

In support of water-resource planning – highlighting key management issues using DRIFT: A case study

C Brown^{1*}, C Pemberton¹, A Birkhead², A Bok³, C Boucher⁴, E Dollar⁵, W Harding⁶,
W Kamish⁷, J King¹, B Paxton⁸ and S Ractliffe⁸

¹ Southern Waters Ecological Research and Consulting, Zoology Department, University of Cape Town, PO Box 12414, Cape Town 8010, South Africa

² Streamflow Solutions, PO Box 889, Gonubie 5256, South Africa

³ Anton Bok Aquatic Consultants, 5 Young Lane, Mill Park, Port Elizabeth 6001, South Africa

⁴ Botany Department, University of Stellenbosch, Private Bag X1, Matieland 7602, South Africa

⁵ ESJ Dollar Consulting, 40 Susan Crescent, Langeberg Heights 7570, South Africa

⁶ DH Environmental Consulting, PO Box 5429, Helderberg 7135, South Africa

⁷ Ninham Shand, PO Box 1347, Cape Town 8000, South Africa

⁸ Freshwater Research Unit, Zoology Department, University of Cape Town, Private Bag, Rondebosch 7700, South Africa

Abstract

The DRIFT (downstream response to imposed flow transformation) methodology was applied as part of a comprehensive Reserve determination study on the Olifants-Doring River, Western Cape, South Africa. DRIFT was used to provide flow scenarios, and descriptive summaries of their consequences in terms of the condition of the river ecosystem, for examination and comparison by decision makers, managers and users. The methods used and results obtained in that study are presented and discussed in the light of the study constraints of time and money, the lack of historical data, and the urgent need to provide clear, easily-understandable information on the consequences for the river ecosystem of various tradeoffs characteristic of water resource developments. The results indicated that abstracting during high flows in winter and river restoration work can have positive ecological and agricultural returns.

Keywords: environmental water requirements; Ecological Reserve; DRIFT; scenarios; river condition; tradeoffs

Introduction

The South African National Water Act (NWA; No. 36 of 1998) is founded on the principle that National Government has overall responsibility for, and authority over, water-resource management for the benefit of the public without seriously affecting the functioning of the natural environment, i.e., sustainable utilisation of the resource. In order to achieve this objective, Chapter 3 of the NWA provides for the protection of water resources through the Ecological Reserve (NWA, 1998).

The Department of Water Affairs and Forestry (DWA) Directorate: Resource Directed Measures (D:RDM) is tasked with the responsibility of ensuring that the Reserve requirements, which have priority over other uses in terms of the NWA, are determined before licence applications are processed, particularly in stressed catchments. The Reserve refers to both the Ecological Reserve and the Basic Human Needs Reserve. The Olifants/Doring River catchment is deemed to be one such system and a comprehensive determination of the Reserve was therefore commissioned in 2003, and Southern Waters Ecological Research and Consulting were appointed to lead the technical aspects of the study.

The study as a whole encompassed separate flow determinations for the river, the estuary and the groundwater systems (Brown et al., 2003). This paper concentrates on the river system and outlines the approach used and results obtained, using

one of the study sites (Site 1) as an example. The results of the study are intended to support water-allocation planning, in accordance with the requirements of the NWA and the National Water Resource Strategy (DWA, 2002).

The process for determining the Ecological Reserve for river ecosystems is stipulated by DWA (DWA, 1999) and comprises eight steps:

- Step 1. Initiate the study
- Step 2. Define the resource units
- Step 3. Ecoclassification
- Step 4. Quantify ecological water requirement scenarios
- Step 5. Ecological consequences of flow scenarios
- Step 6. Decision-making process
- Step 7. Ecological RQOs
- Step 8. Operationalising the Reserve.

Step 1 is essentially an internal DWA process, where the applicability and limitations of different levels of Reserve determination are evaluated and a level appropriate to the study river decided on. The level chosen dictates, *inter alia*, the duration of the study, the disciplines represented, the intensity and frequency of data collection and the method used. In the case of the Olifants-Doring study, a comprehensive level of determination was decided on, which provided for a two-year study period and, for the river component, a team of specialists representing six disciplines, namely: hydrology, hydraulics, geomorphology, water quality, botany, macroinvertebrate ecology and fish ecology.

Step 2 involves the division of the study catchment into representative ecosystems, e.g., rivers, wetlands, estuaries or groundwater, and representative reaches within each of the ecosystems identified. For the Olifants-Doring study, this process

* To whom all correspondence should be addressed.

☎ +27 21 4653135; fax: +27 21 4653901;

e-mail: cbrown@southernwaters.co.za

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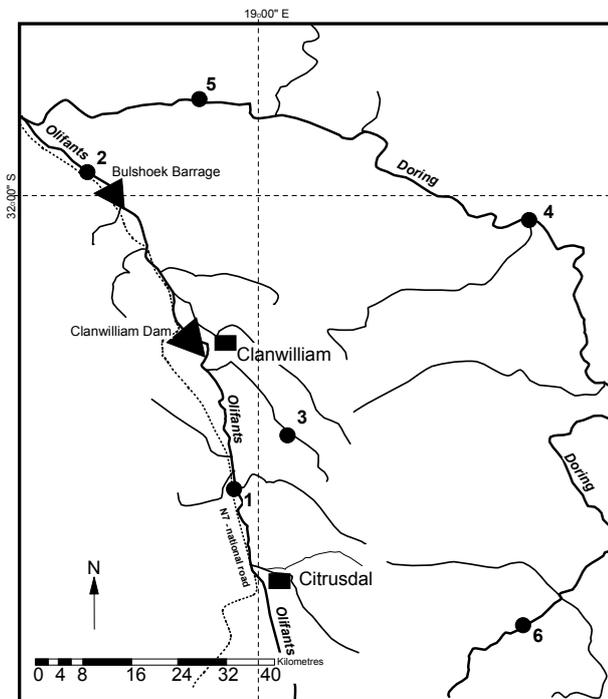


Figure 1

Map of the study area showing the location of the six study sites

is discussed in Brown et al. (2004), and resulted in the selection of six study sites spread throughout the catchment.

Step 3 is an evaluation of the ecological condition of the selected study reaches/sites relative to their natural or undisturbed condition. This again is guided by set procedures provided by DWAF, which are explained in detail elsewhere (e.g. Kleynhans, 1996; Kleynhans et al., 2005).

Step 4 is the actual environmental flow assessment, and is the focus of this paper. It culminated in flow assessments for the six representative sites in the Olifants-Doring catchment, each of which allowed for the evaluation of several flow-related scenarios.

Step 5 involves using the results achieved in Step 4 to evaluate the ecological consequences of one or more future flow regimes, which represent 'realistic' operational scenarios for the system. Step 5 leads into Steps 6 to 8, in which, for each site, one of the scenarios is selected as the Ecological Reserve for implementation, and thereafter is expanded to include monitoring and evaluation criteria, the so-called Resource Quality Objectives (DWAF, 1999), and rules that dictate, *inter alia*, the operation of dams, the issuing of licences and the extrapolation of results to other parts of the catchment.

Study area and study sites

The Olifants/Doring River catchment is situated in the south-west of South Africa, in a winter rainfall region. The Olifants

River itself rises on the Agter Witzenberg plateau, which is an agricultural area situated between the Skurweberge, the Groot Winterhoekberge and the Witzenberg at an altitude of approximately 800 m (Dallas, 1997; Fig. 1). It rises as a network of small mountain streams and wetland areas. Whilst most of these smaller streams do not flow during summer, the main river is naturally perennial. From the plateau, the river flows northwards for 12 km before entering a narrow gorge for 30 km. It emerges into a wide valley at Keerom after which it flows northwards for a further 100 km between the Olifantsrivierberge, Swartberg and the Cederberg Mountain ranges. Numerous small tributaries join the Olifants River in its upper reaches and two major tributaries, the Doring and the Hol Rivers, join the river near the towns of Klaver and Vredendal, respectively. The river reaches the sea at Papendorp (Dallas, 1997).

The mean annual precipitation over much of the catchment is less than 200 mm, with the result that, except in the wetter south-west, the climate is not suitable for dryland farming on a large scale. Approximately 113 000 people live alongside the Olifants River or in its immediate catchment (excluding the Doring River), and the irrigated citrus, deciduous fruits, grapes and potatoes that are grown in the Olifants Valley provide the mainstay of the catchment's economy.

In an ecological sense, rivers should be viewed as continuous longitudinal systems. They possess continuous gradients of physical and chemical conditions that are progressively and continuously modified downstream from the headwaters to the sea (Vannote et al., 1980) and changes taking place in the upstream reaches will influence downstream processes. Different sections of a river can however have different natural flow patterns, and can react differently to flow-related and other external stresses according to their individual sensitivities. As a result they often require individual specifications of their environmental flows. Furthermore, in order to facilitate the best management of a river, it needs to be broken down into discrete, manageable units. Biophysical and social considerations and the practicalities of a certain number of units need to be taken into account when identifying these units. Louw and Birkhead (1999) suggest that, for a comprehensive Reserve determination in South Africa, four EWR sites, selected correctly, will normally cater for a river length of 100 to 200 km. However, the number of EWR sites influences the cost and time required for the study and, in this study (as is often the case), site number was dictated by financial considerations. The total number of sites for the study was limited to six (Fig. 1), with two of these being on the Olifants River, two on the Doring River (its major tributary) and the remaining two small tributaries, *viz.* the Rondegat River, which flows into the Olifants River, and the Groot River, which flows into the Doring River. This equated to approximately two sites per 200 km of river. The locations of the six sites are indicated in Fig. 1. The reasons for their selection and the process adopted are covered in detail in Brown et al. (2004). Site 1 (Table 1), the focus of this paper, was taken as being representative of the Olifants River from Citrusdal to the Bulshoek Dam.

TABLE 1
Details for Site 1 on the Olifants River

Coordinates :	S 32°26.764; E 18°57.601.
Locality :	Adjacent to the N7 downstream of Citrusdal and upstream of the confluence with the Hex River.
Hydrology:	There is no DWAF gauging weir but flows in the river can be estimated from inflows to Clanwilliam Dam.
Access:	From a lay-by on the N7.
Hydraulic cross-sections:	Two cross-sections were selected to characterise the hydraulic relationships at EWR Site 1 (Fig. 2). These were: CS 1a: Across a riffle; CS 1b: Across a pool section.

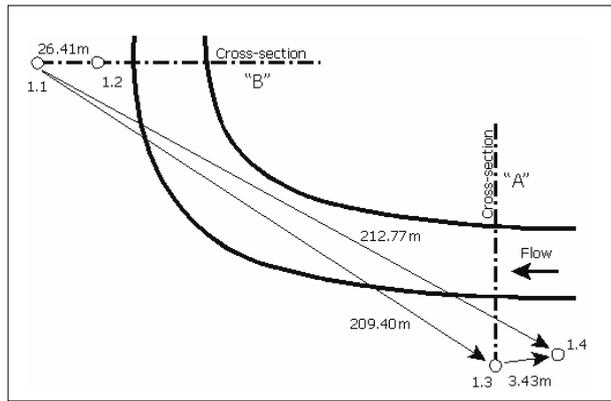


Figure 2
Plan layouts for EWR Site 1

Site 1 was located on a bend in the river, which was a less-than-ideal situation from the perspective of hydraulic modelling. The site, however, offered a wider range of habitat types and was in considerably better ecological condition than the remaining sections in this reach. Thus, as is typically the case, the consideration of a wide array of requirements for a site, including those related to physical safety of the researchers, resulted in the selection of a site that was less than ideal for most disciplines but better than anything on offer elsewhere. The plan layout of Site 1 is provided in Fig. 2. The top portion of the site near Transect 1a was composed of shallow riffle and run habitat, overlying small- to medium-sized cobbles. This cobble-bed section is uncharacteristic of the reach, but was included because such sections are typically more sensitive to flow changes than runs or pools (Gordon, 1992). The banks in this section were relatively steep, and appeared to be artificial. They were composed of large cobbles and boulders, interspersed with patches of palmiet (*Prionium serratum*), with light infestation of *Eucalyptus* spp. at the tops of the banks. Cross-

sections were positioned across the riffle and pool, upstream and downstream of river bend, respectively. The lower portion of the site (Transect 1b) was a sand bed river and was bound by sandbanks and dense stands of palmiet on the right bank, and a steep artificial boulder bank (supporting the N7 National Road between Cape Town and Windhoek) on the left. This lower section of the site consisted of deep sandy runs and pools, which are characteristic of this reach of the Olifants River. The site was approximately 250 m in length.

Methods

Ecoclassification

Present ecological status (PES) was determined using the eco-status model (Kleynhans et al., 2005) and a water quality model (salts only) provided by DWAF: RQS (Jooste, 2004). Results from both models were altered in the event that they did not agree with the specialists' assessment of PES, and motivation for these changes provided, where applicable.

Flow assessment

The DRIFT (Downstream Response to Imposed Flow Transformation) Method (Brown et al., 2005), an interactive, holistic method for advising on environmental flows for rivers targeted for water-management activities, was used to assess the flow requirements for the selected sites on the Olifants-Doring River. In its totality, DRIFT consists of four modules (biophysical, social use, scenario development and compensation economics (King et al., 2003) but only Modules 1 (biophysical) and 3 (scenario development) were used in this study.

The key feature of DRIFT is that it provides a structure to specialist deliberations on the consequences of flow changes. Data collection and subsequent deliberations concentrate on river sites, each of which is selected based on it being representative of a river reach as far as possible.

TABLE 2 Present-day flow categories for Site 1 and change levels considered by the specialists at the workshop						
Flow category	Magnitude (m ³ ·s ⁻¹)	Timing/frequency – present day	Change 1	Change 2	Change 3	Change 4
LOW FLOWS						
Dry season low flows	0.2-4.6 (Fig. 2)	November to April	Reduction: Capped at 20 th percentile	Increase: Minimum dry season lowflow of 0.01 m ³ ·s ⁻¹	Increase: Reinstatement to 50 th percentile on the Naturalised FDC	None
Wet season low flows	16.5-69.3 (Fig. 2)	May to October	Reduction: Capped at the 10 th percentile on the Present Day FDC	Reduction: Capped at the 40 th percentile on PD FDC	Reduction: Capped at the 70 th percentile on PD FDC	Reduction: Capped at the 90 th percentile on PD FDC
FLOODS						
Flood Class 1	7.00-14.20	13 per annum	Decrease (6)	Decrease (3)	Decrease (1)	Decrease (0)
Flood Class 2	14.21-28.40	1 per annum	Decrease (0)			
Flood Class 3	28.41-56.82	1 per annum	Decrease (0)			
Flood Class 4	56.83-113.65	1 per annum	Decrease (0)			
Flood Class 5	126.28	1:2	Absent			
Flood Class 6	166.02	1:5	Absent			
Flood Class 7	194.77	1:10	Absent			
Flood Class 8	194.77	1:20	Absent			

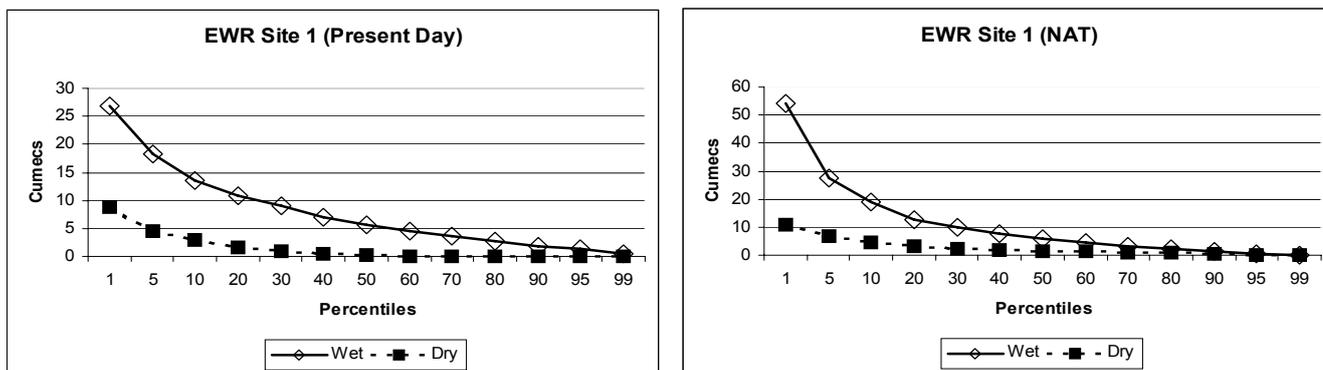


Figure 3
Present day (left) and naturalised (right) low-flow flow duration curves for the wet and dry seasons at Site 1.
Please note the y-axes differ between the two charts.

The present-day long-term daily flow data for each site were separated into ten flow classes (Table 2; Fig. 3), and specialists predict the consequences of up to four levels of change from present conditions in each flow class (Table 2) for different biophysical components of the river ecosystem (Table 3).

The consequences of each considered flow change for each of the study sites were deliberated and decided on at a five-day workshop, attended by the full river team, held in November 2004. The workshop situation enabled specialists to discuss possible consequences with other specialists and ensure that they took into

TABLE 3 The hierarchical arrangement of ecosystems components, sub-components and elements represented on the Olifants-Doring study (river only)		
Component	Sub-component	Element
Hydrology	As per Table 2	
Hydraulics	Not applicable	
Water quality	Temperature, dissolved oxygen, salinity	None listed
Geomorphology	Depth	Pool, riffle
	Width	Pool, riffle
	Bed slope	Pool, riffle
	Potential bed transport	Pool, riffle
	Geodiversity of bed	Pool, riffle
	Quantity of fines on the bed	Pool, riffle
	Overbank sedimentation	None listed
Botany	Floating aquatics	Lemna/Azolla
	Rooted aquatic vegetation	<i>Nymphaea nouchali</i> , <i>Typha capensis</i> , <i>Phragmites australis</i>
	Lower wetbank	<i>Juncus lomatoophyllus</i> , <i>Isolepis prolifer</i> , <i>Prionium</i> , <i>Isolepis digitata</i>
	Upper wetbank	<i>Panicum repens</i> , <i>Sesbania punicea</i> , <i>Salix mucronata</i> , <i>Prionium serratum</i>
	Lower dynamic zone	Woody invasives
	Tree shrub zone	Woody invasives, indigenous woody vegetation
	Upper dynamic zone	Woody invasives, <i>Rhus angustifolia</i>
Macroinvertebrate ecology	Detritivorous mayflies	<i>Pseudopannota</i> sp., <i>Pseudocloeon vinosum</i> , Caenidae, Ecnomidae, <i>Demoulinia</i> (Baetidae)
	Mobile grazers	<i>Emoreptus capensis</i> , <i>Baetis</i> spp. (Baetidae), <i>Afronurus barnardi</i> (Heptageniidae), Teleganodidae
	Less-mobile grazers	Leptoceridae, Elmidae, Blephariceridae, Crambiidae, Dryopidae
	Collectors	Hydropsychiidae, Philopotamidae
	Flow-sensitive predators	Corydalidae, Athericidae
	Hardy predators	Libellulidae, Cordulidae, Gomphidae, Coenagrionidae, Aeschnidae
	Shredders	Notonemoridae, Sericostomatidae
Fish ecology	Invasive centrarchid	Small-mouthed bass
	Large endemic cyprinids	Clanwilliam Yellowfish
	Minnows	Clanwilliam Redfin, Fiery Redfin
	Rock catfish	Clanwilliam Rock Catfish, Barnard's Rock Catfish

Driver components	Component PES	Driver PES	PES
Hydrology	D	D	D
Geomorphology	E		
Water quality	B		
Response components	Component PES	Response PES	
Fish	D	D	
Macroinvertebrates	C		
Vegetation	C		

account as many of the interactions as possible that were likely to affect their component. The full matrix of consequences, completed by the specialists, for the range of possible changes in the ten flow categories (*viz.* two dry season categories and eight flood classes; Table 2), was then entered into the DRIFT Database, together with information on the data sources used. The DRIFT Database is a series of MS Excel spreadsheets that stores the matrix of flow-response couplets, predicted by the specialists, for a range of possible flow changes; uses this matrix to compute the ecological consequences of different volumes and distributions of water being made available for river maintenance (flow scenarios); summarises the ecological consequences of flow scenarios relative to the present ecological state of the river; and allows predictions to be updated should new information become available.

Each consequence was accompanied by an integrity rating, which indicates:

- If the subcomponent (Table 3) is expected to increase or decrease in abundance, magnitude or size
- The severity of that increase/decrease, on a scale of 0 (no measurable change) to 5 (very large change)
- Whether the predicted change represents a move towards (+ve) or away from (-ve) natural.

The DRIFT database was then checked for errors and thereafter used to create summary plots of the predicted results using DRIFT SOLVER and DRIFT CATEGORY (Brown and Joubert, 2003). DRIFT SOLVER contains an integer linear programming multicriteria analysis (MCA) method, which generates optimally distributed flow scenarios for different total annual volumes of water. DRIFT CATEGORY facilitates evaluation of these in terms of river condition.

Hydrology

The naturalized MAR (nMAR) at Site 1 was estimated at 331.5 MCM and present day MAR (pdMAR) at 274.7 (i.e., 83% of nMAR). However, at Site 1, the dry season low flows were considerably reduced relative to their natural levels (Fig. 3). There was thus some merit in predicting the consequences of increasing these, and the selected change levels encompassed both decreased and increased, i.e., restoration, flow. Each biophysical specialist (Table 3) chose her/his own component-specific methods to derive the kinds of flow-related links required to provide answers to the questions posed by DRIFT (Birkhead et al., 2005).

Biophysical components

Specialist data-collection and evaluation for each of the biophysical components took place over 12 months; encompassing one

full hydrological year. Each biophysical specialist chose her/his own component-specific methods for the collection, analysis and interpretation of data that assist in understanding the links with the flow classes in Table 2 (e.g., Arthington et al., 2003).

When recording the consequences of each flow change, the specialists considered a number of subcomponents and/or elements that may be relevant to their ecosystem component (Table 3). Subcomponents may comprise channel (physical) features, chemical features, communities or individual species, and are chosen because of their known susceptibility to flow changes, their role as key species or features, or their relevance to subsistence users (King et al., 2003).

Results

Ecoclassification

The present ecostatus for Site 1 was Category D (Table 4), with the major factors contributing to deviation from the natural condition identified as: manual manipulation of the river channel (non-flow related); cultivation of the floodplain (non-flow related); reduced summer flows and long no-flow periods over the summer (flow related), and invasion by alien vegetation (mainly non-flow related). An explanation of the PES categories is provided in Table 5.

Biophysical consequences

For each site, approximately 1 000 consequences of flow change were recorded for the five biophysical components in the study (geomorphology, water quality, vegetation, macroinvertebrates and fish). These are provided in Brown and Pemberton (2005). An example of consequences returned for one sub-component of the macroinvertebrates for successive reductions, through four change levels, in wet season low flows at Site 1 is given in Table 6.

In Table 6, 'severity rating' denotes the severity of the predicted change (if any) in terms of a range between 0 (no change) and 5 (highly significant change); 'direction of change' denotes an increase (I) or decrease (D) in the abundance of an element; 'towards or away from natural' is an indication of whether the change represents a move towards or away from the natural condition of the river; and, 'data source' denotes the quality of the supporting data, *viz.* high (H), medium (M) or low (L), according to the following criteria (King et al., 2003):

- H Supported by studies on the same species/process/river that have been published in peer-reviewed papers, books or reports

TABLE 5
The South African river categories (DWAf, 1999)

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	Modifications have reached a critical level and the lotic system has been modified completely with an almost complete loss of natural habitat and biota. In the worst instances the basic ecosystem functions have been destroyed and the changes are irreversible.

TABLE 6
Example of consequences returned for one sub-component (detritivorous mayflies) of the macroinvertebrates for changes in wet season low flows

Wet season lowflows	Sub-component Element	Macroinvertebrates							
		Detritivorous Mayflies							
		Riffle/Run		Instream		Marginal vegetation		Stones out of current/sand	
Change level 1	Severity rating	0	1	0	1	0	1	0	1
	Direction of change	Increase		Increase		Increase		Increase	
	Toward/away from natural	Away		Away		Away		Away	
	Data source	M		M		M		M	
	Integrity rating	0	-1	0	-1	0	-1	0	-1
Change level 2	Severity rating	0	2	0	2	0	1	0	2
	Direction of change	Increase		Increase		Increase		Increase	
	Toward/away from natural	Away		Away		Away		Away	
	Data source	M		M		M		M	
	Integrity rating	0	-2	0	-2	0	-1	0	-2
Change level 3	Severity rating	1	3	0	2	0	2	2	3
	Direction of change	Increase		Increase		Increase		Increase	
	Toward/away from natural	Away		Away		Away		Away	
	Data source	M		M		M		M	
	Integrity rating	-1	-3	0	-2	0	-2	-2	-3
Change level 4	Severity rating	2	3	0	2	0	1	2	4
	Direction of change	Increase		Increase		Increase		Increase	
	Toward/away from natural	Away		Away		Away		Away	
	Data source	M		M		M		M	
	Integrity rating	-2	-3	0	-2	0	-1	-2	-4

M Supported by studies in peer-reviewed papers, books or reports on similar species/processes/ivers; unpublished data on the same species/processes/ivers or direct observations in the study river

L The recommendation is made on the basis of anecdotal information or professional judgement.

Finally 'severity rating' and 'towards/away' from natural combine to provide the integrity rating, where the move away or towards natural is illustrated by a positive (+) or negative (-) before the severity rating.

An excerpt of the DRIFTSOLVER spreadsheet for Site 1 is provided in Table 7. Here the integrity ratings for each element have been combined through the sub-component level to the component level for up to four levels of flow change in wet season low flows, dry season low flows and Class 1 floods. The

optimally distributed flow scenarios for different total annual volumes of water are created by off-setting the resultant DRIFT total score against the volume of water associated with each change level (see Brown and Joubert, 2003 for details).

It is interesting to note that changes in the low flows are not expected to affect the physical habitat (geomorphology), whereas changes in the small Class 1 floods are expected to have some impact on physical habitat, with a concomitant effect on the other (biological) components. Similarly, reduction in wet season low flows are not anticipated to have a noticeable affect on water quality until Change Levels 3 and 4, which represent a considerable reduction of water in the river channel (almost half that available at present; PD). Conversely, increasing the amount of water available in summer (dry season low flows Change Level 3) is expected to have a positive impact on the system, as is a change in the distribution of flows in the dry sea-

Flow component	Change level	Indicator for level	Volume (Mm ³ a ⁻¹)	Ecosystem component					DRIFT Total score
				Geomorphology	Water Quality	Vegetation	Macroinverts	Fish	
Wet low flows	PD	0	94	0.00	0.00	0.00	0.00	0.00	0.00
	1	0	87.3	0.00	0.00	-0.21	-0.48	-0.29	-0.20
	2	0	72.5	0.00	0.00	-0.54	-1.14	-0.14	-0.36
	3	0	52.2	0.00	-0.10	-1.04	-2.24	-0.79	-0.83
	4	1	30.8	0.00	-0.30	-1.39	-2.72	-1.50	-1.18
Dry low flows	PD	0	18.4	0.00	0.00	0.00	0.00	0.00	0.00
	1	0	14.3	0.00	-0.90	-0.45	-0.51	-0.88	-0.55
	2	0	18.4	0.00	0.20	-0.29	0.17	0.13	0.04
	3	1	25.2	0.00	1.20	-0.05	1.02	1.63	0.76
Floods: Class 1	PD	0	42.9	0.00	0.00	0.00	0.00	0.00	0.00
	1	1	19.8	-0.43	-0.50	0.00	-1.49	-0.88	-0.66
	2	0	9.9	-0.43	-0.60	0.00	-1.63	-1.13	-0.76
	3	0	3.3	-0.43	-0.90	-0.40	-1.91	-2.38	-1.20
	4	0	0	-0.43	-0.90	-0.40	-1.98	-2.63	-1.27

son, without altering the volume of water made available to the system over that period (dry season low flows Change Level 2).

DRIFT category

The DRIFT category output for Site 1 (Fig. 4) was generated by calculating the maximised DRIFT integrity scores for different annual volumes of water, distributed in the least damaging manner, i.e., distributed over the year in the way most beneficial to the river ecosystem within the limits of the flow categories and change levels assessed. Thus each of the data points in Fig. 5 represents the resultant river condition (relative to the present-day condition) (y-axis) achieved through a stipulated flow regime comprising a specific volume of water (x-axis). The present-day condition of the river is represented by DRIFT integrity score of zero (Table 6 and Fig. 4). Thus, negative changes integrity (below 0) will result in a decline in condition relative to the present-day situation and positive changes (above 0) in an improvement in overall condition, relative to present day. The present-day flow regime (83% nMAR) is indicated by the circle in Fig. 4, but it is clear that (according to the result obtained) the present day distribution of flows is deemed to be less than optimal and that an improvement in condition could be achieved using the same volume of water distributed in a more beneficial manner. In this case, that would translate to a reinstatement of some of the dry season low flows, with a concomitant increase in wet season abstractions.

The solid horizontal line in Fig. 4 depicts the position at which river condition is expected to change from one category to the next, i.e., it estimates the position of the threshold between categories (D and E). For example, the PES of Site 1 is D, and is represented by an integrity score of 0 in the figure. Overall decline in condition, i.e., negative overall integrity score, would lead to an E (i.e., below the solid black line) category river.

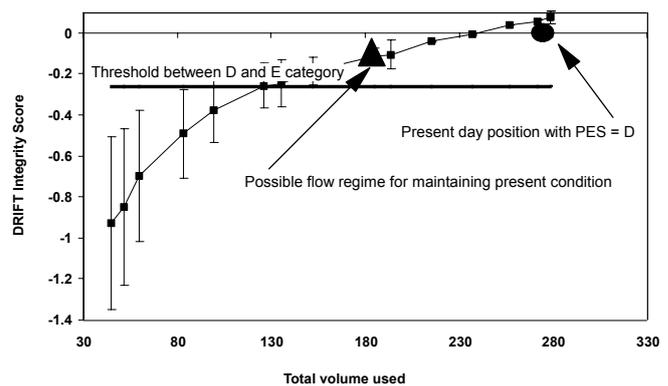


Figure 4
The DRIFT category output for EWR Site 1

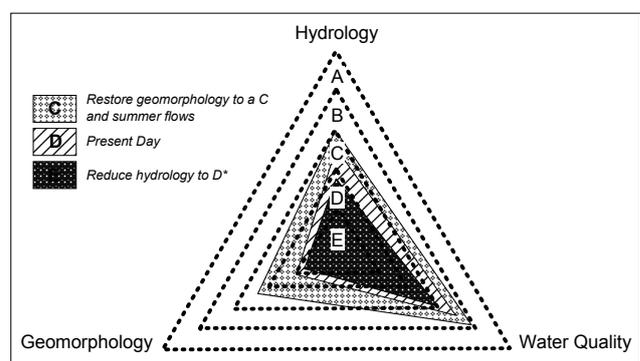


Figure 5
Radar diagram indicating how changes to one of the drivers (hydrology, water quality and geomorphology) of ecosystem condition can affect the overall ecological category of the river.
* would still require reinstatement of summer flows

TABLE 8
Recommended flow regime (water quantity) for maintaining ecological condition at Site 1 on the Olifants River. MCM = 10⁶ m³

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Vol (MCM)
nMAR = 331.5 MCM (estimated). pdMAR = 274.7													
Target condition category = D													
LOW FLOWS Q m ³ s ⁻¹	3.3	0.9	0.1	0.1	0.1	0.1	0.6	2.0	4.5	6.0	6.0	4.0	67
FLOOD CI 1: 9: m ³ s ⁻¹	1.5	3			1			3			1.5	3.3x10	
FLOOD CI 2: 20: m ³ s ⁻¹										1			6.5x1
FLOOD CI 3: 36: m ³ s ⁻¹										1			12.4x1
FLOOD CI 4: 85: m ³ s ⁻¹										-			-
Inter-annual floods	Estimated annual volume (1:5; 1:10 and 1:20 year floods)												45
MAINTENANCE	Annual												185.9
TOTAL (Volume)	Long-term average												128.57

For scenarios that shift and ecosystem away from natural, the assumption behind this are (Brown and Joubert, 2003):

- If at least 85% of the individual Integrity Ratings are ≥ -1, then the ecosystem will remain in the present category (e.g., Category D for Site 1 on the Olifants River)
- If at least 85% of the individual Integrity Ratings are ≥ -2, then the ecosystem will shift to the next lowest category (e.g., Category D (present) to Category E (predicted) for Site 1 on the Olifants River).

The improvement in condition was not deemed to be sufficient to result in improvement to one category up, i.e., a C-category, and thus none is shown. The ‘confidence limits’ shown around each data point indicate the range of uncertainty expressed by the specialists when returning their predictions.

According to the National Water Act (NWA, 1998) and DWAF policy, the Ecological Reserve should strive to maintain river systems in their current condition (or improve the condition if it is a category lower than D). Thus a first step in determining the Reserve for Site 1 would be to recommend a flow regime for maintaining the present condition, which in Fig. 4 could be selected at any point above the threshold between D and E category such as the point demarcated by the triangle.

Flow regime for maintaining the present day ecological condition

The annual summary for the flow regime (quantity only) recommended for maintaining present-day ecological condition is provided in Table 7. The annual volume requested for the environmental flow under the scenario shown in Table 7 is 185.9 MCM/a, i.e., 56% of nMAR, and 89 MCM/a less than present-day flow at the site. It should be noted that values given are an ESTIMATE of the flows required and that actual volumes depend on the climate. The following mix of change levels for the 10 components was selected:

- | | | |
|---|------------------------------|--|
| 1 | Wet season low flows | Level 3, i.e., capped at the 40% percentile of the present-day low-flow duration curve |
| 2 | Dry season low flows: | Level 2, i.e., INCREASED dry season low flows |
| 3 | Class 1 Intra-annual floods: | 10 Class I floods |
| 4 | Class 2 Intra-annual floods: | Present day |

- | | | |
|----|----------------------------------|-----------------------------------|
| 5 | Class 3 Intra-annual floods: | Present day |
| 6 | Class 4 Intra-annual floods: | Level 1, i.e., no Class IV floods |
| 7 | Inter-annual floods (1:2 year): | Present day |
| 8 | Inter-annual floods (1:5 year): | Present day |
| 9 | Inter-annual floods (1:10 year): | Present day |
| 10 | Inter-annual floods (1:20 year): | Present day. |

DRIFT SOLVER actually selected Change Level 3 for the dry season low flows, i.e., reinstate the dry season low flows to the 50th percentile of natural (see Table 2), thus highlighting the perceived importance of dry season low flows. However, the practicalities of reinstating the required flows are such that DRIFT’s output was adjusted to Level 2 change dry season low flow, viz. 0.001 minimum flows during the dry season, and Level 3 change wet season low flow. This results in a slightly higher DRIFT integrity score but was deemed to be a more realistic option. Flow cessation during the dry season (as occurs presently) is extremely damaging to the river as riffles, runs and (often) pools dry up, leaving no riverine habitat, and thus should not form part of any recommended flow regime for the river.

Some of the ten Class 1 floods recommended were required in the wet season, which makes up for some of the variability lost by reducing the wet season low flows.

The annual volume given in Table 8 is calculated as the volume of water required to meet the full requirements every year. However, this is often not the case as requested flows will only be provided if climatic events occur that would naturally have stimulated them, e.g., if there is no rainfall event in October, then the Class 1 flood requested for that month would not be ‘supplied’. This means that the actual volume of water ‘used’ by the river would usually be less than that requested in Table 8, as illustrated by the long-term average, which is calculated using the historical flow sequence, and only ‘releasing’ requirements in response to ‘natural’ cues. Additional detail on the requested flood requirements is given in Table 9. Similar breakdowns can be supplied for each of the data points in Fig. 5.

For a Reserve determination the information provided in Table 8 is typically augmented with so-called ‘rule or exceedance data’ (Tables 9 and 10), which facilitate operationalisation of the Reserve and, in particular, incorporation of the Reserve requirements into the appropriate water resources model so that the practicalities and/or impacts of providing such in a stressed catchment can be evaluated.

TABLE 9
Exceedance data for the complete flow regime shown in Table 4. MCM = 10⁶ m³

Month	Percentiles (data are in m ³ s ⁻¹)													MAR [MCM]
	1	5	10	20	30	40	50	60	70	80	90	95	99	
All	69.087	9.726	6.012	4.354	3.408	2.241	1.752	0.905	0.274	0.01	0.01	0.01	0.01	128.567
Jan	3.41	1.219	0.773	0.323	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.661
Feb	0.69	0.47	0.27	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.16
Mar	2.238	1.57	0.8	0.428	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.637
Apr	4.06	3.532	2.525	1.795	1.257	0.891	0.607	0.363	0.152	0.01	0.01	0.01	0.01	2.683
May	9.705	2.383	2.088	2.03	2.022	2.013	2.008	2	1.8	1.508	0.955	0.522	0.009	5.281
Jun	120.9	43.147	10.913	4.548	4.526	4.515	4.508	4.501	4.072	3.288	2.181	1.927	1.31	25.092
Jul	154.42	70.38	38.196	15.127	6.137	6.049	6.013	6.004	5.698	4.19	3.12	1.69	1.17	40.801
Aug	84.456	38.822	19.608	6.088	6.042	6.026	6.003	6	5.686	4.193	2.912	2.365	1.496	25.741
Sep	70.38	12.14	4.206	4.035	4.03	4.023	4.012	4	3.95	3.221	2.056	1.564	1.027	15.275
Oct	4.499	3.665	3.398	3.337	3.307	3.3	3.27	2.578	1.98	1.465	0.96	0.39	0.1	7.068
Nov	4.52	3.665	3.061	2.241	1.832	1.377	1.056	0.848	0.649	0.279	0.01	0.01	0.01	3.449
Dec	4.289	2.425	1.832	0.975	0.584	0.359	0.105	0.01	0.01	0.01	0.01	0.01	0.01	1.719

TABLE 10
Exceedance data for the low-flow component of the flow regime shown in Table 4. MCM = 10⁶ m³

Month	Percentiles (data are in m ³ s ⁻¹)													MAR [MCM]
	1	5	10	20	30	40	50	60	70	80	90	95	99	
Jan	3.411	3.291	1.901	0.747	0.144	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	14.902
Feb	3.41	1.18	0.76	0.31	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.625
Mar	0.69	0.47	0.27	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.16
Apr	2.01	1.57	0.74	0.39	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.611
May	2.134	2.084	2.053	2.027	2.016	2.012	2.006	2	1.7	1.38	0.85	0.37	0	4.562
Jun	4.716	4.638	4.55	4.528	4.518	4.513	4.506	4.5	4.01	3.22	2.18	1.87	1.31	10.285
Jul	6.32	6.214	6.096	6.049	6.024	6.011	6.007	6	5.62	4.19	3.12	1.69	1.17	14.165
Aug	6.095	6.087	6.066	6.038	6.021	6.003	6	6	5.16	3.94	2.82	2.23	1.39	13.891
Sep	4.625	4.056	4.041	4.032	4.027	4.02	4.01	4	3.93	3.15	2.03	1.48	0.96	9.315
Oct	3.411	3.401	3.371	3.33	3.304	3.3	3.26	2.47	1.97	1.39	0.85	0.39	0.1	6.699
Nov	4.52	3.47	2.67	2.07	1.54	1.28	0.99	0.8	0.59	0.18	0.01	0.01	0.01	3.213
Dec	2.72	2.05	1.43	0.78	0.51	0.33	0.08	0.01	0.01	0.01	0.01	0.01	0.01	1.208

Discussion

In today's world, where competition for resources, in particular water, is high, it is essential that methods and tools used to manage river ecosystems are able to maximise the use of information available to them. They also need to be able to provide quick and simple, but meaningful, inputs to decisions involving tradeoffs between different uses of water and the implications for sustainable development of water resources.

Once populated with predictions from the specialists, the DRIFT database can be used to explore numerous management-related questions in addition to providing a range of scenarios linking flow and river condition. The results presented here from Site 1 indicate there is some opportunity for further abstractions from the river while still maintaining a D-category river BUT only if some summer flows are reinstated. However, an examination of the eclassification assessments and the DRIFT category plot show that additional water could be made available at Site 1, provided restoration work was undertaken to address some of the non-flow related impacts on the river.

Eclassification involves the combination of several aspects of the river, e.g., hydrological, geomorphological, chemical and biological aspects, to arrive at a weighed average (e.g. Kleyn-

hans et al., 2005). This means that if one aspect is in poorer condition than the others, the overall condition score for the system will be reduced. Conversely, an aspect in good condition will help in supporting a higher score. At Site 1, although the overall condition of the river is a D-category, one of the 'drivers' of river condition, geomorphology, is in an E (Fig. 5) as a result of non-flow related impacts on the river system, such as bulldozing of the channel, cultivation of the alluvial floodplains and encroachment of alien and other riparian vegetation. This has two major management implications:

- If the hydrological regime is further restricted (i.e., beyond that indicated by DRIFT category), without undertaking any measures to restore other components of the system, this will result in the river falling to an E category (Fig. 5)
- If, however, river restoration work were undertaken to improve the condition of the geomorphology, this would improve the overall condition. This could mean that the present day starting point (DRIFT Integrity Score = 0) could be at a Category C. This would mean one of two things: either the flow regime shown in Table 8 would support a C-category river; or more water could be made available for abstraction, while still maintaining a D-category river as per the legal requirements.

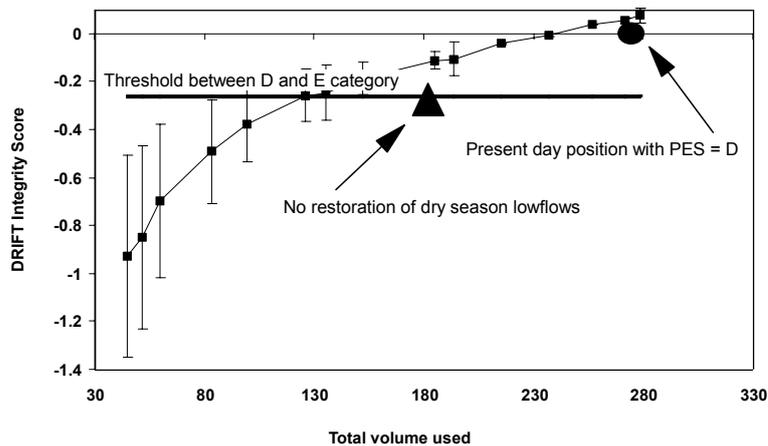


Figure 6
The DRIFT category output for EWR Site 1 showing the likely position if an additional 80 MCM of water were abstracted (from pdMAR) without reinstating the dry season low flows

This means that the actions of the land-owners adjacent to the river reach represented by Site 1 may themselves be restricting the amount of water they can legally abstract.

It is worth noting that, in comparison with other estimates for maintenance of a D-category river (Hughes and Münster, 2000; Brown and Louw, 2001; Brown et al., 2000), the 56% nMAR recommended here for Site 1 is considered high for the Western Cape, and could conceivably be reduced to *c.* 35% with the restoration of the other components so that they share the 'load' of supporting a D-category. Theoretically, this could make available an additional *c.* 70 MCM of water per annum (on average), which in the context of the value of water in the Olifants River valley is a substantial amount of water.

The requirement for reinstating summer flows also carries with it serious management implications. In the Western Cape because the growing season (summer) is the dry time of the year, any water abstracted in the wet season would have to be stored in off-channel storage dams for later use. This of course could have considerable financial implications for farmers in the area, and will need to be strongly motivated for if it is to receive the support of DWAF and water user associations (WUAs) in the area. Thus, using DRIFT category, we can also explore the implications for river condition of additional water abstraction without taking cognizance of the distribution of water. For instance, Fig. 6 shows the resultant position in terms of the river should 80 MCM of additional water be taken from the system without restoring any of the dry season low flows.

Basically, the results suggests that without restoring the dry season flows the river is likely to move from a D to an E-category, which would not meet the government-recommended minimum requirement for a D-category or higher (DWAf, 1999; 2002). Thus, if the NWA is to be implemented, the costs of wet season abstraction for dry season irrigation will need to be brought into business plans for farms in the area. In this instance though it is worth noting that the actual additional volume of water required in the dry season is very small (*c.* 0.01 MCM per annum) but the ecological value of that water is extremely high (*c.* 4 DRIFT Integrity points per MCM). Interestingly, adding more water (i.e., Change Level 3), while deemed beneficial, does not have as high a value attached to it: -0.76 Integrity points for a 6.8 MCM (i.e., *c.* 0.1 DRIFT Integrity points per MCM).

In conclusion, open and clear communication between the various parties is essential if feasible and equitable tradeoffs between water users are to be achieved. Such communication is enhanced and supported by effective and ideally objective information that will not only allow evaluation of a range

of possibilities but also highlight opportunities for innovative and creative interventions, where appropriate. It is hoped that, regardless of the eventual outcome of water user negotiations on the middle Olifants River, the sort of information presented here will contribute towards a more directed and open discussion on the current opportunities and constraints with respect to water availability in that part of the world.

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