Contributing Paper

Definition and Implementation of Instream flows

Jackie King, Rebecca Tharme, and Cate Brown
Southern Waters, University of Cape Town, South Africa

Prepared for Thematic Review II.1:
Dams, ecosystem functions and environmental restoration

For further information see http://www.dams.org/
Disclaimer

This is a working paper of the World Commission on Dams - the report published herein was prepared for the Commission as part of its information gathering activity. The views, conclusions, and recommendations are not intended to represent the views of the Commission. The Commission's views, conclusions, and recommendations will be set forth in the Commission's own report.

World Commission on Dams
5th Floor, Hycastle House
58 Loop Street
PO Box 16002
Vlaeburg, Cape Town
8018, SOUTH AFRICA
Telephone: +27 21 426 4000
Fax: +27 21 426 0036
Email: info@dams.org
http://www.dams.org
Executive Summary

This report is an overview of the nature and use of environmental flow assessments (EFAs), and the context in which they are applied. In Chapter 1 a number of common questions about EFAs are answered. Chapter 2 and its appendix describe the methodologies for EFAs that have been developed world-wide, and the countries that use these are detailed in Chapter 3. The nature of EFAs and their position in different parts of the planning process are outlined in Chapter 4 and conditions for successful implementation are listed in Chapter 5.

An EFA is an assessment of how much of the original flow regime of a river should continue to flow down it in order to maintain specified valued features of the river ecosystem. The river ecosystem is seen as all components of the landscape directly linked to the river, and their life forms. It includes the source area, the channel from source to sea, riparian areas, the water in the channel and its physical and chemical nature, associated groundwater in channel and bank areas, wetlands either through surface or subsurface water, floodplains, the estuary, and any near-shore environment that is dependent on freshwater inputs. An EFA has two main areas of focus: 1) the different flow regimes that would maintain a river ecosystem at various levels of health (condition) and 2) the ways these different levels of river health will affect people. An environmental flow requirement (EFR) is the product of an EFA. It describes the flow regime required to achieve a specific river condition.

EFAs have increased in importance during the last three decades as it has become apparent that flow manipulations are causing serious degradation of river ecosystems. Costs in terms of soil erosion, land loss, loss of valued species, blooms of pest species, loss of fisheries, and much more have profound economic and social implications. As most of these consequences are far removed in space and time from the point of flow manipulation (often a dam) that caused them, they are usually externalised in water-resource plans and costing. The level of such costs is now sufficiently high, however, for EFAs to be increasingly accepted world-wide as an essential tool for water-resource management.

EFAs can be done at several levels of detail, from a simple statement of water depth to provide wetted habitat for a particular fish species, to a comprehensive description of a flow regime with intra-annual and inter-annual variability of low flows and floods in order to maintain complex river ecosystems. Confidence in the suitability of an EFA to meet its objective is linked to the level of investment in appropriate specialist inputs.

Methodologies for assessing EFRs have been developing since the 1950s, with the emphasis gradually changing from flows required to maintain single valued species (usually fish) to those required to maintain complete ecosystems. Today, many methodologies exist, with two main trends emerging for those at the most complex level. In many northern-hemisphere countries, particularly North America, complex modelling continues of the physical habitat provided by different flows and how these conditions meet species’ needs. In South Africa and Australia, with their semi-arid climes, the trend has been to address the condition of the complete river ecosystem using holistic methodologies. A recent development has been strengthening of the link between river condition and the social and economic implications, so that all the short-term and long-term, short-distance and long-distance, tangible and intangible costs of flow manipulations can be understood.

EFAs can be done at different levels of complexity at different phases of the planning process. A coarse-level EFA can be done as a desk-top exercise to aid national and regional planning of water resources at the catchment level. Holistic methodologies or those at a similar level of complexity contribute to a detailed understanding of the merits and drawbacks of a series of competing water-resource options, in terms of required river flow, water available for off-channel use, and the social and economic implications. Sophisticated habitat-modelling techniques provide additional detailed information on the flows required for specific valued river species or features, where the targeted rivers are of high conservation importance or are ones where the conflict over water is likely to be
Monitoring is a vital part of an EFA. Because of the variability, complexity, dynamism and unpredictability of river ecosystems, accurate predictions of flow-related changes to the river may not be possible. Dam releases for river maintenance, or other kinds of EFRs, thus should be monitored to ensure that the right river flows are being delivered, and that they are achieving their objective. Monitoring programmes should be designed to distinguish between flow-related or flow-unrelated river changes, as well as between short-term or long-term changes. Monitoring results should be assessed on a continuous basis, with a formal, independent assessment of results at regular intervals. There should be sufficient flexibility within the monitoring programme and the water-resource scheme it addresses, for either the EFR or the objective it should be achieving to be adjusted if the desired river condition is not being met.

Suggested time scales appropriate for EFAs linked to different levels of water-resource planning are: desk-top regional planning – a few days to weeks, depending on the size and complexity of the river system; reconnaissance investigations – a few weeks to one year; in-depth investigation of a few favoured options – two to five years; monitoring after dam commissioning – ten years or longer depending on the time-scale and severity of expected change, with scaling down of intensity after two years.

Features vital to the successful implementation of EFRs range from the political will and legislation to address flow-related river degradation, to the need to provide specialist EFA training in many fields of river science and related disciplines. The disciplines of hydrology, hydraulics, geomorphology, sedimentology, zoology, botany, water chemistry, sociology, anthropology, veterinary science, public health, public participation and resource economics are all directly relevant. Funding for EFAs should reflect that the ecological and social issues surrounding water-resource developments are as important as the engineering and direct economic costs and benefits. Transparent, widely-accepted decision-making processes should be in place to combine the results of an EFA with inputs from allied engineering, economic and social studies, and produce a decision on the water-resource development. Sufficient expertise and experience now exists to devise a good-practice framework that could aid future water-resource developments.
## Contents

1. **Introduction** ...................................................................................................................... 1
   1.1 Background to this Report ................................................................................................. 1
   1.2 What is an Environmental Flow Assessment? ................................................................. 2
   1.3 What is an environmental Flow Requirement? ............................................................... 3
   1.4 How are Environmental Flow Requirements Assessed? ................................................. 4
   1.5 Why have Environmental Flow Assessments Arisen as a Response to River Regulation? .. 4
   1.6 How many countries now implement Environmental Flow Assessments and since when? .. 5
   1.7 Has the Implementation of any Environmental Flow Assessments been successful? ....... 5

2. **Types of Environmental Flow Methodologies Applied Worldwide and Their Limitations** ................................................................................................................... 9
   2.1 The nature of environmental flow methodologies ............................................................... 9
   2.2 Hydrological index methodologies ................................................................................. 10
   2.3 Hydraulic rating methodologies .................................................................................... 10
   2.4 Habitat simulation methodologies .................................................................................. 10
   2.5 Holistic methodologies ............................................................................................... 10
   2.6 Methodologies geared towards specific ecosystem components .................................. 10
   2.7 General limitations of environmental flow methodologies ............................................ 11

3. **Global Trends in the Application and Advancement of Environmental Flow Methodologies** ..................................................................................................................... 14
   3.1 Methodologies in current use worldwide and a way forward ........................................... 14
   3.2 Environmental flow assessment in developing countries ............................................... 15
   3.3 Summary of future international trends in the development and application of environmental flow methodologies .......................................................... 15

   4.1 Key Phases of the Planning Process ................................................................................. 22
   4.2 Setting Objectives for Environmental Flow Assessments ............................................. 23
   4.3 Stakeholder Involvement in Environmental Flow Assessments .................................... 28
   4.4 The Nature and Role of Scenarios in Environmental Flow Assessments ....................... 28
   4.5 Environmental flow assessments and dam design .......................................................... 29
   4.6 Other considerations when implementing environmental flows .................................... 30
   4.7 Monitoring Environmental Flow Releases ...................................................................... 32
Acknowledgements

The Authors wish to extend their thanks to the following people for their contributions to this report:

- Johan van Rooyen, Head Project Planning, South African Department of Water Affairs and Forestry.
- Bill Harding.
- Justine Fowler.

This report was considerably improved through the many helpful and insightful suggestions from the reviewers of an earlier draft.
1. Introduction

1.1 Background to this Report

Southern Waters was approached by the World Commission on Dams (WCD) in April 1999 to author a report on the determination of instream flows for riverine ecosystems. It was envisaged that the report would address, *inter alia*: international methodologies and approaches for setting and monitoring instream flows; the design features of dams required to deliver adequate releases of water of acceptable quality to the downstream riverine environment; and the criteria and guidelines required to implement recommended practice.

This report addresses the above issues. In the limited time available, it was not possible to complete an exhaustive review of all environmental-flow assessment and allied activities. This was partly because it is an extensive and rapidly growing field of science, but also because much of what is happening is very new and not well documented in the international literature. Additionally, much of the work allied to flow assessments lies in the management milieu, where links with the scientific side are still evolving and are usually even more poorly documented. Thus, it was agreed with the WCD that an overview of the topic would be provided, with the option to add detail in a later follow-up report if required.

It is expected that the readers of this document will represent many disciplines, and range from those who seek a basic understanding of the nature of instream flows to those tasked with assessing and implementing them. We have aimed for a middle course through such an audience, highlighting and explaining areas of concern, but not detailing solutions for each such concern. Possible ways forward, however, are briefly considered at the end of the report (Section 5.10).

The scope of the document is worldwide, but with a bias towards Southern Hemisphere and developing countries. This reflects the fact that most future major water-resource developments will be in such areas, as are most of the people directly dependent for sustenance on well-functioning river systems.

The report consists of five chapters. The remainder of this first chapter answers some frequently asked questions about instream flows (referred to as environmental flows, see below). Chapter 2 provides a brief review of international methodologies for environmental flow assessments (EFAs). A detailed review of world literature on environmental flow methodologies is provided in Tharme (1996, 1997) and is in the process of being updated in Tharme (in prep.). In addition, Grows and Kotlash (1994), Dunbar *et al.* (1998), Pusey (1998), Arthington (1998a), Arthington and Zalucki (1998), Arthington *et al.* (1998a), and others, provide recent international reviews. We have endeavoured to highlight the main global trends in methodology development, availability and application to the end of 1998, as evidenced in the available international literature and through personal communications with freshwater scientists. Data requirements, and specific strengths, weaknesses and limitations of the environmental flow methodologies commonly available worldwide are briefly discussed in Appendix 1 and an indication of their present status of use is outlined in Chapter 3. Appendix 2 summarises some relevant kinds of information on EFAs available on the internet. International environmental legislation pertaining to environmental flows is not examined here, but legal implications of various methodologies are noted in Reiser *et al.* (1989a), Tharme (1996, in prep.), Estes (1996), Dunbar *et al.* (1998) and Arthington *et al.* (1998a). Chapter 4 addresses the positioning of EFAs within the planning process and the nature of the associated components, and Chapter 5 considers the prerequisites for implementation of EFAs.
1.2 What is an Environmental Flow Assessment?

An EFA is an assessment of how much of the original flow regime of a river should continue to flow down it in order to maintain specified valued features of the riverine ecosystem. It is usually linked to a proposed water-resource development or river rehabilitation scheme, probably because interest and funds are focussed on that specific river at that time, but may be done for any river at any time. It is used to assess how much water could be abstracted from a river without an unacceptable level of degradation of the riverine ecosystem or, for a highly modified river with much abstraction, how much of its original flow should be reinstated in order to rehabilitate the ecosystem to some required condition. The riverine ecosystem is seen as all components of the landscape that are directly linked to that river and all their life forms, including the source area, the channel from source to sea, riparian areas (i.e. the longitudinal riverside strips with vegetation types that are distinct from the general terrestrial landscape), the water in the channel and its physical and chemical nature, associated groundwater in channel and bank areas, wetlands linked either through surface or sub-surface water, floodplains, the estuary, and the near-shore marine ecosystem if this is clearly dependent on freshwater inputs.

Initially, in the late 1940s to 1970s, most such assessments had the narrow objective of defining the flow required to maintain suitable conditions for some valued aquatic species, such as a game fish. In the last decade, particularly in South Africa and Australia, the objectives have become more comprehensive, with holistic methodologies (Appendix 1) evolving that describe the flows required for maintenance at some defined condition of most or all components of the riverine ecosystem. Such methods typically address the biophysical components of the ecosystem. The most recent development is to further address the social and economic implications of these modified flow regimes, focusing particularly on the impacts on human communities using the targeted rivers for sustenance. The economic implications focus on the tangible costs of these social impacts as well as wider economic issues, and also may or may not include the intangible costs linked to manipulated flow regimes. Intangible costs could include such elements as the potential loss or gain of income from tourism, as well as the loss of naturalness, beauty or rare river features.

In this context of the wider river environment, neither of the historical terms instream flow assessment or biophysical flow assessment seem appropriate. The Australian term “environmental flow assessment” is more all encompassing, and is adopted in this report.

It should be noted that there is continuing debate on the role of people in EFAs. Virtually all humans affect river flow and river condition through their demands for water and their activities in the catchment. Some humans, however, have much closer ties to rivers, relying on them for daily sustenance, their livelihood and security. Millions of people worldwide harvest fish from rivers and floodplains (e.g., Bruton and Cooper, 1980; Malby 1986; Mountain 1990; Marsh and Seely 1992), collect wild vegetables along riverbanks (e.g., Pollard and Simanowitz 1997), or utilise riparian reeds and trees for medicine, firewood and buildings (e.g., Sechaba Consultants 1999). In a complex river ecosystem of myriad interdependent species, then, to what extent are people a component species of that ecosystem? Some believe that they are the fundamental component, serviced and supported by the rest of the ecosystem. Others argue that the river ecosystem has basic requirements of its own to maintain its own efficient and balanced functioning, and that those need to be understood and catered for before the complex overlay of human activities and aspirations is added. The developing trend in the nature of EFAs, as described above, reflects those views by recognising two main areas of focus: 1) the different flow regimes that would maintain a river ecosystem at various levels of health (condition); and 2) the ways those different levels of river health will affect people. The second area of focus can be subdivided in various ways: the people using the river for sustenance versus all other stakeholders (regional, national and international); or similarly but not necessarily quite the same, the issues that can be costed (loss of resources, cost of development) versus those that cannot (moral and ethical issues, legalities, intangible river values). Each area of focus is addressed by different kinds of
specialists. A comprehensive EFA will employ them all, combining their inputs in a structured and transparent way.

Issues related to the social impacts and resulting economic implications of large dams are addressed in other WCD thematic reviews: Group I reports (social issues) and Group III reports (economic and financial issues). Issues related to the biodiversity of, and interdependence of species in, aquatic ecosystems are addressed in another report in this thematic review.

1.3 What is an environmental Flow Requirement?

A flow assessment produces one or more descriptions of possible future flow regimes for a river, each linked to an objective which this achieves in terms of the condition or health of the riverine ecosystem. Each possible future flow regime is called the environmental flow requirement (EFR) for achieving that objective. For instance, the requirement may be stated as simply as “a water depth of at least 50 cm throughout the year, to provide adequate wetted habitat areas for fish species A”. Alternatively, it may be described with much greater complexity, detailing a comprehensive flow regime, with specified magnitudes, timing and duration of low flows and floods at both intra-annual and inter-annual scales of variability, all designed to maintain fundamental functioning of all ecosystem components (e.g., fish, riparian trees, water chemistry) at a specified level of condition.

Several allied terms are used to refer to managed river flows. The ‘maintenance’ EFR (King and Louw 1998) describes a comprehensive flow regime required to maintain all river ecosystem functions, including balanced and continual recruitment of aquatic and riparian species. The ‘drought’ EFR (King and Louw 1998) describes a drastically reduced flow regime for recognised drought years, to maintain species in a system without necessarily supporting recruitment. ‘Minimum flow’ is a very general term that has been used in several ways to represent an EFR. The concept of minimum flow originated in the western USA (see Chapter 3) as a streamflow standard to constrain the usage of offstream water during the low-flow season. Environmental flows were typically addressed in this way until about 1973. It was assumed that flows for the remainder of the year were adequate if they exceeded this minimum value, and that all higher flows were potentially available for offstream use. In other words, the original use of the term was as a simple baseflow recommendation, below which river flow should never fall. Most scientists are moving away from the term now, because of the implication of the EFR being a single figure. The term EFR, or similar, is gaining in popularity, because it implies a comprehensive flow regime, dynamic over time and with cognisance of the need for natural flow variability.

All of the above terms may, however, be viewed as kinds of instream or environmental flows, with more or less primary focus of the overall condition of the river. This contrasts with diversions of water away from the river channel, which constitute offstream uses. Downstream releases from a dam to manage reservoir levels flow down the river but have no focus on river maintenance, and so cannot be considered environmental flows. Releases for downstream abstraction (for irrigation, for instance) may have environmental flows nested in them, which is acceptable as long as the total flow is not initially too high or finally too depleted, to maintain the desired river condition.

The EFR may be a protective measure to ensure the continued condition of a river of high conservation importance; or a mitigatory measure put in place before construction of a new water-resource development to minimise the potential change in river condition; or a restorative measure designed to enhance the condition of a degraded river.

The linking of “condition” with “flow regime” indicates that rivers may be maintained in a range of conditions. Rivers maintained close to natural require more of their natural flow regime than those for which extensive modification is acceptable. Recognising this, the EFA and resulting EFR can be viewed and used from two perspectives. Firstly, the assessment can be made, and the flow
requirement stated, by any stakeholder group, in order to present in a negotiating forum their aspirations for the river. Secondly, as other stakeholders may have different aspirations and thus different EFRs for the river, compromises may be sought and agreed upon. In this situation, an agreed compromise solution reflects the eventual EFR and condition for the river. If no compromise can be agreed upon, a decision-maker would have to make a decision on the future river condition and associated flow regime (EFR), and be accountable for that decision.

The flow-related roles of various disciplines in a water-resource development or re-allocation process are still evolving. Good practice regarding their involvement would be:

- river scientists provide expert input on the expected condition of the river under a range of different flow conditions;
- water engineers provide expert input on possible kinds of flow-manipulation structures, or other ways of providing water, and the costs of constructing or altering, and operating these;
- social and anthropological consultants provide expert input on the social implications of possible options;
- other specialists may provide expert input on such aspects as land use or agricultural potential of the area of concern;
- economists provide expert input on the economic implications of all potential options, including the costs of compensation, mitigation, development of infrastructure and so on;
- a range of stakeholders provides input on their water requirements and aspirations for the river; their aspirations may reflect the need for rehabilitation of a degraded river;
- water managers identify the need for water-resource development or re-allocation, and manage the process of acquiring the above inputs; this role should preferably not be handed on to any of the parties with a vested interest in the water-resource development;
- government, in some form, makes the final decision on future river condition and water allocations for offstream users and the environment, and is accountable for that decision.

1.4 How are Environmental Flow Requirements Assessed?

This topic is dealt with in detail in Chapter 2, but essentially river scientists link valued features of the river to the amount of water required for their maintenance. Such valued features could include a Red Data Book fish species threatened with extinction, riparian forests, a harvestable resource, or sufficient water of a certain quality for a specific use such as washing clothes or watering livestock. The links can be made at various levels of complexity. At the simplest level, there may be a desk-based study of the past and present hydrological character of the river, linked to a review of any published literature on the riverine ecosystem. This could provide a coarse calculation of the kinds of flow needed in a generic way to support riverine biotas. At the highest level of complexity, there may be an intensive, interdisciplinary, long-term study, with extensive fieldwork, to enhance understanding of the nature and functioning of the river. These data would be used to provide clear, probably quantitative, descriptions of the consequences for all ecosystem components of different potential manipulations of the flow regime. Usually, the greater the investment in the fieldwork and other specialist inputs, the higher the confidence in the output.

1.5 Why have Environmental Flow Assessments Arisen as a Response to River Regulation?

Until about the mid-1900s, water pollution was commonly seen as the main man-made disturbance of rivers. Then new concerns were expressed, initially mainly in the USA, on river changes that seemed unrelated to pollution. These changes often concerned loss of game-fish species, and were voiced by a powerful fishing lobby. The changes in the riverine ecosystem were recognised as being due to loss of flow in rivers, and other kinds of flow manipulations, and the early methodologies for EFAs were then developed as means of guiding conservation agencies on flows required to protect valued fish species.
Since then, the impacts of changed flow regimes on rivers have been recognised worldwide, and an increasing number of countries are incorporating EFAs into their management of water resources. A great variety of river changes are now known to be linked to the manipulation of flow, although many impacts are so far removed in space or time from the original manipulation that cause and effect may be difficult to prove conclusively. As an example, a large dam(s) in the upper reaches of a river, with poor or no downstream releases, may cause one or more of the following: a decline in water quality (e.g., Murray-Darling River, www.altgreen.com.au); the erosion and collapse of river banks (e.g., Nile River, McCully 1996); loss of agricultural land (e.g., Senegal River; Brantly and Ramsey 1998); reduction in life of a downstream in-channel reservoir due to increased sediment loads from the eroding land and banks (e.g., South African dams, DWAF 1986); collapse of a river fishery (e.g., Zambezi River, Davies and Day 1998); salt water intrusion (e.g., Mozambique Rivers, Consultec 1998); loss of an important estuarine wetland or the decline of a marine fishery dependent on that estuary as a nursery area for juvenile fish (e.g., Senegal River; Bousso 1992). These are just a few of the possible direct impacts on the river, some or all of which bear direct or indirect socio-economic costs. Many of the impacts evolve slowly over years or even decades, and so are difficult to link directly to the dam. It is thus easy to externalise them when calculating the costs of the dam, so they remain largely unquantified. However, it is widely recognised that such hidden costs of water-resource developments have considerable long-term implications at a national level (McCully 1996).

1.6 How many countries now implement Environmental Flow Assessments and since when?

Some 25 countries (and groups of states), in all parts of the developed world implement EFAs (see Chapter 3, Table 3.1, for details). In addition, a few developing countries have begun implementation of EFAs or are assessing available techniques. In several instances, EFAs started in earnest in the 1970s and 1980s, although some parts of the world commenced environmental flow studies before that time. Many countries only started to address environmental flows in the 1990s (Chapters 2 and 3).

1.7 Has the Implementation of any Environmental Flow Assessments been successful?

Tharme and King (1998) illustrated that river scientists have a better understanding than other water-related disciplines on flows conducive to river-ecosystem maintenance. Worldwide, such scientists have produced a range of processes for assessing environmental flows that reflect their multidisciplinary understanding of rivers. Few would question that rivers with these flows in place would be in better condition than those that were simply exploited for water or as waste disposal facilities. Thus the process of environmental flow assessments can be pronounced successful.

Further success of EFAs can be judged at two other levels: the effect of EFAs on national attitudes, and the effect of a specific EFA on an individual river.

At the national level, there is no doubt that EFAs have been successful. A growing number of countries now recognise the need for EFAs, and are either searching for or developing suitable methodologies to do them or adopting tried and tested approaches from elsewhere. The Instream Flow Incremental Methodology (IFIM) has long enjoyed legal status in America and the US Federal Energy Regulation Commission requires that operators of many hydro-dams release environmental flows as a condition of renewing their dam licenses. In Spain, 10% of the mean annual runoff (MAR) of a river should be released from dams as environmental flows, which although probably insufficient to sustain the downstream environment, at least acknowledges the need for environmental flows (McCully 1996). The South African Building Block Methodology (BBM, King and Louw 1998) convinced lawyers re-writing the country’s Water Law that environmental flows could be calculated in a...
scientific and defensible way. This led to flows for maintenance of aquatic systems being recognised within the country’s new Water Law as one of only two sectors with a right to water, the other being basic human needs. Together, the water reserved by right for these two sectors has been named The Reserve and enjoys priority of use (SA Water Act of 1998). Specified environmental flows linked to specific projects are now beginning to appear in South African Government White Papers announcing those projects.

In the above countries and many others, the introduction of EFAs reflects, and is partly responsible for, a fundamental shift in attitudes concerning the exploitation of water resources. The accent has moved from complete and often over-utilisation of a water resource, to a more restrained, sustainable use linked with management of the donating aquatic system.

At the level of individual rivers the success of EFAs is less easy to track. Flow assessments may be linked to, *inter alia*, construction of a new dam, re-structuring of release patterns from an extant dam for river rehabilitation or other purposes, or control of run-of-river extractions to ensure some minimum flow in the river. Almost universally, the consequences of completing an EFA are poorly documented. There may be no formal records of whether or not the EFA was accepted and implemented or, if it was not, why not. For those that were implemented, documents of whether or not it achieved its objective in terms of river condition are rare. This is possibly a reflection of the response time of both bureaucratic and river processes, and of the lack of structured funding to record such consequences.

In the case of new dams, there may be a long time-span, years or even a decade or more, between an EFA and the construction of the dam. After more months or years of the construction phase, the dam is commissioned and an environmental flow may eventually be released down the river. Initially, there will be a confused picture of the health of the downstream river, as it will be recovering from the effects of construction. Once these initial impacts have diminished, short- to long-term adjustments to the change in the flow regime will gradually take place within the riverine ecosystem. The success of the EFA then is reflected in whether these adjustments are contained within the bounds of what was originally seen as an acceptable level of health for that river.

Measuring this success is difficult because change takes place over such long distances and time-spans, and also because changes that are not flow-related will also be occurring in the river. As an example, if a channel is becoming narrower, it could be because an upstream dam has harnessed scouring floods, or because alien trees have infested riverbanks and fallen into the water, or both. The former situation is flow-related. The latter may not initially be flow-related, but due to disturbance of the surrounding land, with this in turn allowing invasion into the riparian zone of shallow-rooted alien vegetation with poor bank-stabilising abilities. This condition could then evolve into flow-related degradation of the river as the invading trees would be more likely to collapse into the river during floods than would native riparian ones, thus further destabilising banks. Similarly, the objective to maintain a Red Data Book species within a river may fail despite a very favourable flow regime simply because catchment activities caused deterioration of water quality in the river beyond that which the species could tolerate. In these kinds of complex pictures – which are probably the norm - it is not easy to assess the success of an EFR.

In order to ensure the success of EFAs there is also a vital need to enhance our understanding of river structure and functioning. This is not yet at the stage where accurate, measurable predictions of river change can consistently be produced. The two main reasons are lack of investment in relevant research on rivers as living systems, and the fact that rivers are dynamic ecosystems, each one unique and needing individual management. Thus, even if the river change is seen as flow-related, it is often not clear what to measure to assess the success of an EFA or, except at a coarse level, how these variables might be expected to change as flow changes. A solution to this situation, known to be used in South Africa and Australia but presumably also elsewhere, is to accept that post-development
monitoring of river health is an integral part of the water-resource development. In this way, urgently needed developments can proceed guided by current, limited scientific knowledge, and new understanding can be acquired by post-development studies of the efficacy of the recommended flows in achieving the intended level of river condition. The combination of the newness of EFAs and the time required to assess their efficacy does, however, mean that formal records of successes and failures are rare.

Much the same comments are relevant if the EFA is linked to a proposed re-structuring of releases from an extant dam or intended to guide the control of run-of-river abstractions. However, if either of these is a once-off exercise, success of failure is much easier to assess. For instance, the 1996 controlled flood release (EFR) for the Colorado River downstream from Glen Canyon Dam (US Geological Survey web site data base) was carefully timed and monitored (Box 1). The objective was to re-establish more natural ecological conditions in the downstream reach within the Grand Canyon. Although data from the exercise are still being evaluated, it was successful for instance, in that sand beaches were re-established. By contrast, a single release to maintain the Kromme River estuary (Box 2) was less successful in achieving its objective, and led to a rethink on future releases.

Box 1: Case study: The Colorado River

Between 22 March 1996 and 7 April 1996 water was released from Hoover Dam on the Colorado River, Colorado USA, into the downstream river in an effort to restore some of the features of the downstream river that had been lost as a result of a reduction in flooding. For the first four days, a steady release of 8,000 cubic feet per second (cfs) was made; on March 26th the release was increased at a rate of 4,000 cfs per hour (cfs/h) until 45,000 cfs was achieved at about mid-day, March 27th. The release was maintained at that level for seven days. Between April 2nd and 7th, they were decreased in a three-step fashion to maximise sediment deposition in the river. A team, consisting of aquatic scientists, engineers and managers, closely monitored the releases and their effects on the riverine ecosystem. The results were hailed as a success, with the releases achieving many of their objectives. These included the following:

- at least 55 large, new beaches in the Grand Canyon were created;
- more than half of the existing canyon beaches increased in size due to the flood, 37% remained approximately the same size, and 10% lost small amounts of sediment;
- the flood caused scouring of clay and vegetation bases in backwaters and marshes, thus providing habitat for the humpback chub and other endangered fish species;
- in numerous backwater areas, the increased organic debris (primarily non-native plant species growing very close to the banks of the river), which would not occur on the natural river, was cleared by the floodwaters.

Box 2: Case study: Kromme River

The Kromme River estuary is situated in the Eastern Cape, South Africa. Under natural conditions, aperiodic floods scoured out the estuarine channels, and maintained the biotic diversity in the estuary. However, reservoirs in the Kromme River catchment currently dampen all the floods smaller that the 1:30 year events. The existing environmental flow allocation allows for a single release of 2mm$^3$/s$^{-1}$ per annum for maintenance of the Kromme estuary. As part of the SA Department of Water Affairs and Forestry’s investigations for the new Water Law in that country, a multi-disciplinary study was commissioned to evaluate the response of abiotic and biotic components in the Kromme estuary to an experimental release of the 2mm$^3$/s$^{-1}$ from Mpofu Reservoir.

The objective of the release was to create freshwater conditions throughout the upper half of the estuary. However, the release resulted in the water column becoming highly stratified for about two weeks after which the estuary returned to its marine-dominated pre-release condition. The release also provided no direct or indirect advantages to zooplankton or other biota in the estuary. No scouring took place. It was concluded that the release was too small to effect the desired changes, and that a regular baseflow combined with freshwater pulses into the estuary would be more beneficial to the estuary (Wooldridge and Callahan, in prep).

The success of EFRs designed to control run-of-river abstractions may also be relatively easy to assess. Although such EFRs may be used to ensure sufficient wetted habitat in a river, many are designed to ensure sufficient dilution capacity to control pollution levels (Petts, 1996). In these latter cases, the efficacy of the EFR may be seen immediately as reduced concentrations of pollutants in the river. However, many would not consider this as a true EFR, partly because there may be no overriding concern about the functioning of the whole riverine ecosystem, and partly because it is felt by many that environmental flows should not include water for diluting pollutants. Rather, it is felt that water-pollution issues should be addressed at source.

In summary, EFAs are successful as a process for addressing the sustainable use of the water-resources of rivers. They are also successful at the national legislative and management levels, where they have aided changes in policy and attitudes regarding the exploitation of water resources. At the level of specific rivers, more long-term effort and funds need to be dedicated to structured monitoring, recording and analysing of the efficacy of individual EFAs. Only then, with many case studies, can “regional principles for river flow management” (Arthington et al. 1998a) and a clear picture of the success of EFAs be expected to emerge. Paralleling this increasing understanding of rivers, there should be an evolving way of managing them that reflects their inherent vulnerability, dynamism and unpredictability. Their management thus should include a continual process of evaluation at time-scales that reflect the rapidity and slowness of different kinds of system changes. Because of this dynamism, continued vigilance is needed through time to ensure wise management of these sensitive systems.

Finally, even the most successful EFA will only partially mitigate against the effects of a dam on a river. The physical presence of a dam will, in itself, inevitably result in impacts on the downstream environment related to, *inter alia*, trapping of sediment, reduction in flow variability, and changes in the temperature and chemical composition of the water, with knock-on social and economic impacts. Nothing is gained at no cost – if flow regimes are manipulated the targeted rivers will change. Society decides, pro-actively or through neglect, the extent of that change. This topic is addressed further in WCD Thematic Reviews IV.5, which focuses on existing dams, and V, which focuses on new dams.
2. Types of Environmental Flow Methodologies Applied Worldwide and Their Limitations

2.1 The nature of environmental flow methodologies

Since the 1970s, there has been a progressive evolution of methodologies for assessing the EFRs of riverine ecosystems, from *ad hoc*, case-specific approaches through to well-described, formal methodologies with more broadscale application (Tharme 1996). Historically, and still today in many instances, the focus of environmental flow assessment was entirely on the maintenance of economically important freshwater (and hence associated estuarine and/or marine) fisheries. This is particularly true of methodologies developed and applied in North America, where flows for the spawning, maintenance, rearing and passage of target fish species, notably North American Salmonidae, often represent the primary instream flow objective(s). The inherent assumption in such assessments is that flows that aim to protect target fish populations, habitats and activities will ultimately ensure maintenance of the overall riverine ecosystem. More recently, however, the field has expanded to include assessments of the flow needs for other biota, like riverine invertebrates and water-dependent birds, and for biotic assemblage diversity (Tharme 1996, 1999 in prep.). Many assessments now also encompass aspects of ecosystem structure, such as channel form, riparian vegetation and floodplain wetlands, and to a lesser extent function. The latter includes ecosystem processes like nutrient cycling and primary production.

Over time, it has been recognised that the spatial scale at which EFAs need to be applied varies widely on a case-specific basis, and is dependent on project scope. For instance, the scale can range from a water-resource development scheme encompassing several sub-catchments within an internationally shared large river basin, that includes regulated and unregulated tributaries, to a flow restoration project for a single river reach. Different kinds of methodologies are obviously appropriate over such a wide range of spatial scales (Tharme 1996; Dunbar *et al.* 1998; Arthington *et al.* 1998a), as well as to cope with varying time frames, and constraints in terms of available data, finances, expertise and manpower. The methodologies may range, for example, from simple desktop approaches based on existing data, through to those including intensive field data collection and sophisticated, computer-based modelling software. The majority of approaches can be used for both regulated and unregulated rivers, although there are some methodologies that have been specifically developed for use in cases of river restoration (e.g., the Flow Restoration Methodology, Appendix 1, Section A1.4.1).

Four basic groups of methodology are widely recognised, namely hydrological index methodologies; hydraulic rating methodologies; habitat simulation methodologies and holistic methodologies. Each of these is discussed briefly below and is broadly compared with the other types of methodologies in Table 2.1. Methodologies that are most representative of each type are described at length in Appendix 1. In addition, the data and expertise requirements for each category of methodology are identified, as are their inherent strengths, weaknesses and limitations.

It is apparent from the literature that there is also an array of alternative approaches, often case-specific, that have been developed to deal with environmental flow issues (e.g., energy analysis, Williams and McKellar (1984); see Tharme (1996) for others). All types of methodology, for all applications, however, have in common a considerable reliance on professional judgement.
2.2 Hydrological index methodologies

Hydrological index methodologies rely primarily on historical flow records for making flow recommendations, with attention to ecological criteria in only a few instances. They are discussed in Appendix 1, Section A1.1. The remaining three types of methodology incorporate habitat-discharge relationships in various ways, and typically require some field data collection.

2.3 Hydraulic rating methodologies

Hydraulic-rating methodologies use the relationship between simple hydraulic variables and discharge to develop environmental flow recommendations. The hydraulic variables, such as wetted-perimeter or maximum depth, are usually measured along a single cross-section, across the target river section. These methodologies are further discussed in Appendix 1, Section A1.2.

2.4 Habitat simulation methodologies

Habitat simulation, also known as habitat modelling or rating methodologies also make use of hydraulic-discharge relationships, but provide more detailed analyses of the quantity and suitability of instream physical habitat available to target biota under different flow regimes, on the basis of integrated hydrological, hydraulic and biological response data (see Appendix 1, Section A1.3).

In most instances, hydraulic rating and habitat simulation methodologies have been designed for a specific activity, such as assessment of environmental flows for spawning, or for a suite of related activities like fish passage, spawning, flushing of spawning gravels and incubation.

2.5 Holistic methodologies

Holistic methodologies (sensu Tharme 1996) form a clearly separate group of methodologies that are geared towards addressing the flow requirements for an entire riverine ecosystem, and which may incorporate subroutines derived from methodologies of the first three types (see Section A1.4 of Appendix 1).

Holistic methodologies, in particular, are amenable to also identifying the flows linked to issues of human use and interest, such as maintenance of aesthetic quality, social dependence on the riverine ecosystem, economic costs and benefits of changing flow regimes, protection of features of cultural or scientific interest, and river-related recreation.

2.6 Methodologies geared towards specific ecosystem components

Although ecosystem components such as riparian vegetation, the channel and its sediments, wetlands, including floodplains and estuaries, groundwater, water quality, and wildlife can be considered within holistic methodologies, several alternative methods exist that have diverged from an emphasis on the relationship between physical habitat and flow, to explore other kinds of information suited to these particular components. Such approaches are outlined in Appendix 1, Sections A1.5-1.10.
2.7 General limitations of environmental flow methodologies

Many of the environmental flow methodologies that are in use nowadays are fairly robust and flexible, both in their data requirements and in their output. With appropriate modification, they can potentially be applied in different countries, for different types of rivers or for more than one species or ecosystem component. There are, however, a number of general limitations that should be considered in the selection of a particular methodology for use in an EFA. These include the degree to which the assumptions inherent in the methodology are met, and the extent of its transferability from its region of origin to the specific river basin where it is to be applied. Other limitations include the data and expertise requirements, degree of testing or validation of the methodology, whether or not it lends itself to routine application, access to documentation and training in its use.
### Table 2.1 Comparison of the four main types of environmental flow methodology presently used worldwide.

<table>
<thead>
<tr>
<th>TYPE</th>
<th>Riverine Ecosystem Component(s) Addressed</th>
<th>Data Needs</th>
<th>Expertise</th>
<th>Complexity</th>
<th>Resource Intensity (time, cost, technical capacity)</th>
<th>Resolution of output (EFR)</th>
<th>Flexibility</th>
<th>Appropriate Level of Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrological index</td>
<td>Whole ecosystem – non-specific</td>
<td>L (primarily desktop)</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>Reconnaissance level of water-resource developments, or as tool within other methodology</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Virgin/naturalised historical flow records</td>
<td></td>
<td>Hydrological</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Some use historical ecological data</td>
<td></td>
<td>Some ecological expertise</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>L</td>
<td></td>
<td>Hydrological</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Some ecological expertise</td>
<td></td>
<td>Some ecological expertise</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydraulic rating</td>
<td>Instream habitat for target biota</td>
<td>L-M (desktop, limited field)</td>
<td>L-M</td>
<td>Hydrological</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Historical flow records</td>
<td></td>
<td>Some hydraulic modelling</td>
<td></td>
<td></td>
<td></td>
<td>Water-resource developments where no or limited negotiation is involved</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Discharge-hydraulic variables, typically from single river cross-section</td>
<td></td>
<td>Some hydraulic modelling</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hydraulic variable(s) as surrogate for habitat-flow needs of biota</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>L-M (desktop, limited field)</td>
<td></td>
<td>Hydrological</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Historical flow records</td>
<td></td>
<td>Some hydraulic modelling</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Discharge-hydraulic variables, typically from single river cross-section</td>
<td></td>
<td>Some hydraulic modelling</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hydraulic variable(s) as surrogate for habitat-flow needs of biota</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Habitat simulation</td>
<td>Primarily instream habitat for target biota</td>
<td>M-H (desktop and field)</td>
<td>H</td>
<td>Hydrological</td>
<td>M-H</td>
<td>H</td>
<td>M</td>
<td>Water-resource developments, often largescale, involving rivers of</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Historical flow records</td>
<td></td>
<td>Advanced computer-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

This is a working paper of the World Commission on Dams. The report published herein was prepared for the Commission as part of its information-gathering activity. The views, conclusions, and recommendations are not intended to represent the views of the Commission.
<table>
<thead>
<tr>
<th>Holistic</th>
<th>M-H (desktop and field)</th>
<th>H</th>
<th>M-H</th>
<th>H</th>
<th>H</th>
<th>Water-resource developments, often largescale, involving rivers of high conservation and/or strategic importance, and/or with complex, negotiated offstream/instream tradeoffs; developing and developed countries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole ecosystem – all/most individual components</td>
<td></td>
<td>H</td>
<td>M-H</td>
<td>H</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td>Some consider: groundwater, wetlands, estuary, floodplain, social dependence on ecosystem, as well as instream and riparian components</td>
<td></td>
<td>H</td>
<td>M-H</td>
<td>H</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td>Some consider: channel form, sediment transport, water quality, riparian vegetation, wildlife</td>
<td>Many hydraulic variables – multiple cross-sections</td>
<td>Physical habitat suitability data for target species</td>
<td>based hydraulic and habitat modelling</td>
<td>Specialist ecological expertise on physical habitat-flow needs of target species</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3. Global Trends in the Application and Advancement of Environmental Flow Methodologies

3.1 Methodologies in current use worldwide and a way forward

Although by no means comprehensive, Table 3.1 indicates the environmental flow methodologies that are being applied around the world in both developed and developing countries. The most commonly used or preferred methodologies are noted where such information is available; it is noteworthy that many methodologies are poorly documented in the mainstream scientific literature. Intensive research into environmental flows is underway in North America, South Africa and Australia, while the field of flow assessments is expanding in Europe and parts of Asia particularly. However, vast areas of South and Central America, Asia and Africa do not appear to have begun any significant research or application in this field. Certainly, literature pertaining to environmental flows is markedly less available for these regions.

Realistically, the selection of an appropriate environmental flow methodology or methodologies for application in any individual country is likely to be case-specific and primarily limited by the availability of data on the river system of concern, and existing local constraints in terms of time, finances, expertise and logistical support.

For these reasons, in South Africa, Tharme (1997) suggested a three-tier hierarchy of environmental flow methodologies as an appropriate way forward; similar methodological hierarchies could be adopted elsewhere, preferably within good-practice frameworks.

The broadest level of the hierarchy should comprise reconnaissance-level assessments of EFRs. Historical flow record approaches are likely to be most appropriate at this coarse level of resolution, such as RVA (Table 2.1; Appendix 1, Section A1.1.2). However, all hydrological index methodologies require rigorous testing and comparison, and should be applied with caution for rivers with different flow regimes and channel morphologies from the ones on which they were developed.

Holistic methodologies are the most appropriate type, at present, for routine application at a second, intermediate level, especially as they range from moderately resource-intensive expert panel and benchmarking approaches to highly sophisticated methodologies like DRIFT and the Holistic Approach (Table 2.1; Appendix 1, Section A1.4.1).

At the third, most resource-intensive tier, for use with rivers of extremely high conservation priority and/or for which large-scale water-resource developments exist or are proposed, it is essential to apply the most rigorous and state-of-the-art methodology possible, coupled with long-term baseline data collection and monitoring, given local constraints. There are two options presently being adopted at this level, namely habitat simulation and advanced holistic methodologies, both of which show merit (see Section 3.3).

Typically, in Northern Hemisphere developed countries, in such high profile cases, habitat simulation methodologies like IFIM, or equivalents like CASIMIR, are currently most often used at this level of resolution (Tables 2.1 and 3.1; Appendix 1, Section A1.3). However, such approaches are often less appropriate than holistic methodologies from the perspective of Southern Hemisphere and developing countries, because of the latter’s focus on whole ecosystem and on social dependence on the ecosystem (Tables 2.1 and 3.1; Appendix 1, Section A1.4). Globally, in future, the inherent capacity of holistic methodologies to absorb advanced features, like hydraulic and habitat modelling tools, as
these become available, as well as their consideration of all major ecosystem components, is liable to render them increasingly suitable compared with habitat simulation approaches. At this level of application, in all instances, technical capacity will need to be developed, and users will require up-to-date formal training and ongoing guidance for the successful application of either advanced holistic or habitat simulation methodologies. However, holistic methodologies, such as the Building Block Methodology (BBM, Appendix A1.4.1) were specifically designed for situations where data, time and finances are scarce. The BBM can produce answers on EFRs in a few weeks or months. However, inevitably, the confidence in its outputs increases with investment in time and specialist inputs.

3.2 Environmental flow assessment in developing countries

In contrast with developed countries, in the vast majority of developing countries environmental flow assessment has received significantly little attention (Table 3.1). This applies even to semi-arid and arid parts of the world, where the availability, quality and sustainability of freshwater resources play a crucial role in socio-economic development. It is noteworthy that many countries for which EFAs do not seem to be a priority are undergoing intensive water-resource development, particularly in the form of river regulation by large dams (International Rivers Network database; McCully 1996). In some countries however, for example Indonesia, environmental flow work has been initiated, although it is still in its infancy. To a large extent, this is the result of the importation of expertise from other countries and collaborative research projects. In other countries, such as Mozambique, Argentina and Zimbabwe, interest in environmental water allocations appears to be growing (Tharme in prep.). South Africa represents one of the few developing countries that has invested considerable resources in environmental flow assessment, albeit only in the past ten years or so.

3.3 Summary of future international trends in the development and application of environmental flow methodologies

Several main trends are evident from an assessment of the environmental flow methodologies that have been used and are under development in various parts of the world.

There is a move towards hierarchical application of environmental flow methodologies, with at least two major tiers. The first tier is used at a basin-wide scoping, planning or reconnaissance level, and typically comprises methodologies based on historical flow records. An example of a two-tier application of such methodologies is provided for Alaska (Estes 1996), while South Africa (Tharme 1997; DWAF 1998) and Australia (Arthington et al. 1998a) advocate the use of such hydrological type methodologies at the simplest level of multiple-tier hierarchies. Presently, the application of hydrological index methodologies is widespread, and such approaches are likely to continue to be adopted in planning studies.

There are two main avenues of development of types of environmental flow methodology, beyond planning level. In Northern Hemisphere countries or in developing countries that receive technical support from the USA, there is ongoing advancement and application of habitat simulation methodologies, like IFIM. In most instances, these remain biased towards the assessment of the flow requirements of target fish species, despite the potential several of these methodologies have for ultimately assessing flows for other biota or ecosystem components. Hence, although the USA has historically been at the forefront of the field of EFAs, many of the methodologies developed there have limited application elsewhere in the world, where whole riverine ecosystems often need to be the focus of EFAs. The second branch of development, therefore, is in holistic methodologies, which are probably more appropriate in developing countries than North American approaches. The development and application of such methodologies is presently strongly centred in South Africa and Australia, and has not yet been explored at all in the Northern Hemisphere. Their location in these two countries may well be due to the following factors:
• the absence (South Africa) or low profile (Australia) of indigenous game fish and associated lobby groups;
• semi-arid regions, with highly variable flow regimes, requiring many large dams to increase assurance of water supply;
• the ability of such dams, and associated water transfer schemes, to transform the limnological character of the countries;
• an over-riding concern for whole-ecosystem health and management;
• an over-riding concern (South Africa) for the impacts of flow regulations on rural populations depending on the rivers for sustenance.

The vast majority of methodologies have been developed for rivers or have tended to narrowly focus on the instream features of riverine ecosystems. Currently, only a few approaches, mostly holistic ones, have any potential for modification for assessments of the water requirements of non-flowing aquatic systems, such as wetlands, including estuaries, and lakes. The absence of such methodologies represents a serious gap in the field of EFAs.

In conclusion, awareness of and access to the vast amount of expertise in the field of EFAs is limited for many countries, especially those in the developing world. Moreover, there appears to be insufficient international collaboration in the validation and refinement of existing techniques, in the development of new methodologies, and in the comparative testing of the degree of transferability of methodologies among river types, geographic regions and countries.

<table>
<thead>
<tr>
<th>Country</th>
<th>Environmental Flow Methodologies in use</th>
<th>Most widely used or preferred methodologies</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alaska</td>
<td>IFIM; Tennant Method, including modifications thereof on the basis of professional judgement and fish data; various hydrological indices, including QAM and FDCA; others (unspecified)</td>
<td>Tennant Method, or a modification thereof, is often routinely applied IFIM is used for special cases</td>
<td>Holistic methodologies do not appear to have been applied Estes (1996) provides further information</td>
</tr>
<tr>
<td>Australia</td>
<td>State-dependent wide array of methodologies, including Tennant Method; FDCA and various other hydrological indices; MTA; IFIM; RHYHABSIM; Holistic Approach; BBM, EPAM; SPAM, HAM; WAMP Benchmarking Method; FLOWRESM; professional judgement</td>
<td>RHYHABSIM, IFIM, and various holistic methodologies</td>
<td>Northern Territory and Australian Capital Territory do not appear to have employed any methodologies Methodologies used by each state are detailed in Growns and Kotlash (1994), Tharme (1996) and Dunbar et al. (1998)</td>
</tr>
<tr>
<td>Austria</td>
<td>Habitat modelling; other methods unspecified</td>
<td>Unspecified</td>
<td>A future aim is to combine IFIM with elements of holistic methodologies An holistic framework has been proposed, including: expert opinion; a list of criteria; a 7-point naturalness scale; elements of IFIM, including PHABSIM II A quantitative fish habitat modelling approach is under development</td>
</tr>
<tr>
<td>Britain and Wales</td>
<td>Various methodologies: IFIM; hydrological tools (e.g. Micro LOW FLOWS); hydrological indices (e.g. Q90); Environmentally Prescribed Flow Method; hybrid and alternative approaches, including the Scott Wilson Kirkpatrick Method, Wissey Method, Jones Peters Method, HABSCORE, RIVPACS, Biotopes/Functional Habitats methods; holistic methodologies, such as the River Babingley Method and expert panel approaches</td>
<td>Unspecified</td>
<td>A future aim is to combine IFIM/PHABSIM II analyses for target species with holistic elements Holistic methodologies, specifically the Holistic Approach, BBM and EPAM are recommended for further investigation The Tennant Method could be modified to develop more multidisciplinary stream ecotype-specific methods, with extensive work and use of other methods in its</td>
</tr>
</tbody>
</table>

This is a working paper of the World Commission on Dams. The report published herein was prepared for the Commission as part of its information-gathering activity. The views, conclusions, and recommendations are not intended to represent the views of the Commission.
<table>
<thead>
<tr>
<th>Country</th>
<th>Environmental Flow Methodologies in use</th>
<th>Most widely used or preferred methodologies</th>
<th>Comments</th>
</tr>
</thead>
</table>
| Canada           | Various methodologies: IFIM, including Biologically Significant Periods/Fish Rule Curve Approach; Tennant Method, including set percentages of Average Annual Flow (e.g. 25% MAF Method) and Tessman Modification; Wetted Perimeter Method; correlation of fish year class to spawning flow; WSP model; water quality models: 7Q10 Method; Median Monthly Flow Method; FDCA (e.g. 90<sup>th</sup> percentile); HABIOSIM | IFIM used in all of the 7 provinces that apply instream flow methodologies, and Tennant Method or a modification thereof often routinely applied | Northwest Territories does not employ any methodologies  
Holistic methodologies do not appear to have been applied  
Methodologies used by each province are detailed in Reiser et al. (1989a), Tharme (1996) and Dunbar et al. (1998) |
<p>| Czech Republic   | IFIM                                                                                                   | IFIM                                                                                                        | IFIM-based procedures are under development                                                                                                                                                          |
| Denmark          | Hydrological methods                                                                                   | Median Minimum Method                                                                                      | It is recognised that other low flow hydrological indices are more sophisticated                                                                                                                      |
| Finland          | EVHA and detailed approaches based on physical habitat for fish species                                 | Unspecified                                                                                                  | There are no standard methods                                                                                                                                                                         |
| France           | Habitat simulation methodologies, such as EVHA, AGIRE, ENSAT Toulouse Method                           | EVHA: applied in about 70 cases                                                                             | Ongoing research is taking place into continuous fish population modelling within an IFIM framework                                                                                  |</p>
<table>
<thead>
<tr>
<th>Country</th>
<th>Environmental Flow Methodologies in use</th>
<th>Most widely used or preferred methodologies</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>- Hydrological indices, case-specific expert opinion, and a habitat simulation methodology, CASIMIR</td>
<td>- Mean of minimum daily flows for each year, or a fraction thereof, and expert opinion have been used to assess 100 flows</td>
<td>- CASIMIR has been applied for benthic invertebrates as a benthic shear stress model, and new models are under development for fish habitat and riparian zone plant communities</td>
</tr>
<tr>
<td>Indonesia</td>
<td>- IFIM</td>
<td>- First studies in progress</td>
<td>None</td>
</tr>
<tr>
<td>Italy</td>
<td>- Hydrological indices, including FDCA, daily and annual mean flows; IFIM; Tennant Method; Wetted Perimeter Method; Singh Method, and Orth and Leonard Method for regionalization; hybrid approach using regionalization of Q₉₅ on the basis of geology and catchment area</td>
<td>- Hydrological indices</td>
<td>Relationships between fisheries standing crop and environmental variables are under development</td>
</tr>
<tr>
<td>Japan</td>
<td>- IFIM, including multidimensional hydraulic modelling and multivariate habitat suitability criteria; “Normality” Preservation Flow; Obligated Conservation Flow Release</td>
<td>- Normality PF at some check points and OCF at power dams (both are minimum flow settings)</td>
<td>Re-evaluation using various methods has been underway since the amendment of the River Act 1997.</td>
</tr>
<tr>
<td>Lesotho</td>
<td>- DRIFT</td>
<td>- DRIFT</td>
<td>None</td>
</tr>
<tr>
<td>Netherlands</td>
<td>- Hydrological model, PAWN; alternative approaches, including HEP, a general habitat suitability scoring model, an ecotope classification (ECLAS), a physical habitat model (MORRES), a habitat suitability model (EKOS), and a policy and alternatives analysis model (AMOeba); HSI type model; hybrid methodologies based on habitat simulation, such as a GIS-based microhabitat model</td>
<td>- Unspecified</td>
<td>None</td>
</tr>
<tr>
<td>New Zealand</td>
<td>- Various hydrological, hydraulic and habitat simulation methodologies (unspecified); IFIM; RHYHABSIM; Orth and Leonard Method for regionalization, and other habitat regionalization techniques</td>
<td>- RHYHABSIM: used on 25 rivers; IFIM</td>
<td>None</td>
</tr>
<tr>
<td>Norway</td>
<td>- Hybrid approaches based on habitat modelling, specifically RSS which includes the HEC-2 program, BIORIV I/II and HABITAT habitat models, and temperature</td>
<td>- RSS and microhabitat modelling</td>
<td>None</td>
</tr>
<tr>
<td>Country</td>
<td>Instream flow methodologies in use</td>
<td>Most widely used for preferred methodologies</td>
<td>Comments</td>
</tr>
<tr>
<td>-------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-----------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Portugal</td>
<td>2.5%-5% AAF Method; Tennant Method, and modifications; Texas Method; Wetted Perimeter Method; IFIM</td>
<td>2.5%-5% AAF Method; IFIM</td>
<td>The 2.5%-5% AAF Method is routinely applied.</td>
</tr>
<tr>
<td>South Africa</td>
<td>Various hydrological indices, including FDCA; BWE; IFIM; BBM; DRIFT; MTA; some alternative approaches, e.g. River Conservation Status Model; geomorphological change-flow and riparian vegetation-flow models, Biotopes Approach; multivariate statistical techniques for hydrological and ecological regionalization; hierarchical suite of methodologies for the determination of the Ecological Reserve: Planning Estimate and extended version; Preliminary Reserve Methodology; Comprehensive Reserve Methodology</td>
<td>BBM, DRIFT; and range of methodologies for Reserve determination</td>
<td>The Biotopes Approach is recommended for further investigation, including biotope-level modelling within habitat simulation methodologies. Habitat and water quality modelling techniques are recommended for incorporation into the BBM, and research into linking water quality and quantity is underway. Research is taking place into the identification of ecologically-relevant hydrological indices. An IFR Operating Rule Model and a link model to reservoir operation have been developed.</td>
</tr>
<tr>
<td>Spain</td>
<td>Alternative methodologies, including an approach similar to IFIM with holistic elements and historical flow series, multivariate biomass models, Cubillo’s Madrid Method, and the Basque Method; Modified Tennant Method; Texas Method; IFIM; hydrological indices, specifically the Basic Flow Method; 10% MAR Method</td>
<td>10% MAR Method</td>
<td>A future aim is to combine IFIM with elements of holistic methodologies. Dunbar et al. (1998) provides further information.</td>
</tr>
<tr>
<td>Sweden</td>
<td>RSS</td>
<td>RSS</td>
<td>Only two instream flow studies have been completed.</td>
</tr>
<tr>
<td>Switzerland</td>
<td>Hydrological indices (unspecified); expert opinion</td>
<td>Unspecified</td>
<td>A future aim is to combine IFIM with elements of holistic methodologies, especially incorporating floodplain ecological data</td>
</tr>
<tr>
<td>USA</td>
<td>State-dependent, extremely wide array of methodologies covering hydrology-based, hydraulic rating, habitat simulation, and various hybrid or alternative approaches; IFIM: used in 30 states and cited in majority of cases as the preferred methodology; Holistic methodologies have not been formally applied; Methodologies used by each state are</td>
<td>Holistic methodologies have not been formally applied Methodologies used by each state are</td>
<td></td>
</tr>
</tbody>
</table>
### Instream flow methodologies in use

<table>
<thead>
<tr>
<th>Country</th>
<th>Instream flow methodologies in use</th>
<th>Most widely used for preferred methodologies</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>some methods unspecified</td>
<td>requisite methodology in 3 states</td>
<td>detailed in Reiser <em>et al.</em> (1989a)</td>
</tr>
<tr>
<td></td>
<td>✓ 17 commonly used methodologies: IFIM; Tennant Method, with various regional adjustments accounting for local hydrological regimes and further modifications, e.g. Bayha Modification and Tessman Modification; Wetted Perimeter Method; ABF Method; 7Q10 Method; Professional judgement; R-2 Cross Method; hydrological methods based on flow records/FDCA; Water Quality methods; USGS Toe-Width Method; Arkansas Method; AVDEPTH program; HEC-2 program; HQI; Oregon Method; September Median Flow Method; Vermont Fish-Flow Method</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>✓ Others including: Riverine Community Habitat Assessment and Restoration Concept (RCHARC); Texas Method; Habitat Evaluation Procedure (HEP); Range of Variability Approach (RVA); Singh Method, and Orth and Leonard Method for regionalization</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>✓ 7Q10 Method: used in 11 states; primary methodology in 3 states</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>✓ Wetted Perimeter; ABF; 7Q10 are other 3 methodologies frequently applied</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

**Abbreviations**

Average Annual Flow (AAF); Instream Flow Incremental Methodology (IFIM); Flow Duration Curve Analysis (FDCA); Mean Monthly Daily Discharge (QAM); River Hydraulics and Habitat Simulation Program (RHYHABSIM); Range of Variability Approach (RVA); Multiple Transect Analysis (MTA); Expert Panel Assessment Method (EPAM); Scientific Panel Assessment Method (SPAM); Habitat Assessment Method (HAM); Water Allocation Management Planning Benchmarking Method (WAMP Benchmarking Method); Flow Restoration Methodology (FLOWRESM); Building Block Methodology (BBM); Computer Aided Simulation Model for Instream flow Requirements in regulated streams (CASIMIR); Evaluation of Habitat Method (EVHA); Habitat Suitability Index (HSI); Habitat Evaluation Procedure (HEP); River Simulation System (RSS); Bulk Water Estimate (BWE); Riverine Community Habitat Assessment and Restoration Concept (RCHARC).

4.1 Key Phases of the Planning Process

Terms used in the South African engineering planning process are used for illustration, along with the equivalent flow-assessment activities (King and Louw 1998). Formal links between engineering, EFA and Environmental Impact Assessment (EIA) processes are still evolving and need to be formalised. The equivalent EIA phases are not considered in detail here, but in general terms follow much the same sequence.

Each proposed development has its own peculiarities and required deliverables, and so the planning process should be used as a guideline rather than a rigid recipe. In the following, it is assumed that planning is for a new water-resource development. However, similar key phases would apply for other river-related projects, such as river rehabilitation.

4.1.1 Reconnaissance

**Engineering:** An initial, largely desk-top, exploratory study of an area, to obtain and evaluate existing information, identify potential water-resource problems and identify possible options for future water schemes. The exercise will rely mainly on maps and reports, with limited fieldwork and verification. This level is usually applicable to studies where the accuracy and detail of the results are not likely to be determinants with respect to a final decision on water-resource management. The equivalent phase of an Environmental Impact Assessment (EIA) would be the Scoping Phase (Heydenrych and Claassen 1998) or Issues Assessment, together with initiation of a Public Participation Process (PPP).

**Flow assessment:** Two sets of activities are relevant. Firstly, a coarse desktop level of flow assessment may be made at the catchment level (Chapter 3 and Section 4.2). This would aid in regional planning by indicating areas where future water-resource development could seriously impact on the required condition of the donating aquatic ecosystems. Secondly, in parallel with the exploratory engineering investigations, available information on the river will be gathered, gaps in knowledge identified, and research requirements detailed.

4.1.2 Pre-feasibility

**Engineering:** This level of study requires field work to obtain accurate information and data, and verify present data. Resources and constraints of each engineering option are more clearly identified. The level of accuracy and detail of resulting data are not sufficient for detailed design purposes. Toward the end of Pre-feasibility, a reduced number of most-favoured options will have emerged and then, finally, a most-favoured option will be identified. The equivalent phase of the EIA would be a comprehensive Impact Assessment of all listed options which feeds into the final decision on the selected option. The EIA should also ascertain that all potential options (including water-demand management and the no-development option) received equal attention. The PPP should be linked in a structured way to all activities.

**Flow assessment:** The equivalent activity would be application of a methodology at the second tier of the hierarchy (Chapter 3). All rivers or river stretches that would be affected by the shortlist of favoured options should be targeted for a comprehensive flow assessment at this point. The results should be used when deciding on a final most-favoured option.
4.1.3 Feasibility

*Engineering:* At this level an intensive study of the favoured option is completed. The results should be sufficiently detailed and accurate to allow detailed design of the scheme. The equivalent phase of the EIA is the completion of the Impact Assessment for that option. PPP activities should ensure adequate understanding of the option within the community.

*Flow assessment:* Intensive base-line studies of the targetted river should commence. All uncertainties revealed during the Pre-feasibility EFA should be addressed. This may include application of habitat-modelling techniques such as PHABSIM (see Chapter 2) for species of particular conservation importance, and intensive ecological studies of their habitat requirements and life-histories. Implications of the proposed water-resource development at the catchment level should also be clarified: for instance, would the integrity of far-distant parts of the system such as the estuary or near-shore marine environment be threatened?

4.1.4 Design

*Engineering:* During the Design phase of the project, engineering management plans for the following phases should be compiled. Any base-line studies needing completion before on-site activities commence should be completed during this phase. An environmental management plan for the Construction phase should also be drawn up.

*Flow assessment:* The base-line studies should continue for two or more years, to provide information on the natural variability of the river ecosystem. Results should be used to design a monitoring plan that will record the efficacy of the released EFR. River scientists involved in the EFA should make formal input into dam design.

4.1.5 Construction

The engineering and environmental management plans are implemented. Base-line studies may continue. The environmental monitoring plan should be put into operation.

4.1.6 Operation

The scheme comes online. Engineering and environmental audits should be completed. Adjustments to the operation of the scheme should be possible, based on input from monitoring activities (Chapter 4.7).

4.2 Setting Objectives for Environmental Flow Assessments

The EFA incorporated into the planning process should have a clearly defined management objective of facilitating attainment or maintenance of some agreed condition of the riverine ecosystem. The term “facilitating” is used in preference to “ensuring” as other factors operating within the catchment may jeopardise the success of an otherwise highly suitable EFR.

There seem to be two main ways of setting such objectives. Firstly, an objective may be set, the EFR to achieve it described, and the water for abstraction calculated. The objective may be, for instance, to maintain a specific depth of water in the river, or a specific condition of the ecosystem or a specific resource. Alternatively, the consequences of manipulating the flow regime in a variety of different ways may be predicted, so that a range of possible river and resource conditions can be considered. In the first, top-down approach the management objective is set up front; in the second, bottom-up approach, it emerges at the end as the most acceptable option among the several options of river conditions considered. Each approach has advantages and disadvantages, as explained further below.
Setting the objective up front allows intensive focus on the flow requirements to meet that objective. Good justification for the required flows can usually be given, providing strong supporting data for those negotiating over water allocations or flow manipulations. Additionally, such an up-front objective can facilitate planning of water resources at the regional or national level. This can be done if river condition is categorised, if the link between condition categories and the volumes of water required to maintain those conditions is known, albeit at a coarse resolution, and if each river in the planning region has a condition category assigned to it. For example, in South Africa, early descriptions of required river condition or "desired state" in the Building Block Methodology (BBM) (King and Louw 1998), evolved to Ecological Management Classes (DWAF 1998). These classes or categories of river condition have been coarsely linked to a percentage of the MAR that would need to remain in the river. Different percentages for the same management class might pertain for rivers in different regions, reflecting the different regional nature of rivers. This approach allows forward planning at the catchment level, through tentative identification of a best-possible, realistic future condition (i.e., Management Class) for the river, reference to linkage between condition and required water volume to ascertain the water that should be reserved to ensure that the option of maintaining the river in this condition remains open, and interpretation of this reservation in terms of the extent of possible future development of that catchment. In South Africa, a process along these lines produces a coarse EFR named the Desktop Estimate and a slightly more refined one called the Rapid Determination (DWAF 1998). These methods rely heavily on trends in EFRs emerging from past countrywide applications of the more complex BBM (DWAF 1998; Tharme and King 1998; Hughes and Ziervolgel 1998).

Two main disadvantages to this kind of approach have been recognised. Firstly, as the objective is set up front, its consequences in terms of flow required, harvestable water, social implications and economic implications are not understood until after the specialists have described the EFR. At that point it might become clear that some of these consequences are unacceptable. Then, a revised objective may have to be sought and the whole process repeated. It may be possible to initially set more than one objective up-front and describe the required flow regime for each, but this is an extremely time-consuming approach and there is a limit to how much time specialists can spend in such an intensive exercise. Additionally, the same situation of not knowing the social and economic implications of each option until the end, and thus of being sure that realistic objectives were chosen, still applies. Finally, it may be difficult to identify an objective up front anyway because the PPP may not have matured to the point where constructive input can be made by all. Even if this can be done, consensus may not be reached between all interested and affected parties (I&APs) on what the objective for the river should be. An ensuing EFR faces the danger of addressing an objective agreed upon by only a proportion of the I&APs.

The second disadvantage of this top-down approach is that the objective (river condition, management class) may be described in such woolly terms that its attainment cannot be measured. General objectives of “maintaining the riparian belt”, “maintaining Management Class C” or “maintaining present levels of health of, and resources for, riparian dwellers”, which are all that it may be possible to articulate early in an EFA, give no indication of what should be measured. If the objective can be stated more specifically and thus be measurable, it is likely, particularly in earlier EFAs, to be a very simple one such as “maintain a water depth of X cm and velocity of Y m s⁻¹ for Fish Species A”. There may be no recognition within such an objective of the need to supply a wide spectrum of flows in order to cater for the whole ecosystem upon which that species depends. Nor will the broad spectrum of social and economic implications of such objectives be obvious.

As a final point, because the top-down approach usually considers only one or a limited number of possible future flow regimes and objectives, it is not conducive to revealing the wide range of possible trends in how ecosystem components might change with flow and what might be measured in order to monitor such changes.
In the bottom-up approach, a number of future options are produced in the EFA with the most desirable option evolving as the objective. In a complex form of this approach, consequences of a range of flow changes may be predicted, these flow changes and consequences combined in a number of ways to produce different flow regimes and river conditions, and the various river conditions interpreted in terms of social and economic implications. The objective for the river then emerges as the most acceptable of these outputs.

This kind of approach avoids the disadvantages of the first approach, but has advantages and disadvantages of its own. Because the objective is not stated up front, it cannot be used in coarse, desk-top calculations for regional planning purposes. However, for specific river studies, the approach allows a wide number of potential future regimes and river conditions to be explored. To use this approach to its best advantage, it is essential to complete a comprehensive series of studies of the nature and functioning of the riverine ecosystem, and of its importance in the life of people. Creation and manipulation of large data sets means that the approach is more complex to manage and less easy to understand than the up-front approach. For example, in the South African DRIFT Methodology (Brown and King 1999) and the Australian Flow Restoration Methodology (Arthington 1998b), many decisions have to be taken on such issues as which flow reductions or additions will be considered, how specialists will record the direction and severity of change of each and every ecosystem component, how consequences for a wide range of ecosystem components will be combined to form a composite picture of river condition, and so on. This biophysical component then has to link with equally complex social and economic components. Despite this complexity and perhaps due to it, a major advantage of such approaches is that detailed consequences of flow manipulations are provided for most, if not all, major ecosystem components. These provide a ready-made foundation for an ensuing programme to monitor attainment of the negotiated objective, because they detail what is expected to happen, and therefore what could be measured to check if it does.

There seems to be no reason why a mixture of top-down and bottom-up approaches could not be applied at different phases of water-resource planning. Each case should be treated on merit.

4.2.1 Who or what are objectives set for?

The objectives for each river are set by society. They will reflect the ecological, social and economic importance of the targeted river and its catchment. In some cases the river will be of such high conservation importance that its protection will be of over-riding concern. For others, maintenance of agriculturally-productive land and delivery of irrigation water may be the priorities, with a lower management class (condition) seen as acceptable for the river. In some areas, maintenance of food resources from the river, such as fish, may be a critical issue for riparian dwellers. Then the setting of objectives may be driven by human subsistence needs, whilst meeting them will need deep understanding and sensitive management of the riverine ecosystem. Procedures outlined in the preceding section facilitate identification of the appropriate blend of objectives for any one river.

4.2.2 When are objectives set?

When the top-down approach is used for regional planning purposes, the objectives (i.e., management classes or river condition) may be set at times appropriate to that activity. A sufficient lead-in time should be allowed to ascertain the relationship between management classes and river flow (e.g., MAR) for that region. Time is also needed before this relationship is used in planning estimates, to obtain widespread consensus on what the management class(es) should be for different parts of the river systems of concern.

When the top-down approach is used for single-river EFAs, the objectives are usually set during the Pre-feasibility Phase, so that data collection for the EFA is directed at the appropriate rivers, river sections and ecosystem components.
When the bottom-up approach is used, the objective will be set toward the end of Feasibility as all ecological, social, engineering and economic studies are combined to produce a number of scenarios. The favoured option becomes the objective.

4.2.3 The Feasibility of Defining River Management Objectives (through Environmental Flow Assessments) for large basins

To date, there appears to be little progress in EFAs that encompass large river basins, especially those shared among neighbouring countries. However, in future, it is likely that this will be an area demanding considerable attention. Issues such as international agreements, legislation and policy, institutional arrangements, capacity and good-practice frameworks for environmental flow assessment will need to be addressed, as these appear to be more significant impediments than the availability of suitable methodologies for the assessments.

In the time allowed for this report, it was not possible to search the world literature on this subject. Experience from South Africa, as outlined above, suggests that region-wide objectives can be set, at a coarse level, which allow forward planning on land use and water allocations (DWAF 1998). Additionally, a few basin-wide settings of objectives and EFAs have recently been initiated in the country. These are still in their early stages. More advanced is a project in Lesotho in southern Africa, where identifying objectives and EFRs for the whole of the Lesotho Highland Water Project is nearing completion. Using the DRIFT methodology, the objective for each part of the upper Senqu River system will emerge as the most acceptable scenario, based on ecological, social and economic studies (Brown and King 1999).

Internationally shared freshwater resources frequently cause tensions, particularly where these resources are scarce. Historically, countries with shared watercourses have tended to develop rivers unilaterally to meet their own needs without regard to the needs of neighbouring countries, the ecological integrity of the system or the actual capacity of the basin. An example of such a situation is the development of the Euphrates-Tigris Basin, which has lead to tension and disputes between Middle Eastern countries which share this system, particularly Turkey, Syria and Iraq. Appendix 3 provides a summary list of Internet sites that provide further information on issues surrounding shared water courses.

A number of agreements, commissions and conventions has been devised over the years in order to assist in the development of co-operation between countries that share watercourses. The International Law Association’s (ILA) 1966 Helsinki Rules and the United Nations’ 1997 Convention of the Law of the Non-Navigational Uses of International Watercourses (UN Watercourse Convention) developed by the International Law Commission (ILC) provide a framework for the management of international watercourses for many countries. However, neither the ILA nor the ILC has any lawmaking power, so their rules are not legally binding. Therefore many countries have established multi-lateral commissions, committees and bodies to co-operate and negotiate with neighbours that share common watercourse, within the framework of these conventions.

Although the Helsinki Rules state that each country which shares any river (basin state) has the right to a ‘reasonable and equitable share of the water in the basin’, there is no provision for the maintenance of the ecological integrity of the system. However maintenance of the ecological integrity has been incorporated into several regional agreements. For instance, in southern Africa, the SADC (Southern African Development Community) Protocol on Shared Water Course Systems (based on the Helsinki Rules), which has been ratified by South Africa, Lesotho, Botswana, and Mauritius (DWAF 1997b), indicates that river-basin management institutions between states are responsible for “promoting measures for the protection of the environment and the prevention of all
forms of environmental degradation arising from the utilisation for the resources of the shared watercourse systems” (DWAF 1997a).

The more recent UN Watercourse Convention (1997) specifies that watercourse states “shall individually and where appropriate, jointly protect and preserve the ecosystems of international watercourses”. Among other issues, this section details the prevention of pollution through the setting of joint water quality objectives and the co-operation of states with regard to the regulation of flow of the waters of an international watercourse.

The recommendations of the International Round Table on Transboundary Water Management held in 1998 (BRTWM 1998), state that countries may be forced to change from the old paradigm of supply-side management to address four important issues. Included in these is that “Control of rising salinity, prevention of environmental degradation and maintenance of aquatic ecosystems will be recognised as critical factors in sustainable management resources.”

Prof. Asit K. Biswas, President, Third World Centre for Water Management, Mexico City informed us (pers. comm.) that there are no agreed international policies on setting flow objectives for international rivers. He said that presently the most appropriate is the UN Convention on Non-Navigable Uses of International Watercourses, which has only been ratified by four countries in two years, and so is not really in force. It does provide some general guidelines for use of waters, such as "no appreciable harm", but he doubts its usefulness in solving future conflicts. He suggests that a useful way forward would be to study a series of existing agreements on international rivers, and see what general principles emerge.

In addition to the southern African examples mentioned earlier, environmental flows for a shared water resource are receiving attention on, inter alia, the Murray-Darling River in Australia, the Kunene River in Namibia and Angola and the Mekong River, which has its source in Tibet and flows through six countries (Appendix 3).

In summary, it appears at present that the setting of objectives for shared rivers, particularly with regard to environmental maintenance, is beginning to be recognised as important. However, it often remains an ad hoc process, whereby the countries concerned may or may not take the initiative to negotiate on their shared rivers, guided by one or more of the present conventions or guidelines.

4.2.4 Supporting Legislation for Setting and Achieving Objectives

Successful implementation of EFRs requires a sound policy framework, which mandates them (Rafik Hirji, World Bank, pers. comm.). This should reflect that the allocation of water for ecosystem maintenance is legitimate (ICWE 1992), and is to be given the same, if not a higher, priority of use as potential in-channel and off-channel users. Such a policy framework should specify the types and complexity of methods to be used for various levels of EFA, and the criteria for defining EFRs. Without this support, Dr Hirji points out, each EFA has the burden of not only defining the water required for ecosystem maintenance but also of providing legitimacy for the concept itself. Where an appropriate policy is in place (see Box 3), the EFA can concentrate on defining the water requirement, with the concept already embedded in policy. National legislation requiring EFAs is now emerging in several countries (e.g., the new Norwegian Water resources Law, 1998/99, Tor Ziegler, World Bank, pers. comm.). This topic is dealt with further in WCD Thematic Review V: Institutional and Governance Issues.
BOX 3: The new South African Water Law

At the end of the 1980s, aquatic ecosystems in South Africa had no legal right to a share of their own water. By the early 1990s, the SA Department of Water Affairs and Forestry (DWAF) had moved ahead of legislation, recognising aquatic ecosystems as legitimate users of water, competing for water with established users such as industry, agriculture and municipalities. DWAF also shifted perception of itself from “a supplier of water to meet demand” to “holistic manager of water resources”. By 1994, aquatic ecosystems had acquired another leap in status, becoming recognised as the structures that underpin the nation’s water resources, now and into the future (DWAF 1997b).

The new SA Water Law of 1998 recognises only two rights to water: for basic human needs and for aquatic ecosystem maintenance. Together these are termed “The Reserve”. This Reserve, together with international obligations, is the primary consideration when allocating water, with all other water demands managed through renewable permits.

In ten years, South Africa has evolved from having little official interest or expertise in environmental flows to having one of the most enlightened water laws in the world and an extensive collaborating national body of water managers, engineers and scientists that are highly experienced in this field.

4.3 Stakeholder Involvement in Environmental Flow Assessments

Inherent in some modern EFAs is a comprehensive social component aimed at identifying the population directly at risk from the proposed water-resource project, and providing mitigation or compensation for expected impacts of the project (see Appendix 1).

Additionally, running in parallel with the engineering and environmental phases of project planning, there may be an independent process of public participation. This may be aimed not only at the Population at Risk (PAR), but also at all other I&APs. From the earliest stages of investigation and impact assessment, through to the final consideration of alternative options, specialists with training and experience in the field of public participation may be following a structured sequence of activities with these I&APs. The activities should include: identification of the I&APs; dissemination of information to them regarding the proposed water-resource project; input of I&APs into the preliminary scoping and impact-assessment exercises; explanation of the EFA process being followed; explanation of possible objectives and scenarios (Chapter 4.4); input from I&APs on concerns and levels of acceptability of each scenario; and enhancement of understanding of the decision-making process that will be followed regarding the final approved scenario. It should be clear how the Public Participation exercise integrates with the decision-making process.

The PPP may be run by specialists who are independent of those running the EFA. If this is so, it is essential that the two teams maintain close contact, to ensure that correct information is being passed to the I&APS, and that public concerns are being heard and acted upon by the EFA team where appropriate.

4.4 The Nature and Role of Scenarios in Environmental Flow Assessments

Scenarios may be used in EFAs to present the likely consequences of a flow manipulation. In its simplest form a scenario indicates under which flow conditions a required river condition will or will not be met (see Chapter 4.2). In a more complex form, scenarios may also describe the direct social, engineering and economic implications to the PAR of each predicted river condition. In their most complex form, scenarios may also encompass the wider social, economic and political implications. It follows that the building of agreed-on scenarios occurs in Pre-Feasibility, when several possible
options are still being considered. However, agreement on which scenarios to consider is likely to be an iterative process starting much earlier in planning. An early start ensures that the correct kinds of data are collected or created for building the required scenarios.

Selection of a favoured scenario may involve making decisions that are unpopular to some. Trade-offs may have to be made, and the benefits to one sector of society recognised as costs to another sector. The costs of environmental damage should always be a major factor in considerations, and the no-development and water-demand management options given at least equal considerations to others. Potential conflict can be reduced if a transparent decision-making process, agreed upon by all interested parties, is in place before the scenarios have been produced for consideration. This topic is addressed in the WCD Thematic Review V: Institutions and Governance Issues.

4.4.1 Structuring and Presentations of Scenarios

The nature of scenarios will be influenced by the decision-maker’s needs. A wide range of ecological, social and economic components may be involved, or just a simple statement of required flows during some critical period, and each case should be treated on merit. Scenarios for a river that is not seen as particularly “important”, and where there is no potential conflict over water, may be less detailed than for other more high-profile rivers.

At any level of detail, scenarios may be created to answer different kinds of questions. Three main kinds of scenarios so far encountered are as follows:

- **To meet a specific yield.** The water manager may wish to abstract a specific volume of water. The least-damaging way of doing this could be advised, together with the predicted ecological (and social and economic) consequences.

- **To meet a specific condition.** There may be a wish to maintain a certain river condition, ecosystem feature or social condition. The amount of water that could be abstracted whilst meeting this objective could be advised.

- **To achieve some measure of rehabilitation in a river, within the design limitations of extant structures.** Design limitations could include both those linked to the size and positioning of release structures in dams walls, and the wider picture of water already committed for offstream sale to ensure viability of the scheme. Once “design limitations” has been clearly defined, the best possible flow regime for the river within these constraints can be described.

4.5 Environmental flow assessments and dam design

The feasibility of releasing different size flows from a proposed dam should be a vital input to an EFA. It is pointless describing floods within an EFR that simply cannot be released through a dam. This is not to say, however, that more innovative ways of ensuring required downstream flows should not be sought. Dams situated upstream of the confluence with a major tributary instead of downstream of it, would trap less water but impact the downstream river less by ensuring bigger floods and more flow variability. Release structures should not be decided upon based on construction costs alone, as the cheapest construction option may well be the most damaging one for the river. Engineers should rise to the challenge of designing dams that can release water in ways that do least damage to the river, and not necessarily rest on tried and tested methods.

Because of the need for these kinds of inputs, a coarse estimate of the size of the dam needed to ensure economic viability may be made early in the process, but detailed dam design should not begin until a scenario has been decided upon and the EFR thus clearly understood. This requirement carries important time implications for water-resource planning. The time (preferably up to five years) required to produce scenarios, link in public participation activities and reach a decision on one scenario, should be followed (each with its associated environmental activities) by finalisation of dam
design, construction and operation. All too often, water-resource planning reaches an advanced stage in terms of engineering inputs and meeting water demand before any other aspects are considered. There is then pressure to “match” the EFR with dam design or water demand, thereby compromising environmental considerations. It is vital that engineering, ecological, social and economic phases of a project are given equal weight, initiated at the same time, and inter-linked in a structured way.

Features that should be considered in dam design include:

- multiple-level releases, so that water from different strata in the reservoir can be released separately or in any combination;
- water-chemistry and temperature sensors at the different off-take structures, so that water from the different strata can be mixed to some required quality in the downstream release; computerised control of this facility;
- release or other structures that minimise anticipated water-quality conditions such as anoxic or super-saturated water;
- outlet pipes able to take the volume from all the off-takes simultaneously if necessary;
- continual recording of volumes and quality of all water being released from, or spilling over, the dam;
- linkage between the release structures and a facility recording natural flow higher in the catchment, so that releases can be matched with current climate and thus the natural flow variability of the system;
- the ability to release small floods of specified temperatures as biological cues;
- the ability to release large floods; and
- built-in flexibility of design that allows changes in dam operation, such as for river rehabilitation, during the medium to long-term.

The key constraint to providing these features will probably be financial. Many of the features will add considerably to the overall cost of a dam. If only construction costs are considered and all “knock-on” costs externalised, the increase in cost of including such features may appear to many to be unacceptable. Only if the full spectrum of short- and long-term, short- and long-distance social and environmental costs is considered can the costs of such additional features be placed in perspective. Inclusion of these aspects requires dealing with a further linked constraint, that of entrenched attitudes. Many water managers, planners and engineers have such short horizons in terms of the implications of water-resource projects, that anything beyond the next ten years is deemed to be of no concern. This is understandable, as boundaries have to be defined for any planning activity, to make it manageable. However, long-term and far-reaching environmental and social concerns need to be injected into this mindset, and those making the input need to provide clear and relevant information about the consequences of not meeting EFRs. The blending of different perspectives will take time and cooperation from all concerned.

4.6 Other considerations when implementing environmental flows

The first requirement for successful implementation of an EFR is the legal muscle to support it. Where a country’s water law requires that EFRs be described, accepted in a democratic process and adhered to, government officials have the support they need to manage ever-increasing demands from developers and other land-owners. They are also empowered to manage the process of decision-making leading up to the acceptance of one scenario. Where this legal support is missing, water managers may not be able to provide flow for river maintenance, no matter how pressing the concerns.

Assuming that the legal requirements are in place and a scenario has been decided upon, a dam may then be constructed, and an EFR released down the river. If the earlier phases have been completed satisfactorily, the release should have been accepted as realistic in terms both of capacity of the dam to release it and of the ability of the scheme to provide this volume of water whilst catering for other
water-users. If conflict over water use had been obvious because of high demand exacerbated by the need to supply an EFR, this should have been resolved in the scenario stage, perhaps through a government decision on allocations.

However, other obstacles may stand in the way of the successful release of an EFR. Delivery of water to some permitted offstream users, such as irrigators, may be downstream along the river channel. Such demands may be diametrically opposed to the natural flow regime of the river. In the Western Cape, South Africa, for instance, wet-season high flows are stored in the dam, leaving unnaturally low flows in the river. The stored water is then released downstream during the dry season, causing unseasonally high flows. This tendency toward seasonal reversal of the flow regime can confound attempts to release suitable flows for river maintenance.

Another situation that can be faced when trying to achieve the right flow in the river at the right time, especially where run-of-river abstraction is occurring, is that the EFR may only be achieved in one section of the river. Upstream of that section flows may be too high and downstream too low, as abstractions play their role. With careful manipulation of releases and the co-operation of all abstractors this problem can be reduced. Unfortunately, where the competition for water is high, the issue of regulatory permits often does not control over-abstraction. Long rivers in rugged terrain, with poor policing of abstraction, are likely to be pumped dry sometimes no matter what permits exist and what releases are being made from the dam.

A further set of problems relates to the mechanics of the actual releases of water at the dam. In an ideal world, computerised links to the upper catchment would guide releases synchronised with natural climatic events within that catchment. Intra-annual and inter-annual flow variability would continue to be maintained in the downstream river, and the ecosystem would continue to experience long-term dry and wet cycles. Droughts and floods would continue to stress the system, maintaining habitat and biotic diversity. This is possibly achievable, but requires a commitment to address several areas of difficulty.

Firstly, the EFR should be sufficiently comprehensive and flexible to reflect this level of climatic variability. Secondly, although it is reasonably easy to predict when the catchment is in a dry or wet year, and to release suitable low flows, it is far less easy to predict when floods of certain magnitudes are likely to occur. Knowing this is important, as the small to medium size floods in particular are extremely important for river functioning (Davies et al. 1993) but are highly likely to be completely trapped by a dam. Reflecting their importance, the EFR might require, for instance, a flood of a certain magnitude to be delivered within the first two months of the wet season. It would be advantageous, both for water storage and in terms of natural variability, for ecosystem maintenance, if the flood could be provided partly from dam releases and partly from downstream catchment runoff during an intense rain event. But how to be sure that there will a sufficient contribution from runoff and that the release will not thus be “wasted” on a too-small flood (Hughes et al. 1997)? Who makes the decision, for any day’s release, but particularly for flood releases, of when to release, how much, and based on what information?

Thirdly, linked to this are other logistical issues. For manually operated dams, altering the magnitude of the release at a daily time-step might be an ambitious requirement for remote areas. Additionally, for old dams in particular, it may be difficult to control exactly what magnitude is being released and near impossible to manipulate its physical and chemical nature (Cambray et al. 1997; King et al. 1998). Under all conditions, releases being made by dam operators without the relevant training and understanding of EFRs are less likely to be successful than those where such an investment has been made. Training of dam operators is essential, as is the incorporation of EFR-release protocols into the Operating Rules of dams.
Fourthly, a logistical dilemma might be faced by the water manager who is reluctant to release what many river ecologists, particularly in semi-arid regions, see as one of the most important floods of the year: the first major event of the wet season. This plays a major role in flushing away poor-quality water and dry-season debris, and generally “re-setting” the ecosystem for the wet months. This flood might well be one of the last that ecologists would wish to lose, but it may well also be the last that water managers would wish to release. At the end of a dry season, the success of the coming rains is still uncertain. Under such conditions it takes a particular courage to release, during the first good rains, a fair-sized EFR flood from a depleted reservoir. The wish not to do this often results in flooding in the downstream river being delayed by weeks, or even months compared to the river upstream of the reservoir. Although poorly documented, this may lead to many species not being able to complete life cycle stages that require specific wet-season conditions, and so their gradual loss from the system (Davies et al. 1993).

4.7 Monitoring Environmental Flow Releases

Monitoring that environmental releases are taking place and that they are achieving their stated objectives is an essential part of their implementation. Where the river ecosystem is well understood, monitoring will confirm the success of the recommended flows. However, in many countries it could be essential to proceed with water-resource development despite an inadequate understanding of the nature and functioning of the nation’s river ecosystems. In these cases, scientific guidance may be provided up-front on a “best available knowledge” basis, development may then proceed, hopefully with the Precautionary Principle in place, and post-development monitoring would then enhance understanding by revealing the efficacy of the EFR.

The chances of success of a monitoring programme can be enhanced by its overall design and funding. Programmes that are well funded may well be more successful, as there is a clear commitment to support them, and paid specialists are employed to drive the programme. Many a well-intentioned plan fails simply because it is nobody’s paid job to make it work, and everyone else is too busy to do it part-time. Funds for monitoring programmes should thus be secured and realistic, as part of the operating costs of the dam, so that long-term plans can be made.

“Monitoring programmes risk falling into complacency and stagnation, especially where possible change is expected only in the long term” (Doolan, McMahon and Mentis, 1999, Lesotho Highlands Water Project, Panel of Experts, pers. comm.). Doolan et al. suggest that to minimise complacency and stagnation, aspects to be monitored can be divided into those that change quickly and those that show long-term change. Data from fast-changing variables can be assessed continuously, so that the monitoring design is tested and results provide issues that hold interest. Slow-responding variables can be used to generate long-term hypotheses and test these. For all components, it is essential to begin with clear predictions of the changes that are likely to happen anyway because of flow regulation and to be able to show whether or not changes outside this range happen.

Any of the ecosystem components mentioned earlier in this document are possible contenders for inclusion in a monitoring programme. Those chosen may differ depending on the objective to be achieved: if the intention is to maintain or reinstate a certain fish species or food resource, then that species or feature, together with its main determinants, should be monitored. Whatever components are chosen, it then requires skill and thought to monitor those aspects that will be reflecting flow-related changes and not others unrelated to damming of the river. As flow is an integral part of the river system, it may seem impossible to distinguish the two. However, as an illustration, it would be inaccurate to attribute the lack of riparian seedlings to a lack of bank flooding when they were actually being grazed by cows. Similarly, high nutrient levels in downstream reaches may not be the result of flow reduction by a new dam, but of the coincident release of treated sewage from a new water-treatment plant. The need to deal with this kind of potential situation has to be balanced by the recognition that monitoring is not usually used to explain a problem area but merely to identify it.
Programmes that include too many diagnostic variables often fail due to the complexity and costs involved. Therefore a balance needs to be sought: it is often more appropriate to design a “lean” programme which can be supplemented with additional investigations when areas of concern are identified.

Understanding the natural fluctuations within any ecosystem is also essential to successful monitoring. Changes in the position and extent of sandbars could be natural shifts well within the long-term norm for that river. Shifts in the species composition of fish communities can occur naturally during dry and wet cycles (Weeks et al. 1996), around some dynamic equilibrium. An ideal monitoring programme should be able to distinguish between natural and man-made, flow-related or flow-unrelated change. Too often, the range of natural temporal and spatial variability is not well known, and monitoring contributes to this knowledge rather than feeding on it. Then, it is important to use whatever knowledge exists of region-wide reference conditions, to guide interpretation of monitoring results. Reference conditions may be seen as the near-natural or best-attainable conditions within a group of similar rivers or river stretches (NRHP 1996; Dallas and Fowler 1999), and can help explain whether or not a particular monitored site is showing abnormal trends.

In summary, a good monitoring programme should be recognised as essential, and thus be well-funded. Dedicated specialists should be appointed to the task, and be in close touch with the efficacy of the EFR should be regularly assessed, ideally by an independent group of specialists. Following these regular assessments, perhaps on a 5-year basis, there should be the twin facilities of being able to revise the objective for the EFR if necessary and incorporate any suggested changes in the EFR in the catchment and the water managers operating flow regulation. A structured plan of action should explain and justify the components to be monitored, project the expected results and detail how results will be analysed on an on-going basis. It might be useful to have a multi-tiered approach to monitoring, with a core of essential activities and additional ones that contribute more understanding added as and when needed or as funds become available. The results of the monitoring programme should be able to distinguish between man-made and natural changes in the river, and between flow-related and flow-unrelated changes. Formal report-backs should be built into the plan and the dam’s operating rules.
Figure 1 Flow Diagram Illustrating Feedback Loops for Revision of Either an EFR or the Objectives Underlying an EFR
5. Summary of Features Vital to Successful Implementation of Environmental Flow Requirements, and The Way Forward

The following is a list of features to be aimed for in order to successfully implement EFRs. It is not an impossible wish list; in many countries most items on the list may already be in place, or amenable to being in place within a few years. Local conditions may render some items unnecessary, or require the inclusion of additional items. Thus, the purpose of the list is to provide an idea of the main considerations presently evolving within EFAs, and to help readers highlight areas where more investment may be needed in their countries. Priorities can then be initiated immediately, if possible. Section 5.10 provides some discussion on the way forward. Suggestions, in particular from the following reviewers, were included in its formulation: R.J. Dobias, Asian Development Bank; S. Singh, Indian Institute of Public Administration; T. Scudder, California Institute of Technology, USA; R. Hirji and T. Ziegler, World Bank, Washington, USA; M. Pérusse, Hydro-Quebec, Canada.

Considerations with regards to political will, legislation and management strategies:

- Political recognition of loss of ecosystem values due to flow-related degradation of rivers.
- Political recognition of tangible and intangible costs to the nation of degraded rivers.
- Political acceptance of integrated river-basin management as the goal for nationwide sustainable use of water.
- Acceptance of EFAs as a tool for use in integrated river-basin management.
- Supporting legislation to empower water managers to manage river flows according to EFA recommendations.
- The necessary tools to implement and enforce legislation.
- A structured, transparent and widely-accepted decision-making process whereby the results of engineering and economic studies, EFAs and the PPP are jointly used to decide on future flow allocations and river condition.
- Ethical and moral considerations, and intangible costs (such as Existence Value, a Sense of Place, and Bequest Values whereby environmental wealth is left to posterity) forming important inputs to the final decision-making process.
- Commitment of politicians, developers and dam operators to adhere to agreed upon EFA objectives.
- Regular independent review, possibly every five years, of the operation of a water-resource scheme and the related ecological and socio-economic issues.
- Sufficient flexibility in water-resource management to allow such reviews to lead to adjustment in either the EFR for the river or the objective (condition of the river).

Considerations with regards to data and tools:

- Long-term accurate hydrological data.
- Hydrological models at daily time-step.
- Linked surface and groundwater models for temporary rivers.
- Long-term water chemistry records for rivers (surface and groundwater, where necessary), preferably linked to hydrographs.
- Appropriate EFA methodologies.
- Comprehensive data on the distribution, life histories and flow-related habitat requirements of riverine species in the rivers of concern. Similar data for the abiotic aspects of rivers and, where relevant, for estuaries and coastal marine environments. Data on the tolerance ranges of riverine biotas to physical and chemical variables. If all the above are unavailable, relevant specialists (see below) with in-depth experience who can offer defensible expert opinion.
- A well-designed monitoring programme to assess the efficacy of the EFR.
• A well-structured link between river and estuary EFAs.
• Structured and ongoing assessment of monitoring results, feeding into adjustments in operation of the water-resource scheme if necessary.

Considerations with regards to specialist expertise:

• EFA specialists *au fait* with international developments in EFA methods.
• Senior specialists, all with first-hand knowledge of the rivers of concern, in the river-related and EFA-related aspects of the following disciplines: hydrology, geohydrology, hydraulics, geomorphology, sedimentology, water chemistry, biotic integrity, physical habitat, riparian and instream vegetation, fish, invertebrates, and possibly herpetofauna and river-dependent terrestrial wildlife.
• If socio-economic aspects are to be included in the EFA, specialists in the following disciplines are also required: sociology, human geography, anthropology, public health, domestic-stock health, resource and project economics, public participation procedures. Also required are specialists with first-hand knowledge of the flow-related aspects of water-borne diseases, and those of parasites and/or their hosts.

Considerations with regards to Infrastructure and support systems

• Hydrological gauging points (such as weirs or rated river sections), linked chemical recording points, and catchment rainfall gauge stations, all well maintained and recording accurately.
• Roads to many points along the rivers; helicopters for inaccessible reaches.
• Good facilities for data management and communication: PCs with capacity and software for current analytical and sophisticated report-writing exercises, email, fax machines and telephones.
• Good access to specialist equipment (e.g. current meters, survey equipment, for water-chemistry analysis) and means of maintaining them.
• 4WD vehicles with good maintenance and spares facilities.

Considerations with regards to funds:

• Recognition that ecological and socio-economic aspects of water-resource development are as important as engineering and direct economic aspects.
• Sufficient forward planning to provide adequate funds for EFAs. Modern EFAs may be costly exercises, involving many senior specialists over quite long time spans. They should be formally recognised and catered for in budgets, and not “squeezed” into budgets available for other purposes or funded from contingency funds.

Considerations with regards to time management:

• For any flow-related project, EFAs should be commenced at the same time as engineering and other studies. Suitable planning horizons for flow-related investigations are:
  • Regional Planning at the catchment level: a few days to weeks;
  • Reconnaissance studies: depending on the size of the region and the level of detail required, a few days to one year;
  • Pre-feasibility studies: at least one year, preferably two;
  • Feasibility studies: depending on the ecological and social importance of the river and on the level of potential conflict over water, two to five years;
  • Base-line studies during Design and Construction: Continuation of those initiated in Feasibility until an acceptable level of knowledge exists;
  • Monitoring: at least ten years after commissioning of the dam, or longer if required, because of the long-term nature of river response to flow change. It should be possible to reduce the intensity of monitoring after the first two years, but this should be guided by the independent
Considerations with regards to training and education:

- Biophysical specialists as listed in 5.3 need to be trained in EFA work, then train others through undergraduate and postgraduate studies, technology-transfer workshops and so on.
- Social scientists and economists need to understand EFAs, and then develop structured ways of extending biophysical scenarios (Chapter 4.4) to quantify the social and economic implications.
- Water managers, water engineers, dam owners and dam operators need to understand the philosophy, nature and limitations of EFAs, and the potential implications at all scales from local to international. They need to be willing to explore new ways of managing water resources and be committed to adhering to democratically agree-upon EFA objectives.
- The public, particularly land-owners and NGOs, need to be aware of EFAs and understand their purpose and limitations.
- The roles of all involved in and affected by a proposed water-resource development need to be spelt out and acceptable by all.

Considerations with regards to good-practice framework:

- Sufficient experience now exists worldwide for the compilation of a first-generation good-practice framework to guide the application of EFAs, and this should be undertaken as soon as possible. The framework should be sufficiently comprehensive to indicate effective co-ordination between engineering, ecological, social and economic issues. It should be revised regularly as new information and experience emerge.

Considerations with regards to developed and developing countries:

- Funds might be very limited or abundant, depending on whether the country is funding the EFA locally or receiving international funding. If the funding is international, requirements related to the extent and quality of the EFA may be much higher than with local funding. Because of this, a poorer country may have to undertake a more costly EFA than its richer neighbour.
- Access to rivers may be more difficult due to low grade and/or inadequate road networks, limited availability of vehicles like 4WD vehicles, helicopters and boats, or the presence of land mines and social unrest.
- Data-recording stations may be more sparse and less-well maintained, with a consequent greater likelihood of inaccurate data and greater gaps in data sets.
- Communication may be more difficult due to less reliable telephone, email and fax facilities, poorer facilities for buying and maintaining computer equipment and receiving specialist advice on computer hardware or software problems.
- Science is often not an attractive career choice, so it may be difficult to develop a strong force of experienced local scientists.
- Relevant biophysical and social specialists are thus likely to be rare, whilst those imported from other countries may not understand the local rivers, human communities, or the likely constraints of working within the country. Imported specialists also tend to eventually leave, often leaving inadequately trained local specialists to face any developing problems. Failure rates of EFAs may be higher than in developed countries simply because of the lack of experienced professionals who can detect emerging problems.
- Funds for continuing monitoring of a project may be sparse and thus threaten the success of the EFA.
- Access to specialist equipment, spare parts and maintenance services may be poorer than in developed countries.
6. The way forward

Each country or case for an EFA may face specific and different circumstances. In southern Portugal, for instance, almost all rivers are temporary, and hydrological gauging weirs extremely rare (Bernardo and Alves 1999). EFAs there aimed at maintaining isolated pools in the dry season may have to be based on groundwater hydrology and water chemistry. Temporary rivers in Namibia, are different, usually having no surface water. Underlying groundwater, however, threatened by upstream dams, maintains the “linear oases” of trees across the desert that support pastoralists and migrant populations of large mammals such as elephant, lions and gemsbok (Loutit 1991). Again, geohydrology, this time linked to the requirements of riparian vegetation, would probably form the focus of an EFA.

Many South African rivers are strongly perennial but are now controlled by such large dams that the harnessing of floods and sediments is severely affecting downstream reaches, in such rivers geomorphological studies of channel changes are an essential component of EFAs. New Zealand rivers, by contrast, are also perennial and flow strongly, but sediment and water quality changes and loss of floods in dammed rivers are not seen as a problem because rainfall is high and the floods remain largely intact (Ian Jowett, National Institute of Water and Atmospheric Research, Hamilton, New Zealand). There, the accent is on maintaining suitable baseflows for fish that attract a burgeoning tourist industry, and so physical-habitat studies for these species may be most appropriate. In Senegal and Mauritania, approximately two million people live in the basin of the Senegal River. These people are agropastoralists, relying on a combination of agriculture, animal husbandry and fishing (Brantly and Ramsey 1998). The needs of these people would thus be paramount in any EFA-related activity in this region, and studies of the social and health requirements, and the links between these and the flow-related aspects of the riverine ecosystem, would form the focus of such a study.

Because of such differences, and because of the required overview scope of this report, a practical generic set of guidelines has not been derived from the above list that could be employed for any EFA. Instead, with reference to comments from reviewers, some steps forward are suggested.

- A worldwide review of the trends in implementation of EFAs, to gain an insight into:
  - why some countries undertake EFAs and others do not;
  - how decisions on EFRs are made, and by whom;
  - successes and failures in the longterm implementation of EFAs, with reasons;
  - the main features of EFAs/EFRs in different situations, prioritised;
  - specialist needs and constraints in developing countries, and how (if at all), these are dealt with;
  - the major gaps in knowledge, to focus research efforts.

- Establishment of regional centres of expertise devoted to conservation and development issues associated with water-resource developments, or for addition of EFA and related topics to existing ones. Ensuring the accessibility of adequate numbers of trained EFA specialists in all relevant disciplines. Devising workable methods for applying EFA methodologies in developing countries (Dobias pers. comm.).

- A concerted effort to better understand tropical and sub-tropical river ecosystems, their agricultures, fisheries, flow-dependent functioning and their importance in the lives of people (Dobias, Scudder, pers. comm.).

- A concerted effort to promote the development and application of EFAs, at many levels: government, aid agencies and the private sector.
7. References


This is a working paper of the World Commission on Dams. The report published herein was prepared for the Commission as part of its information-gathering activity. The views, conclusions, and recommendations are not intended to represent the views of the Commission.


This is a working paper of the World Commission on Dams. The report published herein was prepared for the Commission as part of its information-gathering activity. The views, conclusions, and recommendations are not intended to represent the views of the Commission.


Tharme, R.E. 1996. Review of international methodologies for the quantification of the instream flow requirements of rivers. Water law review final report for policy development. For the
Department of Water Affairs and Forestry, Pretoria. Freshwater Research Unit, University of Cape Town. 116 pp.


Wooldridge, T. and Callahan, R. in prep. The effect of a single annual pulse of freshwater released into the Kromme estuary: 3: Response of the estuarine zooplankton.
Annex 1: Types of Flow Assessment Methodologies

1.1 Hydrological type methodologies

1.2 The nature of methodologies based on hydrological data

The simplest type of environmental flow methodologies rely on the use of hydrological data, in the form of long-term, historical monthly or daily discharge records, to derive environmental flow recommendations. A fixed percentage of flow, or some other derived flow index, historically often termed the minimum flow, is selected to represent the EFR intended to maintain a highlighted ecosystem feature at a predetermined acceptable level. The recommended flows are typically set at an annual, seasonal or, less often, monthly time step. The vast majority of this type of methodology rely entirely on flow data for identifying EFRs, while many other more sophisticated approaches, notably holistic methodologies (Section A1.4), utilise such hydrological indices extensively within a suite of tools.

Some hydrological methodologies have been developed with cognisance of hydraulic, biological and geomorphological criteria, such as the Montana Method (Tennant 1976; see below). Others have been modified to include catchment-based variables and ecological criteria in their actual application. For example, Estes (1996) provides an example of a modification of the Montana Method for use in Alaska, with the addition of specialist knowledge of fish periodicity data, flow duration estimates, and use of a hydrological index, the mean of the monthly average daily flows - over all years of record.

Although there are in the order of at least 15 frequently referenced, hydrology-based methodologies, several of these are region- and/or context-specific in their application (see Tharme (1996, 1999 in prep.) and Dunbar et al. (1998) for details). For instance, the Average Base Flow Methodology was developed for use and is applied in New England, USA, although it is used elsewhere in North America (Reiser et al. 1989a). A method recommending flows exceeding the flow representing 2.5-5% of (MAF) is routinely used in Portugal (Alves and Henriques 1994; see also Section 3.1). The 7Q10 Method, using the consecutive 7-day 10-year low flow event as the minimum flow, is used mostly in the eastern and southeastern USA when water quality issues predominate (Reiser et al. 1989a).

1.3 Commonly utilised and advanced hydrological methodologies

To date, the most commonly used hydrological methodologies are the Montana Method (or Tennant Method; Tennant 1976), which is currently the second most widely used environmental flow methodology in North America, and a global suite of methods based on various exceedence percentiles derived from flow duration curves. The latter is a generic approach of Flow Duration Curve Analysis (FDCA; Tharme 1996).

Briefly, in the Montana Method, percentages of the average annual flow (AAF) of the target river are used to formulate baseflow regimes on a seasonal basis, to satisfy environmental flow needs. This is done using a table linking (seven) percentages of AAF to different categories of instream habitat condition. These were originally derived by members of the (then) U.S. Fish and Wildlife Service, on the basis of extensive field assessments to determine correlations between discharge and physical habitat availability and suitability for aquatic biota, and sediment transport and suitability for recreation (see Tharme 1996 for further explanation). For example, 10% AAF represents the minimum instantaneous flow recommended to sustain short-term survival habitat for most aquatic biota, and 60% AAF is considered to provide optimum habitat. Flood requirements are only considered in terms of a single allocation of 200% AAF for flushing.
In FDCA, virgin or present-day historical flow records are analysed over specific durations to produce curves displaying the relationship between the range of discharges and the percentage of time that each of them is equalled or exceeded (Gordon et al. 1992). Discharges representing specific flow percentiles are calculated from the curves, and then used in a variety of ways to produce specific environmental flow recommendations. For example, Hoppe and Finnell’s (1973, cited in Stalnaker and Arnette 1976) percentiles for salmonid fishery requirements: $Q_{17}$ (the discharge equalled or exceeded on 17% of the time on record) for flushing fines from substratum interstices of spawning grounds, $Q_{40}$ to maintain suitable habitat conditions for spawning, and $Q_{80}$ for invertebrate (food) production, cover and maintenance of minimum adult habitat.

Recently, the Range of Variability Approach (RVA), developed by Richter et al. (1996, 1997) has emerged as a more sophisticated form of hydrological index methodology and merits further investigation. It is aimed at providing a comprehensive statistical characterisation of ecologically-relevant features of the flow regime, recognising the crucial role of hydrological variability in sustaining riverine ecosystems. According to its developers, the method is intended for application to rivers where protection of natural ecosystem functioning and conservation of natural biodiversity are the primary management objectives. The methodology comprises six basic steps, the first of which is the characterisation of the natural range of hydrological variation using 32 hydrological indices, termed Indicators of Hydrologic Alteration (IHA) (see Richter et al. (1996) for IHA methods). The IHA statistics are grouped into five categories based on virgin regime characteristics:

1) magnitude of monthly water conditions, e.g., mean value for each calendar month;
2) magnitude and duration of annual extreme water conditions, e.g., annual minima 1-day means;
3) timing of annual extreme water conditions, e.g., Julian date of each annual 1-day maximum;
4) frequency and duration of high/low pulses, e.g., number of high pulses each year;
5) rate/frequency of water condition changes, e.g., means of all positive differences between consecutive daily values.

Ranges of variation are set for each of the 32 IHA parameters, for example mean $\pm 1$ Standard Deviation, as flow management targets. A set of management rules based on the RVA targets as guidelines are devised, that will enable attainment of target flow criteria in most, if not all, years. Re-characterisation of flow variation at the end of each year using the 32 indices, and comparison of values obtained with the RVA target values, as well as ongoing research and monitoring, allows for iterative refinement of the EFRs.

Other relatively new methodologies also based on more complex hydrological indices include the Texas Method (Matthews and Bao 1991), Annual Minima Method (Cassie and Nassir 1994, cited in Dunbar et al. 1998) and Basic Flow Method (Palau and Alcazar 1996).

1.4 Data and expertise requirements for hydrological methodologies

The essential data required for the above methodologies are virgin or naturalised historical flow records over the entire observed or simulated period of record. The flows should preferably be observed, daily average discharges, and should cover the longest period of record possible. Approaches like RVA require at least 20 full years of daily data. In some instances, present-day flow data may be required for comparative purposes or to confirm sequences of years reflecting near-natural flows. Supplementary information, such as photographs of areas of habitat exposed at various discharges or ecological data, for instance on the timing and magnitude of flows for fish spawning, can be used to support the final EFRs. Both hydrological and ecological expertise are required for application of this kind of methodology, though in the simpler approaches only the former is deemed essential.
1.5 Strengths of hydrological methodologies

Methodologies based on flow records are typically inexpensive, rapid, desktop approaches, requiring only historical flow records. As such, they are highly appropriate at the reconnaissance level of water-resource development, to provide simple, yet low-resolution estimates of quantities of water for block-booking for planning purposes. The more sophisticated methodologies, like RVA, that utilise key ecologically-relevant hydrological indices, particularly, have the potential to be modified to produce regionalization methods on a river-ecotype basis and are also able to provide a useful monitoring function. In addition, the sets of hydrological indices derived from such methods can be incorporated as subcomponents of holistic type methodologies, as has been done in the Building Block Methodology (BBM; Section A1.4).

1.6 Weaknesses and limitations of hydrological methodologies

From an ecological perspective, this type of methodology is especially limited in that it does not adequately address the dynamic and variable nature of the hydrological regime. Moreover, the long-term effects of maintaining the minimum flows are rarely the same as the naturally occurring infrequent, short-term effects reflected by instantaneous events in the historic record. The methodologies are also highly limited, in the majority of applications, by the absence of ecological information as input. This restricts their flexibility, degree of resolution, and scope for use relative to other types of methodology, as well as rendering them open to considerable criticism. There is also considerable risk that the single figures that most often constitute the output will be routinely applied and across different countries, geographic regions and river types, without sufficient understanding of their ecological implications. Hence, professional judgement is essential when such methodologies are employed.

The above disadvantages render hydrological methodologies appropriate only at a reconnaissance level, and in cases where no negotiation is involved in the decision-making process. They should also be applied with extreme caution in countries or regions with hydrological regimes that differ vastly from their place of origin. They should not be used for high profile cases such as for river systems of high conservation importance, and/or where there are complex instream/offstream tradeoffs or issues pertaining to internationally shared water courses.

2. Hydraulic rating methodologies

2.1 The nature of hydraulic rating methodologies

Loar et al. (1986) identify hydraulic-rating methodologies as single, river channel cross-section methodologies that use changes in various single hydraulic variables, such as wetted-perimeter or maximum depth, as a surrogate for habitat factors limiting riverine biota, to develop a relationship between habitat and discharge for environmental flow recommendations. In some instances, the relationships between flow and instream hydraulics are simulated using a variety of, typically, one-dimensional hydraulic models (Tharme 1996).

Tharme (1996) and Dunbar et al. (1998) consider these methodologies in many ways a “halfway house” in that they generally represent the precursors of more sophisticated habitat simulation methodologies that use hydraulic data collected from multiple cross-sections, as well as associated microhabitat and biological information. However, hydraulic rating methodologies merit attention in that approximately 15 of them have, historically, frequently been used in parts of the USA (Stalnaker and Arnette 1976), while several are still routinely applied throughout the world (Tharme 1996, 1997, 1999 in prep.).
2.2 Commonly used hydraulic rating methodologies

Probably the most commonly applied hydraulic rating methodology worldwide, and overall the third-most used methodology in North America (Reiser et al. 1989a), is the generic Wetted Perimeter Method. Essentially, it is assumed in the methodology that river or habitat integrity can be directly related to wetted habitat area, typically of riffle biotopes. The approach is reliant on plotted wetted perimeter-discharge curves showing a rapid increase in wetted perimeter with increased flow up to a point, after which wetted perimeter increases gradually as discharge approaches bankfull. Minimum or preservation flows, usually for fish rearing or maximum production by benthic invertebrates, are generally identified from a discharge near the breakpoint, which is presumed to represent the optimal flow. Sometimes, other criteria are used to identify the instream flow standard, for example, an arbitrary percentage like 50% of bankfull/optimum, or for a minimum spawning flow, the discharge that creates suitable flow conditions over 80% of the gravel available at the calculated, optimum spawning discharge. Gippel and Stewardson (1996) provide an in-depth investigation of the methodology.

2.3 Data requirements and expertise for hydraulic rating methodologies

These methodologies generally require some observed stage-discharge data for at least a single cross-section that is deemed representative of each of the river study reaches. Measured hydraulic data, specifically water depth and average velocity, at intervals across the transect, at the observed discharge(s) are required, while additional hydraulic data can be simulated along with wetted perimeters and cross-sectional areas. Simulation is performed using one of a variety of standard hydraulic simulation models, each of which has specific data needs and constraints to application (Tharme 1996, in prep.). Relationships between discharge and hydraulic variables can also be explored empirically, for example using regression equations.

Hydraulic modelling, land surveying, hydrological and ecological expertise are required, with the former and latter, in combination, being critical to the quality of the outputs used to generate environmental flow recommendations.

2.4 Strengths of hydraulic rating methodologies

Such methodologies are an advancement over strictly hydrology-based ones in that they incorporate ecologically-based information on the instream, physical habitat requirements of the biota. They enable a fairly rapid, though simple, assessment of flows for the maintenance of such habitat areas for requirements like invertebrate production, fish spawning and passage. They are also sufficiently flexible to be applied for many aquatic species and activities, as well as being only moderately resource-intensive.

2.5 Weaknesses and limitations of hydraulic rating methodologies

They rely on the simplistic assumption that a single hydraulic variable or group of variables can adequately represent the instream flow requirements of a target species for a particular activity. Moreover, placement of the single cross-section, and the quality of the relationship between discharge and hydraulic parameters, are critical to the results obtained. Notably, explicit links with the hydrological regime are often not considered in the EFA, and the output is seldom dynamic in spatial or temporal resolution. Finally, the focus on instream habitat for target biota means that these methodologies cannot readily be used for other out-of-channel components of the riverine ecosystem like riparian vegetation.
3. Habitat simulation methodologies

3.1 The basic character of habitat simulation methodologies

Over time, numerous, increasingly sophisticated methodologies have been developed in an attempt to address the EFRs of a river on the basis of biotic responses to incremental changes in flow at the level of physical habitat. Instream habitat is assessed in terms of hydraulic variables, most commonly depth, average column velocity and benthic shear stress. Generally, modelled changes in the availability and suitability of combinations of hydraulic habitat over time and space, are combined with information on the suitability of microhabitat conditions for particular species, lifestages or assemblages, to predict optimum discharges as environmental flow recommendations.

Tharme (1996, 1997) and Dunbar et al. (1998) provide summary descriptions of over 25 habitat rating and mapping approaches that in the past have been commonly used and, in many instances, still are used in some form to calculate environmental flows. These include, inter alia: the Oregon Usable Width Method (Thompson 1974, cited in Stalnaker and Arnette 1976); the U.S. Forest Service R-6 Method (Swank 1975, cited in Growns and Kotlash 1994); and Multiple Transect Analysis (Richardson 1986), as well as a suite of computer simulation-based methodologies that represent the current state-of-the-art of this type of methodology (see Section A1.3.2).

3.2 State-of-the-art methodologies based on the simulation of instream physical habitat

Initially devised by the Instream Flow Group of the (then) US Fish and Wildlife Service, Colorado, in the late 1970s, the Instream Flow Incremental Methodology (IFIM) has advanced to become considered the most complex, and scientifically and legally defensible methodology available for quantitatively assessing the environmental flow requirements of rivers (Shirvell 1986; Gore and Nestler 1988). Therefore, it remains the most commonly used environmental flow methodology worldwide (Reiser et al. 1989a; Section 3.1). Furthermore, it has provided the impetus for the development of several other similar habitat simulation methodologies (see below). Importantly, there have been numerous critiques of IFIM, highlighting many of its problems as well as strengths (Mathur et al. 1985; Shirvell 1986; Scott and Shirvell 1987; Gan and McMahon 1990a, b; King and Tharme 1994; Tharme 1996; inter alia).

3.3 The Instream Flow Incremental Methodology

The Instream Flow Incremental Methodology comprises a collection of analytical procedures and computer programs, including the Physical Habitat Simulation Model, PHABSIM II, which, as a collection of some 240 separate programs, is its best known component (Milhous et al. 1989). In its entirety, IFIM is said to evaluate, for selected riverine biota, the effects of incremental changes in river flow on the macrohabitat features of channel structure, water quality, and temperature, as well as on the availability of physical microhabitat within a study reach (Bovee 1982). However, time series of changes in the quantity of suitable physical microhabitat for a target species or group of species, lifestage and activity, with flow, per unit length of river, simulated using PHABSIM II, tend to be the only routine product.

There are two main program groups within PHABSIM II for this purpose, the first of which includes five basic hydraulic simulation programs (IFG4, MANSQ, WSP, STGQS4 AND HEC-2; see Milhous et al. (1989) and Gan and McMahon (1990b)). Individual programs are used to simulate cell-by-cell changes in depths and velocities at each site, over a full range of specified discharges, after calibration using field data collected from multiple cross-sections. One of five primary habitat simulation methods...
programs (HABTAT, HABVQE, HABTAV, HABTAM and HABVD; Milhous et al. 1989) is then used to link the outputs from the hydraulic simulations, with data on the range of microhabitat conditions utilised by the target species, to compute the amount of microhabitat available for it over a range of discharges. The biotic requirements are described by means of habitat suitability index (SI) curves for variables like depth and velocity (see Bovee and Zuboy (1988); King and Tharme (1994) for methods of derivation of SI curves). The end product of the habitat simulation procedure is an index of microhabitat termed Weighted Usable Area (WUA) as a function of discharge, for each lifestage or activity, for the whole study site. These functions can be used to generate habitat time series at a range of time steps (see references in Blažková et al. (1998) for examples) for comparisons among species and flow scenarios.

3.4 Other recent methodologies based on habitat simulation

Over about the past decade, a number of habitat-modelling methodologies of similar character to IFIM, considered by several authors to be of considerable future potential, have been developed and applied in various countries (Chapter 3). Many of the general criticisms that pertain to IFIM also apply to these methodologies (see Tharme (1996, in prep.) for a detailed critique).

The River Hydraulics and Habitat Simulation Program (RHYHABSIM; Jowett 1989, updated in 1995), developed in New Zealand by the Ministry of Works and Development and the Fisheries Research Division of the Ministry of Agriculture, is a simplified version of the PHABSIM II component of IFIM (Gan and McMahon 1990b). It possesses similar, though somewhat reduced, scope for application to IFIM, comprises the same kinds of procedures and has comparable data requirements. Its limitations relative to PHABSIM II are detailed in Gan and McMahon (1990b). The Riverine Community Habitat Assessment and Restoration Concept (RCHARC) is also considered a variant of the IFIM approach in that it is based on the concept that the spatial distribution of depth and velocity conditions can change, and hence their suitability for biota, as river morphology changes. The methodology provides a means of identifying a flow regime that results in similar velocity and depth distributions to those before impoundment, and has been applied on the Missouri River, USA (Nestler et al. 1994). The Computer Aided Simulation Model for Instream Flow Requirements (CASIMIR; Jorde 1996), which is still in the early stages of development, has already received international attention (Chapter 3). It comprises a set of computer models which includes separate units to simulate flow regimes in river sections affected by hydropower use, to simulate and analyse variability of bottom shear stress and other ecologically significant parameters, and to simulate the availability and quality of hydraulic habitat. Other methodologies include the Evaluation of Habitat Method (EVHA; Ginot 1995) and the River System Simulator System (RSS; Alfredsen 1998).

3.5 Data requirements and expertise for state-of-the-art habitat simulation methodologies

The basic field data requirements are similar for the majority of present-day habitat simulation methodologies (see Milhous et al. (1989) for IFIM’s data requirements). Typically, the channel morphology and hydraulics of each river site are described at one or more discharges using data from a number of cross-sections, which together represent all the kinds of in-channel conditions and microhabitats found within the study site, and thus relevant section of the river. Hydraulic variables include depth, velocity, substratum, cover, benthic shear stress and other near-bed indices. Similar point microhabitat data are required to describe the habitat requirements of the biota as input to the habitat simulation programs. The hydraulic simulation programs require both fundamental hydraulic information and program-specific parameters. Average daily hydrological data over the whole period of record are required for time series analyses.

Expertise in hydroecological and hydraulic modelling is essential, as well as specialist flow-related ecological knowledge on the biota under investigation.
3.6 Strengths of habitat simulation methodologies

As habitat simulation methodologies are able to assess the impacts on physical habitat of incremental changes in flow, and typically have dynamic hydrological and habitat time series components, they can be used to examine a variety of alternative environmental flow scenarios for several species, lifestages and or assemblages. Moreover, as they are computer-based, they are able to efficiently process large amounts of hydrological, hydraulic and biological data in a standardised yet flexible, interactive manner. Hydraulic and habitat modelling are also performed at a scale that is relevant to the environmental biota. In addition, the outputs are produced at increasingly high degrees of spatial and temporal resolution, particularly as advancements are made in the field of two- and three-dimensional hydraulic modelling, so as to more accurately reflect both the hydraulic conditions that are experienced by the biota and of different types of rivers (Ghanem et al. 1996; Blažková et al. 1998). Finally, these kinds of methodology can be incorporated easily as tools within holistic type environmental flow methodologies (Section A1.4).

3.7 Disadvantages

The focus is entirely on target or key indicator species, with all its attendant problems (see Tharme 1996). Most notably, where the aim of an EFA is to maintain a healthy river, as is often the case, the selection of appropriate target species is difficult. Moreover, virtually nothing might be known of the riverine biotas in many countries. Although the methodologies are sufficiently flexible to be applied for many species and activities, they cannot be readily used yet for certain components of the riverine ecosystem, such as riparian vegetation, and do not attend to issues pertaining to long-term geomorphological change of rivers. Indeed, although habitat simulation methodologies are resource-intensive, they represent only one of a suite of tools required for a complete EFA. It is an assumption common to the majority of habitat simulation methodologies, that modelling biological response to changes in physical microhabitat, as described by various hydraulic variables, with discharge, is an adequate level at which to make assessments about the EFRs of instream biota. Such an assumption is likely to be highly limited or even inappropriate. As the models are computer-based, there is considerable potential for their misuse without proper training, as applications can be run without adequate understanding of the implications of various data input/output options. Researchers in isolation from the main areas of use and development of specific habitat simulation methodologies, find it difficult to keep abreast of new developments or constraints to their application. Moreover, many current habitat simulation approaches are still in fairly early stages of development, and require further research, as well as rigorous testing and validation.

3.8 Holistic type methodologies

An holistic ecosystems approach to the assessment of environmental flows, in which flows are recommended for all components or attributes of the riverine ecosystem, is heralded by several environmental flow researchers as the future direction in which methodologies are headed (Tharme 1996; Dunbar et al. 1998; Arthington et al. 1998a; see also Chapter 3).

3.9 The present status of holistic methodologies

Prior to the early 1990s, there were no formally recognised, holistic environmental flow methodologies. However, in the past decade, several of this type of methodology have rapidly emerged in the international environmental flow arena, some of which are highly similar in approach and thus, are rather difficult to differentiate. Presently, there are only a few reviews of holistic methodologies, namely Growns and Kotlash (1994); Tharme (1996, 1997, in prep.); Dunbar et al. (1998) and Arthington (1998a). Thus far, no reviews have occurred outside the countries where the methodologies originated.
Two of these methodologies, the South African Building Block Methodology (BBM) and Australian Holistic Approach, provided much of the impetus and basis for derivation of the other holistic methodologies, developing in close parallel from a common conceptual origin (Arthington et al. 1992). The BBM is introduced in King and Tharme (1994) and comprehensively described in King and Louw (1998), including: the background to its development; an outline of its underlying concepts and assumptions; the position of the methodology in the Department of Water Affairs and Forestry’s (DWAF) procedure for water-resource developments; the sequence of activities comprising the methodology, and an overview of each of the main steps; data requirements and outputs; mechanisms included in the methodology for crisis management; and the links between the BBM and water-resource modelling and management.

Briefly, the conceptual foundation of these methodologies hinges on riverine ecosystem theory, particularly disturbance theory (Resh et al. 1988). It is assumed firstly, that the natural hydrological regime of a river dynamically maintains all the instream biota, channel geomorphology, and riparian, floodplain and wetland systems, as well as any estuarine and offshore coastal systems affected by river flow (i.e. the entire riverine ecosystem) (Arthington 1998a). It is further assumed that some baseflows and floods within the complete flow regime are more essential than others for maintenance of the riverine ecosystem. Adequate description of these flows in terms of magnitude, duration, timing, and frequency, and their incorporation in the regulated flow regime should allow the extant biotic characteristics and functional integrity of the river to persist (King and Tharme 1994; Arthington 1998a).

The BBM and Holistic Approach are similar in that both rely on a bottom-up approach to constructing a modified flow regime, on a monthly-by-month and element-by-element basis, where each element represents a well-defined, feature of the flow regime intended to achieve particular, well-motivated ecological, geomorphological, water quality or social objectives in the modified riverine ecosystem. They both require intensive baseline data collection, followed by multidisciplinary input in a workshop situation. The BBM is currently more structured and its procedures are better documented than those of the Holistic Approach. It is also one of few methodologies that includes assessments of social dependence on the riverine ecosystem. In contrast, the Holistic Approach more explicitly includes hydrological indices of flow variability, and includes several modelling subroutines to assess tradeoffs between the provision of environmental flows in the system and offstream water needs (Arthington 1998a).

A holistic methodology that evolved from the BBM over the past couple of years, within the Lesotho Highlands Water Project, the Downstream Response to Intended Flow Transformations Methodology (DRIFT; Brown and King 1999), has taken holistic methodologies in a new direction. DRIFT represents a top-down approach, based on the same conceptual tenets and multidisciplinary interaction as the BBM and Holistic Approach, and exhibits some parallels with the WAMP benchmarking approach (see below). However, it focuses on the identification, first, of water levels in the river associated with a particular set of biophysical functions and of specific hydrological and hydraulic character. The consequences of reducing discharges through these identified flow bands and their thresholds, in terms of deterioration in biotic and abiotic condition, are then described by specialists in each discipline; the identification of the “minimum degradation” reduction level and its consequences typically provides the starting point. Once a wide range of flow reduction have been assessed, there is considerable scope for the comparative evaluation of a vast number of EFR scenarios, each reflecting the presence or absence of different flow bands with attendant consequences. Furthermore, in DRIFT, the links between social consequences, evaluated alongside ecological and geomorphological ones, and economic costs are explicit and comprehensive.

The Flow Restoration Methodology (FLOWRESM) represents a newly developed framework for the application of the Holistic Approach to river restoration projects (Arthington 1998b). In this context, the essential features are those flows that need to be built back into the flow regime to shift the...
regulated river system in the direction of the pre-regulation state (Arthington et al. 1995, cited in Arthington 1998a). In other areas of Australia, parallel approaches to FLOWRESM are under development (Arthington 1998a), while various other elements of the Holistic Approach are being incorporated into strategies for environmental flow management (e.g. Gippel et al. 1994, cited in Arthington 1998a).

A number of other holistic methodologies based explicitly on expert opinion in a workshop situation, rather than quantitative assessments, are in use in Australia. The Expert Panel Assessment Method (EPAM), was the first multidisciplinary team approach to EFA, and was developed jointly by the New South Wales (NSW) departments of Fisheries and Water Resources (Swales and Harris 1995). It is considered appropriate at the reconnaissance-level and relies on the professional judgement of a panel of scientific experts to assess the suitability of environmental flows for riverine ecosystem components and processes, at study sites and in a subsequent workshop setting. The assessment is made using only collated available data for five ecosystem components for which “management performance criteria” can be identified: fish; trees; macrophytes; invertebrates; and geomorphology. The criteria are applied for three habitat elements: flow regime; individual hydrographs; and physical structure. The Expert Panel Assessment Method has been applied in two forms, depending on whether or not the study river is presently regulated. For regulated rivers, visual assessment and interpretation of multiple trial flow releases from impoundments at one or a few sites, form the basis of the EFA by a panel of experts (see Swales and Harris (1995), for details; Walter et al. 1994, cited in Thoms et al. 1996). For unregulated rivers, the approach is modified, with key ecosystem and hydrology features and interactions as its basis (Thoms et al. 1996).

The Scientific Panel Assessment Method (SPAM) is considered by its developers, Thoms et al. (1996) to be a more sophisticated and transparent version of EPAM. However, it shares many features with the Holistic Approach, and the two approaches previously have been confused (e.g. in Dunbar et al. 1998). The Scientific Panel Assessment Method has been applied to an unregulated but highly modified Australian river (see Arthington (1998a) for further discussion). An extension of EPAM and SPAM, with similar tenets to the Holistic Approach, has been developed by the Queensland Department of Natural Resources, Australia, namely the Habitat Assessment Method (HAM; Arthington 1998a). The method employs a specialist Technical Advisory Panel (TAP) to recommend EFRs, uses habitat as a surrogate for assessing the flow requirements of aquatic biota, and does not include field data collection. It assumes that maintenance of the full suite of healthy habitats will perpetuate the physical, biological and functional features of the riverine ecosystem (Walter et al. 1994, cited in Arthington 1998a).

Most often in association with HAM, a Water Allocation Management Planning (WAMP) Benchmarking procedure, has been increasingly used to develop EFRs (Arthington 1998a). Presently, it is the only process being used in Australia to predict the possible impacts of flow regulation in poorly studied systems (Bunn 1998, cited in Arthington 1998a). It provides a top down process in which various environmental flow scenarios are analysed to produce a series of key statistics for the river of interest, each describing the quantitative and temporal dimensions of critical flow thresholds (e.g. frequency of floodplain inundation), as typically specified by a TAP or similar group of experts. Each statistic can then be compared with the value calculated for the natural flow regime, for the study river or other basins with similar natural flow regimes, and the percentage change from natural determined and interpreted (Arthington 1998a). An Integrated Quantity Quality Modelling platform (IQQM; Arthington 1998a) is used extensively within the benchmarking approach, as well as in conjunction with other Australian holistic methodologies, to generate hydrological time series, both pre-regulation and reflecting various flow modification scenarios. It also enables the development of real time flow management rules at a whole catchment level, with simulations of the extent to which EFRs are met at points in the river system under different scenarios of offstream use (see Arthington (1998a) for a full description of its use).
3.10 Strengths and weaknesses of holistic methodologies, data needs and expertise

Holistic methodologies exhibit several advantages over other types of environmental flow methodology, most importantly perhaps in that they can potentially be used to address all components of the riverine ecosystem, and have strong links with the natural hydrological regime. Also, they consider all aspects of the flow regime, such as the magnitude and timing of both baseflow and flood events, and their outputs can be generated at several levels of resolution. Hence, they are pragmatic, flexible and robust, and designed to cope with EFAs where time, finances, available data and expertise are constraints. However, they rely to a considerable extent on professional judgement, so care must be taken to apply them in a rigorous, well-structured manner, in order to ensure sufficiently reproducible results. As with most other current environmental flow methodologies, there are few applications of holistic methodologies other than in their place of origin, and only local critiques are provided in the literature. Moreover, they all require comparison with other international approaches, testing and verification of their assumptions, and assessments of their predictive capacity. Although detailed physical habitat and water quality modelling are not routinely performed in holistic methodologies to date, there is scope for the advancement of these methodologies through the progressive incorporation of such tools.

As a result of the multidisciplinary nature of holistic methodologies, and the broad range in data requirements, ranging from expert panel assessment of existing information, in SPAM and others, to intensive baseline data collection in approaches like DRIFT, it is not possible to specify all the data requirements and types of expertise. However, specialists in the flow-related requirements of each of the ecosystem components to be addressed are needed, as well as, as much supporting data as possible. Comprehensive hydraulic and hydrological data are also essential, and in formats that are readily usable by specialists. In methodologies like the BBM and DRIFT, data on the needs of the local people dependent on the river for their livelihood (the PAR) are also essential.

4. Methodologies for the maintenance of channel form, and fluvial geomorphological and sedimentological processes

Flows to maintain channel morphology and associated habitats, and to provide for transportation of sediments, commonly referred to as flushing flows, are critically important for riverine ecosystems and their biota. However, the recommendation of such flows is one of several facets of EFAs that has not been adequately investigated to date (Tharme 1996; Reiser et al. 1989a). Historically, most flushing flow methodologies have been focused on maintenance of fish habitat (Reiser et al. 1989b), while more recently, there has been a move towards addressing geomorphological and sedimentological flow needs as one component of a more comprehensive EFA (Section A1.4). Guidelines for conducting flushing flow studies and for assessing the need for, and timing, magnitude and effectiveness of flushing flows are reviewed in detail in Reiser et al. (1987) and Reiser et al. (1989b).

Five broad categories of methodologies appear to exist for the establishment of flushing flow recommendations. The first two types, namely holistic (Section A1.4) and habitat simulation methodologies (Section A1.3), in the latter instance specifically IFIM, are commonly used nowadays (Tharme in prep.). Hydrologic event methods, channel morphology methods; and sediment transport methods comprise the three component-specific groups of techniques (Tharme 1996). Hydrologic event methods utilise streamflow records to develop a statistical correlation between a particular hydrological variable and the observed flow at which adequate flushing or channel maintenance is achieved (Reiser et al. 1989b). Many of these methods are based on flood frequency analyses, focusing on bankful or dominant discharge, or use flow duration analysis. Methods that rely on
features of channel morphology explore the ways in which the relationship between discharge and sediment quantity affects channel hydraulic geometry (Reiser et al. 1989b). Sediment transport relationships rely upon the concept of a threshold of motion, where a certain minimum flow is required to mobilise the stream bed before significant sediment transport occurs. This fifth group includes the majority of available techniques.

Reiser et al. (1987, 1989b) and Tharme (1996, in prep.) document the basic data requirements, advantages and disadvantages of roughly 25 approaches employed throughout the world.

Presently, there is no recognised standard or state-of-the-art office or field methodology for the prescription of flushing flows, and many uncertainties are associated with existing approaches. Many flushing flow recommendations are largely made on the basis of professional judgement, and follow-up or verification studies are generally not undertaken. Of the three component-specific types of methods, Hey's (1981, cited in Reiser et al. 1989b) observation of test flow releases is considered the most reliable one, and where test releases cannot be made, sediment transport methods previously have been advocated. Although no single methodology entirely addresses magnitude, duration, effectiveness, timing and frequency of flushing, it would seem that holistic methodologies presently provide the greatest scope for such a comprehensive assessment (Section A1.4). The documented variability of results generated by different flushing flow methodologies amplifies the importance of monitoring studies, which are the only way in which the adequacy of the recommendation can be verified, and the effectiveness and predictability of the method itself.

The full data requirements are specific to each methodology, but typically include information on channel geometry, cross-section hydraulics, flood frequencies, sediment particle size distributions and transport velocities, as well as sources and types of sediment inputs. Expertise in the fields of river hydraulics, hydrology, sedimentology and fluvial geomorphology is required.

5. Environmental flow methodologies for water quality purposes

Historically, environmental flow methodologies have tended to focus exclusively on flow quantity, and water quality has often been disregarded, this despite its obvious importance (Tharme 1996). Currently the three most commonly used approaches for assessing environmental flows for water quality purposes are water quality models, IFIM, and holistic methodologies (Tharme 1996).

Several sophisticated, state-of-the-art water quality models, such as CE-QUAL-RIV1 (Bedford et al. 1983, cited in Dortch and Martin 1989) exist for application to regulated rivers. However, links between model outputs and final recommended EFRs are often not explicit. Malan et al. (1999 in prep.) provide a review of current models and discusses approaches geared towards dynamically linking water quality and flow data. IFIM has been used to assess environmental flows for water quality by linking various water quality and temperature models, for instance QUAL-2E (Brown and Barnwell 1987, cited in Armour and Taylor 1991) with other components of IFIM. Within IFIM, SI curves can also be constructed for temperature and various chemical variables in relation to biotic activities like fish incubation and spawning that can be incorporated directly into PHABSIM II. Finally, all the holistic methodologies make provision for the inclusion of water quality criteria for ecological and, sometimes social needs, to various degrees (see references in Section A1.4 for further explanation).

Although the water quality modelling of rivers is fairly well developed (Dortch and Martin 1989), the extreme complexity of water quality-discharge interrelationships and of biotic responses to changes in quality, makes it difficult to reliably predict environmental flows for water quality, even with models of high resolution. Furthermore, with most water quality models for regulated rivers, guidelines are seldom provided on how the outputs can be used to generate EFRs for the maintenance of downstream
water quality. Although holistic and some habitat simulation methodologies include water quality in a more comprehensive manner than many other approaches, the assessments are often limited by the absence of modelled data on changes in chemical constituents and temperature with changes in discharge. Additionally, there is generally insufficient information on the tolerance levels of the biota to changes in chemistry with alteration of the flow regime. For these kinds of reasons, the development of methodologies that specifically address EFRs for water quality has largely lagged behind the development of other environmental flow techniques.

The kinds of expertise best suited for assessing environmental flows for water quality include specialised hydro-chemical modelling skills, as well as an understanding of the chemical tolerance ranges of aquatic biota (ecotoxicology).

6. Methodologies addressing the ecological flow requirements of riparian vegetation

Despite widespread recognition of the ecological importance of riparian zones and their numerous functions (Kondolf et al. 1987), and the development of a considerable body of research on sources of water that sustain riparian vegetation (Stromberg and Patten 1990, 1996), there is a notable lack of formal methodologies for addressing the EFRs of riparian vegetation. The various approaches that have been developed to determine the flow needs of riparian vegetation, appear to have evolved only since the 1980s, mostly within specific case studies (Tharme 1996).

Currently, there are three major, often partly integrated, ways in which EFRs for riparian vegetation are assessed. The first entails the linkage of stream discharge and associated hydrological variables with variables associated more directly with the riparian belt, particularly the riparian groundwater table. An indirect link is then sometimes established between the latter variables and the vegetation. Kondolf et al.’s (1987) Hydrogeomorphic Site Characterisation Methodology is an example of this type of approach. Flow-vegetation growth models represent the basis of a second set of techniques (Stromberg and Patten 1990, 1996). Data requirements, and applications, advantages and disadvantages of the two approaches are summarised in Tharme (1996). Thirdly, holistic methodologies are used in the Southern Hemisphere for assessing EFRs for riparian species and/or communities, and are probably the best structured methodologies as yet for this purpose (Section A1.4).

For all the above approaches, specialist botanical expertise in riparian vegetation is required, with additional understanding of surface and groundwater interactions with vegetation. Hydrological and hydraulic skills are also needed.

Considerable research is required to improve the level of understanding of relationships between riparian vegetation and flow, if successful methodologies are to be developed for routine application. Such methodologies will need to consider multi-species responses and several aspects of the flow regime, when determining the EFRs of entire riparian communities.

7. Methodologies addressing ecological flow requirements of wildlife

Inadequate emphasis is being placed worldwide on research into ecological flows for wildlife, with assessments appearing to be recent and restricted to New Zealand, South Africa and the USA. Information on the topic is scarce, and Kadlec (1976), Tharme (1996) and Ferreira (1998) provide the only reviews.
There are no reconnaissance-level methodologies or guidelines for assessments of environmental flows for wildlife, yet the majority of information necessary for this level of assessment probably already exists.

Currently, the emphasis is on habitat simulation methodologies, with case-specific development of predictive models (see Tharme (1996) for examples of wildlife models), or most commonly, application of IFIM through the development of SI curves describing habitats on which various wildlife species are dependent. Mosley (1983) provides a case study on the influence of environmental flows on the availability and quality of riverine habitats used by birds, while Gore et al. (1990) used IFIM to assess EFRs for a semi-aquatic mammal. Environmental flow assessments using holistic methodologies, specifically the BBM and DRIFT, have included EFRs for herpetofauna and water-dependent birds, as well as some considerations of use by terrestrial wildlife (see Ferreira (1998) for an example). However, although holistic methodologies have the potential to include environmental flows for wildlife in a structured manner, this is not routinely done at present.

There are several areas where research is required for advancement of methodologies for wildlife (Tharme 1996, in prep.). Most importantly, effort needs to be expended on detailing the degree of dependence of wildlife species on instream and adjacent riverine habitats, and on the identification of species that are entirely dependent on the riverine ecosystem. As many groups of wildlife are dependent on riparian and floodplain habitats, work is needed to further the development of relationships between riparian vegetation and environmental flows, and to expand knowledge on the functions of floods in maintaining non-channel habitats like wetlands and floodplains.

8. Methodologies addressing the ecological flow requirements of wetlands, floodplains and estuaries

While consideration of EFRs have, to-date, focused very little on wetlands in a broad context, including floodplains and estuaries, the need to address problems pertaining to reduced or altered hydrology of wetlands, or reduced freshwater inflows to estuaries, has been recognized for some time. This is particularly important in that wetlands form transitional buffer zones or nodes of immense ecological diversity and importance, and provide unparalleled environmental, wildlife and socio-economic values (Harding 1999 in prep.).

Although discussion of related EFRs for nearshore coastal environments and fisheries, linked to estuaries, is beyond the scope of this report, Bunn et al. (1998, cited in Arthington et al. (1998b) discuss the present status of such approaches.

Progress in addressing EFRs has been slowed by several factors, such as the sheer ecological complexity of wetland systems, and the difficulties inherent in delineating and classifying them; the difficulties of modelling water flows within complex wetlands; problems pertaining to the use of linear modelling procedures in estuaries where dual sources of water, fluvial and marine, and their different seasonal time scales, require consideration; lack of consensus on appropriate indicators of estuarine ecosystem health; insufficient monitoring, on a continuous basis, of the biota of individual ecosystems, and the lack of concurrently-collected data to allow inter-comparison of ecosystems; and prediction of the river flows, or ranges of river flows which bring about significant changes on the biophysical environment of wetlands, floodplains or estuaries.

Notwithstanding the above information barriers, studies aimed at determining EFRs for wetlands and estuaries are currently underway in several countries (see below), although there is virtually nil practical validation of the theoretical concepts at the present time. International initiatives are broadly centred on the determination of features such as: runoff and river flow scenarios; definition of key biological indicators and components; identification of interactive processes amongst components; description of natural and present conditions; and predicted changes which would accompany the
various scenarios. They typically require expertise in hydrodynamic modelling, as well as multidisciplinary knowledge of the structure and functioning of the various wetland systems.

In South Africa, within the framework of Ecological Reserve determination (DWAF 1998), a preliminary method for determining estuarine flow requirements has been developed, while one for wetlands is expected to be available for pilot testing during the second half of 1999 (Harding 1999 in prep.). A number of initiatives are underway in Australia (Harding 1999 in prep.; McCosker 1998, cited in Arthington et al. 1998b). In North America, attention is being devoted to procedures for the delineation and characterisation of wetlands and to restoration strategies (Harding 1999 in prep.). In South America, some work is underway on the dynamics of floodplain lakes and wetlands (Harding 1999 in prep.), while elsewhere in the world, details are presently less clear, especially with regard to work on estuaries. In the United Kingdom and Europe, the interdisciplinary pan-European “Functional Assessment of European Wetland Ecosystems” project has yielded valuable conceptual framework and functional assessment protocols, as well as indicators of riverine wetland functioning (Harding in prep.). However, field-testing of guidelines and protocols for the EFRs of wetlands and estuaries appears to be still in its infancy, and it will be some years before definitive patterns of biotic response begin to emerge. Moreover, there are very few case studies for which the details are available now.

9. Methodologies addressing groundwater and its links with surface flow in rivers

The international literature on this topic has yet to be intensively reviewed (Tharme in prep.). However, it is evident that methodologies that explicitly assess EFRs for groundwater, particularly in terms of links with surface flows in the river channel, as well as with conditions in the riparian zone, wetlands and floodplain, are virtually absent (Arthington et al. 1998b). However, cognisance of groundwater is taken in some assessments of EFRs for riparian vegetation and wetlands (see Sections A1.7 and A1.9). Geohydrological investigations have also formed part of several South African holistic EFAs using the BBM (Tharme in prep.). In South Africa, within the framework of determination of the Ecological Reserve (DWAF 1998), procedures are being formulated for the calculation of EFRs for groundwater at several levels of resolution, and for the integration of groundwater requirements with other components of riverine ecosystems like wetlands (Parsons 1998).

Available information relevant to EFAs was sought using Netscape Navigator software. Search topics used to generate the information include:
- Instream Flow Assessments (or Requirements)
- Environmental Flow Assessments (or Requirements)
- Biophysical Flow Assessments (or Requirements).

Some of the sites were accessed via links provided by other relevant sites.

<table>
<thead>
<tr>
<th>Description</th>
<th>Geographic distribution of research</th>
<th>Web site</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information on the Colorado Water Conservation Board and their environmental flow programme, including a list of their environmental flow reports, current projects, methodologies and contact personnel. Their newsletter is also available on this site.</td>
<td>Colorado</td>
<td><a href="http://www.dnr.state.co.us/cwcb/isf/programs/instream.htm">http://www.dnr.state.co.us/cwcb/isf/programs/instream.htm</a></td>
</tr>
<tr>
<td>This is the Stream and Riparian Ecology section of the Midcontinental Ecological Science Centre (MESC) which offers a subscription to IFIM-news to keep you posted on items of general interest. This site provides access to the IFIM chronicle and gives information about current projects (which include issues of dam management and stream flow regimes).</td>
<td>California, Oregon, Colorado, Utah, Arizona, Montana, Dakota</td>
<td><a href="http://www.mesc.usgs.gov/sre/sre.htm">http://www.mesc.usgs.gov/sre/sre.htm</a></td>
</tr>
<tr>
<td>This is the site of the University of California’s “Centre for water and wildland resources”. It describes some of the current research projects at the centre which includes EFAs.</td>
<td>California</td>
<td><a href="http://www-cwwr.ucdavis.edu/water_center.currentp9899.shtml">http://www-cwwr.ucdavis.edu/water_center.currentp9899.shtml</a></td>
</tr>
<tr>
<td>This is the Land and Water Resources Research and Development Corporation (LWRRDC) site. LWRRDC is an Australian institute involved in EFAs. This site provides a list of projects related to flow being undertaken by various Universities and Governmental institutions in Australia that are administered by LWRRDC.</td>
<td>Australia</td>
<td><a href="http://www.wrrdc.gov.au/index.html">http://www.wrrdc.gov.au/index.html</a></td>
</tr>
<tr>
<td>This site details the topics covered</td>
<td>UK, New</td>
<td><a href="http://www.eardc.swt.edu/ief/index.html">http://www.eardc.swt.edu/ief/index.html</a></td>
</tr>
<tr>
<td>Description</td>
<td>Geographic distribution of research</td>
<td>Web site</td>
</tr>
<tr>
<td>-------------</td>
<td>-----------------------------------</td>
<td>----------</td>
</tr>
<tr>
<td>during the Instream and Environmental Flows Symposium on technology and Policy issues held in Houston, Texas in December 1997. This Symposium brings together technology and policy issues in a series of sessions on EFRs.</td>
<td>Zealand, Canada, USA: Colorado, Georgia, Virginia, Utah, Montana, North Carolina, Nevada and Colombia</td>
<td></td>
</tr>
<tr>
<td>Cooperative Research Centre for Freshwater Ecology website. It gives details of centre research on EFRs (mainly in Australia). The site also provides a list of current projects, publications and links to various other water related sites.</td>
<td>Australia</td>
<td><a href="http://enterprise.canberra.edu.au">http://enterprise.canberra.edu.au</a></td>
</tr>
<tr>
<td>Web site for the Water Studies Centre at Monash University, Australia. This institute is involved in environmental flow-related studies in Australia and the site lists the projects which they are currently involved in, contact personnel and links to related water sites on the web.</td>
<td>Australia</td>
<td><a href="http://www.wsc.monash.edu.au">http://www.wsc.monash.edu.au</a></td>
</tr>
<tr>
<td>Centre for Catchment and Instream Research (CCISR) at Griffith University, Australia. This Centre is involved in environmental flow management research funded by LWRRDC (see above). A description of their current research is available on this site.</td>
<td>Australia</td>
<td><a href="http://www.gu.edu.au/centre/ccisr/">http://www.gu.edu.au/centre/ccisr/</a></td>
</tr>
<tr>
<td>This site gives access to the abstracts of papers published by Prof. A. Arthington (CCISR) on river ecology and flow management since 1983.</td>
<td>Australia</td>
<td><a href="http://plato.ens.gu.edu.au/ecology/ccisr/aasyn1.htm">http://plato.ens.gu.edu.au/ecology/ccisr/aasyn1.htm</a></td>
</tr>
<tr>
<td>Proceedings of the 23rd WEDC Conference titled “Water and sanitation for all: Partnerships and innovations”, held in Durban, South Africa in 1997. This site provides the papers that were presented at the conference and one in particular titled “Environmental flow requirements: a social dimension” is relevant.</td>
<td>South Africa</td>
<td><a href="http://www.lut.ac.uk/departments/cv/wedc/23c">http://www.lut.ac.uk/departments/cv/wedc/23c</a> prefs.htm</td>
</tr>
<tr>
<td>The home page for the American Geophysical Union. Navigate through “meetings”, then “past</td>
<td>Australia</td>
<td><a href="http://www.agu.org/">http://www.agu.org/</a></td>
</tr>
</tbody>
</table>
This is a working paper of the World Commission on Dams. The report published herein was prepared for the Commission as part of its information-gathering activity. The views, conclusions, and recommendations are not intended to represent the views of the Commission.

<table>
<thead>
<tr>
<th>Description</th>
<th>Geographic distribution of research</th>
<th>Web site</th>
</tr>
</thead>
<tbody>
<tr>
<td>meetings” in order to find the list of papers presented at the 1996 “Western Pacific Geophysics Meeting” held in Brisbane, Australia in July 1996. One of the sessions at this meeting dealt with “Assessment and Provision of Environmental Flow Requirements”.</td>
<td></td>
<td><a href="http://www2.ncsu.edu/ncsu/wrri/reports/">http://www2.ncsu.edu/ncsu/wrri/reports/</a></td>
</tr>
<tr>
<td>This is the site of the publications available through the “Water Resources Research Institute”, University of North Carolina. Some of these publications are relevant to EFAs.</td>
<td>USA</td>
<td><a href="http://www2.ncsu.edu/ncsu/wrri/reports/">http://www2.ncsu.edu/ncsu/wrri/reports/</a></td>
</tr>
</tbody>
</table>
**Annex 3: Summary List of Internet Sites that Provide Further Information on Issues Surrounding Shared Water Courses.**

<table>
<thead>
<tr>
<th>Description</th>
<th>Geographic Distribution Of Involvement</th>
<th>Web Site</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protocol on shared watercourse systems.</td>
<td>SADC countries</td>
<td><a href="http://www.sn.apc.org/afwater.sadcptcl.htm">http://www.sn.apc.org/afwater.sadcptcl.htm</a></td>
</tr>
<tr>
<td>This site outlines research undertaken on the international problem of managing shared freshwater resources. It is titled “International agreements and collaboration in the environmental area: The case of freshwater resources in an era of global environmental change.”</td>
<td>Case studies on the Mekong and Ganges-Brahmaputra rivers</td>
<td><a href="http://www.susx.ac.uk/Units/gec/fellsumm/thomas.htm">http://www.susx.ac.uk/Units/gec/fellsumm/thomas.htm</a></td>
</tr>
<tr>
<td>This site presents the issues of concern between Turkey, Syria and Iraq regarding the Euphrates-Tigris Basin.</td>
<td>Turkey, Syria and Iraq</td>
<td><a href="http://www.mfa.gov/tr/grupa/ad/adg/default.htm">http://www.mfa.gov/tr/grupa/ad/adg/default.htm</a></td>
</tr>
<tr>
<td>This site, titled “The Euphrates-Tigris basin: an overview and opportunities for co-operation under</td>
<td>Turkey, Syria and Iraq</td>
<td><a href="http://ag.arizona.edu/OALS/ALN/ln44/kaya.html">http://ag.arizona.edu/OALS/ALN/ln44/kaya.html</a></td>
</tr>
<tr>
<td>Description</td>
<td>Geographic Distribution Of Involvement</td>
<td>Web Site</td>
</tr>
<tr>
<td>----------------------------------------------------------------------------</td>
<td>----------------------------------------</td>
<td>----------</td>
</tr>
<tr>
<td>international law\textsuperscript{(n)}, describes the development on this system and disputes arising from utilisation of a shared watercourse.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix A: Comments Received from Review Panel

The WCD is committed to an open and consultative process. To broaden the scope for participation and input from interested groups and stakeholders, the Commission invited specialists, centers of excellence and WCD Forum members to prepare comments on the thematic drafts. Comments were received throughout the progression of the thematic review. The comments were incorporated to the extent possible into subsequent drafts of the thematic.

Every comment has been read carefully. Some are informed individual perspectives on which the WCD can not mediate. For example, there are some comments that seek the endorsement of the WCD, and the WCD’s mandate is neither to adjudicate nor to mediate on specific dams or disputes. Others may go beyond the scope of the individual thematic review.

Please note that section numbers referred to in individual commentaries will have changed in the final version of the report.

I: Comments on the July 1999 Draft

<table>
<thead>
<tr>
<th>a) Cristina Rivero</th>
<th>ENDESA, Spain</th>
</tr>
</thead>
<tbody>
<tr>
<td>b) Shekhar Singh</td>
<td>Indian Institute of Public Administration, New Delhi, India</td>
</tr>
<tr>
<td>c) Rafik Hirji</td>
<td>World Bank</td>
</tr>
<tr>
<td>d) Pip Steneke</td>
<td>Water Policy coordinator, Nature Conservation Council, Australia</td>
</tr>
<tr>
<td>e) Martin Perusse</td>
<td>Direction Environnement, Hydro Quebec, Canada</td>
</tr>
<tr>
<td>f) Hans Wolter</td>
<td>FAO-AGLD</td>
</tr>
<tr>
<td>g) Robert Dobias</td>
<td>Senior Environment Specialist, Environment Division, Asian Development Bank</td>
</tr>
<tr>
<td>h) Yogi Carolsfeld &amp; Brian Harvey</td>
<td>World Fisheries Trust, British Columbia, Canada</td>
</tr>
<tr>
<td>i) Takehiro Nakamura</td>
<td>United Nations Environment Programme</td>
</tr>
<tr>
<td>j) Shunroku Nakamura</td>
<td>Toyohashi University of Technology, Toyohashi, Japan</td>
</tr>
<tr>
<td>k) Tor Ziegler</td>
<td>World Bank</td>
</tr>
</tbody>
</table>

a) Comments by Cristina Rivero

General Comments
We find very interesting the proposal of environmental survey studies after the construction of the dams, as we think it is the only way of testing the real effectiveness of the mitigation, prevention or compensation measures used and therefore of making progress. Though the survey and monitoring programmes are mandatory in many countries legislation, it is a fact that they continue to be a weak point in the process.

The Building Block Methodology is not per definition a method for determining minimum required instream flows but a protocol or guideline for the process of calculating the minimum flows. The calculations are made trough diverse techniques existing before in the fields of geomorphology, hydrobiology, etc.

It is very convenient to make understandable that the IFR is a regime or set of flows (minimum, bankfull discharge, flushing flows, etc.) and not only a single minimum value. Nevertheless it seems quite complicated to think that the BBM is able to integrate all the ecosystem structure in the process of calculation of the IFR and maybe some difficult to believe given the extreme complexity of the river ecosystems.
In Spain, though the criteria of using the 10% of the mean annual flow is often used, other methods are followed in different regions, as hydrobiological methods (PHABSIM) and methods based in Flow Duration Curves.

The paper proposes trying to obtain the IFR from a multidisciplinary experts panel and from social consensus. This implies to invest time and money in the previous phase of obtaining the IFR, without any guarantee that the obtained IFR will “work” adequately, not even at social level (changes of criteria, new expectations, etc.) given that the rivers are complex and highly variable systems especially in some regions. It could be an approach to:

Keep separated the social and ecological requirements. It has to be taken into account that depending on the development stage of each region or country and on the existing water uses and requirements (acquired “water culture”), the ecological aspects can be influenced in very different ways by the ecological aspects, and in many cases in detriment of the former.

To establish a quick, economic and ecologically coherent methodology (from the existing ones) to obtain the IFR along with the generic objectives pursued.

To validate the results with follow-up studies carried out after the implementation of the IFR, testing really what is working and what is not and which objectives can or cannot be reached. The modifications will be minimum if the initial generic objectives are well identified and the calculation method for the IFR is an adequate one. This is the only way of reaching really valid IFR values from an environmental point of view and of having the possibility of reaching social consensus.

Foreseeing that the environmental and social requirements are variable and changing in time, the methodology for the determination of the IFR should propose or recommend the periods and frequency for its review and/or renegotiation in the future. It has to be beard in mind that no methodology guarantees a perfect functioning. In this sense, if the method used is a good one, its adjustment to real conditions will mean minor changes.

We consider very interesting and convenient to elaborate a methodology for river classification according to its value and conservation status with the aim of being able to decide the alteration degree that can be admitted in every case. The techniques used for the evaluation of natural protected areas could be adapted to this objective.

b) Comments by Shekhar Singh

1. In general, the paper is informative and well structured. The comments that follow are mainly about focus and stress. Some seeming gaps are also pointed out.

2. The fact that the downstream adverse impacts, both social and environmental, of dams are very severe, has till recently not been acknowledged. Focus has mostly been on upstream social and environmental impacts. Even today, in many countries, this is a neglected area. Therefore, this paper is very critical in raising awareness about this important but neglected issue.

3. In the paper under review, there is frequent mention of “valued river species”. Insofar as the reference is a part of a description of certain methodologies, it is legitimate. However, perhaps the paper should stress that the scientifically correct approach is to focus on all species, as they are interdependent and constitute the biodiversity of the riverine ecosystem.

4. Following from this, perhaps there could be greater stress on distinguishing between the economic value of specific components of the riverine ecosystem and the ecological value of the whole and its parts. Needless to add, ecological value also translates into medium and long term economic value, but much else besides.
5. It is a pity that the adverse impacts on the flow of silt and nutrients, because of the dam, are not taken up but only mentioned in passing (page 6 for example). I do not believe any study of downstream impacts can be complete without taking into consideration the changes in the flow of nutrients and silt. This affects all the various parameters of the riverine ecology and should, to my mind, be stressed in this paper. The disruption of silt and nutrient flow is especially a problem in rock fill dams which do not have sluice gates but only spill-ways and, as such, trap most of the silt and nutrients at the dam site.

6. It is repeatedly mentioned that the nature and level of an EFA depends on the objectives set for the river. Though this is technically correct, such a statement might appear to legitimise a system where the basic ecological (and social) functions of a river get ignored or become subservient to its economic and “development” functions. Perhaps the paper should stress that there are certain values and functions which are non-negotiable. In India, some of the work we have done in this direction accepts two basic assumptions. First, that under no circumstances can the ecological integrity of a river be compromised. This means that there must always be enough water (and nutrients) in the river to ensure that the ecosystem is not permanently damaged and that none of the natural species become extinct. This is also necessary if we want to ensure the sustainable use of the river system. The second assumption is that the drinking and subsistence water needs of the local population dependent directly or indirectly on the river would be the first priority on the surplus available, after the ecological functions have been safeguarded. Only after this can the remaining surpluses be distributed for other functions. I feel that some such approach needs to be stressed in the paper.

7. Also, whereas some stretches of the river can be sacrificed, this should only be done after it is ensured that adequate portions of the river remain ecologically functional and that the sacrifice of a few sections of the river does not have irreversible adverse impacts on the total ecosystem. The paper needs to stress this point.

8. I think the paper would benefit from a greater stress on the adverse social and economic impacts of dams due to the disruption of flows. Though a lot of detail is given about the ecological impacts, the social and economic aspects are relatively ignored.

9. There is mention of the cost of preventing and mitigating environmental damage. However, there is not a corresponding stress on the cost of environmental damage and the cost of inaction with regards to the environment. Clearly any EFA proposal should stress on the costs to the economy and to the society if the riverine ecosystem was degraded. Alternatives to the proposed levels of withdrawal of water must then be worked out. In India, for example, we have proposed a physical budgeting where a certain amount of water in a river is reserved for ecological and social functions. In case the surplus available is not enough to meet various other economic needs, then investments have to be made in treating the catchments or in water conservation technologies so that either additional dry season flows become available or the demand for water goes down, releasing larger surpluses.

10. Similarly, the irrigation practices and even the crops that are to be grown need to be designed keeping in mind water availability. In other words, the ecological integrity of the river must be the first concern, followed by the subsistence needs of the dependent populations, and only after that should the use of water for other purposes be planned for. This should, to my mind, be the predominant theme of the paper.

11. As already mentioned, the stress should be on establishing a water use system that is not only socially just but also allows for the sustainable use of the river system, over time and in all its functions.

12. The paper states, on page 6: “it is felt by many that environmental flows should not include water for diluting pollutants. Rather, it is felt that water pollution issues should be addressed at source.” However, it might be worth mentioning here that whereas pollution control at source is possible in cases of “point” pollution, it is very difficult in cases of “non-point pollution”. In case this is required to be done in order to allow the extraction of a greater amount of water, then the costs of this must also be put onto the project and be a factor for determining the economic viability of the project.
13. Another common misconception, at least in India, among dam builders is that as long as the minimum flow of the river does not in any season fall below the minimum dry season flow, there could be no possible harm to the ecology. Though the paper does talk about the ecological role of floods, especially first rain floods, perhaps it could also stress that reduced rainy season flows, even if they are higher than minimum dry season flows, also have a lot of adverse impacts on the ecosystem. Many species of fish, for example, breed in the ample waters of the rain fed flows.

14. In general, the paper is somewhat ambiguous on the adverse environmental impacts of various river valley projects. Perhaps the tone is set by the scoping paper which says that “in some cases dams have improved the environment through...”. This is, of course, a common refrain from the builders and promoters of dams. One must ask what “improving the environment” means. Surely the replacement of forests and grasslands by a lake cannot _prima facie_ be considered an improvement. There is an assumption that the provision of water for any dry (arid or semi-arid) ecosystem must be an improvement. There is also an assumption that the planting of trees on all land, whether it be erstwhile grasslands or wetlands or even deserts, is also an “improvement” of the environment. These, alas, are not well-founded assumptions. Current thinking suggests that all that whereas a degraded environment can perhaps be rehabilitated, humans cannot “improve” upon the environment, at least not as long as maintaining natural ecological and species biodiversity is a prime objective.

c) Comments by Rafik Hirji

I have read the King et al paper and generally found it very interesting. Although it is very well written, I have several concerns regarding the extent to which it addresses the 3 questions posed below (which form the scope of the paper).

> The review addresses three broad questions:

> 1. How many countries are using instream flow methodologies, how effective are they, and what constitutes good practice in this field?

While the paper provides a broad overview of the different countries using different IFR methodologies, and a typology of the methodologies themselves, they do not provide enough specific recent examples, where IFRs have been mandated. For example, the Central valley project Improvement Act essentially mandated an additional 800,000 Acre feet of already allocated water to be re-allocated for instream purposes in California in 1992, marking a major shift in water management in that region. Also, in 1996, the Murray Darling Basin Commission mandated a permanent cap on water use in the Murray and Darling Rivers at the 1993 level of use (implying a reduction in 1996 to 1993 level of use). It would be useful to understand the principles and methodologies employed to define the 800,000 AF and the cap for Instream purposes in such real world cases and this could contribute to a better understanding of the competing values that are being traded.

Likewise, there are a number of specific examples in Southern Africa, which could also be useful to highlight and draw lessons from.

> 2. How are instream flows defined and implemented during the project cycle?
The Definitions appear to have been covered well, but the implementation of the IFRs were less clear to me. In many cases, IF are being defined after the fact...thus their implementation is a restorative measure compared to those implemented earlier as protective or mitigatory measures. It would be useful to clearly distinguish such cases as they have been applied in real world cases.

> 3. What are the prerequisites for successful implementation?

In my opinion, IFRs will only be implemented successfully if there is a sound policy framework which mandates them (which essentially implies that ecological demands of water have to be considered important, legitimate or priority uses along with other consumptive and non consumptive uses) and which also specifies appropriate methods and criteria for defining IFRs. This to me is the central issue. Currently, it seems to me that the general practice has been to use and adopt reactive means (typically using the EIA process to define the downstream needs, and this typically takes place in the absence of a sound water policy framework). In such a case, the EIA has a burden of not only giving legitimacy to the instream flow requirements but also to than define them. Whereas in a pro-active approach where the water policy (such as in South Africa) defines the water reserve and gives it the primacy of use, the EA process is used to only fine tune the definition of the reserve (but not to deal with the legitimacy question which is already embedded in the policy) using the appropriate IFR methodology to define specific flow requirements for particular hydrological periods.

The authors have mentioned the water policy of south Africa, but only in passing. That section needs to be developed and underscored futher.

d) Comments by Pip Stenekes

I would like to make the following comments about the World Commission on Dams Thematic Report: Definition and Implementation of Instream Flows (‘the Report’) and the terms of reference:

➢ Overall, I think this report will make a valuable contribution to the literature on techniques for environmental restoration of rivers due to dams. However, I found some parts of the report a little unanalytical. Greater emphasis could be put on measuring some techniques against others and providing some real cases where techniques have worked, or not, and why.

➢ It should be emphasised that the scoping paper for this report (II.1 Dams, Ecosystem Functions and Environmental Restoration) is poor. It has a strong ‘economic’ approach to ecosystems - it makes it appear that ecosystems are only important as far as they provide economic benefits and that all ecosystem services can be realistically costed in cash terms. Little or no mention is made of debates over the intrinsic value of healthy riverine ecosystems, of their cultural, spiritual and aesthetic values, or of their vital role in providing livelihoods to hundreds of millions of people.

I quote from Patrick McCully:

“The Ecosystem Functions and Environmental Restoration scoping paper cites a list of "services" and "functions" of ecosystems but no overview of how ecosystems are affected by dams. A short summary of the latest scientific knowledge of the ecological impacts of dams would seem to be a basic necessity for this scoping paper."
One of the major ecological impacts of dams is the huge reduction they have caused in fish biodiversity. Yet the only mention of fisheries in the body of the paper is to say that dams "have improved the environment" through the creation of lake (sic) fisheries. A footnote mentions that fisheries issues are being discussed with FAO. This is hardly reassuring given that the main contribution of FAO to fisheries issues has been to promote the industrial fishing practices which have led to the collapse of fisheries worldwide. The fisheries issue needs to be addressed as one of impacts upon biodiversity as well as one of impacts on human livelihoods (eg 80-85% of the protein intake of the people in the Mekong region is estimated to come from freshwater fish) and culture (eg the major cultural importance of salmon for Native Americans in the Pacific Northwest).

The paper repeatedly mentions the impacts of dams on downstream ecosystems although it gives no outline of what the main downstream impacts may be. The only mention of specific downstream impacts is under 'Scope of Work', where it states that the review will assess downstream impacts "from the perspective of water quality and flow changes". However these are just two of the major areas of downstream impacts which would need to be addressed. Others include biodiversity, sedimentological and geomorphological changes.

The only material on upstream impacts is to discuss how reservoirs have supposedly "improved" the environment and had "productive and valuable" national parks declared along their shores. No mention is made of upstream impacts such as the massive areas of ecosystems flooded by reservoirs, the blocking of migration routes, and the deforestation often resulting from the fact that dams can provide access to previously inaccessible areas for loggers, colonists and developers.

This leads to a dangerous focus in the report now being reviewed. It is important to recognise that environmental flows should not be scene as a panacea for dams and weirs. I think the report does not make the point strongly enough that environmental flows (EFs) are unlikely ever to adequately mitigate the effect of a dam/weir.

Although the report talks about the full spectrum of costs needing to be considered for new dam developments, the whole report should be careful not to indirectly advocate EFs as a 'vindication' of dams (ie. there is no such thing as an environmentally responsible dam). EFRs are a last resort method for dams that are already constructed, and should in no way justify dam-building. This has been the experience in Australia where the proponent of a proposed dam development in NSW actually arguing that the development would 'assist' the environment even more by releasing more environmental flows after the dam was built.

Recognising the time constraints with such a report, a major problem with the aim of the draft report is the focus on 'best practices' at the exclusion of a similar emphasis on past and current practices, and the lack of analysis of individual case studies. This focus may give an unrealistically optimistic impression of the actual experience of dams and EFs as a 'mitigation technique'. While it is certainly vital to assess what type of EFs do 'work' and why (and to analyse whether what is claimed to work actually does so), it is also essential to understand that environmental restoration is limited at best when employing such mitigation techniques.

The report uses fairly scientific, sometimes technocratic, language. It would be perhaps useful to identify the target audience. Rural and community groups and NGOs would probably have difficulty in understanding some parts of the paper.

Table 2.1 – it is unclear what this table is trying to relay to the reader in the columns on the right-hand side.

Section 4.5 and 4.6 was very good, and contains useful information. The point should be made in Section 4.6 (about water legislation) that the reverse is true ie. that just because there is a good
water law in place, doesn’t mean that good practice will take place. In NSW, Australia, the water reforms have taken a very ‘policy’ focussed approached and have so far been quite successful despite the fact that EFs are not enshrined in legislation (although this is, of course, the ultimate aim of government and conservation groups).

- The analysis of how and whether environmental externalities can be incorporated into the economic analysis of dams is important. However this analysis should not start with the position that all externalities can and should be converted into monetary terms in some sort of politically ‘neutral’ or ‘unbiased’ way. Assessing the importance of environmental impacts relative to economic benefits often involves ethical, spiritual or other cultural judgements. These judgements need be negotiated in the political sphere, rather than reduced to supposedly ‘rational’ economic cost-benefit analyses which hide the essentially political nature of weighing up for example, a fish species versus a quantity of megawatts.

- Again, recognising time restrictions, the report should provide more examples of where mitigation of environmental impacts has been successful and where it has been unsuccessful. The report will be much stronger if it deals with unsuccessful mitigation, and analyses the frequency of successful compared to unsuccessful mitigation measures, and why some mitigation measures work and others do not.

e) Comments by Martin Perusse

**General Comments**

I acknowledge that this kind of mandate is not an easy task. So, given the time available, the paper shows a good review of methods available. However, if this is a good draft, I think it needs to be worked on since it is still a little too academic and thus does not reflect adequately the limits and constraints of the field. You must not forget that this question is tightly linked to the decision-making process in which any project lies.

1- I think this report should show more examples and should be more practical in order to help the WCD, the dam industry and all the decision-making process focus on the main issues.

2- Efforts should be made to summarize more adequately the methods in chapter 2 since many readers do not read appendices.

3- Implications of holistic methods should be made clearer. When you read the paper, you see that it pushes, in a subtle manner, for holistic methods. But it is not clear enough what these methods really are, that they rely on a lot of data, time, money and scientific expertise which in turn also need data, science, etc on which to base their judgment. In different domains, in ecology for example, holistic approaches have always been seen by many as the way to study problems and to solve them. But this paper lacks clarity on the limits and the constraints of such methods. In theory it may be the solution, but in practice and in the business field where time is everything, it is not that obvious that we can afford holistic methods. I am not saying that holistic methods should not be looked at, but rather that these complex questions must be debated from all angles: environment, science, human needs, economy...

4- More efforts should be made in identifying the crucial questions, the challenges, the gaps, the limits of all this. What are the consequences and how far should we go before making
choices of any kind? Chapter 5 does not provide that crucial understanding because it just flies over these important points.

5- All kinds of statements are made about studying this and that, about obtaining all the data needed. But what are the implications of all this in terms of delays, time and money? Furthermore, it is not very useful to read that one must consult (4.3) or that we have to think long term (4.5), since we already know this. These must be grounded into reality, which means: how can we do it in an efficient manner so that the environment and the economics are considered?

6- The paper should also clarify what is already known, what should be done in terms of research and development, what directions must be set to improve the practice on a long term basis, but how do we manage this question right now, as we are planning, studying and actually building water projects? The world will not just stop and wait until we have the right methods and all the data we should, especially in developing countries where basic needs are still to be fulfilled.

7- It seems to me that what would be very useful for the WCD and the commissioners is some kind of tool, such as a decision-making grid, in order to tackle this complex question. I understand that this suggestion is not an easy one, that is why I am committing myself here, hoping that it will help! So here is an example of a decision-making grid that could be developed in order to help the WCD, decision-makers and politicians everywhere in the world involved with dams and water projects.

A dam is usually built for one or more often many of the following purposes: irrigation, navigation, freshwater supply, flood/water control, or hydropower. Thus, regarding instream flow, the crucial questions are:

- Why and for whom do we need instream flow in a given river?
- When do we need the flow?
- How much flow do we need?

One way to deal with these questions is through simple steps such as the following.

**STEP 1.** Uses of the river water must be identified.
Then, parameters can be assigned for each water use in order to characterize the needs.

<table>
<thead>
<tr>
<th>EXAMPLES OF POTENTIAL USES AND NEEDS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PARAMETERS</strong></td>
</tr>
<tr>
<td>Basic needs</td>
</tr>
<tr>
<td>Physical environment</td>
</tr>
<tr>
<td>(erosion,sedimentation)</td>
</tr>
<tr>
<td>Biological environment</td>
</tr>
<tr>
<td>Drinking water</td>
</tr>
<tr>
<td>Water quality</td>
</tr>
<tr>
<td>Aesthetic</td>
</tr>
<tr>
<td>Projects needs</td>
</tr>
<tr>
<td>Navigation</td>
</tr>
</tbody>
</table>

This is a working paper of the World Commission on Dams. The report published herein was prepared for the Commission as part of its information-gathering activity. The views, conclusions, and recommendations are not intended to represent the views of the Commission.
<table>
<thead>
<tr>
<th>Irrigation</th>
<th>Types of cultures, growth season, timing of harvest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power generation</td>
<td>Electricity needs, demand profile</td>
</tr>
<tr>
<td>Freshwater supply</td>
<td>Quantity and quality, demand profile</td>
</tr>
<tr>
<td>Flood control</td>
<td>Flood profile</td>
</tr>
</tbody>
</table>

*Obviously, timing and amount of water are always crucial for assessment of needs.

**STEP 2.** All the data and any other type of knowledge must be assembled.

Traditional knowledge may be very useful in this context, for example on the minimum and maximum water level observed in a given river. Based on what is known, an evaluation of what remains to be known can then be made.

**STEP 3.** Impacts of the proposed project on these uses must be known.

We must have a clear idea of the potential impacts. This can come from experience on similar projects elsewhere and from an environmental and social impact assessment for that specific project. An important question here is: What is the minimal information needed to make a safe assessment?

**STEP 4.** Calculations of Environmental Flow Requirements (EFRs) can then be done.

Which method should be chosen to make the calculations on the amount and timing of the water needed? Choices would have to be made, keeping in mind the availability of data and the effort (in time and money) to obtain it. Again, the important question is: What is the minimal information needed to make a safe assessment?

**STEP 5.** Assessment of the applicability of the EFR regarding the project must be done.

Is the project still delivering the services it was planned for after applying the EFR? Is irrigation still efficient after more water stays instream for fish? Is the waterpower project still economically viable after applying the EFR?

**STEP 6.** Arbitration/mediation will finally have to be made.

All scenarios will eventually have to go through arbitration in order to accommodate the parties involved and the health of the ecosystem. How do we reconcile opposing needs for the same water in the same river (irrigation vs fish for example)?

This is just an example of the kind of work that could be done. There may be other ways to do it and it may be more exhaustive but any exercise of this type will eventually have to handle these parameters and questions. But what will always be important to consider is the identification of the crucial data, but only the crucial ones, needed to tackle this question adequately along with some kind of mediation process, so that in the end, projects are environmentally and socially acceptable.

**SPECIFIC COMMENTS**

**INTRODUCTION**

1.3

- The multiple and often contradictory needs for water is one of the greatest challenges about instream flow but it has not been acknowledged seriously anywhere in the text.
• Good practice regarding their involvement « could » be: (because it is still evolving).
• Why anthropological consultants? Scientists?

1.4

• « Usually, the greater the investment in the fieldwork and other specialist inputs, the higher the confidence in the output. » Yes, but the greater the time and money involved. One must be careful before assuming that the best thing to do is to study in details for a long time. In theory yes, but in real life it is not that simple.

1.5

• « As an example, a large dam in the upper reaches of a river, with poor or no downstream releases... »
This does not appear relevant or very useful. I would prefer to see real life examples to demonstrate the need for EFAs. We need to go beyond theory and general claims if we want to be of any use in this process.

1.7

• « Tharme and King (1998) illustrated that... ». This demonstration is neither clear nor convincing to me. It looks like I have to read this reference in order to understand the argument. Again, examples would be helpful.
• « At the national level, there is no doubt that EFAs have been successful. A growing number of countries now recognize the need for EFAs... » It is not because the need is recognized and research is going on that implementation is successful (see title of the section).
• « In the above countries and many others... ». Is it not the opposite, where a shift in attitudes and concerns about water pushes for EFAs?
• « Because of this dynamism, it might be said that there really is not a time when an EFA can be proclaimed a success... ». You cannot provide such a conclusion, it is not viable. From experience we should learn and know what is good and what is not. You will not sell EFAs to managers and decision-makers by saying that your tool cannot tell you if you have achieved the objectives identified, that there is no way to proclaim success and that on top of it, you will have to continue monitoring for the rest of your life! What kind of tool is that?!

3-TYPES OF ENVIRONMENTAL FLOW METHODOLOGIES APPLIED WORLDWIDE AND THEIR LIMITATIONS
(This chapter should read number 2 instead of 3)

• This section should be augmented because your resume does not stand by itself. If you are not very familiar with these methodologies, you have to read the appendix to really get a clue about each method (put back some of the text from appendix 1). This section should be the heart of the document since you must have an idea of the tools available, the advantages and disadvantages, the limits, the expertise needed, etc... in order to address the instream flow question. How can the reader say that we should do this or that if he does not understand the « science » around the question?
3. GLOBAL TRENDS IN THE APPLICATION AND ADVANCEMENT OF ENVIRONMENTAL FLOW METHODOLOGIES

3.1

- « However, such approaches are often less appropriate than holistic methodologies from the perspective of Southern Hemisphere and developing countries... » WHY? Such claims are important and must be supported by arguments and by facts to be of any use.

4. THE POSITION OF ENVIRONMENTAL FLOW ASSESSMENTS IN THE PLANNING PROCESS, AND POINTS OF LINKAGE

4.1

- Is this the process applied in South Africa, the process usually used in the world or the ideal process?... it is not clear. I do not find this section very informative and useful as it is. I did not recognize the Hydro-Quebec process in different places and my guess is that different readers will come to the same conclusions. Attempts to make a generic description of a process is generally deceiving since by definition such a process is site and project specific.

4.1.1

- At Hydro-Quebec, there is no field work involved.

4.1.2

- Again at Hydro-Quebec, there is rarely, if any field work involved at this stage.

4.1.3

- « All rivers or river stretches that would be affected by the shortlist of favored options should be targeted for a comprehensive flow assessment at this point. » At Hydro-Quebec we don’t do comprehensive studies for all options but rather rank them with an environmental evaluation by using environmental criteria. We then retain one or a few options in order to add detail to the feasibility studies.

4.2

- We do not necessarily and automatically make intensive base-line studies for each project. It depends on the project itself, the knowledge and data we already have at hand, the environmental issues, etc...
• «To use this approach to its best advantage, it is essential to complete a comprehensive series of studies of the nature and functioning of the riverine ecosystem, and of its importance in the life of people.» This is not clear at all and it sounds like one must study everything in detail.

• «There seems to be no reason why a mixture of top-down and bottom-up approaches could not be applied at different phases of water-resource planning. Each case should be treated on merit.» This conclusion sounds strange since it seems to me that the bottom-up approach is more advantageous in your text.

4.3

• This section is important, but too general and does not add much to what we already know. What about conflicting objectives: fishermen, irrigation, hydropower, fish, etc... How can we accommodate opposite needs?

4.5

• «Acknowledging these inputs during the EFA, detailed dam design should not begin until a scenario has been decided upon and the EFR thus clearly understood. This requirement carries important time implications for water-resource planning. The time (preferably up to five years)...» Be realistic, you need to do some calculations (how big the dam will be, approximately) to see if the project is economically viable. You cannot sit and wait for 5 years. All this means compromising between economic and environmental needs, this is where the challenge is!

• «The key constraint to providing these features will probably be financial. Many of the features will add considerably to the overall cost of a dam.» Not necessarily. The costs of studies and the delays are important and most of all the costs of not passing a fraction of the flow through the turbines.

5 SUMMARY OF FEATURES VITAL TO SUCCESSFUL IMPLEMENTATION OF ENVIRONMENTAL FLOW REQUIREMENTS

• «Political recognition of loss of ecosystem values (5.1); EFA specialists au fait with international developments in EFA methods (5.3); Recognition that ecological and socio-economic aspects of water-resource development are as important as engineering and direct economic aspects. (5.5)»

Such recommendations are too general to be very useful. It is not that I do not agree with them, in fact I do, but it is useless to repeat it here again. It would be preferable to show practical solutions that meet these types of challenges. How can we achieve this?

• «Long-term accurate hydrological data (5.2); Long-term water chemistry records for rivers, preferably linked to hydrographs (5.2); Senior specialists, all with first-hand knowledge of the rivers of concern, in the river-related and EFA-related aspects of the following disciplines: hydrology, hydraulics, geomorphology, sedimentology, water chemistry, biotic integrity, physical habitat, riparian and instream vegetation, fish, invertebrates, and possibly herpetofauna and river-dependent terrestrial wildlife. (5.3)»
Yes, in theory it would be preferable to have that kind of data but you cannot give such recommendations and hope that no problems arise along the way. This may be unrealistic for projects even in developed countries, so let us imagine how it would be in developing countries! Such recommendations do not help in solving the problems nor in tackling the challenge between environmental and economic constraints.

- Through 5.1 to 5.8, there are recommendations stating we need this and that, without considering the time and money involved and then in 5.9 it is said there is a problem in developing countries since they lack this and that but that they cannot afford it. And that’s it! What a conclusion! All this needs to be put into perspective.

f) Comments by Hans Wolter

The TOR asked for review of:
* best practice world-wide in fixing objectives, and setting and monitoring the instream flows;
* the design features of dams required to deliver adequate releases of water of acceptable quality when the dam is not spilling;
* criteria, guidelines and incentive frameworks to implement recommended practice.

The report describes well all major issues surrounding contemporary methodology and practice concerned with the complex and in many ways still controversial issue of the in-stream flow assessment; it argues that in the context of the wider river environment and its ecosystem the traditional terms such as "in-stream" or "biophysical flow assessment" are too narrow and that, therefore, they should be replaced with the term "environmental flow assessment" (EFA), introduced recently by Australian specialists, as more adequate and all-encompassing. An EFA is defined in the report as an assessment of how much of the original flow regime of a river should continue to flow downstream in order to maintain specified valued features of the riverine ecosystem. The riverine ecosystem itself is seen as all components of the landscape that are directly linked to the river and all their life forms, including the source area, the channel from source to sea, the riparian areas (i.e. the longitudinal riverside strips with vegetation types that are distinct from the general terrestrial landscape) the water in the channel and its physical and chemical nature, wetlands linked through surface or subsurface water, floodplains, the estuary, and the near-shore marine ecosystem which is clearly dependant on freshwater inputs.

Some important issues concerned with the methodology and process of EFAs, determination of adequate environmental flow requirements (EFRs) and their practical implementation and subsequent monitoring have not been sufficiently covered. The report admits this, but states that it has been unable to complete an exhaustive review of all environmental-flow assessment and related activities, partly due to limited time available for the review and partly because it is an extensive and rapidly growing field of science which as of yet has not been well documented. Much of the work concerned with flow assessments lies in the management sphere, where links with the scientific side are still evolving and are usually poorly documented as well. These topics deserve to be elaborated further in view of their
importance and wider environmental and socio-economic implications.

Overall, we think that the report presents a balanced view of the subject. The authors have rightly recognized that development means change and that EFA is an instrument to minimize the damage to the riverine ecology or avoid unacceptable level of degradation. EFA should not dictate the level of development but should create awareness of the consequences of water development and point to options to reduce the damage.

g) Comments by Robert Dobias

1. As someone who must deal with these issues in discussions with government officials, engineers, private sector power companies, financial analysts, national and international NGOs, and others, I found the draft paper to be a potentially useful reference and, once it is finalized, I no doubt will be making use of it regularly. The authors are doing a worthy job in tackling such a complex and evolving issue.

2. The following comments reflect a perception of the general situation in the developing countries of Asia, and particularly hydropower projects, so they may not be fully relevant to the conditions in other parts of the world. Nonetheless, I hope that they are useful. I should also state that these are my personal views and not necessarily those of ADB.

3. Perhaps the best place to start is with the final chapter of the report, Chapter 5 on the summary of features vital to successful implementation of environmental flow requirements. Looking at the Table of Contents, section 5.9 on developed versus developing countries promised to be a particularly important part of the report for readers like myself by providing insights on steps that can be taken to transfer the lessons learned in developed countries to developing countries. Unfortunately, while the preceding sections in this chapter provide key considerations on “features vital to successful implementation”, this section simply states the obvious problems faced by developing countries. In fact, after reading this section, one cannot help but feel that EFA may not be feasible for many or most of the countries that really need it.

4. Water resource development in developing countries should be deserving of special attention in the report because these countries often contain sites of international biodiversity importance that, like medium and large dams, are often located in the difficult-to-access uplands, and in coastal areas that are affected by changed river flows. They generally have large human populations that are dependent on rivers for subsistence, particularly for fish as a main protein source. And some of the most active water resource development programs are located in these countries. They have a different set of problems, as the authors are aware, so it was somewhat disappointing not to see more specific discussion of these problems, how lessons from elsewhere might be adapted to these different sets of conditions, and recommendations made specifically on how to foster the use of EFA in developing countries.

5. The authors might consider revising section 5.9 or, better still, adding an additional chapter on the special needs and constraints faced by developing countries in applying EFA to their water resource development projects and programs. Some items that may be worth considering are:

   (i) Encouraging bilateral and multilateral aid agencies, and large private sector or government hydropower bodies that invest abroad, to undertake EFA in all projects in which they are involved. They could also be encouraged to include EFA as part of their policy dialogues with governments, and to target funds for research and
development of EFA methodologies in developing countries. There are examples of this happening in Asia (an ADB-assisted hydropower project in Nepal that employed a habitat simulation methodology, for example), albeit on a limited scale.

(ii) Working with the private sector in developing EFAs, including valuation methods, which will be important to the successful implementation of EFAs. The report is absolutely correct when stating that political will and supporting legislation are prerequisites to meaningful utilization of EFA. But while that is being worked on, special emphasis could be given to winning over the private sector. Largely at the urging of developed countries, developing countries are increasingly turning to the private sector to participate in joint ventures, BOT projects, and other arrangements, especially in hydropower development. The private sector, including firms engaged in major hydropower projects, have some of the most capable economists and financial experts in developing countries, and the resources to recruit scientists.

(iii) Fostering a better understanding of tropical river ecosystems in general and fisheries in particular. For example, the Mekong basin fishery is very poorly understood, and yet it is the primary source of protein for millions of subsistence-level households. Significant disruption of natural flows in the mainstream Mekong could have large adverse consequences for myriad economic activities in the delta.

(iv) Devising workable methods for transferring EFA methodologies to developing countries. A good argument might be made for establishing regional centers of excellence devoted to conservation and development issues associated with water resource development, or for the addition of EFA and related topics into existing centers. Alternatively, the adaptation and development of EFA and related technologies is a topic on which national universities could potentially build a reasonable post-graduate program. Given seed money and initial guidance, universities could find it to be in their best self interest to continue with research and development of such methodologies for years to come.

(v) Introducing and helping to apply EFA as a component in river basin management (or vice versa). While EFA may indeed aid in policy and attitude changes regarding the exploitation of water, there are several other developmental (and economic) factors outside of direct water resource development that can affect how water is exploited. In developing countries, EFA alone may not be sufficient to change policies and attitudes, and may need at least some level of acceptance of river basin management concepts to lead the way.

(vi) Establishing data recording stations with personnel and other essential supporting arrangements immediately, particularly on rivers that will be regulated in the future.

(vii) Disseminating examples of legislation, methodologies, valuation, and so forth. This report when finalized will be a useful contribution to this.

6. A last comment on Chapter 5: if long-term accurate hydrological data, long-term water chemistry records, comprehensive data on the distribution, life histories, and flow related habitat requirements of riverine species, and similar data are truly vital to successful implementation of environmental flow requirements (EFRs), then many (most?) of the countries in this region will not be able to successfully implement EFRs until most of the rivers have already been regulated. Should this refer to certain methodologies, or should the definition of “successful” be liberally defined?

7. On to other sections of the report, in a somewhat random fashion.
8. The report correctly points out that the implementation of recommendations for flexibility in water release mechanisms (multiple-release structures, sensors, structures to improve water quality, etc.) is constrained by financial issues as this can substantially add to construction costs. Surprisingly, though, no mention could be found of the potentially far greater costs that are incurred in the form of income foregone when water is released for environmental reasons. This is a particularly sticky issue with private firms, who may be less susceptible than governments to arguments in favor of the social good or conservation of biological resources. The firm’s position often may be that mitigation would be less costly. The problem, of course, is that mitigation may be less costly to the dam operator but, due to the present constraints on accurately predicting and monitoring impacts, the costs may be very high for communities or ecosystems. This presumably would be another argument for moving forward with EFA.

9. The need to apply the appropriate type of methodology for site-specific conditions is a good point. However, in this part of the world, particularly for medium-to-large water resource development projects on unregulated rivers or rivers with only limited regulation, there probably will be a need to rapidly move toward holistic methodologies that take social and economic conditions into account. With Asia’s large and mainly rural population, it is difficult to undertake any sizable water resource development project without directly or indirectly affecting a great number of people and changing local practices and economies. Less complex methodologies may be appropriate for some projects, and perhaps are justified for large intrusive projects when the capacity or willingness to undertake complex EFAs is absent, but an immediate focus on developing the means to undertake holistic EFAs would seem to be the way to go. It was interesting to learn that holistic methods have not been explored in the Northern Hemisphere. Why have South Africa and Australia taken this on, but not America or Canada?

10. The report states that it is “noteworthy that many countries for which EFAs do not seem to be a priority are undergoing intensive water-resource development, particularly in the form of river regulation by large dams”. Can the authors speculate as to the factor(s) that help trigger some level of political acceptance for the application of EFRs? As mentioned, the users of EFAs/EFRs are almost exclusively from developed countries, and many of these have started only recently. Does the overall economic level of the country play a role, or are there other factors? It would appear that dry conditions (and thus limited water supplies) at least in part spurred Australia to explore ways to equitably allocate water a century ago. Why should the Ministers responsible for hydropower development in Lao PDR or Viet Nam bother with this? Perhaps more instructively, why has Indonesia (presumably in the Brantas basin) decided to explore EFA methodologies? Is the importation of expertise really a basic factor? – the bookshelves of governments are bursting with failed introductions of new technologies. Some insights here could be helpful to those who are attempting to nudge governments in the direction of EFA/EFR. These are important questions precisely because political will and legislation are fundamental to implementation of EFRs.

11. On a related point, while the assertion may be correct that EFAs have been successful at the national policy, legislative, management, and “attitude” levels, it is difficult to understand why success has been achieved at the national level without being able to point to success at the level of specific rivers. This seems to be a bit counter-intuitive. Normally, one would expect that national acceptance of an idea or approach would evolve after that approach has been shown to work at a project level.

12. It would be interesting to see a short discussion on river basin planning (which is almost as rare in Asia as EFA) versus EFA as the first tool in gaining “best use” or equitable distribution of benefits from dam projects. Clearly these two are closely linked. But under many circumstances, it would seem that convincing governments of the need for integrated river basin planning would be easier than convincing them of the need for EFA as a regional planning tool. Once integrated basin planning is accepted, then it should be a relatively simple matter to immediately get EFA and related technologies for sustainable development accepted so that integrated basin planning could be done effectively. The question is, how do we best approach governments with the EFA idea, particularly as
there seem to be no concrete examples of how well it has worked? Perhaps, as with protected areas, EFA will simply be perceived as something that is “good”.

13. It would seem that if EFAs/EFRs are to work, and particularly the holistic EFAs, supporting studies must begin well in advance of project prefeasibility studies. Otherwise, how will EFAs fare any better than EIAs, which are often constrained in their ability to fully influence development at such a relatively late date? If this is the case, then clearly the required financial and human resources will not be available in most developing countries to do EFAs everywhere that they may be needed. In discussing how to get EFAs/EFRs implemented in developing countries, it may be useful to take a step back to look at how water resource development projects get into the pipeline and eventually get constructed. For hydropower programs, governments generally rely on least-cost analyses of feasible projects (or some variation of this) to work out a pipeline of projects. More must be done in terms of introducing social and environmental costs into the analysis (including EFA). Perhaps EFA should start at that point, but reality indicates that EFA may not be a factor in least-cost analyses for some time to come. In this case, it may be best to assess which rivers are (i) scheduled for major development in the least-cost plan, and (ii) most sensitive to disruption for social or environmental reasons. This could then provide a manageable “hit list” of areas where resources and funds could be devoted to undertake studies needed for developing holistic EFRs. This would necessarily miss projects that are placed at the head of the pipeline, but here less complex EFAs might be employed, as suggested in the report.

14. The argument in section 4.2 (setting objectives for EFAs) that setting multiple objectives first and then applying EFAs is extremely time-consuming and so is less desirable than using the EFA to establish objectives is not convincing. The same section states that the latter approach requires a comprehensive series of studies, is more complex to manage, and is less easy to understand. It would therefore seem to contradict the earlier statement. Also, it is unclear why the former approach is considered “top-down” planning and the latter “bottom-up” planning; the setting of objectives up front could (and perhaps should) be done through an extensive public participation process. The point about the possible immaturity of public participation processes is well taken, though, and could certainly be a serious constraint.

15. In conclusion, then, some suggestions have been offered here for further consideration by the authors, particularly in terms of providing more analysis of the needs, constraints, and potential approaches for introducing and implementing EFA in developing countries. Overall, though, the draft report is well presented, and I very much look forward to seeing the final product.

h) Comments by Yogi Carolsfeld & Brian Harvey

Brian Harvey and I have read the commendable draft report on Instream Flow Methodologies that was sent to us for review. Our comments concern the scope and point of view of the document, some observations on developing countries including our own experience in Brazil, and a few suggestions on presentation.

First, some general comments on coverage and point of view. The main text is rather lightly referenced, making it hard to tell if information is personal opinion, international consensus, or a summary of local experience. This is particularly important for the first two chapters, where arguments are made for an alternate name and approach to instream flow measurements. While there may be advantages to using the term “Environmental Flow Assessment” and a “holistic” approach in doing the work (particularly in Brazil), this argument could be better substantiated in the main portion of the report. A much fuller treatment is presented in the first appendix, but one may not reach this until much later.
Most of the references cited for the main text are not peer-reviewed and may not be readily available to the public. We can’t judge if this is an accurate representation of this field; nor, we expect, could the commissioners. Time constraints are cited as a reason for not pursuing a more in-depth survey of the literature, but the trade-off may be that one cannot judge the reliability of the information from an international perspective. Some relevant items we’re aware of but are not addressed adequately are: the Norwegian emphasis on building adaptive management into project criteria, the North American approach of using fish as bio-indicators of ecosystem health, and the use of in-stream flow methods for management of regulated ecosystems based on current conditions rather than virgin potential.

EFA procedures are described as “successful” by virtue of being an established process and becoming politically and legally accepted. This may be premature: acceptance is an important step, but doesn’t necessarily mean the methods work. The only valid measure of success is the effectiveness in mitigating the effects of flow regulation. The authors identify this as the third category of “success”, but suggest that its assessment is not yet possible in most cases due to unrelated factors. To present a rounded picture, a summary of international successes and failures for instream flow measures, using cases where clear objectives were stated, would be most useful.

The later chapters of the report have something of the flavour of a manual for applying the authors’ technique of choice, and this section is also very lightly referenced. If this impression is correct, commissioners may also wonder whether sections on such items as the setting of objectives, criteria for successful implementation, and suggestions for developing countries are based on a sufficiently broad sampling of international experience.

We found the relationships between engineering components, EFA, EIA, and public consultation difficult to follow. Editing of the report would probably resolve this.

Setting “realistic” objectives is stressed repeatedly in the report. However, the definition of “realistic” could clearly cut several ways, depending on the particular stakeholder’s viewpoint. A summary of examples of criteria that have been used in defining “realistic” would be very interesting, together with their implications.

There is a wealth of important and hard-to-find information here, but the organization and style of the paper makes it a little difficult to extract. Better organization might help make points more efficiently. The small investment in hiring a professional editor to look at the paper up would, in our opinion, help bring out the many strengths of the work. We have some editorial comments and could send them along in a couple of days if you like.

With regard to South American content of the report, the authors are probably quite correct that little or no work has been done on instream flow measurements for dam developments. However, published information is available on the importance of seasonal flooding, floodplain lagoons, and modifications of fish communities by dams. I believe that Brazil also has legislation that dictates a minimum downstream flow, as may some of the other countries. I have not yet been able to discover what the basis or the effectiveness of this regulation is.

Regarding constraints to applying instream flow-based methodology in developing countries, we would put less emphasis on the lack of appropriate knowledge and technology than do the authors. This may be true in some countries, but local resourcefulness given appropriate incentive should not be underestimated. Our opinion is that economics, political will, and public opinion are key elements, but such things really need to be determined by consultation in the countries. We are preparing to do this in Brazil, but would be interested in knowing how the criteria the authors promote were derived.

We appreciate the opportunity to read the draft and hope that our comments are constructive.
i) Comments by Takehiro Nakamura

Takehiro Nakamura

Dear Jamie,

Thank you for sending me the draft thematic report on definition and implementation of instream flows for my review. The limited time did not allow me to investigate in details actual examples and data in relation to the description in the draft based on UNEP’s previous programmes and projects, and the comments below are still limited to general ones based on our experiences in our previous activities.

1. In relation to Chapter 1, in some cases, particularly when newly built reservoirs are being filled, it may be necessary to define temporary flow requirements considering the EFRs cannot be implemented fully. The report places emphasis on the operation of dams after dams are completed, but during the construction of the dams, such issues have to be considered under more severe conditions.

2. In relation to Chapter 2, besides the models listed in this Chapter, there are many other models which are partially contributing to the listed models (such as the ones introduced in the Appendix) and the others which may be used for assessing specific issues of EFAs. As indicated, water quality models, although considered important, are not well incorporated into the models introduced. Water quality is an important factor of aquatic ecosystems and without due consideration to these issues, it may be difficult to consider the EFAs. It is understood that some of the models introduced in this draft incorporate some types of mixing models within them.

3. In relation to page 13, bullet point No.3, although not in the form of EFAs, there are many models developed for lake ecosystem and to a lesser extent, estuaries and wetlands.

4. In relation to Chapter 4, we are recognizing more and more a need to consider impacts of national-level policies on the environment. The Strategic Environment Assessment is a tool used for such purposes in developing countries (in Western Europe). It is to be further analyzed how the EFAs objectives can be incorporated into national policies (not only legal instruments). Further, how EFA objectives can be incorporated into river basin objectives will be also an important subject, because EFRs are trade-offs among various components of river basin management and development.

5. As indicated in 4.2, river basin management is changing from the traditional water resource management approach to ecosystem management approach. UNEP’s Environmentally Sound Management of Inland Waters programme, and further in GEF’s International Waters portfolio clearly are oriented to the ecosystem management approach. The Mekong river flows through 6 countries instead of 7 (China, Myanmar, Laos, Thailand, Cambodia and Vietnam).

6. In relation to 4.2.2, consideration should be given to how internationally-shared rivers can consider EFAs in a harmonized manner. UNEP has worked on various internationally-shared river basins, and has experienced difficulties in assisting the riparian countries in establishing a harmonized objectives in the form of concrete numbers in flow requirements or water demand.

7. In relation to 4.5, there are several bullet points relevant to dam design. Engineering design of reservoir system (water quality in particular) is also linked to designing of a dam and future operation of dams.

8. In relation to 5.2, many data are yet to be collected on ecological responses to hydrological conditions.

9. The draft presents a very interesting information and description, and if this thematic
review report is reviewed in combination with the other reports, for instance, river basin requirements, it would provide further opportunities in creating its organic linkages with river basin objectives and requirements.

**j) Comments by Shunroku Nakamura**

My comment to the draft is as follows:

I think this is an excellent review paper on definition and implementation of instream flows, even though some part especially on "holistic methodologies" is not clear for me because I am not familiar to the methodology and the draft does not include the detailed explanation on it (maybe a part of the full volume). I don't have any opinion to add or change something to it, except on the Japan's part in the summary of "Environmental flow methodologies in use in various countries" (Table 3.1) as follows:

Japan:
1) IF Methodologies in Use: IFIM, Normality P. Flow and Obligated C. Flow: OK
2) Most widely used methodologies: Normality P. F. at some check points and O. C. F. at power dams (both are minimum flow setting).
3) Comments: Re-evaluation using various methods has been under going since the amendment of River Act in 1997.

**k) Comments by Tor Ziegler**

First comment and questions relate to last chapter

The subsections and bullets in chapter 5 is an exhaustive list of features that ideally should be in place for successful implementation of EFR. If I were to add anything, I would have a separate subsection for Dam-Owner/Developer/Operator commitment to environmental stewardship and compliance. This is particularly relevant in these days when there is so much deregulation and privatization going on.

However, among all these ideal requirements I am glad that subsection 5.9 elaborates on developed versus developing countries. My first question is therefore:

_The preceding list 5.1-5.8 of ideal conditions is very long and demanding. Are there some that are more vital than others?_

After having read the draft, my question no. 2 remains hanging in the air:

_What do those do first and next and thereafter, who have the water and power demands that require dams, but do often not have the knowledge, resources, institutional framework/capacity, and environmental awareness and acceptance required to adress the issue of defining and implementing environmentally acceptable instream flows?_

General comment to the WCD report

Experience from OECD countries suggests that next to implementation phase resettlement issues demonstrated mainly in developing countries, issues related to Instream Flows is the other largest environmental/social sensitive and controversial issue related to dams.

On a personal note, let me express how interesting and inspiring it has been to read this draft, and then first provide some more general impressions and observations:
The contents are well and logically structured. The 3 first chapters that introduce and provide perspective on the subject matter could in my view be broadened in terms of reflecting international experience. There should also be some estimate of the magnitude of demand for instream flow assessments that potentially need to be addressed in the next 20 years, preferably separated into two groups: a) Restoration of rivers, and b) Potential new rivers developed (range, low scenario/high scenario). This could be included under 1.6.

The South African (SA) experience (which is very interesting) dominates among experiences referred to in the text. This may be highly relevant, as much focus should quite rightly be on developing countries where the potential for new dams is greatest, and guidance is most needed. SA seems to be a worthy member for defining and piloting a methodology that in many cases may be well suited for developing countries.

In describing the broader process of instream flow assessment (ch 4), I find many similarities with the process earlier defined and followed in my own country, and also believe the US subscribes to, where the IFIM methodology is only one building bloc, and where the other broader environmental/social riparian and catchment issues are considered in addition to IFIM when found relevant within the framework of environmental assessment.

These days it seems that the aesthetic and landscape value of running water is one of the most valued features in many instream flow assessments in my own country. The value of different features seems to change over time as society develops. This observation brings me to the question of how the present instream flow report can draw on examples from different WCD focal dam/basin case studies like Pak Mun, Tucurui, Tarbela, Columbia river, Glomma/Laagen and others, and from their respective countries.

It would be helpful to have a statement in the report on whether its scope is worldwide or developing countries.

A general point that could also come out clearer is that the instream flow considerations will necessarily feed into a trade-off process between the purposes for which the dam investment is done, and the (third-party, -people and nature) interests that need to be safeguarded through a consultation & decision-process adopted by regulatory authorities. Therefore it is excellent that for instance the BBM methodology is suited for developing optional flow scenarios that can help clarify levels of ambition that again can be related to objectives.

As this report will be read by many most familiar with an already developed terminology (like using the terms “instream flow” and “trade-off”), it may be a help to facilitate their reading if some of the older terminology is introduced (?). The most common terminology is of course to a large extent North American, but has spread to much of the rest of the English speaking world.

I miss a few important references and some mention of them with relevance to international policies, guidelines and experiences that underpin the message of the present WCD Instream Flow report: a) The “Dublin Principles” for Water Resources Management (WRM), stressing the importance of strengthening consideration for environmental issues in WRM by observing the ecosystem principle (I have earlier sent a copy to the WCD secretariat) b) These principles are also reflected in the 1993 World Bank Policy Paper on Water Resources Management; and c) the recent “Stream Corridor Restoration, -principles, processes and practices”-handbook, prepared by the US Federal interagency Stream Restoration Working Group in 1998. (I believe this one can be obtained from the Bureau of Reclamation). d) I believe the European Union also have developed a water resources policy statement that is adopted and under implementation in EU countries. e) In addition there is an ICOLD “Position Paper on Dams and the Environment” from 1997. f) I also mention the IEA “Hydropower and Environment” report currently in near final draft form. As the two latter documents in one way may be considered as advising a voluntary code of conduct between dam-operators, they may be worthwhile referring to as an indication of dam-operator commitment to exercise good stewardship. (Ask reviewer
Joseph Milewski for the draft EIA report). Several utilities are also introducing ISO 14000 standard Environmental Management Systems and environmental objectives into their corporate strategies.

The above general comments relate to a number of different sections of the report and I have no specific suggestion to where in the structure of sections each one can be dealt with.

The EFA definition, a question
The report (section 1.2) has a definition of what the Australians name: “Environmental Flow Assessment” EFA:

“An EFA is an assessment of how much of the original flow regime of a river should continue to flow down in order to maintain specified valued features of the riverine ecosystem”.

A question that arises is whether the EFA is synonymous with terms like “instream flow”, “maintenance flow”, “minimum flow” etc, (much used terms in OECD countries), or should be regarded as a subset of, or overarching one or more of these?

There is a further definition of what a riverine ecosystem is: “The riverine ecosystem is seen as all components of the landscape that are linked to the river and their life forms.”

How broadly should “their life forms” be interpreted?

Experience from my part of the world indicates that the environmental flow may be conceived as nesting within flows released for navigation, timber-floating, or even hydro-production when these releases remain instream, (all non-consumptive), or for water supply, irrigation and other consumptive uses downstream. The provision is of course that the remaining flow in the river does not go below a certain critical minimum and that the release patterns are not harmful in themselves (like peaking patterns may happen to be).

Do not these differences of purposes and specifics of individual regulation schemes require a certain pragmatism in relation to the above definitions?

This may be a reason why the US terms “Instream and Offstream” flows seem to have achieved wide recognition.

I suppose my problem is that there are so many terms for what flow remains in the river that I have problems with every new one that is introduced. I believe many others have the same problem as me.

Suggestions for specific additions
Main suggestions for additions that I (and others may) find helpful are:

1) Add a section (perhaps 1.8?) that explains how layouts and operation of river regulation schemes may differ in whether they divert flows (offstream) completely or return it to the river further downstream, or just alter the pattern of flows on a daily or longer term basis (instream). The distinction between regulation/storage for consumptive, non-consumptive and multipurpose uses (in which EFA may be nested) does also have significance in this context. Relate the concept of EFA/Instream flow definition and implementation to these variants.

There are certain aspects of regulation through dams that are not dealt with in the report and that it should be made clear that are not considered like: - Operation/regulation of reservoir levels, - handling of flows in (lowerlying) rivers to which diversion do take place, - altering the river into a series of ponds through cascade development, - etc.
2) Practice from OECD countries show that EFA/instream flows are rarely the only compensation or mitigation measure. Water may be saved for the intended purpose of the dam by combining instream flows with measures like using weirs to create pools, structural adjustments of the river bed, creation of spawning and rearing channels, fish stocking, fish ladders, measures to improve water quality, etc. My suggestion is that in a section on that, it is pointed out that EFAs should be considered in consort with other measures (perhaps as 2.8).

The report already refers to that even between the different stakeholders with interests in ecosystem services, compromises are often required. If for instance the opportunity for angling (sometimes requiring considerable flow) is defined as an ecosystem service, the possible extra water required for such a practice may be relinquished/"sold" for the primary use of the dam, in case of periods of water shortage. Survival flows would still be maintained.

3) In my view, the existence and use of computer simulation models in decision support (state of the art) deserves elaboration in a section of the report (maybe 3.4?)

4) In the context of the planning process which often leads to a public authority clearance or license that defines constraints and conditionalities, the rules of operation (relating both to reservoir level operation and releases through the dam and/or offstream) is a key instrument. Also other environmentally motivated covenants in the licence that the dam owner operator must be held accountable for. I suggest that a section be devoted to making clear that these are the rules the operator has to live by, and can be taken to court for not complying with. Consider explaining the roles and responsibilities of the different players, the regulator, the operator and other stakeholders. (4.8?)

5) Several places in the report it is pointed out how EFAs need to be tested monitored and maybe reset. This uncertainty will often be regarded as a risk by the investor who builds the dam for a specific output. I believe that some discussion of this kind of risk is warranted some place in the report (perhaps as 4.9).

6) In relation to the description of the key phases of the planning process, emphasis is rightly placed on addressing the question of EFA/Instream flow needs early in the process, with quick methods suited for indicating amounts of releases required. Currently, not least here at the World Bank, the trend is that the reconnaissance and pre-feasibility studies are integrated into broader Strategic Assessments with Sectoral and Regional Environmental Assessments that support Governmental/regulatory authority decision-making. I believe these approaches will be dealt with in another WCD thematic, and there should be some harmonization between what that report and this one describe in this context. (Chapter 4).

7) There are several references to critical needs for knowledge development. In order to promote action into R&D it would be good to have these summarized in a subsection of Chapter 4.