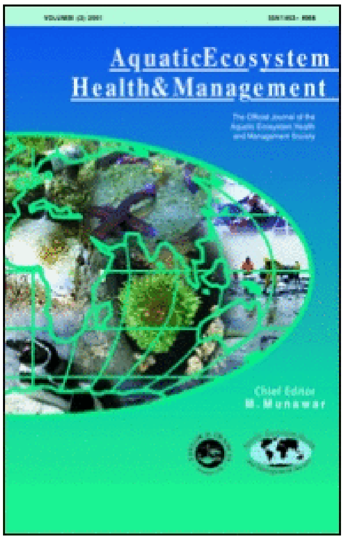

Aquatic Ecosystem Health & Management
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713393886

Instream flow assessments for regulated rivers in South Africa using the Building Block Methodology

J. King [a]; D. Louw [b]
[a] Freshwater Research Unit, Zoology Department, University of Cape Town, Rondebosch, South Africa
[b] Environment Studies, Department of Water Affairs and Forestry, Pretoria, South Africa

To cite this Article King, J. and Louw, D.'Instream flow assessments for regulated rivers in South Africa using the Building Block Methodology', Aquatic Ecosystem Health & Management, 1: 2, 109 — 124
To link to this Article: DOI: 10.1080/14634989808656909
URL: http://dx.doi.org/10.1080/14634989808656909

ELSEVIER

Aquatic Ecosystem Health and Management 1 (1998) 109–124

Aquatic Ecosystem Health & Management

Instream flow assessments for regulated rivers in South Africa using the Building Block Methodology

J. King[a,*], D. Louw[b]

[a]Freshwater Research Unit, Zoology Department, University of Cape Town, Rondebosch 7700, South Africa
[b]Environment Studies, Department of Water Affairs and Forestry, Private Bag X313, Pretoria 0001, South Africa

Abstract

The demand for water from South Africa's growing population is creating an ever-increasing pressure on the country's rivers. The urgent need to provide more water services often conflicts with the desire to maintain or improve the ecological condition of the rivers. To provide guidance on the sustainable use of a river's water-resources, the Building Block Methodology (BBM) has been developed for assessing the instream flow requirement for any river. Development has been done jointly over the last five years by the national Department of Water Affairs and Forestry (DWAF) and river scientists, and the accent is on identifying a complex of different magnitude flows for maintenance of entire river ecosystems. The BBM caters for the almost universal reality in South Africa of having rapidly to provide scientific guidance on such flows for a river in cases where biological data and understanding of the functioning of the river are limited. However, the methodology works equally well in data-rich situations. The BBM depends on available knowledge and expert opinion, gleaned from experienced river scientists in a structured workshop process. Limited new data of a specific nature are gathered to facilitate the process. Relevant data on the river are prepared in a way that workshop participants can easily understand and quickly begin to use. Scientists typically involved in the workshop, all with specific roles, are those with specialist knowledge of the river or similar rivers in terms of the fish, aquatic invertebrates, riparian vegetation, river importance, habitat integrity, fluvial geomorphology, local hydraulics, water chemistry and social dependence on the riverine ecosystem. Hydrological and hydraulic modelers provide data inputs and facilitate the workshop process by answering questions and producing additional data as requested. The workshop output, reached by consensus, is a quantitative description in space and time of a flow regime that should facilitate maintenance of the river ecosystem in some pre-determined desired future state. Information from a BBM workshop is used by DWAF in the Planning phase of a proposed water-resource development. Further development of the BBM, to extend it into the Design, Construction and Operation phases, has been initiated. This includes linking with a public participation process, input into design of the scheme, base-line studies of the river and subsequent monitoring to assess the efficacy of the recommended flow regime.

Keywords: River ecosystem; Water-resource development; Instream flow requirements; Structured workshop

1. Introduction

There is growing concern within South Africa regarding deterioration of the condition of the country's rivers. One of the major causes of this deterioration is the demand for water from a rapidly growing population, which has resulted in large-scale direct abstraction of water from rivers and an extensive programme of dam building. With this has come pressure on the scientific community to advise on flows for sustaining the river ecosystems.

The issue of instream flow requirements for river

* Corresponding author. Fax: + 27-21-6503301.

1463-4988/98/$19.00
PII: S1463-4988(98)00018-9

maintenance was first addressed nationally in 1987, through two major workshops (Ferrar, 1989; Bruwer, 1991). At that time, DWAF policy was shifting from one of the provision of water in response to demand, to one of holistic management of the nation's water resources. This policy shift was reflected in documents explaining established and new thinking on water quality management (DWAF, 1991), on water for the environment (DWAF, 1992), and on managing low flows to address water quality problems and for the benefit of rural, developing communities and riverine ecosystems (Water Research Comission, 1993). The White Paper on Water Supply and Sanitation Policy (DWAF, 1994) outlined a major dilemma facing modern South Africa. There was recognition that the riverine environment is not a user of water in competition with other users but is the base of the resource itself, and needs to be actively cared for if development is to be sustainable. There was also recognition that in this semi-arid country of about 45 million people, 12 million people do not have access to an adequate supply of potable water, and nearly 21 million lack basic sanitation. Inevitably, the urgent need to provide more water services will often be in conflict with the desire to maintain or improve the condition of the nation's rivers.

Scientific initiatives have paralleled evolving DWAF policy. Among these was an assessment by King and Tharme (1994) of the Instream Flow Incremental Methodology (IFIM) developed by the US Fish and Wildlife Service (Stalnaker et al., 1994); flow-related studies of two of the largest rivers flowing into the Kruger National Park (Chutter and Heath, 1993; O'Keeffe et al., 1996;Weeks, 1996); and the launch of the Kruger National Park Rivers Research Programme. This programme is a long-term research initiative and the most comprehensive attempt ever organized in this country to promote an understanding of river functioning and to develop ways of managing rivers and their waters in a sustainable way (O'Keeffe and Coetzee, 1996).

With growing experience, a need was recognized for a practical and rapid methodology for assessing instream flow requirements. King and Tharme (1994) had concluded that IFIM could not provide a comprehensive answer on this requirement in the way needed in South Africa. The traditional IFIM approach was hampered by the country's severe limitations in terms of data and time, and its use of target species seemed inadequate in a country where the accent was on management of the complete instream and riparian components of river ecosystems rather than of important aquatic species. IFIM's routine output falls short of being a comprehensive description of a recommended modified flow regime, as was needed for whole-river management. There were also scientific concerns with IFIM, such as the way the output of its model, PHABSIM II, is interpreted and used (King and Tharme, 1994).

These conclusions and DWAF's urgent need to provide extensive extra water services led to the development of a local methodology that could rapidly inform on instream flow requirements. Its basic concepts are simple. These are that some flows within the total flow regime of any river are more important than others for maintenance of that river ecosystem. These flows can be identified, and described in terms of their timing, duration and magnitude. Where a water-resource development is planned, the identified flows for the downstream river can be combined to define a recommended modified flow regime that is specific for the river. This information can be used as input at the planning stage of the development and, if the scheme proceeds, to guide design of an appropriate monitoring programme and eventual day-by-day flow management.

Because of time constraints, it was recognized from the outset that the methodology would have to rely to a large extent on best available knowledge and expert opinion. The core of the methodology has thus become, for any river, a workshop attended by senior river scientists representing specified fields of expertise. Such a workshop has been found to be the most successful way of gleaning information from the specialists, and of guiding them to a consensus decision. This decision takes the form of a recommended flow regime that it is felt should facilitate maintenance of the river in some pre-determined desired state. Water managers and engineering and social consultants linked to the proposed water development also participate in the workshop, contributing knowledge on hydrological, hydraulic and social aspects, and gaining knowledge on why particular flows are

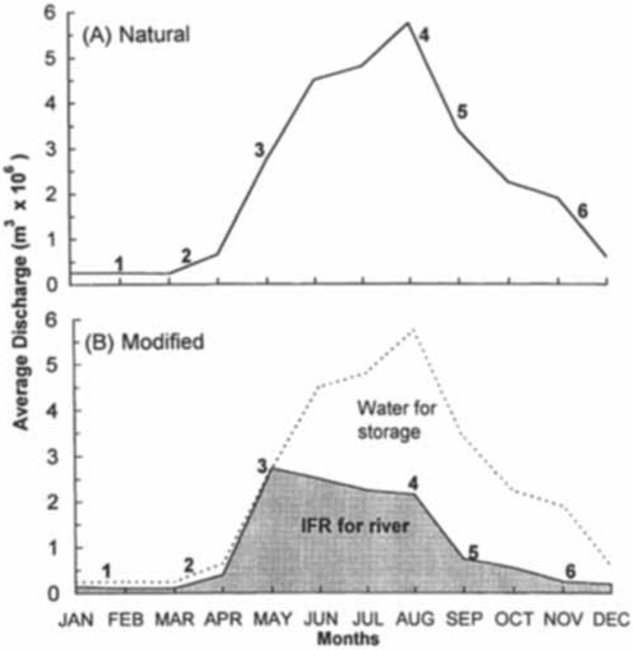

Fig. 1. Focusing thought on (a) perceived important features of a river's natural flow regime and (b) which of these should be retained in an IFR. For instance, features 1 and 6 may recognize the perenniality of the river (a) and the wish to retain this (b); features 2, 4 and 5 may recognize the wish to retain the fundamental difference between wet-season and dry-season low flows; and feature 3 may recognize the timing of the first major flood of the wet season and the wish to retain this.

important from the perspective of river functioning. Around the core activity of the workshop has developed a structured process for compiling the specified workshop material and for using the workshop output in further phases of the development. The complete process has been named the Building Block Methodology (BBM), and this paper describes its main features.

2. Overview of the BBM

2.1. Origin of the BBM

The BBM originated in two major South African workshops on instream flow assessments, where parts of it began evolving in the form of the ''Cape Town'' and ''Skukuza'' approaches (King and O'Keeffe, 1989; Bruwer, 1991). Parallel development by Australian colleagues led to a joint description of an approach (Arthington et al., 1992), at that time termed ''The Holistic Method'' and still called so in Australia. Further, separate development took place in South Africa during applications of the methodology, which was recognized through its final South African name of the Building Block Methodology (BBM). These workshop applications, each designed to produce a rapid first estimate of the instream flow requirement for a river targeted for water-resource development, were mostly convened by the Environment Studies sub-directorate of DWAF, and involved many of the country's most experienced river scientists.

Between 1991 and 1996, BBM workshops were held for the following rivers: the Lephalala, Berg, Olifants (Western Cape), Olifants (Transvaal), Letaba, Luvuvhu, Lomati, Koekedouw, Senqu (Lesotho), Mooi, Tugela, Mvoti, Sabie, Bivane and Logan (Australia). Documents of the information prepared for, and the proceedings of all these workshops, except that for the Logan, can be obtained from the second author. Documents for the Logan River workshop can be obtained from A. Arthington, Griffith University, Brisbane.

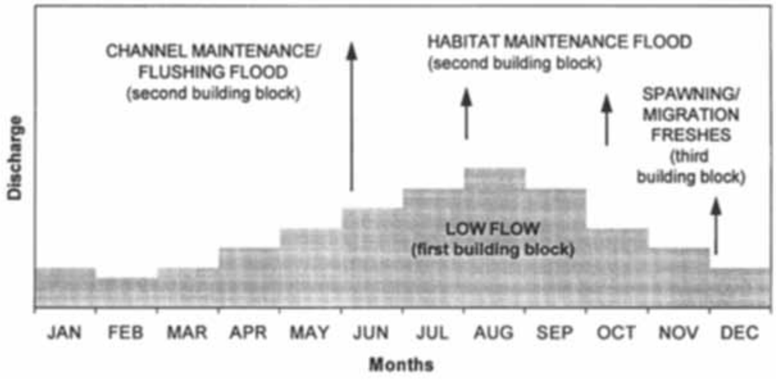

Fig. 2. An hypothetical IFR created using the Building Block Methodology.

2.2. Assumptions and character of the BBM

In the methodology the following assumptions are made.

- The biota associated with a river can cope with those low-flow conditions that naturally occur in it often, and may be reliant on higher-flow conditions that naturally occur in it at certain times. This assumption reflects the thinking that the flows that are a normal characteristic of a specific river, no matter how extreme, variable or unpredictable they may be, are ones to which the riverine species characteristic of that river are adapted and on which they may be reliant. However, flows that are not characteristic of that river will constitute an atypical disturbance to the riverine ecosystem and could fundamentally change its character.
- Identification of what are felt to be the most important components of the natural flow regime and their incorporation as part of the modified flow regime will facilitate maintenance of the natural biota and natural functioning of the river.
- Certain kinds of flow influence channel geomorphology more than others. Identification of such flows and their incorporation into the modified flow regime will aid maintenance of the natural channel structure and diversity of physical biotopes.

In total, the flows incorporated into the modified flow regime will constitute the instream flow requirement (IFR) for the river. As the minimum acceptable value will have been entered for each flow component incorporated, the IFR describes, in space and time, the minimum amount of water that it is felt will facilitate maintenance of the river at some pre-defined desired state.

The recommended flows are identified and their magnitudes, timing and duration decided upon in the BBM workshop. Initially, thought is focused on the characteristic features of the natural flow regime of the river. The most important of these are usually: degree of perenniality; magnitude of base flows in dry and wet seasons; magnitude, timing and duration of floods in the wet season; and small pulses of higher flow, or freshes, that occur in the drier months (Fig. 1). Attention is then given to which flow features are considered most important for maintaining or achieving the desired state of the river, and thus should not be eradicated during development of the river's water resources (Fig. 1). The described parts of each flow component are considered the building blocks that create the IFR, each being included because it is understood to perform a required ecological or geomorphological function (Fig. 2). The first building block, or low-flow component, defines the required perenniality or non-perenniality of the river, as well as the timing of wet and dry seasons. Subsequent building blocks add essential higher flows.

The process to prepare the necessary information, run the workshop and guide use of its output is described in Section 3.

Table 1
DWAF's engineering and environmental phases for a water-resource development, showing positions of the BBM activities. IEM = Integrated Environmental Management

Engineering/IEM phase	Engineering activity	Environmental activity	BBM Activities
Phase 1: Reconnaissance	Catchment/systems analysis	Issues assessment	Bulk water estimate; Habitat integrity assessment
Phase 2: Pre-feasibility	Possible development options identified	Impact assessment of each option (ROIP)	BBM workshop produces IFRs
Phase 3: Feasibility	Detailed investigation of selected option	Environmental impact assessment completed	Refinement of IFR; Yield analysis; Catchment water budget; Scenario meetings
Phase 4: Design	Engineering management plan	Environmental management plan	Base-line studies for monitoring programme
Phase 5: Construction	Implementation of engineering management plan	Implementation of environmental management plan	Base-line studies continue; Monitoring
Phase 6: Operation	Engineering audit	Environmental audit	Monitoring; Validation of IFR; Flows adjusted if necessary

2.3. Position of the BBM in DWAF's procedure for water-resource developments

The BBM workshops are linked to the main engineering phases followed by DWAF during a water-resource development (Table 1). From the engineering perspective, a situation assessment takes place during the Reconnaissance phase, often in the form of a catchment (drainage basin) study or a regional systems analysis; this identifies several possible options for the development. At the same time an assessment is done of environmental issues of concern. As part of the BBM, a bulk water estimate can be completed. This uses the results of all past BBM workshops to predict the likely IFR for the river in question. It is used mainly to highlight options where conflict between the IFR and potential offstream demand is likely to be high. Some options might be dropped at this stage.

The most probable of the remaining options from an engineering perspective are then investigated during the Pre-feasibility phase. This is paralleled by an environmental impact assessment of each option (ROIP – Afrikaans acronym of Relevant Environmental Impact Prognosis) (Louw, 1995), where some may be identified as environmentally unacceptable. The ROIPs usually also highlight the need to reduce potential impacts of any of the remaining options on the downstream river, by adherence to an agreed flow regime. The BBM workshop is used to define these flow regimes (the IFRs). These in turn aid determination of whether or not the proposed development is still environmentally acceptable and, if so, the preferred option(s).

In the Feasibility phase and beyond, the engineering activities are again matched by ones related to environmental and social issues (Louw, 1995). This link between engineering, social and environmental aspects of the proposed project is discussed further in Section 3.3, but for the next part of the paper only the flow-related activities linked to the BBM workshop are dealt with.

It should be noted that the BBM is restricted to stating the case for the riverine ecosystem, and does not directly take into account the requirements of offstream water users. Indirectly however, it acknowledges offstream users in three ways. It is recognized that water-resource development of some kind is almost always inevitable and so constructing an IFR that is the same as the original flow regime would usually be inappropriate. Direct dependence on the riverine ecosystem by, for instance, rural dwellers who gather food or medicines from the riparian vegetation, is also recognized by attempting to cater for this with appropriate flows. Lastly, the overall and hopefully consensus wishes of interested and affected parties are encompassed in a statement of desired state of the river, which guides the recommendation of flows at the BBM workshop. Direct demands for water from potential offstream users, such as irrigation boards or municipalities, are dealt with during Feasibility, where they are assessed together with the IFR for the river. Consideration of offstream demands, the desired state of the river, the IFR, and the consequences for the river of flow regimes other than the IFR, lead to a decision from DWAF on how the water will be allocated (see Section 3.3).

3. Sequence of activities in the BBM

The BBM has three main parts which encompass preparations for and running of the workshop, and follow-up activities that link the workshop with the engineering and planning concerns.

3.1. Part One of the BBM – preparation for the workshop

A structured set of activities has been designed to collect and display the best available information on the river for consideration by the workshop participants. The time available for completion of this part is usually not more than six months, and there is a small budget for collection of the new data needed for adherence to the workshop format. Co-ordination of the activities takes place early in the process through a BBM planning meeting. The topics dealt with, each by a senior specialist in the field, are explained below, and further detailed in Louw and King (1995).

- Identification of the study area (which part of the river would be directly affected by flow manipulations from the proposed development and thus should be dealt with in the workshop?). This could be a stretch of river less than one to several hundred km long, stretching downstream of the proposed development to, and perhaps beyond, its next major confluence.
- Determination of the present habitat integrity of the study area (what is the present condition of the river, in terms of available instream and riparian habitat for riverine plants and animals?). A low-altitude aerial survey along the river by helicopter is completed during low-flow conditions. A video film taken during the flight is used to analyze instream and riparian habitat integrity separately. Results are given per 5 km stretch of river. The method is described by Kleynhans (1996).
- Determination of the importance of the study area, at the local, regional, national and international level (how important is the river in terms of its economic, social and ecological importance?). Existing literature is used to provide the information for the analysis. The criteria used for economic importance are: current and projected water demand; the potential to meet this demand; current and projected economic activities; and the potential economic consequences of not meeting the demand. Those used for social importance are: aesthetic, scientific, recreational, historical, archaeological, cultural, educational and tourism values; accessibility; and subsistence and informal water utilization. Those used for ecological importance are: representativeness; biodiversity; uniqueness; important associated ecosystems; and ecological condition. A procedure is being developed to combine these varieties of information to produce scores for the river.
- Completion of a social survey of the study area (are there rural communities, or any other group(s) of people, directly dependent on the riverine ecosystem for their subsistence in terms of food, potable water, medicines, building material, grazing, or cultural and religious activities?). The information feeds into a determination of desired state (see below) from a community perspective. A process is being developed which uses Participatory Rural Appraisal as well as key informant interviews (S. Pollard, Wits Rural Facility; personal communication).
- Assessment of the geomorphological characteristics of the study area (which reaches of the study area are different in terms of geology, channel shape, substrata and diversity of physical biotopes?). Maps of catchment geology, topography, sediment production, land use, precipitation and runoff are used to identify likely linkages between the catchment and the changing character of the river. The results are combined with information gleaned from the helicopter survey and any aerial photos, to produce a description of the present geomorphological nature of the river, and identification of sensitive areas likely to change with future flow manipulation. The method is described by Rowntree and Wadeson (1998).
- Assessment of the past, present and required future

water chemistry of the study area (bearing in mind the desired state of the river, then from an ecosystem perspective and from that of humans directly dependent on the river, what chemical criteria should be adhered to in future?). This section is not well developed, although it is recognized that the IFR cannot be effective in terms of the desired state unless water quality conditions are also suitable. A structured input on water-chemistry modeling is required, as well as better knowledge of the ranges of tolerance of riverine species to chemical constituents. At present, future chemical problems are identified and a general description of their probable ecological consequences given. Dilution flows to solve water-quality problems are not seen as environmental flows, but as superimposed on the IFR.

- Completion of biological surveys at selected points throughout the study area, and of literature surveys, in order to update knowledge of species distributions and to determine longitudinal zonation of the river (which reaches of the study area are different in terms of the biota, and what is the characteristic biota of each? Are there any sites, species or communities of special importance?). In addition, any information on life history data, ranges of tolerance to environmental variables, or the water quantity or water quality requirements, of any of the species that occur in that river, will be summarized. Ecosystem components always reported on are the fish, the riparian plant communities and the aquatic invertebrates. Inputs on aquatic mammals, reptiles and amphibians, water birds and macrophytes can be included if available. Thus, the methodology can incorporate and use any relevant information on the river.
- Identification of BBM reaches and BBM sites within the study area. These sites will form the focus for most of the collection or creation and analyses of new data required specifically for the workshop (knowing the longitudinal zonation and special attributes of sections of the river, which reaches need an individual assessment of their instream flow requirement and which sites within the reaches will be used for those assessments?). Each site will have an IFR described for it. At a minimum, the fish, riparian and invertebrate ecologists, the geomorphologist, the hydraulic modeler, the survey team and the BBM specialist will be involved in the selection of the sites. One to five cross-sections, covering major physical biotopes, are surveyed in at each site, together with details of size of substrata and position of macrophyte and riparian species.
- Description of the virgin and present daily flow regime, simulated where necessary, for the selected sites along the river (what are the essential natural and present characteristics of the various BBM flow components at the selected sites?). Flow duration curves are also produced for each month, as well as statistics such as the return period of different magnitude floods.
- Analysis of stage-discharge curves, channel cross-section profiles, and other data on discharge-related links between hydraulics, channel morphology and biotopes for each surveyed cross-section at each site (what is the shape of the channel at each site, how do hydraulic conditions change with discharge and where does the water lie in the channel at those discharges? What physical biotopes are present and how are these likely to be affected by changes in discharge?).
- For ephemeral, sand-bed rivers, analysis of groundwater hydrology at each BBM site (what is the depth of the water table during times of no surface flow?). This is linked to information on the use of water holes in the riverbed by rural communities, stock or wildlife and, where available, on the root depth of riparian trees.
- Determination of the desired state for the study area. (In what environmental condition should the river be maintained, in the future?). Determination of a "working guide desired state" takes place through informal discussion with a range of relevant institutions, including DWAF, the Department of Environment Affairs and Tourism, and the Provincial Nature Conservation body. The objective is to identify a realistic desired state, which could be closer to or further from its pristine state than at present, or about the same. Updated knowledge on all the above topics is taken into consideration, as well as general catchment concerns about the condition of the river, and present and possible future land-use. This desired state guides deliberations at the BBM workshop,

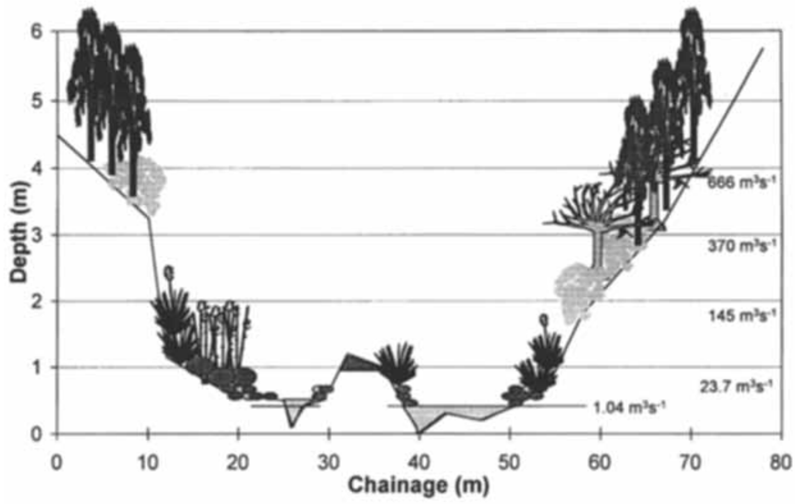

Fig. 3. Example of cross-sections used in the workshops to link ecological knowledge to water volumes.

where the IFR produced is designed to aid its achievement and maintenance. More intensive public participation regarding the desired state occurs later at the scenario meetings, in the light of the results of the hydrological yield analyses (see Section 3.3).

Part One culminates with production of a document for the workshop, which contains background information on the proposed water project and a chapter by each specialist.

3.2. Part Two of the BBM — the BBM workshop

Each workshop usually involves about 20 people, including water managers, engineers, hydrologists, hydraulic modelers and the scientists involved in Part One. Over a period of two to four days a chairperson and facilitators, experienced in the BBM, guide workshop participants to consensus on an IFR for the river. The workshop consists of four main sessions.

- Session 1: A visit to each BBM site. This usually occupies the first half of a day. The sites need to be as unmodified as possible, so that clues on required flows can be gleaned from, for instance, the position of riparian species and the degree of inundation of various biotopes. Finding such sites is often a problem. The specialists describe the sites from their perspectives, cross-section and stage-discharge data are provided and discussed, and a questionnaire on each site is completed by each participant to aid later discussions. The discharge at the time is given.
- Session 2: The exchange of information. This also takes about half a day. Short presentations are given of each paper in the workshop document. Participants are expected to be familiar with all the material presented, and the session is used to clarify uncertainties through questions.
- Session 3: Compilation of the IFR. Participants are allocated to groups, each containing at least one specialist from each of the relevant sciences and facilitated by a river scientist experienced in the BBM. The sites are allocated to the groups, and each group then focuses on the IFR, one site at a time.
- Identification and description of the IFR for each site is done in a specific way. After general discussion of the kind of flow regime that would facilitate maintenance of the desired state, required flows are identified month by month, starting with the low flows. For each month, each river specialist except the hydrologist and hydraulic modeler is asked to describe the low flow needed from his or her perspective, stating its significance as knowledge

Instream Flow Requirements

Site: 4 River: Sabie v. MAR: 549 $m^3 \times 10^6$ v. Median: 512 $m^3 \times 10^6$

IFR BUILDING BLOCKS		OCT	NOV	DEC	JAN	FEB		MAR	APR	MAY	JUN	JUL	AUG	SEP	VOL ($m^3 \times 10^6$)	% MAR	% MED
CAPPING of LOW FLOWS (m^3s^{-1})																	
Maintenance IFR	LOW FLOWS (m^3s^{-1})	3.0	4.0	5.0	6.0	9.0		8.0	7.0	6.0	5.2	4.5	4.0	3.4			
	1. FDC % (v)	100	99	99	100	94		96	98	98	98	98	98	98	170	29 (v)	33 (v)
	2. FDC % (p)	54	69	86	79	74		77	76	65	59	55	48	49		41 (p)	50 (p)
	FLOODS																
	1. Magnitude (m^3s^{-1})	6	8	30	12	50	130	12	10						32		
	2. Duration (d)	3	3	7	5	10	14	5	5								
	3. Return period (y)					1:1	1:3										
	4. FDC % (v)	75	75	18	78	25	7	80	90							5 (v)	6 (v)
	5. FDC % (p)	17	31	8	45	20	7	60	57							8 (p)	9 (p)
															Total (v)	34	39
															Total (p)	49	59
Drought IFR	LOW FLOWS (m^3s^{-1})	2.0	2.5	3.0	3.5	4.0		3.7	3.3	3.1	2.8	2.5	2.3	2.1			
	1. FDC (v)	100	100	100	100	100		100	100	100	100	100	100	100	91	15 (v)	18 (v)
	2. FDC (p)	72	87	92	97	95		95	95	93	90	87	81	77		22 (p)	27 (p)
	FLOODS														3	0.5 (v)	0.6 (v)
	1. Magnitude (m^3s^{-1})		5	6	7		8	7	6							0.7 (p)	0.9 (p)
	2. Duration (d)		3	3	3		3	3	3						Total (v)	15.5	18.6
															Total (p)	22.7	27.9

FDC = Flow Duration Curve v = virgin p = present

Figure 4. Example of an IFR table.

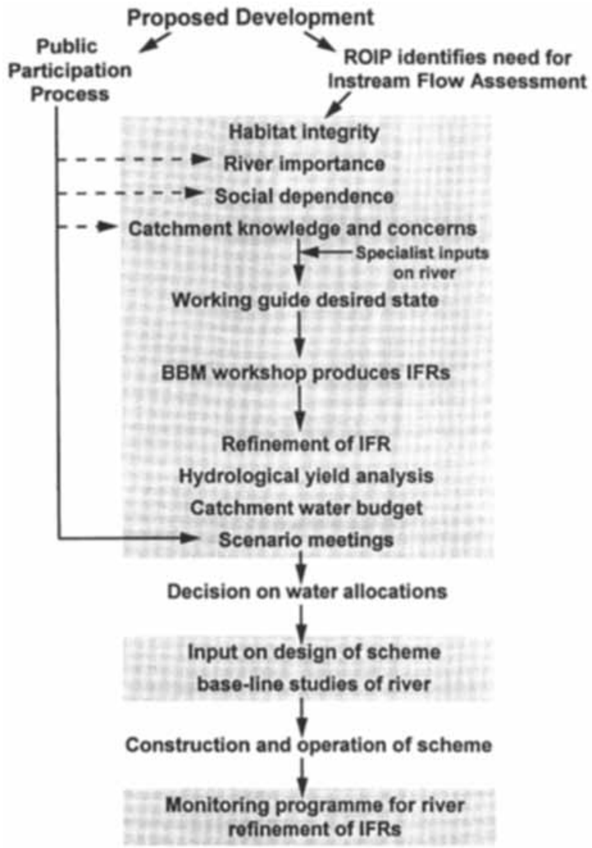

Fig. 5. The main BBM activities (shaded) and their links with the public participation process.

and data allow. Required higher flows are then described. Throughout the process, the hydraulic modeler will interpret the implications of flows described, in terms of depth, wetted perimeter, velocity, or areas inundated, using the surveyed cross-sections (Fig. 3) and plots of the various hydraulic relationships. These cross-sectional profiles and associated hydraulic plots are the vital communication link between ecologists and engineers, allowing intuitive or formal knowledge on species' flow requirements to be converted to discharge values of use to the planner. The details of the flows identified are added one by one to a blank IFR table of discharge (rows) versus calendar months (columns) (Fig. 4). Each addition is described in terms of three criteria: magnitude, timing and duration, with relevant motivation being supplied by each contributing specialist. Floods up to those with a three-year return period are described, and the continued occurrence of larger ones is checked separately during the whole-catchment analysis in Feasibility (see section 3.3). Usually, each entry remains within the limits of the virgin hydrograph, with the IFR thus being a skeleton of the virgin flow regime. Each entry is also identified as a volume of water and a percentile on its month's flow duration curve. Finally, the low-flow and high-flow components of the IFR are expressed as percentages of the mean annual runoff and the median annual runoff. When consensus is reached on the IFR for a site, and not before, the flows requested are compared to the virgin hydrograph for the site, as a check that realistic figures have been produced. Flows are also recommended that will stress the river ecosystem in drought years (IFR for drought – Fig. 4), for such stress and variability in flow is felt to be an essential feature of the country's rivers. Capping low flows may also be identified, to guide on upper limits for high-volume dam releases down the river. Plenary report-back sessions are convened when appropriate. Typically, it will take two groups 1.0–1.5 days to compile the IFR for four sites (two sites each).

- Session 4: The final session of the workshop contains five main activities spread over about half a day. The recommended flow regimes for all the IFR sites are compared to check there are no major mismatches in what is proposed. Statements are made regarding the environmental acceptability of the options considered in the workshop. Further necessary work is identified and usually falls into three categories: short-term research required in addressing serious uncertainties so that the IFR can be refined if necessary; medium-term research required to improve the BBM; and long-term fundamental research on subjects about which little is known. There is no funding automatically available for any of this work, but gradually an increasing amount of research is being triggered to fill data gaps revealed by application of the BBM. A post mortem of activities also takes place at the workshop, and any other statements that participants wish to make are noted and discussed if necessary. Reports on all these activities form part of the workshop report.

3.3. Part three of the BBM — linking environmental and engineering concerns

Part Three occurs after the BBM workshop, linking in at the end of DWAF's Pre-feasibility phase. It is the least developed part of the BBM, with the sequence and nature of necessary activities gradually being devised as the various water-resource projects for which the BBM has been applied evolve through Planning to Design, Construction and Operation (Fig. 5). A brief indication of the type of activities involved follows.

Hydrological yield analysis reveals, at the level of daily average flows, whether or not the IFR can be met without conflict with potential offstream users. Where conflict is likely, the possible consequences for the functioning of the river of flows that do not meet the IFR are interpreted by the workshop scientists. The process is aided by a new hydrological model designed to transform the rigid numbers of the IFR table into a daily hydrograph, through linkage to current catchment climate (Hughes, 1997). This, in turn, is now being linked to national water-resource models, through development of a conceptual IFR algorithm.

Additionally, the scope of the study broadens from an instream flow assessment for the study area, to a coarse flow-related assessment of the implications for the complete river system. Findings from all these activities are combined to produce for the public descriptions of the "working guide desired state", with its IFR. Two or three other possible states which would require less or more water than the IFR are also described. Each state is also linked to its probable social and economic consequences, such as the amount of irrigable land and the cost of water.

These are used in scenario meetings linked to the public participation process, in a way presently being developed. The process ends with a decision by DWAF on water allocations, which reveals whether or not the project will proceed and the IFR will be met. If the project proceeds with agreement to meet the IFR, key workshop participants make input to scheme design, and the planners use the IFR numbers to reserve water for the river during the planning process.

During late Feasibility or Design phases, it is planned that base-line studies will take place to record, in greater detail than is usually possible for the BBM workshop, pre-development conditions in the river. These studies will aid design of a monitoring programme, which will be used to assess adherence to the agreed desired state of the river. Adjustments to the IFR could then take place based on the monitoring results. Design of such monitoring programmes is already underway for some rivers.

If a decision is taken not to meet part or all of the IFR, the BBM specialists would be able to advise on the least damaging way of managing the remaining flows in the river and, again, design an appropriate monitoring programme.

4. Discussion

4.1. Summary analysis of the BBM

The BBM provides quantitative information on the instream flow requirement for a river, which can be used in the planning and design phases of a proposed water-resource development. The information is produced in a format required by water managers: volumes of water are described in space and time, and the significance of each is explained. Hydrological models will be used to transform the rigid format of the IFR table back to a variable flow regime linked to climate, for actual management of flows during operation of the scheme.

The BBM can be used where time and data are limited, but there is a clear lower limit to the amount of each needed for successful application of the methodology (Louw and King, 1995). At the very least, experienced freshwater ecologists, fluvial geomorphologists, low-flow hydraulic modelers and hydrologists with knowledge of that, or a similar, river should be involved, as should a social scientist with first-hand knowledge of the use made of the river by rural dwellers. Additionally, the workshop chairperson and facilitators should be experienced in the methodology, and the latter, at least, should be experienced river ecologists. The workshop process develops cross-disciplinary communication and understanding, so that all participants feel able to contribute, and in turn benefit by being able to talk of the process in their own work life with some understanding and conviction.

The BBM has been contributed to by most senior river scientists within the country through their participation in the workshops. Nevertheless, it is simple in concept, pragmatic, and easily understood by the non-scientist. The whole process, including that at the workshop, is transparent, and the documents produced are freely available to the public. A parallel public participation process links into the methodology in the early phases and after the workshop. These links have no formal structure yet.

The methodology does not have to be linked to a proposed water-resource development. Thus, it could also be used to define a less damaging flow regime for an impacted river, or for regional planning purposes to assess the volume of water still available for development within a region or catchment.

Analysis of the results of IFR workshops held to date has revealed a possible trend related to where the IFR site is situated in the catchment. It may be that for sites high in the catchment a greater percentage of the mean annual runoff at that point is being asked for in the IFR than for sites lower down with the same level of desired state. This had led to considerations that the methodology might be biased against big or ''mature'' rivers. It is now felt that the methodology is not so biased, but that the level of understanding of the ecological and geomorphological significance of large bodies of slowly moving water is poor and so suitable statements on IFRs for such reaches might not be made. For this and other reasons, some scientists would prefer a reactive approach, whereby response is made to the developer's plans. However, pro-active statements such as that made in the IFR are recommended in the guidelines on Integrated Environmental Management issued by the Department of Environment Affairs and Tourism (DEA, 1992). Also, reaction to a developer's plan implies an understanding of the importance of various components of a flow regime and so some version of the activities described above must presumably be gone through anyway. Certainly such knowledge would be needed by DWAF decision-makers, who require detailed motivation of why specific flow regimes are required, which the BBM produces.

Results of the IFR workshops also reveal a link between the percentage of the mean annual runoff (MAR) asked for as the IFR and desired state. Categories of present or desired state are presently under discussion in the country, ranging from pristine (category A), through various levels of modification (probably four to six categories in total). Each category is linked to a level of utilization of the river as a resource. IFRs for what could be category B rivers (largely unmodified) have encompassed as much as 70% of the MAR, whilst those for critically modified rivers have encompassed as little as 5% of the MAR. Critically modified rivers are ones where realistically there is little chance of enhancing the natural functioning of the river, perhaps because of present canalization or nose-to-tail weirs. IFRs for such rivers tend to represent a small percentage of the MAR because little motivation can be provided for most kinds of river-maintenance flows.

4.2. New developments

Development of the BBM has gained a momentum of its own, through many voluntary initiatives by the scientific community. In this way guidelines have been drawn up both for the way that hydrological data should be presented for an IFR workshop and for the social consultants to use in rural areas. Other initiatives have already been referred to.

The process related to desired state needs further development. At present there is no structured method for identifying who should decide the desired state for any river and how. Additionally, from a scientific perspective, the statements on desired state tend to be general and descriptive rather than specific and quantitative, because often little is known of the river. Success in achieving the desired state thus cannot easily be measured at the monitoring phase. Two kinds of initiatives are addressing these problems. Formal and informal catchment forums are appearing, where interested and affected parties work with DWAF to resolve common problems related to rivers. These could be used for gleaning general wisdom on the river and for more detailed determinations of desired state. Scientific research is also underway to develop a process whereby an objectives hierarchy can be produced by consensus for the management of any river (K. Rogers, University of the Witwatersrand, personal communication). This will allow, inter alia, achievable and measurable goals to be identified for use in monitoring programmes.

Changes in flow regimes almost always result in long-term changes in river ecosystems, but these cannot be addressed comprehensively in a flow assessment methodology with quite severe time and data constraints. However, the potential for long-term change is recognized in the BBM, and dealt with in two ways. Channel-flushing flows included in the IFR are designed to facilitate maintenance of channel form and biotope diversity. Additionally, post-construction monitoring of the river will guide adjustments to the IFR where necessary. It is recognized that a better understanding of the nature and function of channel-maintenance flows in semi-arid environments is needed. Research on long-term geomorphological change and linked ecosystem responses is one of the main topics in the Kruger National Park Rivers Research Programme (O'Keeffe and Coetzee, 1996).

The use of cross-sections and stage-discharge relationships to describe the hydraulic biotopes at each IFR site could be developed into a three-dimensional modeling approach. A technique for mapping hydraulic biotopes, presently being addressed in several different ways in South Africa, could be useful for informing on the loss and gain of physical habitat with changing discharge. Additionally, the kind of modeling facility offered by PHABSIM II in IFIM (Stalnaker et al., 1994) could further enhance this understanding, where sufficient species data are available.

A manual for the BBM is presently being written, with specialist chapters written by the senior scientists who participated in its development.

4.3. Validation of the BBM

Two features of the BBM workshop are seen as strong features by advisors on water law. First, IFRs for different sites along the river are produced by two independent groups and then compared. The groups tend to describe very similar flow regimes. Second, reference to the hydrological record after the flows have been agreed upon, acts as an independent check on whether or not the IFR is realistic in terms of the natural flow regime of the river.

A formal scientific assessment of the methodology occurred in August 1996, at a BBM workshop for the main river involved in the Kruger National Parks Rivers Research Programme. This workshop, for the Sabie River, brought together for the first time those developing the BBM with those carrying out long-term fundamental research on a specific river. It was felt that the BBM could not use the full range of available scientific data directly, but accessed most of this successfully through the knowledge of scientists at the workshop. The same kind of limitations as described above were highlighted; as noted, most of these are the subject of continuing development.

Validation of the IFR is planned through the monitoring programmes. Thought is being focused on variables to measure that will reveal flow-related change, and monitoring protocols have been written for some rivers but not yet implemented. It is recognized that successful monitoring will be hampered by the paucity of scientific data and understanding of the rivers. However the BBM, through its practical nature, clearly identifies knowledge gaps that affect the confidence of scientific recommendations. This has consistently led to funding of relevant research.

4.4. International context

In a review of international approaches to instream flow assessments, Tharme (1996) identifies four main kinds. These are: hydrological approaches based on historical flow records; hydraulic rating methods, where a surrogate for the biota, such as wetted perimeter or maximum depth, is generally assessed in relation to discharge; habitat rating methods, where hydraulic information linked to discharge is directly related to the requirements of target biota; and holistic approaches, in which all components or attributes of river ecosystems are addressed. The hydraulic rating methods were generally the precursors of the habitat rating methods, with these in turn including the precursors to IFIM.

Tharme (1996) suggests that, because of South Africa's urgent need to develop water resources in situations where ecosystem data are limited, a three-tier hierarchy of methodologies should be used. The broadest level of the hierarchy, for use for any river targeted for water-resource development, could be a desktop reconnaissance-level assessment using historical flow records. The Bulk Water Estimate part of the BBM would be positioned at this level, as would the Montana Method (Tennant, 1976), and Flow Duration Curve Analysis (Richardson, 1986; Gordon et al., 1992) which uses different percentiles from flow duration curves to identify flows for specific purposes and for different times of the year.

Following this, for all rivers targeted for water-resource development, Tharme suggests use of the intermediate level of the hierarchy. This could consist of the holistic approaches, such as the BBM, the Holistic Approach (Arthington et al., in press), and the Expert Panel Assessment Method (Thoms et al., 1996). The BBM is the best documented of these approaches. Holistic methodologies are pragmatic, robust, designed to address flow requirements at the ecosystem level and can be used where data and time are limited. The methodologies could be improved by including formal modeling of local hydraulics at the biotope level, more substantial habitat-discharge relationships, and more structured methods for assessing the requirement for flushing flows and flows for maintaining riparian vegetation.

IFIM (Stalnaker et al., 1994) is seen as too complex for routine use at the intermediate level, and is inappropriate for use for several types of river or hydrological regime (Tharme, 1996). Additionally, it is not designed to address flow requirements for ecosystem maintenance, and presents several problems of a scientific nature (Mathur et al., 1985; Shirvell, 1986; Scott and Shirvell, 1987; Gan, 1990a, b; King and Tharme, 1994). However, it has many valuable features, including the description of flow-related habitat requirements for species, and hydraulic models designed specifically to simulate flow conditions at the microhabitat level.

For this reason, Tharme suggests it, or another species-orientated approach, could be used at the highest level in the hierarchy for rivers of the highest conservation priority. She suggests that an holistic approach could be linked with some of the valued features in IFIM, to produce an assessment that has an ecosystem perspective as well as a focus on the flow requirements of important species. Advances in IFIM, such as the linkage of modeled temperature and water chemistry to ecological routines, should be considered; these are recognized current limitations in the BBM. Models presently being developed within the Kruger National Park Rivers Research Programme have similar features and could also be used. They are designed to predict changing abiotic (hydrology, geomorphology, chemistry, temperature) conditions within rivers and the responses of ecosystem (fish, riparian vegetation, aquatic invertebrates) components (O'Keeffe and Coetzee, 1996).

5. Conclusion

In the six years since its inception, the BBM has gained institutional acceptance and support from DWAF and local river scientists. Its results are now used by national and provincial conservation institutions as their negotiating point in later decision-making meetings on water allocations. For each of several proposed developments with IFR assessments which have already moved to the design phase, all or almost all of the IFR described for that river has been recommended by DWAF for approval by government. To aid the growing demand for instream flow assessments, detailed guidelines for practitioners will appear in the BBM manual now being written. A training course is planned.

Whilst helping guide management decisions on rivers, scientific activities related to the BBM have not been neglected. In addition to continuing development of the methodology, attention is being given to the assumptions made when using it. Early research is nearing completion on the ecological significance of all the major flow components recognized in the BBM (King, personal communication). Strong links with similar research within the Kruger National Park Rivers Research Programme and with the new National Aquatic Ecosystem Biomonitoring Programme are facilitating a countrywide network of co-operative research and research planning.

Acknowledgements

The following are major contributors toward the continuing development of the Building Block Methodology: Neels Kleynhans (Institute for Water Quality Studies, DWAF); Charel Bruwer (Environment Studies, DWAF); Nigel Kemper (Ninham Shand Consulting Engineers); Jay O'Keeffe and Denis Hughes (Institute for Water Research, Rhodes University); Bill Rowlston (Strategic Planning, DWAF); Kate Rowntree and Roy Wadeson (Geography Department, Rhodes University), Rebecca Tharme, Geordie Ractliffe and Cate Brown (Freshwater Research Unit, University of Cape Town), Sharon Pollard (Wits Rural Facility) and Greg Huggins (SWK Planning and Developing Resources). Angela Arthington (Griffith University, Brisbane) and her colleagues have also generously shared their thoughts and experience in their parallel development of the Holistic Approach. Many other South African scientists, engineers and planners have taken part in BBM workshops and their contributions are gratefully acknowledged; they are named in the workshop documents. Major funders of the exercise have been DWAF, through their funding of the workshops and the contributions of their specialists, and the Water Research Commission, through its funding of the first author and many of the other specialists actively involved in development of the BBM. The authors wish to thank the Water Research Commission and Director-General of DWAF for permission to publish this paper. Also, grateful thanks to two very helpful referees.

References

Arthington, A.L., King, J.M., O'Keeffe, J.H., Bunn, S.E., Day, J.A., Pusey, B.J., Bludhorn, D.R., & Tharme, R.E. (1992). Development of an holistic approach for assessing environmental water requirements of riverine ecosystems. In Pigram J.J. Hooper, B.P. (Eds.), *Water allocation for the environment — Proceedings of an International Seminar and Workshop Armidale, Australia* (pp. 69–76). Armidale, Australia: The Centre for Water Policy Research.

Arthington, A.L., Pusey, B.J., Bludhorn, D.R., Bunn, S.E., & King, J.M. (in press). Holistic Approach for assessing the environmental flow requirements of riverine ecosystems: origins, , theory, applications and new developments. Land and Water Resources Research and Development Corporation Report. Canberra.

Bruwer, C. (Ed.) (1991). Flow Requirements of Kruger National Park Rivers. Department of Water Affairs and Forestry, Technical Report TR149, Pretoria.

Chutter, F.M., Heath, R.G.M., 1993 Relationships between Low Flows and the River Fauna in the Letaba River. Water Research Commission report 293/1/93, Pretoria.

DEA (Department of Environment Affairs) (1992). Integrated Environmental Management Guideline Series, Vol. 1-6. Department of Environment Affairs and Tourism, Pretoria.

DWAF (Department of Water Affairs and Forestry) (1991). Water Quality Management Policies and Strategies in the RSA. Department of Water Affairs and Forestry, Pretoria.

DWAF (1992). Water for Managing the Natural Environment. Draft Policy Document, Department of Water Affairs and Forestry, Pretoria.

DWAF (1994). Water Supply and Sanitation. White Paper, Department of Water Affairs and Forestry, Pretoria.

Ferrar, A.A. (Ed.) (1989) Ecological Flow Requirements for South African Rivers. South African National Scientific Programmes Report Number 162, Council for Scientific and Industrial Research, Pretoria.

Gan, K. C., & McMahon, T. A. (1990). Variability of results from the use of PHABSIM in estimating habitat area. *Regulated Rivers*, *5*, 233–239.

Gan, K.C., & McMahon, T.A. (1990b). Comparison of two computer models for assessing environmental flow requirements. Centre for Environmental Applied Hydrology Report. University of Melbourne, Victoria, Australia.

Gordon, N.D., McMahon, T.A., & Finlayson, B.L. (1992). *Stream hydrology. An introduction for ecologists.* Chichester: Wiley.

Hughes, D.A., O'Keeffe, J.H. Smakhtin, V., & King, J. (1997). Development of an operating rule model to simulate time series of reservoir releases for instream flow requirements. Water SA.

King, J.M.,& O'Keeffe, J.H., 1989 Looking to the future – South Africa's requirements. In: Ferrar A.A. (Ed.), *Ecological flow requirements for South African rivers.* South African National Scientific Programmes Report Number 162, Council for Scientific and Industrial Research, Pretoria.

King, J.M., & Tharme, R.E. (1994). Assessment of the Instream Flow Incremental Methodology and initial development of alternative instream flow methodologies for South Africa. Water Research Commission report 295/1/94. Pretoria.

Kleynhans, C. J. (1996). A qualitative procedure for the assessment of the habitat integrity status of the Luvuvhu River (Limpopo system, South Africa). *Journal of Aquatic Ecosystem Health, 5*, 41–54.

Louw, M.D. (1995). The ROIP Manual. Department of Water Affairs and Forestry, Pretoria.

Louw, M.D., & King, J.M. (1995). Sequence of necessary actions for the determination of instream flow requirements in DWAF. Internal report, Department of Water Affairs and Forestry, Pretoria.

Mathur, D., Bason, W. H., Purdey Jr, E. J., & Silver, C. A. (1985). A critique of the instream flow incremental methodology. *Can. J. Fish. Aquat. Sci., 42*, 825–831.

O'Keeffe, J.H., Coetzee, Y. (1996). Status report on the Kruger National Parks Rivers Research Programme: a synthesis of results and assessment of progress to January 1996. Water Research Commission Report No 711/1/96. Pretoria.

O'Keeffe, J.H., Weeks, D.C., Fourie, A., & Davies, B.R., (1996). A pre-impoundment study of the Sabie-Sand river system, Mpumalanga with special reference to predicted impacts on the Kruger National Park. Vol. 3. The effects of proposed impoundments and management recommendations. Water Research Commission Report No 294/3/96. Pretoria.

Richardson, B.A. (1986). Evaluation of instream flow methodologies for freshwater fish in New South Wales. In: Campbell, I.C. (Ed.), *Stream protection: the management of rivers for instream uses*(pp. 143–167). Water Studies Centre: Chisholm Institute of Technology, Australia.

Rowntree, K.M., & Wadeson, R.A. (1998). A geomorphological framework for the assessment of instream flow requirements. *Aquatic Ecosystem Health and Management, 1*, 125–141.

Scott, D., & Shirvell, C. S. (1987). A critique of the instream flow incremental methodology and observations on flow determination in New Zealand. In J. F. Craig & J. B. Kemper (Eds.), *Regulated streams: advances in ecology*, New York : Plenum Press p.27-43.

Shirvell, C. S. (1986). Pitfalls of physical habitat simulation in the Instream Flow Incremental Methodology. *Can. Tech. Rep. Fish. Aquat. Sci., 1460*, 68.

Stalnaker, C.B., Lamb, B.L., Henriksen, J., Bovee, K.D., & Bartholow, J. (1994). The Instream Flow Incremental Methodology: a primer for IFIM. National Ecology Research Center, internal publication. Fort Collins, CO, USA.

Tennant, D. L. (1976). Instream flow regimes for fish, wildlife, recreation and related environmental resources. *Fisheries, 1(4)*, 6–10.

Tharme, R.E. (1996). Review of international methodologies for the quantification of the instream flow requirements of rivers. Dept. Water Affairs and Forestry. Pretoria.

Thoms, M.C., Sheldon, F., Roberts, J., Harris, J., & Hillman, T.J. (1996). Scientific panel assessment of environmental flows for the Barwon-Darling River. A report to the Technical Services Division of the New South Wales Department of Land and Water Conservation.

Water Research Commission (1993). Low-flow hydrology. Proceedings of workshop. Water Research Commission, Pretoria.

Weeks, D.C., O'Keeffe, J.H. Fourie, A. & Davies, B.R. (1996). A pre-impoundment study of the Sabie-Sand river system, Mpumalanga with special reference to predicted impacts on the Kruger National Park. Vol. 1. The ecological status of the Sabie-Sand river system. Water Research Commission Report No 294/1/96. Pretoria.