CHAPTER 13

The importance of instream flow requirements for decision-making in the Okavango River basin

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Abstract

This chapter provides an overview of instream flow requirements (IFR) for the protection and maintenance of aquatic ecosystems, with particular reference to the Okavango River basin. The chapter covers the conceptual basis of IFR, indicating the links between the sustainability of water resources and the maintenance of aquatic ecosystem health, structure and function, and hence the need to allocate adequate water for ecosystem maintenance. There is a range of available methodologies for the determination of IFR, and the selection of an appropriate methodology depends on issues such as scale, resolution, the level of confidence required, data availability and capacity constraints. These aspects are broadly discussed, with specific reference to the Okavango River basin. In the final part of the chapter, recommendations are provided to guide possible future determination and implementation of IFR in the Okavango River basin.

Background

Instream flow requirements (IFR) is a generic and widely used term that refers to the water required to protect the structure and function of aquatic ecosystems at some agreed level. Other terms that are sometimes used include ‘environmental water allocations’ or ‘environmental flow requirements’. In the United States, the term ‘minimum ecological flows’ is also used.

Methodologies to determine IFR were originally developed in response to the question posed by engineers designing outlet structures for large dams: What is the minimum flow that must be released from the dam for the downstream aquatic ecosystem to survive? However, the generally accepted approach has more recently been to determine not just the absolute minimum flows required, but those that will maintain an aquatic ecosystem in a particular desired state of ecosystem health. In recent research and studies, explicit links have been made between the state of aquatic ecosystem health that is desired or maintained, and the level of ‘goods’ and ‘services’ provided by such an ecosystem, including recreational potential, fisheries, and aquatic plants for food, basketwork or housing construction (Turpie et al 1999). The required flows are therefore currently seen as a critical element in protecting the value of and benefits provided by the natural ecological functions of healthy aquatic ecosystems.

Conceptual basis for instream flow requirements

Why protect aquatic ecosystems?

The conventional approach to water resource management, especially in developed countries, sees water resources as being important primarily for the volume of water that can be abstracted and supplied to users to meet offstream demands such as those for urban water supply, irrigation and industrial development. What this approach does not normally take into account is that the commodity aspect of water is only one part of a complex ecosystem, which includes an aquatic component (streams, rivers, wetlands, groundwater) and a terrestrial component (the land and soils over or through which the water flows). Ecosystems provide much more benefits than just water. In particular, if the aquatic ecosystem is healthy and functional, humans can enjoy an array of ecosystem goods and services, among others:

- the assimilation, decomposition and transport of certain biodegradable wastes, within limits, due to the natural decomposition and dilution processes;
- sequestration of heavy metals that might otherwise cause toxic effects on aquatic organisms and on humans who might consume those organisms;
- attenuation of floods and mitigation of potential damage due to flooding;
- storage of water for later release during the dry season, which is a particularly important function of headwater seeps, sponges and springs, as well as wetlands, and which helps to ensure the reliability of flow in surface water resources;
- food resources such as fish, shellfish and plants;
- material resources such as reeds for thatching and timber for building;
- medicinal plants;
- support of subsistence livelihoods such as floodplain or recession agriculture; and
- maintenance of cultural, spiritual and recreational activities that, in cases such as ecotourism and recreational fishing, may have important economic spinoffs.

Many of these benefits are difficult to measure in economic terms, and have tended to be ignored or discounted in major water resource development projects. Yet, in developing countries, many people may depend on the natural ecosystem structure and function for their livelihoods. If ecosystem goods and services are lost, reduced or degraded, those people who have been reliant on such goods and services must be compensated or provided with alternatives. Such alternatives are seldom economically or environmentally sustainable, and may require cross-subsidisation by another sector of the population.

There is growing awareness that, particularly in developing countries, aquatic ecosystems must be protected in order to ensure that the benefits of ecosystem goods and services can be sustained in the long term. Aquatic ecosystems in Southern Africa have become adapted to natural seasonal cycles and generally high interannual variability, and are thus resilient to some degree. However, if they are overutilised – for example, if too much water is taken out or too much waste put in – they will become degraded, their structure and function will be compromised, and key species, components or processes may be lost. A balance must be found between the consumptive use of water for offstream activities, and the provision of instream flows for maintenance of the ecosystem structure and function on which people depend for goods and services.

It is reasonable to assume that there is a relationship between the health status of an aquatic ecosystem and the abundance, variety and value of the goods and services that are provided by such an aquatic ecosystem. A healthier aquatic ecosystem should clearly be able to support a greater diversity or quantity of goods and services to humans. Ecological research has been directed towards the quantities or flow of goods and services that are associated with different levels of aquatic ecosystem health, while recent research in the field of resource economics has been aimed at quantifying the value of those ecosystem goods and services in monetary currencies (Turpie 1999). Thus, the costs and benefits of managing aquatic ecosystems at different levels of ecological health can be assessed, and decisions about water utilisation can be made accordingly.

What is needed to protect and maintain the health of aquatic ecosystems?

A healthy aquatic ecosystem is where the major ecological components of habitat and biota are present, and all the major ecological processes are supported and functioning well. This includes natural processes such as decomposition and nutrient cycling, oxygenation and carbon sequestration, photosynthesis and primary production, grazing, predation and reproduction. An ecosystem does not have to be pristine to be healthy, although generally speaking, the closer to natural a system is, the healthier it is likely to be.

In order to protect the health of an aquatic ecosystem, four components of the ecosystem must be addressed:

- A sufficient volume of water must be provided, distributed in as close to natural a pattern as possible.
- Water quality, including the physico-chemical and biological characteristics, must be maintained at appropriate levels to protect biota and their associated ecological processes.
- The character, extent and condition of instream and riparian habitat must be maintained to provide sufficient habitat of a suitable quality to support viable biotic populations.
- The character, distribution and condition of biotic populations (fauna and flora) must be preserved to maintain ecological processes that depend on these populations.

The overall health of an aquatic ecosystem will depend on the degree to which these four components are supported by water resource and land management activities.

The measurement of ecosystem health is still a developing science, and many monitoring tools and techniques are now available that allow an assessment of the health of an aquatic ecosystem in comparison to some reference condition – usually the natural, unimpacted condition (Roux et al 1999). Within the limits of uncertainty, it is therefore possible to set quantitative objectives for aquatic ecosystem health, and then allow utilisation of water resources, such as abstraction and waste discharge, to the extent that the desired level of ecosystem health can still be maintained.

It is important to note that aquatic ecosystems are impacted directly through the consumptive uses of water resources, as well as indirectly through the effects of land-use practices. It will not help to design and build a dam that can release sufficient water of the right quality at the right time to protect downstream aquatic ecosystems, if aquatic habitat, at the same time, is degraded due to unsustainable land-use practices, the destruction of riparian vegetation, smothering by sediments as a result of catchment erosion, and the loss of local species due to the introduction of invasive alien plant and animal species. This is dealt with in more detail later in this chapter.

What are instream flow requirements?

For the purposes of this chapter, instream flow requirements are defined as:

- the quantity and quality of water, expressed in terms of the magnitude, duration, timing and frequency of specific flows; and
- the quality of water, expressed in terms of the ranges, frequency and duration of occurrence of concentrations of key water quality variables that are required to maintain a desired level of aquatic ecosystem health.

The desired level of aquatic ecosystem health is usually related to the ability of the ecosystem to provide certain desired ecosystem goods and services, or to the maintenance of a single specific good or service, such as a subsistence or commercial fishery.

Why are IFR important for decision-making?

Traditionally, decision-making about water resources has been primarily focused on the volume of water that could be abstracted from a river or other water resource, and kept in storage or diverted for offstream use. There are many examples of large water resource development projects in Africa where cost-benefit analyses were carried out to ascertain the feasibility of a development, but these cost-benefit studies did not take into account the economic value (usually non-monetary) of the goods and services provided by the natural aquatic ecosystem. These goods and services were often lost or severely reduced if provisions for IFR were not made once the development was implemented. Hence, the long-term social and environmental costs of water resource development projects were often not accounted for, although these costs frequently outweighed the benefits of the development itself.

To make water resource and allocation decisions without considering the aquatic ecosystem and the IFR to maintain the aquatic ecosystem is an approach that is deeply flawed. The report of the World Commission on Dams (WCD 2000) has highlighted the need to determine and make provision for these requirements, and to broaden cost-benefit studies to include all ecosystem goods and services.

Most countries in the Southern African Development Community (SADC) now subscribe to the principles of Agenda 21 and the Dublin principles on water, which require development, use and management of water to be environmentally sustainable. In addition, as awareness grows of the real value and importance of aquatic ecosystem goods and services, the realisation also increases that water use must be balanced with ecosystem protection, not only to protect the intrinsic value of the ecosystem itself, but also to protect the value of ecosystem goods and services for people. In order to protect aquatic ecosystems, there is a need to understand their water requirements, and how these ecosystems are affected by changes in the water regime due to development and use. Only once this understanding is gained, can the limits of sustainable water use be quantified so that water resources are not overutilised.

In many countries, and SADC countries are no exception, decisions about water resource developments and water allocations are made by a national or catchment-based water agency, while the protection of aquatic ecosystems is usually the responsibility of an environmental or wildlife agency. The situation may be complicated if an agricultural agency has overlapping responsibilities, as may be the case with the subsistence utilisation of ecosystems, for example, in floodplain agriculture or fisheries. Policy and legislation are often fragmented or even contradictory, and when this is added to the problem of multiple agencies with overlapping or interlinked responsibilities, the common result is that decisions on water management do not take the requirements or objectives for aquatic ecosystem management and protection adequately into account.

Whatever the governance arrangements, all relevant agencies within a country (and in all basin states in the case of a shared river basin) need to:

- agree on the importance of IFR in sustainable water resource management, the protection of ecosystems and biodiversity, and the maintenance of subsistence livelihoods;
- cooperate at national level and with local stakeholders in the setting of objectives for aquatic ecosystem health and the determination of IFR to achieve these objectives; and
- collaborate in regulating impacts in their own sectors, including land use, water use and resource use, so that aquatic ecosystems are fully protected.

If the principle of making water allocations for aquatic ecosystems is to be implemented with any real commitment and effectiveness by governments and stakeholders, then the water allocated to ecosystems should lead to enhanced quality of life for people, and should not prejudice the provision of basic water supply, sanitation and food security. This is particularly important in Southern Africa, where large numbers of people rely on the natural functions and processes of aquatic ecosystems for subsistence livelihoods. If IFR are not determined and included at the planning stage of water resource development projects or water allocation strategies, it becomes much more difficult to ‘retrofit’ these requirements once developments are in place. Not only may physical constraints have been imposed due to the design and construction of flow release mechanisms at large dams, but the reallocation of water from existing users to ecosystems can lead to lengthy negotiations and legal processes while water users seek to protect their perceived rights.

Main issues associated with instream flow requirements

Policy and legislation

National policy to support the allocation of water to meet IFR, specifically to protect and maintain aquatic ecosystems, is fairly new in most countries where it has been implemented. Commonly, the issue is addressed in environmental policy, legislation or regulations. However, experience is beginning to show that, unless IFR or water allocations for aquatic ecosystems are explicitly mentioned and given clear status in water policy and legislation, they are not likely to be implemented in practice, even though the water requirements of aquatic ecosystems may be determined in the planning phase of water resource development projects and in environmental impact assessments. It is not sufficient to have the issue only addressed in environmental policy and legislation (MacKay et al 2002).

The SADC Protocol on Shared Watercourse Systems provides a framework for collaborative decision-making on the utilisation and protection of water resources in a shared river basin, but does not specifically mention IFR. However, the principles on which the protocol is based support the protection of the aquatic environment and the control of water utilisation by each member state through an authorisation or permit system. Each member state would administer the permit system and make water allocations according to procedures set out in its own national policy and legislation, but within the limits of an agreed ‘fair and equitable share’.

This means that the national policies and laws of states that share a particular watercourse or river basin may need to be reviewed and aligned to establish the status of IFR, to determine these requirements and the allocation of water to meet them, and to support the authorisation of domestic and other water uses in a way that respects and gives effect to IFR.

Consideration should be given to the incorporation of local customary law into policy and regulations for the determination of IFR in particular river basins. Customary law has often been developed over long periods and is tailored to the sustainable management of ecological resources in a river basin. It represents an important knowledge resource related to management, and is likely to have much wider support at community level than policy imposed by central government, leading to a better chance of the successful implementation of measures to fulfil IFR.

In relation to the Okavango River basin, it will be necessary to take into account the deliberations and resolutions of the 8th conference of parties to the Ramsar convention (November 2002). Two resolutions were adopted at the conference, one dealing with the implementation of the recommendations of the World Commission on Dams, and the other related to the determination and management of water allocations for wetland ecosystems. The second resolution addresses the needs for contracting parties to review national water policy and legislation to ensure that water allocations for wetland ecosystems are given clear status in water law, and that procedures for allocating water to users take environmental water allocations into account.

Determining instream flow requirements

There are two primary ways in which IFR can be expressed:

- either as the volume and quality of water that must remain in a river, watercourse or water resource at specific points in the resource to maintain a particular desired level of aquatic ecosystem health; or
- as the volume of water that may be abstracted from specific points in a river, watercourse or water resource and the magnitude of change in water quality that may be allowed in a river, watercourse or water resource for aquatic ecosystem health to be maintained at a particular desired level.

In general, IFR are expressed in relative terms, as the proportion of the virgin or present-day flow that must be maintained, or that may be abstracted, and the allowed deviation from natural or background water quality conditions. Although the aim in both cases is the same – to protect aquatic ecosystems and maintain a certain desired level of aquatic ecosystem health – the scientific process to determine these levels may be slightly different depending on the approach that is taken.

How much water must be left in the ecosystem? This approach is suited to situations where water utilisation is already fairly high, possibly even tending to the overutilisation of water resources in the basin, and to fairly well-regulated systems, where major abstractions are made from dams or weirs rather than run-of-river, and where scheduled releases can be made from flow control structures to meet IFR. The determination of IFR then establishes the conditions that must be achieved in the river or water resource for flow and water quality, and establishes the limits of utilisation that can be allowed, through the following relationship:

Total allowed abstraction = total virgin flow – IFR

This relationship is multidimensional, and must address the spatial and temporal variability (seasonal and interannual) of the flow pattern that is required to support ecosystem functions and processes. Overall, water allocations to individual users should not add up to more than the total allowed abstraction. The decision on the total allowed abstraction must be embedded into local and regional development planning processes to ensure that developments are planned and implemented, while recognising the constraint of total allowed abstraction.

This approach is somewhat similar to strategic environmental assessment as limits are set to establish the allowed level of development of water resources, irrespective of the nature of each individual project. Individual projects such as dams and large weirs, or substantial discharges that may have a significant impact on the aquatic environment, may still require a separate environmental impact assessment. If water resources are already overutilised when the IFR are determined, then a strategy can be drawn up for progressively implementing water demand management measures and achieving a situation where water use is contained within the limits so that these requirements can be met.

The disadvantage of this approach is that, if the IFR that are initially determined turn out to be too low after monitoring to offer adequate protection to the aquatic ecosystem, then it can be difficult to reduce already authorised water use or to reverse impacts to meet new, higher requirements. Thus, it is prudent to ensure that the determination of these requirements is conservatively done.

How much water can be abstracted from the ecosystem? The alternative approach to provide water for the protection of the aquatic ecosystem is rather to determine how much water can safely be abstracted from the system, or how much change in water quality can safely be allowed, before the impact becomes unacceptable or exceeds some agreed target level. In this case, the absolute water requirements of the ecosystem are not determined as IFR, and only the allowed relative change is determined and translated into use limits.

This approach is similar to environmental impact assessment as several water-use scenarios may be developed and tested to ascertain their impact on the aquatic ecosystem. A water-use scenario is then selected that corresponds to the maintenance of a desired level of ecosystem health (which may be the present state, or the ‘no observable effects’ level). Water uses are evaluated and authorised, as long as the combined impact of all water uses does not exceed the allowed abstraction or change in water quality.

This approach is more suited to river basins where there has been little or no large-scale development of water resources, and the impact of human activities is still relatively insignificant. It is appropriate for systems that display a high level of natural variability in rainfall, runoff and water chemistry, since it is difficult to design an appropriate flow regime in these cases for the water that must be left in the system. However, it is usually possible to assess what the impact may be of removing certain flow components such as interannual floods. The approach is also suited to unregulated rivers, where abstraction is mostly run-of-river, and those where there are few hydrological gauging stations and few large flow control structures from which to make releases dedicated to meet IFR. Auditing and control of human activities are mostly through measures directed at the sources of impact, so that regulation occurs through the metering of abstractions and the imposition of effluent discharge standards.

The disadvantage of this approach is that, unless regulation and auditing of individual water uses are effective, it can open the door to cumulative impacts, where a project-based environmental impact assessment is carried out for each successive ‘small’ development project, and where each demands ‘just a little more’ water. Without an effective programme to monitor ecosystem health of which the results are regularly reviewed and incorporated into management and regulatory activities, the condition of the aquatic ecosystem can gradually degrade until the desired level of health is no longer maintained.

Uncertainty and confidence in the determination of instream flow requirements

Ecosystems are inherently uncertain. There is always a degree of randomness in their responses to environmental driving forces such as flow and water quality. A degree of uncertainty thus exists in any prediction of either the response of an ecosystem to a change in one of the environmental drivers, or the specification of the driving force needed to maintain a particular level of ecosystem health. Each ecosystem is also unique. Although general principles and an understanding of causal relationships can be extrapolated from one ecosystem to another, the determination of IFR for one ecosystem may not be directly transferable to another, even a neighbouring ecosystem.

Uncertainty can be reduced and confidence increased by the lengthening of timeseries datasets, so that causal relationships within the ecosystem and between the ecosystem and its environmental drivers can be identified and quantified as far as possible. In general, the less data available for a certain ecosystem, the lower will be the confidence in the IFR designed to maintain such an ecosystem in a particular state. The typical problem, though, is that highly confident answers on IFR are immediately required, or in the short term for decision-making in a river basin. To get around this conflict, any determination of requirements should ideally provide results that are conservative, with a safety factor built into the determination to allow for uncertainty. The lower the confidence, the higher should be the safety factor. As a result, whatever water resources or water allocation decisions are taken should at least not lead to irreversible damage to the aquatic ecosystem. As monitoring programmes are implemented and datasets built up, it should be possible to review the determination of IFR on the basis of a better understanding of ecosystem dynamics, possibly reducing the safety factors and potentially making more water available for allocation or development as confidence improves.

Ideally, before entering into water-sharing negotiations, a high-confidence, agreed upon determination of IFR should be available. In the short term, this might not be possible in the Okavango River basin. Although many studies have been undertaken about Panhandle and the delta, data from the upper and middle reaches of the basin is sparse. Any determination based on present data is likely to yield medium confidence answers for the Panhandle and delta, low to medium confidence answers for the middle reach of the basin between the confluence of the Cuito and Cubango rivers and the Panhandle, and low to very low confidence answers for the reaches above the Cuito-Cubango confluence.

Methodologies to determine instream flow requirements

Setting habitat-based endpoints

In determining IFR, it is necessary to select quantitative, verifiable management endpoints towards which the ecosystem is managed. An endpoint usually represents a particular desired level of ecosystem health, expressed in terms of the water quantity, water quality, habitat conditions and biotic conditions required to meet this level. Requirements would then be set that would achieve these endpoints.

For reasons of scale and resolution, the endpoints for management are generally habitat-related and expressed at the river-reach level (DWAF 1999). Since patterns of flow and water quality vary between headwaters and downstream reaches, it is not appropriate to set IFR as a ‘single number’ (such as the percentage of mean annual runoff), which applies throughout a river basin. The basin must be divided into representative reaches, of which each would require a separate determination and specification of its IFR.

To be useful in developing operational rules for a river basin, any method for determining IFR must address the magnitude, timing, frequency and duration of flows, and must indicate both intra-annual and interannual variability. Generally, the ecologically important flows are (King et al 2001):

- ‘maintenance’ dry season low flows, which maintain ecological processes and critical habitats and refuges for biota during the low-flow season;
- wet season low flows, which maintain important wet season ecological processes and habitats;
- intra-annual floods or freshets, which are often triggers for ecological processes such as spawning and migration, and which flush out poor quality water and small debris that may accumulate during the dry season; and
- larger floods, which maintain channel geomorphological characteristics, flush out accumulated sediment and reshape the cross-section of the watercourse.

Freshets and interannual floods play an important role in moving and distributing sediment in a rivercourse or water resource. The geomorphological habitat is formed through a complex interaction between water and sediment. This interaction has its origins in sediment delivery mechanisms from the land surface of the catchment to the river, which are influenced by topography, soil characteristics, rainfall characteristics and land uses. Depending on what is happening on the land surface, and what the instream flow regime is, sediments can accumulate in certain places in the aquatic ecosystem and be lost from others, thus changing the balance between different types of habitat. The determination of IFR takes into account this interaction between sediment and water by requiring geomorphological studies to be conducted, of which the results are used to predict the outcome of certain modified flow regimes with regard to sediment distribution, gains and losses in the aquatic ecosystem, and the subsequent impacts on availability of instream habitat.

Resolution, confidence and application of methodologies

There are several types of methodologies to determine IFR. Selecting the appropriate methodology will depend on the confidence required in the final determination, the quantity and type of data available, and the resolution required.

Low-confidence, low-resolution methodologies usually rely on hydrological data inputs (observed or simulated virgin and present-day hydrology), and generate as outputs relatively coarse estimates of IFR such as the mean or median annual flow volume required at a certain control point or points in a river basin (known as IFR sites) in order to maintain a desired level of aquatic ecosystem health. While this level of determination is adequate for coarse planning purposes, it is not of sufficient resolution to allow development of dam operating rules or abstraction permitting rules. The seasonal distribution and timing of flows required for the ecosystem can usually not be resolved. However, the advantage of low-confidence, low-resolution methods is that they are relatively rapid and cheap to apply.

One of the best known low-confidence methodologies is the so-called Montana method (Tennant 1976), in which the proportion of the virgin mean annual runoff provided to a river ecosystem can be related empirically to the ecological condition of the ecosystem. This methodology relies on observations of ecological conditions made by its developer in many North American rivers, which were then related to flow in the river at the time of observation. The method is suitable only for northern temperate ecosystems, and cannot be applied with confidence elsewhere, especially in ecosystems where flows are strongly seasonal or episodic. However, a modified version of the Montana method has been developed in South Africa (DWAF 1999), based on experience from local studies, and has been extensively used for planning purposes and in the scoping phase of some environmental impact assessments.

A range of methods is available for high-confidence, high-resolution determination of IFR. Spatial resolution is at river-reach level or smaller, temporal resolution ranges from monthly to daily flows. Application of these methods in a specific river system can take anywhere from several months to several years, since they are generally data-intensive, require detailed ecological, hydraulic and hydrological surveys, and usually involve multidisciplinary teams in numerical modelling studies.

The best documented examples of more comprehensive methods are the building block methodology (King et al 2001), which has been developed and extensively applied in South Africa, the instream flow incremental methodology (IFIM), which is widely used in the US, and the holistic approach, which has been applied in Australia (Tharme 1996). These methodologies are suited for application in the 'how much must be left in' approach. A more recently developed methodology, the downstream response to imposed flow transformations (DRIFT) (Brown & King 2000) has been tested in the Lesotho Highlands Water Project, and is suited for application of the 'how much can be taken out' approach. The comprehensive methods rely on:

- identification of and agreement on the desired ecosystem goods and services to be maintained;
- quantification of the required state of ecosystem health to provide these goods and services; and
- translation of the desired state of ecosystem health to flow and water quality specifications (the IFR), which will maintain this level of ecosystem health.

Methodologies to determine instream water quality requirements

The commonly used approach to setting requirements for instream water quality is to determine the natural background conditions from results of water quality monitoring at relatively unimpacted sites, and then to establish an allowed deviation from natural conditions. This may be represented as an allowed proportional change from natural conditions or an allowed change in concentration of a particular water quality variable. The change is usually inferred from the results of field or laboratory studies of the tolerances of aquatic biota to changes in water quality.

One of the most common problems in Southern African ecosystems is the lack of long-term water quality monitoring datasets that can be used to describe and quantify natural unimpacted conditions accurately. This is particularly relevant for certain 'system variables' such as temperature and salinity, which often provide cues to trigger important seasonal ecological processes such as spawning and migration of fish and other fauna, and germination and flowering of plants. If the timing or magnitude of seasonal changes in these variables is altered too far from what is natural, then these ecological processes may be compromised or may not occur at all in a particular season.

Another common problem is also data-related. Most national water quality monitoring networks in Southern Africa do not include concurrent monitoring of ecological indicators such as aquatic invertebrate populations and very little information is available on the tolerance ranges of indigenous organisms under field conditions. Few local or regional laboratories have the facilities to conduct the experiments required to establish tolerance ranges of indigenous organisms in the laboratory, and information is therefore often limited to species that may be native to the northern hemisphere. Tolerance ranges, deviations and non-exceedence levels for Southern African water resources are usually established on the basis of water quality criteria used in developed countries such as the US and Australia, although these have not been thoroughly tested to ascertain their applicability for Southern African conditions. The *South African water quality guidelines for aquatic ecosystems* (DWAF 1997) represent the current best effort to derive locally applicable instream water quality guidelines. These guidelines were developed using international studies on warm water northern hemisphere species that can be expected to have similar tolerance ranges to equivalent Southern African species.

The determination of instream flow and water quality requirements must be integrated. Once the IFR have been determined, the implications of the altered flows for water quality must be ascertained, since there may be a loss of dilution or an increase in evaporation, particularly in low-flow seasons. This could cause concentrations of certain substances to exceed the determined instream water quality requirements and possibly reach toxic levels, a situation that might not have occurred under natural flow conditions. The effect of the proposed IFR on water quality should ideally be modelled prior to implementation, and their determination adjusted until the instream water quality requirements can be met with an acceptable degree of assurance.

Data for the determination of comprehensive instream flow requirements

Hydrological data

Of primary importance is hydrological timeseries data for each of the sites selected as being representative of specific river reaches, and for which IFR are set (King et al 2001). The timeseries should be constituted from daily hydrology, and average daily flows in m^3/s are required, for as long a period as possible, in order to establish typical ranges of daily flows and to provide information on seasonal and interannual cycles and their variability. Since the IFR sites for a river basin will seldom coincide exactly with hydrological gauging stations, hydrology data from a nearby gauging station are usually extrapolated to an IFR site through the use of a hydrological model. In many cases, little hydrological data is available, and the daily hydrology for IFR sites must be simulated using a rainfall-runoff model.

Hydraulic data

At each IFR site, a cross-sectional profile of the channel is surveyed, and a stage-discharge calibration curve is generated from water-level measurements made concurrently with a range of different measured flow rates. It is particularly important to have measured flows and water levels for periods of low flows, since there may be significant non-linear effects of friction in shallow water. This necessitates site-specific empirical determination of flow-related parameters (such as Manning's 'n' value) that are used to quantify the relationship between water depth and flow rate at an IFR site. The hydraulic calibration curve is used to translate the habitat parameters of velocity and depth at the IFR site, as recommended by specialist ecologists, to the hydrological parameter of flow rate that is used by water managers to operate and manage the river basin. Much of the confidence in the final determination of IFR thus rests in the accuracy of the hydraulic calibrations. A minimum of four flow calibrations should be undertaken at each IFR site, covering the full seasonal range of flows in any one year.

Geomorphological information

Geomorphological studies for the determination of IFR usually require an assessment of current sediment distribution patterns along a river, including an analysis of particle sizes, and of medium-term historical records. The historical analysis is often best done through the study of past aerial photographs. During the determination of IFR, the geomorphological information is used to predict what instream flows will be needed either to maintain the current patterns of sediment movement and distribution, or to restore patterns that will lead to geomorphological habitat meeting the necessary conditions for the desired ecosystem health status.

Water quality data

Timeseries water quality data should ideally be available for each IFR site or for a monitoring point nearby. The minimum sampling frequency required to establish seasonal patterns of water quality changes would be one sample every month. In addition, timeseries water quality data for an unimpacted site should be available in order to determine natural background conditions. In practice, however, this is seldom the case, and water quality patterns, variability and trends must be inferred from only a few samples. If at all possible, water quality and flow rate should be measured concurrently at the same site, in order to determine empirical flow-concentration relationships for each water quality parameter. These flow-concentration relationships are used to predict possible water quality changes that could result from a change in the flow regime once the IFR are implemented.

Ecological data

The availability of suitable ecological data is most often the weakest point in any determination of IFR, since there are very few long-term ecological monitoring programmes currently in place that measure specific characteristics of biotic populations at the appropriate scale and resolution. Most of the comprehensive methods to determine IFR require timeseries data related to the character, distribution and condition of riparian and instream vegetation, aquatic invertebrates and fish. Other species may also be used as representatives of the aquatic ecosystem if these species are of high conservation importance (such as endangered species) or of commercial importance. The timeseries data is required to establish seasonal and interannual variability in biotic communities, to identify important ecological processes and the environmental cues that initiate these processes, and to identify long-term trends in ecosystem health. Ideally, timeseries ecological data should have been measured at the same time and place as hydrological and water quality parameters, since the relationship and response of local biota to changes in flow and water quality can then be quantified, rather than assumed on the basis of expert judgement or extrapolated from laboratory studies.

Socioeconomic information

The social and economic importance of goods and services provided by the aquatic ecosystem is usually ascertained through extensive public consultation and participation processes. Surveys are designed to identify the current and desired uses being made of the ecosystem, including resource harvesting, recreation, ecotourism, water abstraction and offstream uses, and to estimate their economic value. The social and economic surveys are usually carried out as part of the specialist studies associated with the actual determination of IFR, although they can be done as part of baseline monitoring. The objective of these socioeconomic studies is to identify the agreed suite of desired goods and services that should be provided by the aquatic ecosystem so that ecologists can translate these requirements to a desired level of ecosystem health.

Prior and post-determination monitoring

For the effective determination and implementation of IFR, careful attention should be given to two aspects of monitoring:

- pre-determination monitoring, of which the objectives are to establish background and baseline conditions prior to implementation, to identify major spatial and temporal trends in hydrological, water quality and ecological parameters, and to describe the biophysical and biotic characteristics of the ecosystem; and
- post-determination monitoring, of which the objectives are, first, to check that the recommended IFR actually result in the desired ecosystem health status being achieved and to adjust them if necessary, and secondly, to check that the IFR are actually being delivered and to take corrective action if necessary.

Time and money spent on a well-designed pre-determination monitoring programme, which incorporates the proposed IFR sites, will significantly enhance the confidence in the process and its outcome. This in turn supports acceptance by stakeholders and other water users, thus helping to ensure successful implementation. Pre-determination monitoring programmes typically last for one to three years, although the longer the period covered by the dataset, the higher the confidence in the final determination.

Post-determination monitoring is important, since it can generate valuable learning about the response and sensitivity of an aquatic ecosystem to changes in the flow and water quality regimes, allowing for more refined management and delivery of IFR as understanding grows about causal linkages within the ecosystem.

Implementation of instream flow requirements

The development of methodologies for the determination of IFR was originally initiated in order to derive more environmentally friendly operating rules for rivers that had become highly regulated for power generation or water supply, or to provide information to support mitigation of the downstream impacts of proposed large dams. Hence, the building block methodology (King et al 2000) generates output that is primarily suited for use by dam designers and operators. However, not all water uses in a river basin are focused around large dams. In many cases, information on the IFR is needed to:

- manage and control run-of-river abstraction, either small-scale or large-scale;
- regulate discharges of wastewater; or
- control groundwater abstraction that may impact surface flow from springs and eyes or baseflow in streams.

The sections below address some of the issues around the implementation of IFR, whether in regulated or unregulated river basins.

Dams, weirs and flow-control structures

Most dams, weirs and flow-control structures are built to store and deliver water to places where it is not usually found in one season or another, for example, to provide water for dry-season irrigation. The resulting flow regime is thus often very artificial, and can have severe impacts on the downstream aquatic ecosystem. In the design phase of large dams, it is necessary to determine the IFR, particularly the peak flood flow rates, to ensure that the dam can deliver the required flows at the required times. If the outlet structures are too small, the important flushing and scouring floods cannot be released, and this may lead to substantial changes in habitat downstream, including sedimentation and reed encroachment. If normal daily flow releases are too high, serious erosion of downstream habitat, changes in banks and incision of the river channel may result.

Large dams also cause significant changes in water quality downstream, especially when the water column becomes stratified in the reservoir behind the dam. If water is released from the bottom layers of a stratified reservoir, the resulting outflow is likely to be much colder than the surface waters and will probably have a low dissolved oxygen content and high concentrations of dissolved substances. These factors can cause severe mortality of biota in the downstream ecosystem. Many large dams are now designed to incorporate variable-level outflow structures so that water can be released from any chosen depth in the reservoir, depending on the downstream water conditions. Operating rules need to address this aspect of water quality, providing for monitoring of water quality at various depths in the reservoir and in the river downstream, in order to select the correct release scenario.

Dams and weirs also trap sediment and nutrients, leading to a deficit of these in the downstream ecosystem. This may affect habitat, through net erosion downstream, and ecological processes through a lack of nutrients to support primary production. It is possible to design dams that can bypass some sediment, although the costs of construction will be increased.

Dams and weirs form physical barriers for most migratory species, which can lead to losses of key species if they are unable to migrate to and from breeding and spawning areas. Any dams and weirs should be designed to incorporate appropriate fish ladders or equivalent structures to enable the passage of migratory species.

Once IFR have been converted into daily operating rules for a dam or for a river basin, there is a need to ensure that the required flows are delivered to the downstream ecosystem in a pattern that is as close to natural as possible. If river flows upstream of the dam rise due to a rainfall event, then the flow releases from the dam to meet the IFR should be timed to coincide with this rise. Usually, this will require real-time monitoring of river flows at a site upstream of the dam where the flow pattern is reasonably natural.

Similarly, if a natural drought occurs, then the IFR during the drought period should be adjusted downwards in order to ensure that the downstream ecosystem also experiences drought conditions. A determination of IFR usually includes flow specifications for maintenance conditions (such as normal rainfall years), as well as drought conditions. The natural stresses associated with drought conditions are necessary to maintain the health and resilience of the downstream ecosystem. However, once the natural drought has passed, instream flows should be returned to maintenance levels. Artificial prolonging of drought conditions can result in severe, irreversible changes to an aquatic ecosystem, particularly when a naturally perennial river is forced into a seasonal flow regime, or a seasonal river into an episodic or ephemeral regime.

Managing run-of-river abstraction

Implementing IFR can be especially challenging in an unregulated river basin where most abstraction is run-of-river. There may be little or no opportunity to compensate for abstraction by making dedicated releases from a dam for the downstream ecosystem. In this case, abstraction has to be managed, controlled and monitored in order to ensure that the IFR are met.

Control options include metering of abstractions, and limitations on pump capacities or pipe diameters. While this may be practical in the case of large commercial water users, it may be extremely difficult for small-scale or subsistence uses of water. Yet if population density is high, the sum of many small-scale abstractions can represent a significant removal of water from the system, possibly compromising the IFR. Water tariffs can be applied to encourage reduction in water use or more efficient water use, but awareness creation and the education of water users are generally more effective in promoting understanding and support for IFR.

Customary law or water-sharing practices may provide important mechanisms for gaining and maintaining community support for the implementation of IFR, since such customary practices have often been developed over long periods of time to suit local socioeconomic and environmental conditions (MacKay et al 2002).

Groundwater abstraction and baseflow

In many perennial rivers, dry-season flows may be maintained largely or solely by inflows from groundwater or from the water stored in the soils of river banks. Excessive abstraction of groundwater through wells or boreholes in the riparian zone or close to a river may cause dry-season flows in the river (known as baseflows) to be reduced or to stop altogether.

In determining IFR, some indication should be provided of how much abstraction of groundwater can be allowed in the riparian zone or near the river without compromising baseflow in the river. There are techniques available to determine the contribution of groundwater to baseflow in a river: the simplest is hydrograph separation, a form of analysis of hydrological timeseries data. If higher confidence or resolution is required, then it may be necessary to carry out a geohydrological survey when the field ecology studies for the determination of IFR are conducted.

This issue will be particularly relevant in the Okavango River basin, since there is a strong and complex link between surface water and subsurface water. Uncontrolled abstraction of groundwater from aquifers that are near to or in hydraulic connectivity with surface waters could lead to significant changes in surface water flow and chemistry (McCarthy et al 1991; 1993). The total allowed abstraction from the Okavango basin should be expressed in terms of the allowable groundwater abstraction from certain delineated aquifers, as well as the allowable surface water abstraction from specific points in the system.

Tributary management and offstream storage

Efficient and effective implementation of IFR requires integrated planning at the river basin level. The sites of dams, weirs and flow-control structures relative to the main stem of the river must be considered. Large dams on the main stem of a river generally have a more significant impact on downstream ecosystems than do smaller dams on tributaries. A recent international trend has been to discourage the building of large dams on the main stem of a river in favour of offstream storage reservoirs and smaller dams on tributaries.

The impacts of dams and weirs in a river basin can be mitigated to a degree if key tributaries are maintained in a relatively undeveloped condition. The flow contributions from these tributaries help to maintain a more natural flow regime in the main stem of the river. In addition, the undeveloped tributaries provide important ecological refuge areas, from which the main stem ecosystem can be repopulated in the event of loss of species due to natural disasters or accidents. An IFR determination, if carried out at river basin scale, should address these issues and identify the key tributaries that should be protected and on which development should be limited.

In the Okavango basin, the Cuito and Cubango sub-catchment systems exert significant influence on the flow regime downstream of the confluence of these two rivers, particularly in terms of the timing, duration and magnitude of the annual flood that reaches the Okavango Delta. If the pattern of inflow to the delta is to be maintained as close to natural as possible, then it will be necessary to identify those tributaries within the Cuito and Cubango sub-catchments that are most important in determining the timing, duration and magnitude of the annual flood, and to consider limiting development on these tributaries, or at least developing them so that their flow patterns remain close to natural.

Water quality management

Water quality management strategies should be linked to the determination of IFR. For example, if the IFR will result in less water being available instream in the dry season, effluent discharge standards may need to be made stricter to take account of the reduced dilution capacity. Many countries utilise uniform national effluent discharge standards, but may need to consider developing basin-specific or reach-specific standards to be consistent with the specifications of IFR.

The question whether more ‘clean’ water should be made available for instream dilution of pollution impacts is controversial and varies with the policy of each country. However, it is generally accepted that:

- Once IFR have been determined and altered flows lead to water quality problems due to the impacts of pollution from human activities, then the sources of pollution should be managed and controlled, rather than simply diluting the problem with higher flows of clean water from upstream.
- If altered flows lead to water quality problems related to natural causes, for example, naturally occurring high concentrations of dissolved salts, then IFR should be adjusted upwards until sufficient dilution is achieved in low-flow seasons to maintain the concentrations of key water quality variables within the allowed ranges or levels.

Habitat and alien species

In the determination of IFR, specific flow rates are usually set to ensure inundation of certain key habitats at critical times of the year. The assumption behind this approach is that, if flow rates are sufficient to maintain an adequate distribution and extent of critical habitats, the biota will be supported and ecological processes will be maintained. However, if aquatic ecosystems are to be protected, there are two kinds of impacts on aquatic habitat that must be addressed: flow-related and unrelated impacts.

Flow-related impacts on habitat include change, loss or degradation of habitat due to changes in flow. Changes in flow may be due to regulation, abstraction of water, or input of excess water such as stormwater and effluent discharges. The parameters of hydraulic habitat (velocity, depth and wetted perimeter) may be affected to such an extent that:

- an insufficient area of inundated habitat remains (for example, if the water in a rapid or riffle becomes so shallow that fish can no longer migrate through the rapid);
- hydraulic characteristics are changed (velocity may be increased so that biota cannot maintain their position and are washed out of refuges, or velocity may be reduced leading to increased warming of water, evaporation and concentration of salts); and
- critical habitats are no longer accessible at the necessary times of the year.

Flow-related habitat impacts can generally be mitigated or reversed by providing an appropriate flow regime.

Impacts unrelated to flow include loss or degradation of habitat, and subsequent loss of species due to structural changes in a water resource or watercourse. These can include:

- the imposition of barriers to movement such as dams and weirs, where no fish ladders are provided;
- the removal or destruction of riparian vegetation due to poor land-use practices;
- the smothering of habitats by erosion-induced sedimentation, or loss of habitats due to instream and bank erosion; and
- the introduction of alien fauna and vegetation, which either cause damage to habitat (such as grass carp that have been released in the Limpopo system and that damage the roots of riparian trees and instream vegetation), or which destroy indigenous species (such as water hyacinth that covers water surfaces, reducing light penetration and oxygen diffusion).

If these impacts are to be mitigated, impacts unrelated to flow usually require some structural intervention or physical management efforts to restore habitat and remove invasive alien species.

Participation in the determination and implementation of instream flow requirements

A participatory approach to both the determination and the implementation of IFR is essential. This primarily aims to ensure that stakeholders, water users and communities are properly represented in the decision-making process, and that those ecological processes or components on which people depend are identified and protected by an appropriate determination of IFR. In addition, especially where there is a long tradition of subsistence use of various components of the aquatic ecosystem, indigenous knowledge may provide valuable information about ecological processes, and help to identify causal relationships between flows, water quality and ecosystem responses. Indigenous knowledge may be able to compensate to some degree for lack of long-term monitoring data, if this knowledge is properly captured and formally incorporated into the process of determining IFR.

Participation also helps to ensure support for implementation. If stakeholders, water users and communities understand the rationale for the determination of IFR, and the benefits that they will gain in terms of the protection of ecosystem goods and services, they will be much more likely to change their behaviour, water and land-use practices to help achieve the objectives of the IFR.

Determining and implementing instream flow requirements in the Okavango River basin

A study of instream flow requirements in the Okavango basin would need to answer the following questions:

- If a particular agreed suite of ecosystem goods and services is to be delivered, what is the desired ecosystem health status, within natural patterns and ranges of change, of each representative reach of the Okavango River basin?
- If the desired ecosystem health status is maintained in each reach, how much water can be abstracted, from which points in the system and at what times of the year? Which instream water quality and habitat conditions must be maintained?
- What form can abstraction take – groundwater abstraction, run-of-river abstraction, small weirs and dams, a few large dams or offstream storage?

The impact of individual water resource development projects would still have to be assessed against the allowed abstraction as determined in the study of IFR. For dams and weirs, more detailed studies might be needed in each case to derive daily operating rules for flow releases.

Much attention has been focused on the water requirements of the Okavango Delta ecosystem in recent years, and recent studies have addressed the allowed abstraction immediately upstream of the delta and Panhandle system (CSIR 1997). However, the water resources in the basin all provide ecosystem goods and services to some degree, particularly for subsistence purposes. To focus only on the delta would be short-sighted at best. Technically, it would reduce the confidence in the determination of IFR, since upstream-downstream dependencies, whether ecological or hydrological, would not be adequately addressed.

It is necessary to take a more strategic view of medium and long-term development needs in the basin as a whole, and consider how best to develop the water resources of the basin in such a way that critical aquatic ecosystem components, of which the delta is only one, are not compromised. There still remains a chance to be proactive in the Okavango basin with this kind of planning, whereas in many other African river basins, the options for maintenance or restoration of aquatic ecosystems are now severely limited due to incremental development and planning that have not encompassed the basin as a whole integrated unit.

The most significant constraint to the implementation of such an integrated approach is not technical but political. The three basin states would jointly have to agree on how and where water resource developments would be sited and operated in order to meet the needs of each country in an equitable but environmentally sustainable way. Political and economic stability would be essential for successful cooperation, since storage facilities and other water resource developments might be situated within the borders of one country, but might be utilised by other basin states. Overcoming sovereignty issues will be very challenging, although the Permanent Okavango River Basin Water Commission (OKACOM) could play a critical role in facilitating this process.

Technical aspects of the determination of instream flow requirements in the Okavango River basin

Data limitations

Although there have been several studies in recent years in the Okavango basin, particularly focused on the lower reaches and the delta, there is a critical data gap in long timeseries of flow, water quality and ecological parameters. Most studies tend to be research-focused or ‘once-off’, with insufficient long-term monitoring programmes to deliver the kind of data needed for the determination of IFR. Such data must enable the specialists to identify longer term trends and patterns, which are necessary to ascertain the natural ranges of variability of the ecosystem and hence to derive appropriate flow and water quality specifications to maintain a desired level of ecosystem health.

Another critical aspect is to gain a better, quantitative understanding of the complex interaction between water and waterborne sediments in the Okavango basin. This interaction sustains most of the key habitats in the middle and lower reaches of the basin, including the delta, and it is essential to obtain improved predictive capability on the potential impacts on habitat of a reduction in flow, a reduction or increase in sand supply to the river and the combined effects of these.

The need for a single independent basin study

Information on the Okavango basin, especially on ecological responses to changes in the flow regime, is limited and confined to certain areas of the basin. Hence, there is neither wide agreement on the primary driving hydrogeological and geomorphological processes that maintain the aquatic ecosystems of the basin, nor on the possible ecological responses to changes in these driving processes. Expert opinions differ and it is extremely difficult to reach agreement on the IFR that would maintain particular levels of ecosystem health. The allowed rate of abstraction of water therefore cannot be determined with any more than low confidence. It is likely that water-sharing negotiations will require, as a basis for agreement, a high-confidence determination of the IFR, but it may take several years to achieve this level of confidence.

The other consequence of inadequate studies is that upstream-downstream linkages and causal relationships cannot be identified and quantified throughout the basin, making it difficult to assess the significance and extent of downstream impacts of proposed water resource developments.

It is essential that a single, independent basin study should be commissioned to determine IFR. Through OKACOM, the basin states should all participate in developing the terms of reference for the study, so that the outcome can properly serve the negotiation and decision-making processes. Agreement on the terms of reference should help to achieve later agreement on the study outputs and outcomes.

Regulatory aspects of the implementation of instream flow requirements

The most important aspect of IFR is not so much their determination but rather their implementation. Some thought will need to be given to how IFR would be implemented in the Okavango basin, and agreement reached on this aspect, before or at the time of determining IFR.

In theory, IFR could be implemented either by building a series of large dams and operating the whole system somewhat artificially, making dedicated releases for downstream ecological needs. This is not a realistic scenario, especially given the recent recommendations of the World Commission on Dams regarding the need to justify the costs and benefits of large dams.

In practice, IFR in the Okavango basin are likely to be implemented through some system of allocating and controlling offstream and instream water uses. Important questions that must therefore be addressed and resolved include:

- Will minimum standards be set for allowable impacts or water uses? Will these be applicable throughout the basin? On what basis will they be set, and how will they be enforced (through auditing, self-regulation or economic instruments such as tariffs and charges)?

- Will water uses be individually licensed or permitted throughout the basin? If so, who will be responsible for evaluating and issuing licenses or permits? Will this be done by a single basin authority with delegated powers, or will each basin state retain responsibility for licensing and permitting in its own territory?
- If each basin state retains responsibility for licensing and permitting, what will the arrangements be for consultation with and approval of the other basin states, particularly in the case of large impacts?
- Will a system of real-time water accounting be instituted to ensure that each basin state takes only its agreed share of water? If so, how can this be achieved in a relatively ungauged basin such as the Okavango, and who will take responsibility for it?

The resolution of these questions will have implications for institutional development in each of the basin states, as well as for a possible river basin management organisation. Depending on the approaches that are adopted, regulation and administration may have significant cost, technology and manpower implications. There must be upfront agreement on how these will be addressed, who will pay and how much they will pay for the long-term management of the basin's water resources.

Post-determination monitoring and response

The design of the post-determination monitoring programme is usually part of determining IFR. The specialists who are involved in the determination collaborate with the future basin managers to design a long-term monitoring network that will provide appropriate information to assess whether or not the desired objectives are being met, but which is cost-effective and can be implemented. Carrying out the monitoring network design without either the specialists or the basin managers present is not advised, since considerable resources may then be expended on a programme that cannot deliver information on which actions can be taken. Recent programmes based on the objectives hierarchy concept (Rogers & Bestbier 1997) have proven to be robust, cost-effective and focused. This model should be considered in the design of a long-term monitoring programme for the Okavango River basin.

Part of the monitoring network design includes the identification of appropriate responses to situations that arise, or issues that are identified as a result of monitoring. This must be agreed between the basin states prior to the implementation of IFR.

Recommendations

If water-sharing agreements are to be put in place in the Okavango River basin, a medium to high-confidence determination of IFR will be necessary prior to the start of negotiations. Considerably more data is required to achieve this level of confidence, and there are other elements of the successful determination and implementation of IFR that must also be addressed. It is necessary to develop a five to 10 year programme, which may culminate in a water-sharing agreement, but which comprises considerable technical foundation work in the initial years. The main elements of a comprehensive programme to support water-sharing negotiations and, ultimately, the achievement and implementation of a water-sharing agreement, are:

- alignment of policy, legislation and regulation requirements for the implementation of IFR in each basin state;
- design and execution of a baseline monitoring programme to provide the data necessary for a medium to high-confidence determination of IFR;
- capacity-building for the determination and implementation of IFR;
- actual determination of the IFR for the basin;
- design and installation of an appropriate gauging network to provide information for long-term management of the basin; and
- institutional development within each basin state, and of a river basin management agency (which is not addressed in this chapter).

There must be appropriate sequencing of the activities listed above, since there are dependencies between them. These elements are discussed in more detail below.

Policy, legislation and regulation

Basin states will need to agree in legislation on the status of water allocations (quantity and quality) for the protection of aquatic ecosystems. Following this, a review will be needed of relevant national policies and legislation in the environment, water and agricultural sectors. An initial analysis of the current situation should provide guidance on the extent of the review and revision needed in each country. The bureau of the Ramsar convention has provided considerable technical guidance for such initiatives, and this should be accessed when necessary.

Basin states will also need to agree on how water use will be regulated and controlled, and national regulations regarding water allocation, permits, discharge licences and resource utilisation may require revision and harmonisation. Agreement must also be reached on the consultation process between basin states related to the approval or veto of water resource developments that may have significant downstream impacts. If a river basin agency with statutory powers is envisaged, decisions will be required on the licensing and auditing responsibilities that will be delegated to the agency by the basin states.

Determination of instream flow requirements for the Okavango basin

Basin states should provide input into and agree on the detailed terms of reference for the determination of IFR. It is recommended that specialist consultants with appropriate experience are appointed to develop detailed terms of reference for a three to five year programme leading up to the determination of IFR. This programme could include:

- low-confidence determination of IFR to provide initial, conservative estimates for planning purposes;
- review of available methodologies and selection of an appropriate high-confidence methodology;
- early selection of IFR sites for a high-confidence determination; and
- design of a three to five year pre-determination baseline monitoring programme, focused on the chosen IFR sites, which will provide the necessary data for a medium to high-confidence determination throughout the basin, or at the IFR sites.

The development of these terms of reference could be done through OKACOM, and would take six to 12 months, given the need for consultation with and agreement by the basin states.

Baseline monitoring programme

The data requirements for the determination of IFR should be identified as part of the terms of reference, and a baseline monitoring programme should be designed. Given the extreme natural variability of the Okavango system, as long as possible (three to five years) should be allowed for baseline monitoring. Flow monitoring will be most important, at least to provide calibration data for hydrological modelling. Simulated hydrological data will have to be used, since there are no datasets of sufficiently long duration. It is likely that, at the least, IFR sites will need to be selected that will be representative of the Cuito and Cubango systems upstream of their confluence, a site between the confluence of these two and the Okavango Panhandle to represent inflow to the Panhandle-delta system, and sites within and at the distal end of the delta. Hydrological, water quality and ecological parameters should be monitored at the selected IFR sites.

Given the difficulty of access to remote monitoring sites, the problem of landmines in Angola, the lack of capacity and probable funding constraints, remote-sensing may prove a cost-effective and efficient way of monitoring, especially the ecological parameters related to vegetation and geomorphology. For other aspects such as water level and some water quality parameters, basic measurements and fixed-point photographic monitoring can be carried out by local people, schools and ecotourism operators.

Capacity-building programme

Once the detailed terms of reference have been formulated, it will be clear what specialist expertise is required for the determination and implementation of IFR. At this point, it would be useful to identify key personnel from each basin state who will be involved, directly or indirectly, in the determination, and ensure that there is sufficient capacity available within the basin states to carry out a significant portion of the work programme. It is essential, both for acceptance of the IFR and for their successful long-term implementation, that local expertise is utilised as much as possible. The Okavango system, in its variability and complexity, is unlike any in the northern hemisphere, and expertise from this part of the world will be of limited value in determining IFR for this system. Allied to this is the need to understand and address the close relationship between people and aquatic ecosystems in the Okavango basin – this can really only be done adequately by those who know the region, the system and its people well.

Capacity-building for the determination of IFR in the Okavango basin can be proactive. South Africa is initiating several large IFR studies over the next 10 years, using various methodologies. These will provide ideal opportunities for graduate students and young professionals from the Okavango basin states to work alongside experienced specialists prior to the Okavango study commencing.

Gauging network

A permanent gauging network and post-determination monitoring programme should be designed during the IFR study, and implemented as soon as possible afterwards. The determination of IFR specifies flows to be met at particular IFR sites, and gauging and monitoring stations should ideally be close to the IFR sites to allow for auditing of delivery of the specified instream flows. However, the gauging network must be appropriate to both the level of confidence required, and the capacity and resources available to maintain a network. Local people can be used very effectively to collect long-term data, as long as there is some central coordinating point in the basin (possibly OKACOM) and data quality is assured through appropriate training.

Conclusion

In order to make sound decisions about the sustainable, equitable utilisation not only of water in the Okavango basin, but also of the goods and services provided by water resources, it will be essential to undertake a medium to high-confidence determination of IFR for all reaches in the basin. Such a determination should be seen as one element in a broader long-term programme that will culminate in a water-sharing agreement and a strategic plan for water resources in the basin.

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