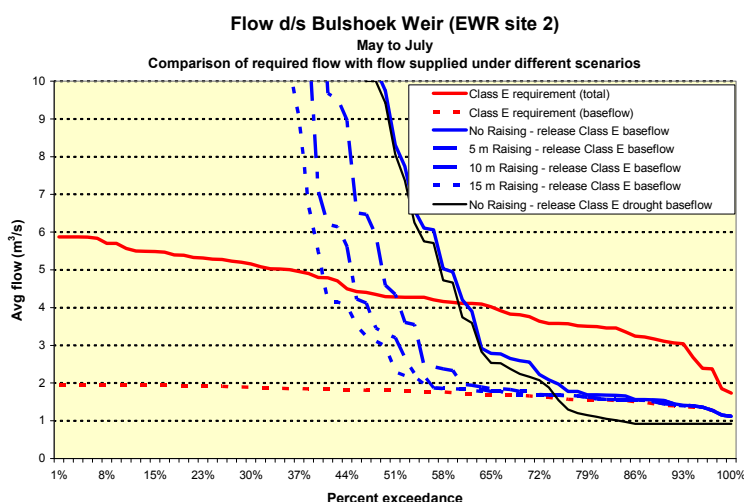


Figure 4
Flow d/s Bulshoek Weir for different scenarios (May to July)

Table 9 Summary of proposed approach for operationalising the ecological Reserve for the Olifants River and its estuary			
River	Reach	Issue	Proposed solution with a raised CwD
Olifants	Upstream of CwD	Current EC: D	Target EC: C, with improved management of non-flow impacts to increase to C
		Present-day flows good, except for cessation of flow in summer months when run-of-river abstractions exceed available flows	Meet EF, including summer low-flows
			Compliance monitoring to ensure that irrigators do not intercept these EFs
			Encourage development of limited off-stream storage
	CwD Dam to Bulshoek Weir	Current EC: D	Target EC: D, with improved spawning opportunities for yellowfish
		CwD bottom outlets not able to meet the EF discharge- and temperature-requirements for small floods in October to January to trigger the spawning of Clanwilliam yellowfish	Include multi-level outlets in raised CwD
		CwD releases approx. 8 m ³ /s during the summer months, significantly more than natural summer flow	Stagger irrigation releases as a series of small flood events, rather than constant release of 8 m ³ /s
	Bulshoek Weir to confluence with Doring River	Current EC: E	Target EC: E, with improved spawning opportunities for yellowfish
		Until <i>ca.</i> 2004, summer low-flows of about 1.2 m ³ /s maintained by the leakage through the weir, although concessions were given to some downstream irrigators to use the leakage (estimated at 0.5 m ³ /s). Repairs to weir reduced leakage to 0.25 m ³ /s.	Release EF low-flow requirements (Table 7) from CwD as part of low-flow releases for estuary
			Withdraw concessions to use leakage
			Allow a portion of the staggered irrigation releases from CwD to spill over the Bulshoek Weir to maintain EF low-flow
			Early winter EF requirements will not be met but later winter requirements will be exceeded. Figure 4 shows that for May to July raising of CwD by 15 m results in reduced unregulated spills, and the total EF being satisfied 40% as opposed to 60% of the time if CwD is not raised. Low-flow requirements are met throughout.
	Estuary	Current EC: C with negative trajectory	Target EC: C
		The present ecological state of the estuary was may be worsening due to the low summer inflows and non-flow related activities such as: Over-exploitation of fish resources (gill net fisheries) Nutrient inputs from agricultural activities	Improved management of non-flow impacts to increase to B
			Releases from CwD and Bulshoek Weir to increase the summer inflows to 1.5m ³ /s
			Compliance monitoring to ensure that irrigators do not intercept these EFs
			EF flood requirements provided by undeveloped Doring River, plus spills from CwD
Doring	All	Current EC: B	Target EC: B
		Doring River provides 50% of the flows to the estuary, including floods and winter low-flows. The Doring River and its main tributaries also contain the bulk of the good quality fish habitat remaining in the basin.	No major water-resource developments in the Doring sub-basin
			Water-resource developments to be restricted to small off-channel dams in the headwaters of the Groot River (the main tributary of the Doring River)
		Apart from the upper reaches of the Groot River, the catchment of the Doring River is largely desert and unsuitable for large-scale agriculture	EFs at EF Sites 4, 5 and 6 to be met in full – no exceptions Mid-size and major floods to be unimpeded

be met are EF Site 2, downstream of Bulshoek Weir, and 2 extrapolated sites: EF Site 7, downstream of the confluence of the Olifants and Doring rivers and EF Site 8, between Clanwilliam Dam and Bulshoek Weir. Thus the general DWA policy guideline that all water resources should be managed in at least a Category D was not applied, as the benefit offered by the Doring River being left relatively untouched by water resource developments far outweighed those of 'forcing' the reach represented by EF Site 2 into a D category.

Under Scenario 5, the impacts on estuarine fisheries and nursery value are lowest, and thus so are the impacts on the livelihoods of small-scale fishers of Ebenhaeser, many of whom do not benefit from agriculture.

Provided that water resource developments are limited in the Doring River and it continues to provide the flood flows at the estuary, Scenario 5 also means that it is unnecessary to create large outlet capacity for a raised Clanwilliam Dam, as the outlet capacity required of Clanwilliam Dam is limited to that

dictated by the EF requirements between Clanwilliam Dam and the confluence with the Doring River, i.e., approximately 20 m³/s. This, of course, affects the costs of raising the dam.

Here we have shown that small adjustments in the EF requirements that form the ecological Reserve can greatly enhance the possibility, and reduce the costs, of successful implementation.

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