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Integrated basin flow assessments: concepts and method development in Africa and South-east Asia

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SUMMARY

1. This study summarises our development and application in developing countries of a process for assessing the ecological, social and economic costs and benefits of water-resource developments, as an aid to basin planning.
2. During 15 years of work in Africa and Asia, the process sequentially included the whole river ecosystem and the whole flow regime in the assessment; used a multidisciplinary team and a scenario-based approach that gave equal weighting to the ecological, social, resource-economic and macro-economic costs and benefits of development; quantified or semi-quantified the costs and benefits in data-poor situations, capturing expert opinion and local wisdom as well as data; recognised that the final allocation of water for ecosystem maintenance should be a societal choice of trade-offs between resource protection and development.
3. Flow assessments were increasingly done at the basin rather than project level and introduced the concept and practicality of Development Space as a tool to aid basin planning.
4. Later assessments included valuation of regulating, cultural and provisioning services provided by rivers as part of the cost-benefit analysis.
5. Implementation of managed flows as outlined above is a complex and long-term process that should include a number of major steps, from development of the appropriate legislation to monitoring of management decisions and adaptive management. Country or region-wide implementation at this scale could well take one to two decades, even where the political will and technical skills exist.
6. We conclude by offering eight principles that we believe would promote genuinely sustainable use of rivers.

Keywords: environmental flows, integrated basin flow management, river ecosystem services, subsistence use

Introduction

In a world of rapidly growing human populations, wise management of freshwater ecosystems is globally important (Gleick, 2002; Vörösmarty, 2002). We face a critical challenge of how to support national development goals, meet food needs, safeguard the livelihoods of rural people and protect an increasingly degraded environment (King & McCartney, 2007; United Nations, 2007). Sustainable development of inland water ecosystems is now regularly espoused (e.g. World Commission on Dams, 2000; World Water Forum, 2003; Brisbane Declaration, 2007) and is encompassed within the declaration from the Earth Summit held in Johannesburg in 2002: 'From the African continent, the cradle of humankind, we

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solemnly pledge to the peoples of the world and the generations that will surely inherit this Earth that we are determined to ensure that our collective hope for sustainable development is realised'.

A commonly accepted definition of sustainable development is 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (WCED, 1987). This does not focus solely on environmental issues but accentuates the importance of creating a balance among the three 'interdependent and mutually reinforcing pillars' of sustainable development: economic wealth, social justice and environmental integrity (after UN, 2005). The term can, however, have different implications for developed and developing countries.

Developed countries tend to have well developed social and economic systems, often achieved at the expense of environmental resources, and modern sustainable development may well focus on restoring, to various extents, goods and services originally provided by the ecosystems but now lost or diminished because of development. Examples are relicensing of hydroelectric power (HEP) dams to reduce environmental and social impacts (FERC, 1996); the Freshwater Directive of the European Union, which aims to achieve good ecological status in surface waters by 2015 (European Union, 2000) and the 1997 cap on water diversions from the Murray-Darling system in Australia (Murray-Darling Basin Commission, 2000).

Developing countries typically have weaker financial and social pillars but may still have a substantial environmental resource base. This may be seen as an exploitable resource to generate funds for relieving poverty and improving standards of living. In Africa, for instance, at least 114 new major dam developments, mostly for hydropower generation, are either under construction or review (Achamyeleh, 2003; McCartney, 2007). Such dams will inevitably have some impact on the environmental resource base and thus on the social structures depending on that base. A major challenge will be to develop the targeted rivers within the ethos of sustainable development, ensuring that the full suite of environmental and social costs is considered as seriously as are traditional economic and social benefits before development decisions are made (WCD, 2000).

This paper outlines lessons learnt whilst introducing the concept of flows for ecosystem maintenance as a cornerstone of water-resource planning in some African and Asian countries. We begin with a discussion of the costs and benefits of water-resource developments, and consider the new insights that integrated flow assessments can provide. We then provide six case studies that illustrate various aspects of including flows for environmental maintenance in water-management activities. Then we outline our perspective of the wider meaning of implementation, and finally offer eight principles that we believe would promote genuinely sustainable use of rivers.

The costs and benefits of water-resource development of rivers

Most of the developed world benefits in some way from river development, such as irrigated agriculture, hydropower generation, assured water supply, flood control and/or improved navigation (WCD, 2000) and these benefits are increasingly sought by developing countries (King & McCartney, 2007). Such development has costs as well as benefits, in the form of social and ecological impacts (e.g. McCully, 1996; WCD, 2000; CGIAR, 2002; Millennium Ecosystem Assessment, 2005).

These costs can be appreciated through considering the ecosystem services that rivers naturally provide. Provisioning services are goods that may be harvested from the river ecosystem and sold, used directly or traded, such as water, fish, wild vegetables, medicines, firewood and reeds. Regulating and cultural services reflect the hidden functioning of river ecosystems from which all of humanity benefits: flood attenuation; water purification; groundwater recharge; bank stabilisation; habitat for species of value to people; and more. Human links with the river are strongest in developing countries, where livelihoods respond to its annual cycle of flows; cultural, religious and recreational ties to the river have deep meaning; and the river's resources provide a back-up in times of family trauma such as death of a bread-winner or loss of a job. Although uncounted, the number of people globally depending on river systems in this way must be in the order of hundreds of millions (e.g. Fearnside, 1999; Adams, 2000a; Corbett, 2000; Beilfuss *et al.*, 2002).

Developing countries are targeted for the majority of future large-scale water developments. These can degrade rivers in many ways that have human costs: bank erosion and loss of land; reduced life of reservoirs through sedimentation; decline of river, estuarine and marine fisheries and many other natural resources; increasing animal and plant pests of humans and livestock; and declining water quality that needs ever more costly purification to be made potable. Floods and droughts can become more severe in developed rivers (Adams, 2000b) and, if a dam is the option implemented, the ecological and social impacts can stretch from upstream of the dam wall, where people may be 100% impacted through inundation of their land, to long distances downstream, where orders of magnitude more people may suffer less complete but still severe livelihood changes due to a declining river condition. Poor rural populations with close livelihood links to the river are likely to be impacted most and benefit least from river development (WCD, 2000), a situation that can be changed if decision-makers consider predictions of the full suite of implications of development instead of only those illustrating benefits. This would better adhere to the principles of sustainable development (UNESCO, 2005).

Insights revealed by Environmental Flow Assessments

The scale of impacts on river ecosystems, such as those mentioned above, is now generating global concern (McCully, 1996; WCD, 2000; Global Water Partnership, 2003; Pearce, 2006; Malley *et al.*, 2008). Whilst the case for developing rivers has been effectively promoted by engineers, economists and water managers (the top block in Table 1), the case for doing this with due consideration for the condition of the targeted rivers and its users has not, until very recently, been well articulated by ecologists, sociologists and resource economists (the bottom block in Table 1). Without this input, decision-makers could understandably strive for development scenario E in Table 1, seeing only benefits. With the additional information contained in the bottom block, however, scenario E appears less attractive and some earlier scenario, represented here by scenarios A to D, might be seen by government(s) and other stakeholders as the optimum trade-off between costs and benefits. The flow regime encompassed within this optimum trade-off scenario would become the environmental flow (EF) for that river, representing the agreed trade-off between development and resource protection for that basin and that society.

The point of trade-off could thus differ from basin to basin, with rivers across the landscape being held at different levels of ecosystem health depending on society's aspirations. Rivers running through national parks, for instance, may be held at higher health levels than those in agricultural areas where the priority is food production. This concept of a landscape mosaic of different river health levels, adopted in South Africa for instance, differs from the EU Directive,

Table 1 Hypothetical example of the matrix of information that could be developed for each part of a river basin

	Scenarios of increasing levels of water-resource development					
Indicators	PD	A	B	C	D	E
Man-made benefits						
Hydropower generation	x	x	x	xx	xxx	xxx
Crop production	x	x	xx	xxx	xxxx	xxxx
Water security	x	xx	xxx	xxx	xxxx	xxxx
National economy	x	x	xxx	xxxx	xxxx	xxxx
Aquaculture	x	xx	xxx	xxx	xxx	xxx
Ecosystem attributes						
Wild fisheries	xxxx	xxx	xxx	xx	xx	x
Water quality	xxx	xxx	xx	xx	x	x
Floodplain functions	xxxx	xxxx	xxx	xx	x	x
Cultural, religious values	xxxx	xxx	xxx	xxx	xx	xx
Ecosystem buffer against need for compensation of subsistence users	xxxx	xxx	xx	xx	x	x

The indicators would be more numerous than shown and could differ from river to river. The crosses illustrate possible trends in the level of beneficial use under each scenario, and would normally be replaced by quantitative or qualitative details from supporting research. PD, Present Day – not necessarily pristine.

which aims to achieve good ecological status in all EU rivers, lakes and wetlands.

In Table 1 Present Day is shown as the starting point for the scenarios because that is the situation that developers, ecologists and social specialists can understand and describe. Scenarios can move the situation away from the Present Day, either toward increasing development, as shown in Table 1, or in the opposite direction toward increasing rehabilitation of the ecosystems, in which case Table 1 would show increasing beneficial uses in the bottom block and declining beneficial uses in the top block. The last indicator in the bottom block represents the link between subsistence users and ecosystem health. Development may well benefit people far removed from the river, whilst those depending on its resources for subsistence may be least benefited and most impacted. With a healthy ecosystem, their traditional livelihoods can continue; with development, the ecosystem decreasingly offers support and the question arises of whether they should be compensated.

The bottom block has become the responsibility of river, social and resource-economic scientists, and completing it in harmony with the top block appears to be moving beyond what has been called an Environmental Flow Assessment (EFA) to an exercise that is probably closer to a Strategic Environmental Assessment (Therival *et al.*, 1995). Because there are differences, at its present stage of evolution we have chosen to call the process we use an Integrated Basin Flow Assessment (IBFA), a term that evolved over about a decade. Our work has taught us that resource-economic, health, culture and macro-economic issues need to be embraced in the IBFA for, without that, specialists from these disciplines often have no avenue at present for integrating their findings into one comprehensive and balanced assessment of potential change (King & Brown, 2006). All-inclusive methods that provide such multi-faceted views can illustrate, for any considered development option, the potential changes in, for instance, channel configuration; bank erosion; water chemistry; riparian forests; river, estuarine and near-coastal marine fisheries; rare species; pest species; human and livestock river-related health; availability of baptism areas; household incomes; gross domestic product; job creation; HEP production and much more. Decision-makers in several countries receiving such IBFA outputs have commented that they have never before understood, or often even been aware of, the wider implications of development decisions they make (J. King and C. Brown, pers. obs.). Multidisciplinary teams should be motivating that this kind of work is done, and developing the skills to do it, for every river, wetland or estuary targeted for development or rehabilitation (Brisbane Declaration, 2007).

Providing both sides of the development picture in this way for discussion and negotiation by stakeholders contributes to the requirements of Integrated Water Resource Management (IWRM). IWRM is 'a process that promotes the coordinated development and management of water, land and related resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems' (Global Water Partnership, 2000). It is a concept that promotes sustainable use of water, encouraging people to move away from traditional project-driven ways of operating and toward a larger-scale basin or regional approach that takes into account the overall distribution and scarcity of water resources and the needs of other potential water users. In essence IWRM is a political procedure that aims for sustainability of use; a process of balancing all water demands and supplies including those for environmental maintenance; an iterative approach that recognises the need for adaptive management; and a way of life.

The following case studies reflect our growing awareness of the vital role that IBFAs can play in IWRM activities. We present the conceptual and methodological advances and the main lessons learnt in each study. The lists are limited to major items, and advances noted in one study are not repeated in subsequent ones unless it was felt that another major step forward had been taken. Because this is an analysis of an evolving process, methodological details are referenced rather than provided. Study outcomes are also referenced and summarised where possible, but in several cases outcomes cannot be given because the projects are still underway or there are as yet no public documents. The section on Implementation revisits this topic.

Case studies

1. Luvuvhu River, South Africa, 1994

Overview. From the mid-1980s, the South African government moved to include 'instream flow assessments' in all proposed water-resource developments involving rivers and asked river scientists to 'speak on behalf of the rivers' (Tharme & King, 1998). In response, a new holistic approach to flow assessments for river maintenance was developed both conceptually and practically in real water-development projects (Ferrar, 1989; King & Tharme, 1994), starting in the late 1980s and linked to similar research in Australia (Arthington *et al.*, 1992).

As the sixth in this series of South African activities, the flow assessment for the Luvuvhu River in 1994 was generally regarded as the first in which the developing method could address the major issues being considered. The disciplines that should be represented in a multidisciplinary team had been identified, and topics such as river importance, to guide decisions on the appropriate trade-off between development and resource protection, and habitat integrity, to guide assessment of present river condition, had been introduced (Tharme & King, 1998). Because the government had no structure at that time for defining the desired future condition of the river, the scientists were asked to recommend such a condition and define the flows to attain and maintain this. This prescriptive approach, which later became known as the Building Block Methodology (BBM; King, Tharme & de Villiers, 2000), played a major role in a decade of conceptual development and persuaded the legal team writing the country's new, post-apartheid water law that water for ecosystem maintenance could be quantified and thus enforced (Fig. 1). In what was seen as a major recognition of the importance of healthy ecosystems for people, a reserve of water for ecosystem maintenance was written into South Africa's new Water Act of 1998 as one of only two water rights – the other being for basic human needs. For this and other reasons the Act was hailed as one of the most advanced in the world, for which the South African Minister of Water Affairs received the Stockholm Water Prize in 2000 (http://www.siwi.org).

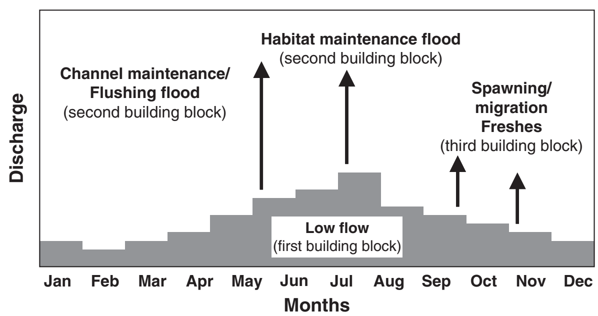

Fig. 1 The building blocks of an environmental flow requirement as described by the Building Block Methodology (after King & Louw, 1998).

Although modest in achievement by today's standards, the flow assessment for the Luvuvhu was revolutionary within South Africa, establishing that water for ecosystem maintenance could be quantified and that doing this was a legitimate project cost, and paving the way for its inclusion in the National Water Act (No. 36) of 1998.

Contribution to concept and method development

1. Recognised the need for an holistic approach that would address the condition of the whole river ecosystem, including its riparian zones, floodplains and estuary. The most advanced alternative methods available globally at that time were not appropriate for a developing region where many people were subsistence users of rivers, as they mostly concentrated on maintaining instream hydraulic habitat for single valued species such as game fish (e.g. Bovee & Milhous, 1978).

2. Recognised that the greater the divergence from a natural flow regime, the more a river ecosystem could be expected to change and thus that the concept of a minimum flow for ecosystem maintenance was fatally flawed. Instead, this approach recognised that rivers could be held at various flow-related levels of ecosystem condition, and that the level could differ from river to river across the landscape.

3. Recognised the need to capture expert knowledge and local wisdom as well as data, as most flow assessments would be done in data-poor situations.

4. Accepted that decision-makers often could not wait for long-term research results and could be obliged to make decisions with or without scientific input; therefore adopted the approach that river scientists must step forward with their best available information and understanding to 'speak on behalf of the river'.

5. Adopted a multidisciplinary approach, involving hydrology, hydraulics, sedimentology, fluvial geomorphology, water chemistry, riparian and aquatic botany, zoology (fishes, invertebrates and sometimes birds and mammals) and sociology. Other biophysical and socio-economic disciplines would be included later as required.

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6. Recognised that the whole flow regime needed to be managed, not just the low flows, and divided the regime into rudimentary ecologically relevant flow classes (low flows, small floods, large floods) for the purpose of predicting development-driven change of the river ecosystem.

Lessons learnt

1. Rural people rely on rivers for far more than water, and so ecosystem condition and its links to livelihoods must be factored into flow assessments. At that time, the social inputs were weak and needed to be strengthened by encouraging river scientists and sociologists to develop a common language in the way that the former had with water engineers and managers.

2. The BBM prescriptive approach was ultimately shown to be flawed, as stakeholders questioned the right of scientists to define a future condition for a river. Additionally, queries from planners on the consequences of further modifying the recommended flow regime provided by the BBM could not easily be answered. For both reasons, a more appropriate approach would be one of scenario development and analysis. This would provide both government and other stakeholders with a range of options to consider.

3. The water needed to maintain rivers at various levels of ecosystem health can be quantified in terms of frequencies, durations, timing and magnitudes of each flow class, using a structured repeatable process, and these needs can be included in planning scenarios alongside water demands from other sectors.

4. Consensus among experts, such as occurs in an expert-based EFA, has strong legal standing (later described by Kriminsky (2005)).

2. Lesotho Highlands Water Project, Lesotho, 1997–2005

Overview. The Lesotho Highlands Water Project (LHWP) is a multi-billion dollar water transfer and hydropower project implemented by the governments of Lesotho and South Africa, and is one of the world's largest water-resource developments (http://www.lhwp.org.ls). It is envisaged to eventually comprise seven major dams on the headwaters of the Senqu River in Lesotho, which becomes the Orange River as it passes into South Africa. The LHWP was conceived and negotiated in the mid-1900s before the upsurge in concern about the downstream impacts of water-resource developments on rivers and people's livelihoods. But by completion of the first dam, Katse, on the Malibamatso River in 1998, global concerns over environmental degradation had grown to the point that international pressure forced a reconsideration of the downstream impacts of the LHWP dams. This was done in a flow assessment that adopted a scenario-based approach named Downstream Response to Imposed Flow Transformation (DRIFT: King, Brown & Sabet, 2003; Brown & Joubert, 2003) and, according to a World Bank global audit of EF work, was the first one to be documented that describes and quantifies not only the biophysical consequences of various development scenarios, but also the social and resource-economic consequences (Dr Rafik Hirji, World Bank, pers. comm.). River goods were identified and valued, as was compensation for riparian people for loss of river resources, and the health implications for people and livestock were described (Metsi Consultants, 2000, 2002).

The scenarios formed the basis for protracted negotiations between the Lesotho Highlands Development Authority (LHDA), the World Bank, and the governments of Lesotho and South Africa. These led to the publication in 2003 of Instream Flow Requirement (IFR) Policy and Procedures (LHDA, 2003), which included performance standards to guide the mitigation of impacts and the assessment of socio-economic losses and compensation values. The study resulted in downstream environmental degradation and social losses associated with reduced flows being accepted as legitimate project costs. Changes were made to the design of the dam outlet valves and to the operating rules for Mohale Dam, the next in the development sequence, to allow flood releases for river maintenance. Downstream releases increased by 300–400% compared to those that had been originally specified for Katse and Mohale Dams before the flow assessment: the releases at Katse Dam increased from 3% to 10% of mean annual runoff (MAR) and at Mohale Dam from 4% to 14% of MAR; these percentages excluded the larger floods that overtop the structures. A capacity-building component was designed to ensure that the LHDA could implement the IFR Policy and Procedures (World Bank, 2006).

When the policy was implemented in 2003, the focus switched to monitoring the flow releases and the condition of the downstream rivers, and administration of compensation payments to local communities. Payments were limited to villagers living in the proximal reaches downstream of the LHWP Phase 1 structures. This distance varied but was in the region of 60 km downstream of the structures and included approximately 7000 households. Compensation was to be paid as two tranches, one immediately and one after 10 years. The total compensation was calculated as the 2003 value of predicted resource losses over the life of the project (50 years), at an appropriate discount rate and adjusted for inflation from the start date of the project. The first tranche payments totalling about US$ 3 million were made in 2004. The payments were vested in local legal entities or community trusts (LHDA, 2005).

The work was recognised by the World Bank as a significant advance in the scientific foundations of flow assessments, providing the guidelines for sustainably maintaining an agreed river condition, and enabling the Bank to develop policy and procedures for its Regional Managers to follow. It was also a major step forward in recognising the rights of downstream subsistence users. The final agreed releases for ecosystem maintenance were low and the target ecological conditions for the rivers immediately downstream of the dams were lower than their pre-dam condition, reflecting other priorities of the project authorities, the countries and, perhaps, the views of other stakeholders consulted. The study was widely used by the Bank as a training example for flow assessments, and in 2007 an independent audit by the Institute of Natural Resources at the University of Natal, South Africa, concluded that the LHWP's approach to flow assessments was at the forefront of global practice (INR, 2007).

Contribution to concept and method development

1. Recognised that flow assessments should be neutral, technical activities, with the role of the scientists being to provide objective information to decision-makers on the likely consequences of specified flow changes rather than to advocate a specific flow regime as with the BBM. This information is best described through a series of scenarios representing a range of development options, and thus a range of options for ecosystem condition, each with its required flow regime.

2. As the first step in scenario creation, DRIFT formalised the definition of 10 ecologically relevant flow categories as opposed to the three recognised in the BBM (Table 2) and developed software to analyse and summarise long-term daily hydrological data sets using these categories (Brown *et al.*, 2005). The flow categories recognised were dry- and wet-season low flows, four categories of intra-annual floods with Class 1 being the smallest, and four categories of larger inter-annual floods ranging from a 2- to 20-year return period.

3. Developed a site-based Excel database tool that captured the issues of concern to stakeholders and the best understanding of the flow-assessment team of the links between flow, river condition, and social and economic impacts. This tool was then used to describe any number of scenarios of interest to decision-makers (Brown & Joubert, 2003).

4. Described scenarios in terms of the three pillars of sustainable development (Fig. 2) (King *et al.*, 2003),

Table 2 Summary data for each of the DRIFT flow categories for the natural state and for four scenarios of increasing development at Site 2 on the Malibamatso River downstream of Katse Dam, Lesotho (Metsi Consultants, 2000, 2002)

Flow categories	Natural	Minimum degradation	Design limitations	Fourth Scenario	Treaty
Wet-season low flows ($m^3 s^{-1}$)	0.05–30.85	0.07–25.00	0.07–1.90	0.00–1.90	0.50–0.50
Dry season low flows ($m^3 s^{-1}$)	0.08–23.01	0.05–9.00	0.05–1.20	0.00–1.20	0.50–0.50
Class 1 floods (# $annum^{-1}$)	8	3	3	2	1
Class 2 floods (# $annum^{-1}$)	2	2	1	0.5	0
Class 3 floods (# $annum^{-1}$)	2	2	2	0.5	0
Class 4 floods (# $annum^{-1}$)	1	1	0	0	0
1 : 2 floods (present/absent)	Present	Present	Absent	Absent	Absent
1 : 5 floods (present/absent)	Present	Present	Absent	Absent	Absent
1 : 10 floods (present/absent)	Present	Present	Absent	Absent	Absent
1 : 20 floods (present/absent)	Present	Present	Present	Present	Present
Mean annual runoff (Mcm)	554	367	184	97	22
% natural mean annual runoff	100	66	33	18	4
Total system yield ($m^3 s^{-1}$)	N/a	18.3	22.8	25.2	26.8

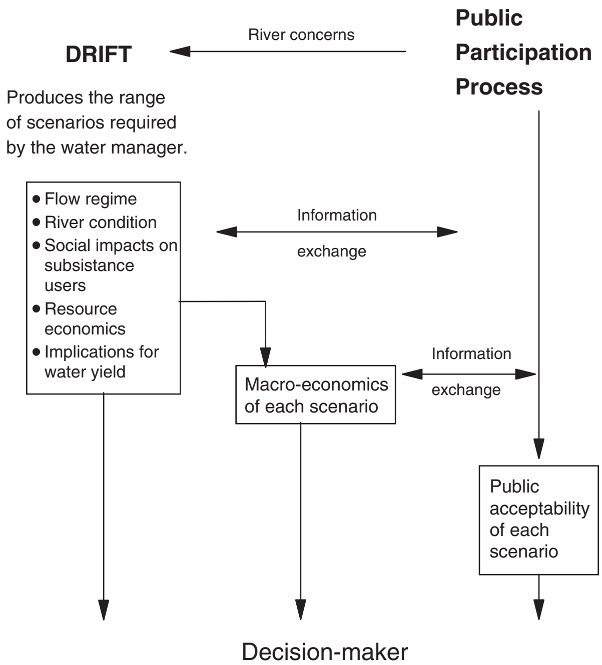

Fig. 2 Envisaged interdependence of the holistic flow-assessment method DRIFT, a Public Participation Process and a macro-economic assessment, in a proposed water-resource development, with the outputs representing the three pillars of sustainable development (King *et al*., 2003).

giving each equal weight, and included compensation costs to rural subsistence users for declining river resources.

5. Provided monitoring data to test the efficacy of the EF being released and begin the process of adjustment if necessary, to meet ecological and social targets. With firm data on the resulting river condition, decisions on adaptive management became more feasible and acceptable.

Lessons learnt

1. A flow assessment should be undertaken before detailed engineering design in order for the infrastructure to be able to deliver the agreed EF (Watson, 2008).

2. A decision-making process to consider the scenarios should be agreed by all stakeholders, and should be in place before the scenarios are produced.

3. Major stakeholder groups must be consulted. In the case of the LHWP, initial assumptions of no rural ties to the river and therefore no social impact from proposed dams were incorrect. Investigations recorded 154 587 people living downstream of the dams within Lesotho with livelihood links to the rivers (32 682 households; Boehm & Hall, 1999), leading to a complete redesign of the EFA and its output, and influencing the content of the 2003 Policy.

4. In the LHWP scenarios the compensation costs for even the most highly developed scenario were trivial compared to the potential economic gains from the industrial use of the water, with the latter overwhelming all other issues if only economics was considered. This highlighted the need for ecological and social considerations to be addressed at the same time, with equal weight, and in the same formal process as the economic ones. Intangible impacts, such as loss of quality of life, were not included in this assessment but were addressed in later IBFAs.

5. Flows for ecosystem maintenance need not greatly affect the economic rate of return (ERR) of water-resource developments, and it can be economically defensible to increase the environmental water allocation for ecological or social reasons (Brown & Watson, 2007). Failing to deal with ecosystem costs does not make them go away, it simply distorts the ERR calculations to the extent that the true costs of the project to the community are not taken into account (Watson, 2008).

6. The cost of a flow assessment is low in comparison with the related engineering and other water-resource studies. In LHWP Phase 1, the costs, including the flow assessment and compensation to subsistence users, were ≈0.5% of project costs. Downstream compensation costs for river degradation were about one-fifth of those upstream of the dam for river inundation (Brown & Watson, 2007).

7. Water delivery for ecosystem maintenance is a complex process for the life of the dam. It requires, *inter alia*, baseline data against which to measure change, a commitment to adaptive management, sufficient funds and appropriately skilled personnel (Brown, 2008).

3. Mekong River, South-east Asia, 2001–07

Overview. Of the world's great rivers, the Mekong is one of the least developed and least degraded and its flow regime is essentially natural. Sixty million people live in its basin, most depending on the river fishery, which, as the world's largest inland fishery, is worth more than US$200 million per annum (Deap, Degen & van Zalinge, 2003). The Tibetan Plateau and China contribute 16% of the river's flow, with virtually all of the rest from the four downstream countries: Cambodia 18%, Lao PDR 35%, Thailand 18% and Viet Nam 11% (Mekong River Commission, 2005). Fourteen large dams already exist on the system, with up to 34 more planned, mostly for HEP generation (IRN, 2007), including a cascade of eight dams within China (Li & He, 2008). The Mekong River Commission (MRC), representing and run by the four downstream countries, has a Decision Support Framework that at the beginning of the 2000s consisted mostly of hydrological and hydraulic models under configuration with some rudimentary social, economic and ecological tools. In 2001, the World Bank introduced the concept of flows for ecosystem maintenance to the four countries and in 2005, through the MRC's Integrated Basin Flow Management (IBFM) activities, a first demonstration assessment of the predicted positive and negative impacts of three possible future levels of basin development was completed for representative reaches from the China border to the Delta.

The assessment took 9 months, only used available knowledge, and was undertaken by a multidisciplinary team consisting of hydrologists, hydraulic modellers, geomorphologists, aquatic chemists, ecologists specializing in fisheries, aquatic invertebrates, water birds, herpetofauna and vegetation, sociologists and economists. Each discipline was represented by an international and a regional specialist (MRC, 2006).

This was the first flow assessment undertaken by the authors, and possibly globally, where all riverine services, including harvestable goods, wetland and estuarine functions, groundwater recharge, flood attenuation and much more, were tentatively valued, revealing the present multi-billion dollar value of the Mekong's resources. Most of the value resided in fisheries, wetlands, hydropower and irrigated agriculture. The results of the flow assessment, although numerically of low confidence because of limited ecological knowledge, limited time and low budget, revealed major trends that could result from further basin development. These included the potential threat to the Tonle Sap Great Lake, the heart of Cambodia's national fishery, from water-resource developments that could be hundreds to thousands of kilometres upstream; and the shifts in economies between countries that could occur as beneficial uses changed with, for instance, hydropower generation increasing in some countries and wetlands being lost in others. The results also suggested that although the overall value of the Mekong resources would increase with development, this would be relatively small because of the expected loss of wetlands. Their inclusion in the economic analysis completely transformed the picture of development from one of large benefits to one of very modest gains.

The assessment enhanced awareness among the Mekong Basin's collaborating governments of the two sides of development, and the negative effects that development in one country could have on a neighbouring one. The IBFM work continued at a lower level through 2006–07 but was halted by the countries in 2008 partially due to lack of funding.

Contribution to concept and method development

1. Recognised the need to pair discipline specialists by bringing together international experts with global experience in their fields and/or flow assessments and regional experts with a deep understanding of the river, in a two-way capacity-building partnership.

2. Included intangible aspects such as cultural features of the river, iconic species and areas of religious significance.

3. Estimated the value of the present and predicted total value of all beneficial uses of the river system, including regulatory and cultural services, by country.

4. Recognised the importance of basin level planning, as development projects with local benefits could have ecological impacts over much larger spatial scales. Recognising the importance of processes such as fish migration, introduced consideration of longitudinal river connectivity, so that impacts in one part of the basin could be interpreted as predictions of change in another, often distant, part.

5. Employed response curves with numerical detail where possible (Fig. 3), to capture in the software the specialists' data and expert opinion, as well as local wisdom, regarding the relationships between:

- Flow and ecosystem services.
- Ecosystem services and socio-economic well-being.

These curves used ratings of change from 0 (no change) to 5 (severe change) to describe the predicted severity of change in abundance of an ecosystem indicator to a specific flow change (King *et al.*, 2003).

6. Introduced the concept of Development Space (Fig. 4). This was defined as the difference between current conditions in the basin and the furthest level

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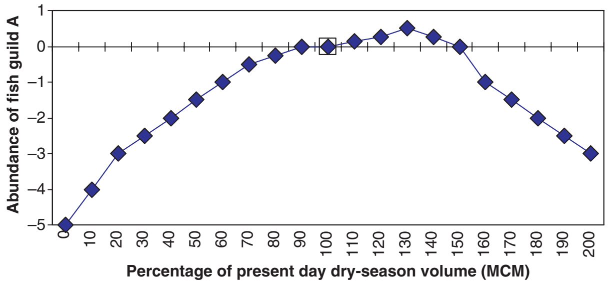

Fig. 3 Hypothetical response curve for *Fish Guild A*, a floodplain breeder in the Mekong River. Abundances are shown as the predicted change from Present Day (0) on a severity scale of 1–5, which may then be interpreted as a per cent change (King *et al.*, 2003). The square indicates Present Day flow conditions.

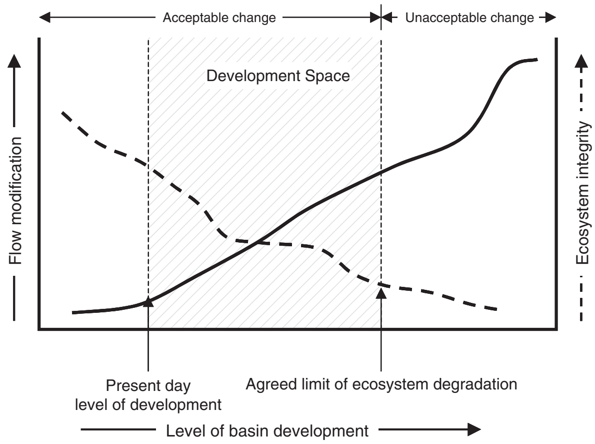

Fig. 4 The concept of Development Space, which is defined by present day conditions and the negotiated limit of ecosystem degradation as basin development proceeds.

of water-resource development found acceptable to stakeholders through consideration of the scenarios. Beyond this point, costs would be perceived to outweigh the benefits of development (Table 1). Negotiations could apportion the recognised Development Space among stakeholders – in this case, the countries of the basin – in an agreed way that allows slower-developing countries to still have their share as and when desired. The Development Space could be perceived as being negative in over-developed basins, with unacceptable degradation of the natural resources of the river already present, indicating the need to rehabilitate the flow regime and river. Although introduced in the Mekong IBFM project, the concept was not taken into practice because the

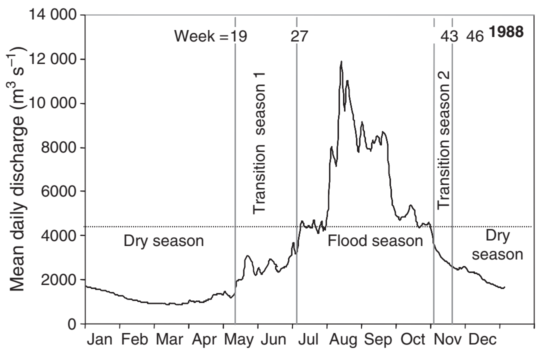

Fig. 5 The four ecologically relevant flow seasons recognised for the Lower Mekong River, showing their start and end weeks at Luang Prabang in 1988. Data source: Mekong River Commission; analysis Peter Adamson.

project had only proceeded to the point of presentation of the scenarios by its end.

7. Because of the monsoonal nature of this very large river, the 10 ecological flow categories used for hydrologically flashy southern African rivers (Table 2) were inappropriate, and instead four flow seasons were recognised (Fig. 5) and used to guide predictions of change. These allowed assessment of not only changes in flow magnitudes per scenario but also the timing of the onset of each season. Under present conditions the onset and duration of the four flow seasons are remarkably constant and almost certainly have been for many centuries, with the standard deviation of onset of the flood season, for instance, being just 2 weeks (Peter Adamson, MRC, pers. comm.). These seasonal timings, which are thought to play a key role in the ecological functioning of the system, are probably the most exposed and susceptible aspects of the flow regime to modification through upstream developments and are predicted to move outside their 2-week norm with planned upstream dam developments.

Lessons learnt

1. Limited river-specific data, global understanding of river functioning and local experience can be combined to capture available knowledge and describe broad zonal responses to development along a river, to create awareness and highlight transboundary trends of potential concern.

2. Software that describes holistic scenarios is a major technical step forward but needs support from simple, effective graphics that can be understood by non-technical stakeholders.

3. The concept of Development Space has the potential to be used to identify thresholds beyond which ecological or social systems reflect unacceptable change.

4. Zambezi Delta, Mozambique, 2005

Overview. Water-resource developments in the Zambezi River basin in Africa have substantially altered the hydrological regime of the Zambezi Delta over the past century. With the completion of Kariba Dam in 1959 and Cahora Bassa Dam in 1974, nearly 90% of the catchment area of the Zambezi basin became regulated. The nature and timing of flooding events in the delta changed significantly, essentially controlled by Cahora Bassa releases for hydropower generation, which resulted in a wide array of ecological and socio-economic changes, many of which harmed residents of the area (Beilfuss, 2001). Floods in the delta, when they occur, are now considerably smaller than natural and depend upon local rainfall-runoff within the lower Zambezi catchment or upon unplanned and aseasonal water releases from the upstream dams (Beilfuss, 2001). Lowflows, on the other hand, are considerably higher than natural with little or no seasonal variation. In 2005, the Gabinete do Plano de Desenvolvimento da Região do Zambeze and partners undertook a preliminary flow assessment for the Zambezi Delta using a DRIFT-type approach (Beilfuss & Brown, 2006). The main aims of the project were to identify potential conflicts/trade-offs among users in the Zambezi Delta area with respect to flow requirements and to explore the potential for improving the overall situation for delta users through varying the pattern and magnitude of flow releases from Cahora Bassa Dam.

The assessment used existing information, particularly from hydrological and hydropower models, limited hydraulic data and input from a wide range of delta stakeholders on which aspects of ecosystem functioning were relevant to their activities and how these might change in response to future changes in flow release patterns. The stakeholders represented the following sectors within the delta: agriculture; river, estuarine and coastal fisheries; large mammals; water birds; natural vegetation resources; water quality and supply; and navigation.

Stakeholders defined the future conditions they would like to achieve (target conditions) and thus all bought into the study in a way that greatly strengthened the outcome. The scenarios revealed minimal conflict among different user groups regarding the flows that would improve their situations. An overall 15% move towards users' target conditions could be achieved with only a 3% loss in hydropower generation, and a 46% improvement with a 30% loss in hydropower (Beilfuss & Brown, in press). The study has aided planning of a major flow assessment for the Zambezi River in Mozambique, which is scheduled to start in 2009 (R. Bielfuss, International Crane Foundation, pers. comm.).

Contribution to concept and method development

1. Moved from the classic approach of using ecosystem features (e.g. pools) and social features (e.g. household income) as the indicators of change, to an approach that used stakeholders themselves as the indicators of change and, in a structured multi-criteria decision analysis, predicted the change for each stakeholder group in terms of its desired target condition.

2. Illustrated that the DRIFT-type approach can be used to explore river rehabilitation, as well as development, options.

Lessons learnt

1. Challenged a common perspective that the flows required by river users are so disparate that there is no clear way forward. In the Zambezi Delta, by focusing on stakeholder issues and basing the flow assessment on how releases would affect user benefits it was shown that small-scale agriculture, estuarine and coastal fisheries, freshwater fisheries, livestock farmers, large mammals, water birds, vegetation, water quality, ground water and natural resource utilisation would all benefit from improved timing and nature of the annual flood. These benefits increased with increased peak discharge to a maximum of 10 000 m^3s^{-1}. Furthermore, irrigated commercial agriculture and in-channel navigation would be unaffected by the flood provided it had a peak discharge of less than 7000 m^3s^{-1} (Bielfuss & Brown, 2006).

2. Operating rules for existing infrastructure can be changed to improve the downstream river condition and the dependent social situations.

5. Olifants-Doring Basin, South Africa 2006

Overview. In the Olifants/Doring Basin north of Cape Town, South Africa, the Olifants River sub-basin is

Table 3 South African Ecological Status categories (Kleynhans, 1996)

Category	Description
A	Unmodified, natural
B	Largely natural with few modifications
C	Moderately modified. A loss and change of natural habitat and biota have occurred but the basic ecosystem functions are still predominantly unchanged
D	Largely modified. A large loss of natural habitat, biota and basic ecosystem functions has occurred
E	The loss of natural habitat, biota and basic ecosystem functions is extensive
F	Modifications have reached a critical level and the lotic system has been modified completely with an almost complete loss of natural habitat and biota. In the worst instances the basic ecosystem functions have been destroyed and the changes are irreversible

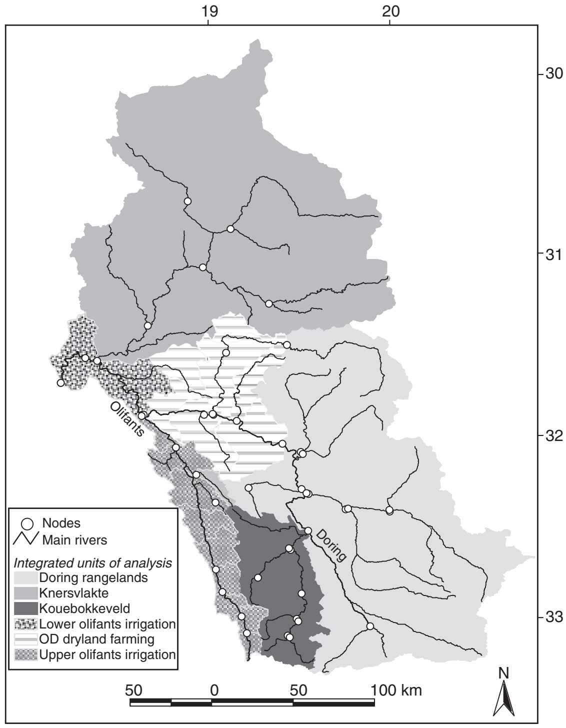

Fig. 6 The Olifants/Doring basin, showing Integrated Units of Analysis (IUA, shaded areas) and the 40 nodes.

suitable for agriculture and moderately populated, whilst the Doring River sub-basin drains a more arid landscape and is more sparsely populated. Both rivers flow through spectacular landscapes and have a high conservation value, supporting seven endemic fish species (Paxton, Clarke & Brown, 2002). The Olifants River estuary is a vitally important nursery area for commercially exploited marine fishes (DWAF, 2004). Its middle and lower reaches and the endemic river fish species are heavily impacted by a storage dam and barrage (Paxton *et al.*, 2002). The Doring River has an Ecological Status of A to B, and the lower Olifants a status of E to F (Table 3).

Reflecting the concept of Development Space and recognising the need for a structured process to identify the agreed trade-off point between resource protection and development of river basins, the Olifants-Doring Basin was used for the design of a national Water Resources Classification System (WRCS) for South Africa (Dollar *et al.*, 2006, in press). To facilitate the integration of social, ecological and economic aspects, six Integrated Units of Analysis (IUAs) were identified in the basin (Fig. 6), based on sub-basin hydrological boundaries and socio-economic zones, and characterised at a finer scale in terms of the river ecosystem at 40 nodes.

The flow assessment defined the flow regime needed at each node to maintain its upstream river section in an A, B, C or D condition. Additionally, potential water-resource developments and their yield of water were defined per IUA. These two sets of information formed the basis for water-resource scenarios that will be developed in consultation with stakeholders. Recognising that the South African 1998 Water Act requires that no part of a river system should be below a D Ecological Status, one scenario will define the bottom line in terms of the Act by developing one or more basin-wide configurations of flows that will maintain all parts of the system at a D-Status or higher (Brown *et al.*, 2006). This scenario, in its various forms, will represent the furthest extent of development available for stakeholder consideration. Other scenarios, driven either by the development options or by social or biodiversity protection issues, will represent other permutations of ecological conditions that are higher than the D-Status bottom line. The D-Status scenario may be seen as defining the negotiating space in discussions with stakeholders, and the eventual chosen scenario as defining the Development Space, which may be considerably smaller than the initial negotiating space.

Once the process of stakeholder consultation and government decision has been completed then essentially a basin development plan has been defined that includes the ecological flow requirements for every part of the basin. This eliminates future needs for flow assessments for individual proposed projects or water-license applications, although the whole basin plan would need to be revisited periodically.

The WRCS has been published in the Government Gazette for comment, and no classifications have yet been completed for South African river basins. Nonetheless, the exercise done in the Olifants-Doring Basin to develop the WRCS indicated options for discussion and negotiation. One option could be to halt development in the Doring Basin in return for an increase in the capacity and yield of the dams on the Olifants River. This option would be more cost effective, more efficient and more sustainable than options such as building a major impoundment on the Doring River. The Doring River would be conserved to continue to provide the required habitat for the endemic fish species, as well as floods that would provide flow variability to the estuary, whilst the already impacted Olifants River would bear the burden of further development.

Contributions to concept and method development

1. Resulted in the WRCS, which brings together an already-existing set of procedures and tools in a structured process that facilitates equal consideration of ecological, social and economic issues to determine the Development Space within a basin.

2. Recognised that management decisions pertaining to flows for ecosystem maintenance should be made at a basin level, as this allows for the identification of configurations that optimise ecological, social and engineering outcomes.

3. Gave context to South Africa's legal requirement that all river systems must be maintained in a sustainable condition (i.e. Ecological Status D or higher).

Lessons learnt

To achieve basic sustainability in the lower reaches of a basin, it is often necessary for the upper reaches to be in better condition as they provide the water, recruiting populations, breeding areas and refuges that support the lower reaches.

Pangani River Basin, Tanzania, 2004–08

Overview. The Pangani River Basin lies almost entirely within Tanzania, rising as a series of small streams on the southern sides of Africa's highest peak, Mt Kilimanjaro, and on Mt Meru. The Pangani River is about 500 km long, flowing through the arid Masai Steppe and draining the Pare and Usambara Mountain Ranges before emptying into the Indian Ocean at Pangani town. The main activities in the basin are agriculture, mining and hydropower generation, plus an assortment of resource-based subsistence activities, such as fishing.

The World Conservation Union (IUCN) and the Pangani Basin Water Office (PBWO) initiated the Pangani Basin Flow Assessment (PBFA) in 2004. Its aim was to collect and synthesise present knowledge on the Pangani River system and its users, and to help promote an integrated approach to future water-allocation decisions. The project used an holistic, scenario-based approach with a strong capacity-building focus, in which a multidisciplinary team of Tanzanian scientists and managers, and international EF specialists, worked side-by-side on every aspect.

From scenarios suggested by stakeholders at a series of structured workshops, 18 possible future development pathways were chosen by IUCN and PBWO for consideration. Each was based on water allocations for Basic Human Needs, domestic and industrial use, irrigated agriculture, HEP generation, maintenance of the river system and climate change, with the amounts or priorities for allocation varying per scenario. The outputs of each scenario were the predicted implications for HEP generation, area of irrigated agriculture, fishery production, many aspects of physical, chemical and biological river/estuary condition, household incomes, a human well-being index and resource-economic indicators. The PBFA is an ongoing project and documents on the above are not available to the public yet.

The scenarios revealed previously unrecognised opportunities for gaining more benefits with minimal loss of present ones, through viewing water management at the whole-basin level. For instance, hydropower production and improved ecosystem condition could be managed together to allow rehabilitation of parts of the basin as explained in the first 'Lessons learnt' below.

In line with the Tanzanian National Water Policy, the tools developed in the project will inform basin authorities about future considerations on water allocation and implementation, and the local team will act as a nucleus of expertise for similar assessments of other Tanzanian river basins. Through the inputs of IUCN, the PBWO and a linked Dialogues project, this work produced our strongest links yet with a wide range of stakeholders from central government to rural people.

Contribution to concept and method development

1. Used training workshops, mentoring visits and stakeholder meetings to enhance awareness of flows for ecosystem maintenance and IWRM, and to undertake practical hands-on capacity building.

2. Developed a software package to integrate river, estuary, social and socio-economic outcomes of scenarios into one comprehensive picture of predicted change.

3. Developed flow-ecology and ecology-social/economic response curves (Fig. 3) using general principles of river relationships learnt elsewhere and local knowledge, on the understanding that these would be refined through ongoing monitoring. The response curves were housed in a custom-built Decision Support System, allowing flexibility in the number and nature of scenarios analysed.

Lessons learnt

1. Basin-wide flow assessments can provide insights into win-win situations that are not apparent in project-based assessments. For instance, in the Pangani system, a basin-wide revision of the operating rules for hydropower dams could allow re-flooding of a swamp and a more abundant fishery in a poor area of the basin, with no decrease in hydropower production.

2. Hands-on involvement of water managers and a range of other stakeholders throughout the project increased cohesion, buy-in and relevance of the outputs.

3. Developing a deep understanding of the complexity of flow assessments and IWRM is a long process. Senior scientists and managers in any country may never have approached their knowledge and work from this perspective before. Grasping that river ecosystems react to imposed flow changes, and approaching their data and knowledge in new ways to predict how this may manifest itself, takes time, as does learning new ways to cope with data-poor situations. In the Pangani project, as the local scientists and managers grappled with a host of new concepts, two slow-down training phases were inserted to provide additional training.

Summary of IBFA approach in the case studies

The IBFA process used in the case studies evolved over time, with a common set of attributes emerging (Table 4). These continue to be tested and revised, but enable the IBFA to take place within the same time frame as engineering and other related studies, and to link in with water-resource systems models and national economic models.

Implementation

The efficacy of flow assessments is most often judged in terms of the flow released or maintained in the river and the resulting river condition. This may be seen as implementation, but we now realise that implementation, in terms of truly moving to manage for sustainability, is much wider and more complex (Table 5), occurring over a considerable time-span.

Implementation as outlined in Table 5 may well take one to two decades, even where the political will, funds and technical skills exist. In the case studies described:

1. Environmental flows for the Luvuvhu have not yet been signed off by the Minister of Water Affairs and Forestry, but in the interim releases from the newly constructed Nondweni Dam include an environmental component for downstream ecosystem maintenance including for Kruger National Park.

2. The Lesotho scenarios were produced in 2 years and decision-making took a further 3 years. This project then moved quickly through to releases and monitoring because of commitment from the Lesotho and South African governments, the World Bank and LHDA. Monitoring has been on-going since 2005. The first audit, completed in 2007, found that implementation had been 60% compliant with the IFR Policy and identified issues likely to affect the sustainability of the process, which LHDA has committed itself to addressing (INR, 2007).

3. The Mekong scenarios have recently been revived as one input to the MRC's evolving Basin Development Plan.

4. The Zambezi Delta assessment received wide national coverage and attracted considerable interest from a range of stakeholders including the Mozambique government. It is presently being used to plan a comprehensive IBFA for the Zambezi Basin.

Table 4 Attributes of the IBFA process that evolved through the series of studies

Attribute	Detail
Data/knowledge	Used in the following order of priority to develop flow-ecosystem or ecosystem-socio-economic response curves: 1. Data on the specific ecosystem/basin attribute (e.g. pool, fish species, household income) from the river being assessed 2. Data on the specific ecosystem/basin attribute from a similar river 3. Data on similar ecosystem/basin attributes from the same or similar rivers 4. International expert opinion per discipline 5. Local wisdom
Data input into relationships	All specialists use their own internationally recognised techniques and models and the above sources when preparing their inputs to creation of the response curves. Fish biologists, for instance, may use wetted-perimeter analysis, PHABSIM, hydraulic habitat mapping or other techniques to provide response curves of the predicted response of a fish species to, say, loss of intra-annual floods
Indicators	Indicators are used to describe the scenarios. They are chosen in consultation with stakeholders, so that the scenarios describe issues of concern to them. Indicators can be for physical (e.g. pool depth), biological (e.g. area of a riparian tree community), social (e.g. health index for people or livestock) and economic (e.g. household income) attributes of the system.
Process for using relationships	To make scenario predictions of change in any indicator as a result of a flow change, using any or all of the above inputs: 1. Original predictions were made using expert opinion of the relationships in a BBM-type approach 2. Now made using response curves (two-dimensions) or domes (three-dimensions) that capture the relationships and are amenable to updating as research and monitoring proceed
Quantification	Predictions semi-quantified through Severity Ratings of change and conversion to percentages for economic evaluation only (King & Brown, 2006)
Software	1. DRIFT-SOLVER for optimisation of flow regimes for ecosystem maintenance (Brown & Joubert, 2003) 2. DRIFT-HYDRO for converting hydrological series into ecologically relevant summary statistics (Brown *et al*., 2005) 3. Pangani Flows DSS, which links hydrological systems model outputs with ecological consequences of flow regimes and socio-economic outcomes for multiple scenarios (PBWO/IUCN, 2008) 4. DSS for Integrated Basin Flow Assessment – under construction (Beuster *et al*., 2008)

Table 5 Sustainable use of rivers: key attributes of implementation

No.	Attribute
1	Development of appropriate policy, legislation and basin agreements
2	Structured and continual engagement with stakeholders
3	Development of holistic flow-assessment methods
4	Re-organisation of institutions to meet new laws
5	Design of new kinds of infrastructure and operating rules to deliver and monitor environmental flows
6	Development of regional regulatory mechanisms for licensing or re-licensing
7	Creation of awareness among governments and other stakeholders
8	Continual investment in research and capacity building
9	Delivery of the environmental flow
10	Monitoring and adaptive management

5. The Pangani project is still underway, with continual interaction with the relevant government departments.

6. The South African WRCS is presently undergoing revision before final publication and application in priority catchments.

In conclusion

Three international conferences dedicated to EFs, in Cape Town in 2002, Brisbane in 2007 and Port Elizabeth in 2009, produced clear messages on the need to protect rivers globally through flow allocations for ecosystem maintenance (e.g. Brisbane Declaration, 2007). The over-riding message was that flow assessments should be integrated into every aspect of land and water management as a matter of urgency. This requires going beyond the token set-figure allocation of water 'for the environment' in many basin system models (Brown, 2007) to an approach that provides a range of options for environmental water allocations, each with its predicted ecological and social consequences and assessment of acceptability by stakeholders. Only once this becomes the norm will the assessment and management of water for ecosystem maintenance become fully embedded within and accepted as a central feature of IWRM, and only then can truly sustainable use of water be achieved.

From the case studies above and work with colleagues in other countries, we have gleaned eight principles that could guide the incorporation of EFs into IWRM in developing countries. Water developments here refer to any planning or other management activity that affects the flow, chemical, sediment or temperature regimes of rivers and through this the related ecological and social systems.

Principle 1 – Ecological and subsistence issues should be factored automatically and in a structured manner into water-resource development plans

Rafik Hirji (World Bank, pers. comm.) stated in 1999 that much of the work in EFAs is still focused on justifying this to countries and developers, and that we need to progress to the point where this requirement is encompassed in national laws, international treaties and similar, so that time and energy can be focused on the technical work of the flow assessment. Watson (2008) pointed out that labour safety rules probably played a minor role in the building of the pyramids but that no-one today would plan projects without considering worker safety. In the same way, water-resource planning and management must move on, with water for ecosystem maintenance and subsistence users becoming legitimate items that are factored in automatically – and not in a token way – in all development plans. Many governments, other stakeholders, consultants and funders appear not yet to recognise that the ecological and subsistence impacts of water-resource developments can be quantified, and so may not require their formal and structured inclusion in development plans or may settle for a token inclusion.

Principle 2 – IBFAs should be done at an early stage of water-resource planning and at the basin level

With legislative and political support in place, IBFAs should begin at the earliest stage of water-resource planning, describing the possible future extent of basin-wide development and ecosystem degradation, and thus helping stakeholders identify the boundary of acceptable development – the Development Space. This could then be formalised in a basin development plan, with individual projects then assessed in terms of whether or not they jeopardise the plan. With this process in place, no more flow assessments need to be done, until the whole basin plan is revised periodically.

Principle 3 – IBFAs should be holistic in approach, scenario-based and objective

The specialist teams that undertake EFAs should be multidisciplinary, involving experienced people in the physical, chemical, biological, social, resource-economic, macro-economic and management fields relevant to water developments. Their task is to provide objective information on the full suite of impacts, costs and benefits of development through a series of scenarios describing possible development pathways. The no-development/no change option should be included, with its costs and benefits clearly illustrated.

Principle 4 – It is never too early to get started

Decisions will always be made with incomplete data and understanding no matter how long the preparation time, but with time, money and data limitations, there is still always something that can be done. Experienced team members and local wisdom can to some extent replace data, providing incomplete or inexact data that can be seen as hypotheses to create awareness, inform decisions and for testing in later research and monitoring programmes. Techniques are available that capture what knowledge there is, such as flow change-ecological response relationships (Fig. 3), and severity ratings for semi-quantifying change, as applied in DRIFT (King *et al.*, 2003). Each scenario can be made relative to the present day so that specialists can use the river they see and can measure today as their starting point, predicting changes in indicators as the extent of change from the present condition. Capturing existing knowledge of flow–response relationships electronically using custom-built software provides consistency and transparency on the assumptions made, and allows the relationships to be updated as understanding increases.

Principle 5 – Involvement of stakeholders is essential at every stage of the flow-assessment process

Stakeholders should include national and local governments and all other recognised water-user groups, including commercial enterprises, conservation authorities and rural subsistence users of the water. They may differ from basin to basin. Scenarios should be designed around stakeholder issues so that each scenario describes the predicted outcome for each issue. Information transfer at each major stage of the flow assessment will enhance understanding of the process, buy-in, ownership and the ability to respond in an informed way to the development options eventually presented for discussion. All outputs of the flow assessment should be made available in accessible language to support this process, and investment should be made in building capacity among stakeholders so that they can use the information.

Recommendations to decision-makers regarding future flows, river condition, acceptable and unacceptable scenarios, and potential development space should emanate from stakeholder groups who have access to, and understand, the scenarios provided by technical practitioners. The practitioners themselves should focus on providing neutral, balanced technical information. If stakeholder groups considering the scenarios do not include those who can speak effectively for biodiversity, ecosystem condition and natural resources (such as those responsible for a country's biodiversity commitments, representatives of National Parks and so on), then such groups should be strengthened to enable this rather than using the flow-assessment practitioners as both objective technical advisors and in an advocacy role.

Principle 6 – The decision-making process should be structured and transparent

The chosen scenario represents the trade-off between development and resource protection – a selected development pathway – decided upon by government, ideally after feedback on the acceptability of all the scenarios by all the major stakeholder groups. It defines the agreed condition for each part of the river system, which can be used in monitoring for compliance, and also provides the EF required for ecosystem maintenance. Clearly, the choice of this scenario should be through a previously agreed, structured and transparent process. The classification system described in the Olifants-Doring case study provides one such process.

Principle 7 – Infrastructure should be designed and operated to deliver the agreed EFs to the river

Planned infrastructure should not be designed in detail before the basin development pathway has been agreed on. It should then be designed, with appropriate operating rules, to deliver water, including the agreed EF, to the river. This may require new or more expensive kinds of dam design with, for instance, release structures and sensors to manage the off-take depth and chemical and thermal quality of released water. The design and operation of existing infrastructure should be re-evaluated once a basin development plan has been finalised.

Principle 8 – Commitment to EFs is commitment to a long-term complex management process

See the section on Implementation (Table 5). Finally, even aware managers and decision-makers may still be reluctant to recognise the flow assessment outputs, because the two-sided descriptions of what might be gained and lost by development may be unwelcome information if there is a commitment to develop. In such cases, comprehensive stakeholder engagement can open up the discussion, but to date this largely remains elusive.

Acknowledgments

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