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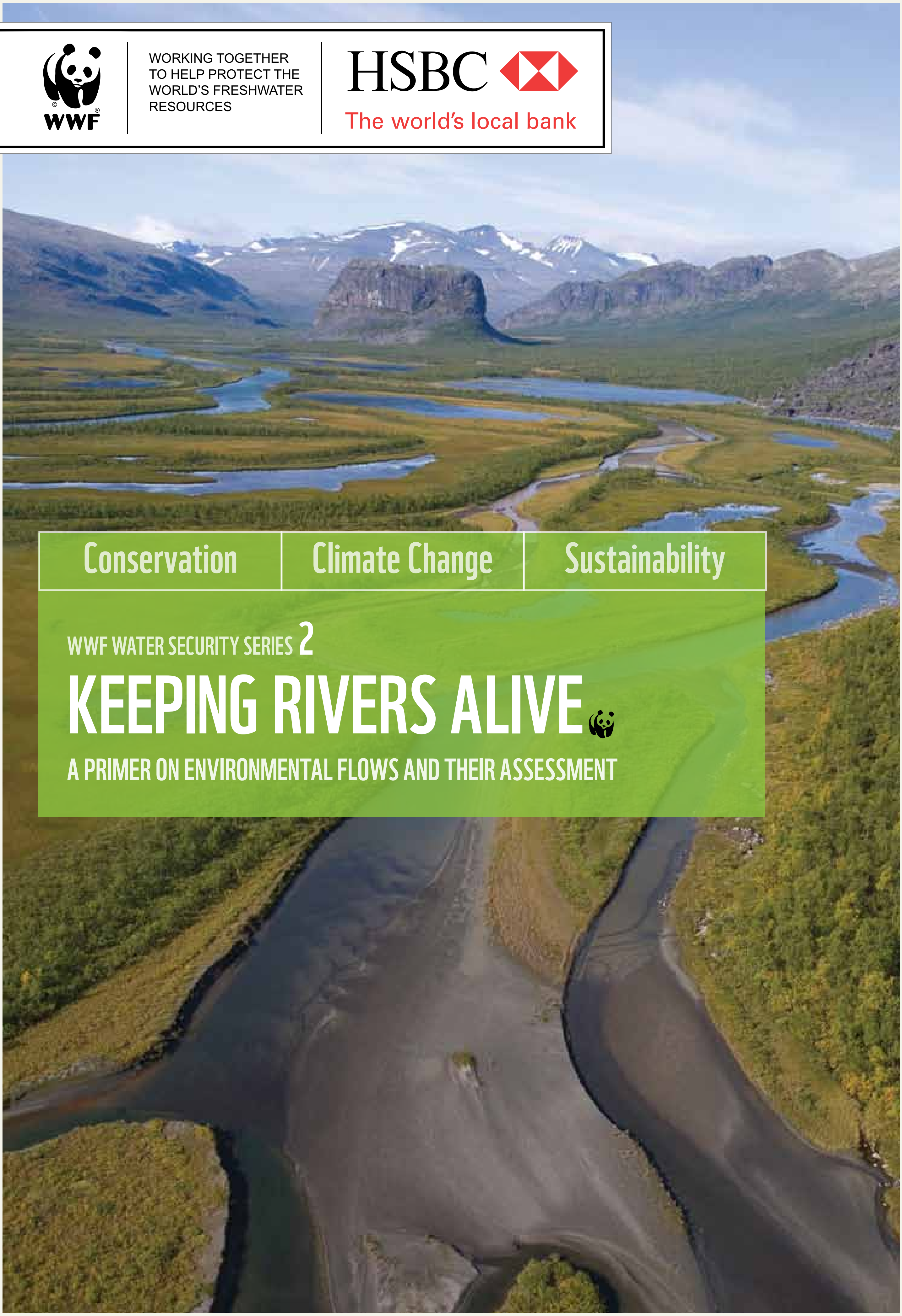

Conservation | Climate Change | Sustainability

WWF WATER SECURITY SERIES 2

KEEPING RIVERS ALIVE

A PRIMER ON ENVIRONMENTAL FLOWS AND THEIR ASSESSMENT

WWF's Water Security Series sets out key concepts in water management in the context of the need for environmental sustainability. The series builds on lessons from WWF's work around the globe, and on state-of-the-art thinking from external experts. Each primer in the Water Security Series will address specific aspects of water management, with an initial focus on the inter-related issues of water scarcity, climate change, infrastructure and risk.

Understanding Water Security

As an international network, WWF addresses global threats to people and nature such as climate change, the peril to endangered species and habitats, and the unsustainable consumption of the world's natural resources. We do this by influencing how governments, businesses and people think, learn and act in relation to the world around us, and by working with local communities to improve their livelihoods and the environment upon which we all depend.

Alongside climate change, the existing and projected scarcity of clean water is likely to be one of the key challenges facing the world in the 21st Century. This is not just WWF's view: many world leaders, including successive UN Secretaries General, have said as much in recent years. Influential voices in the global economy are increasingly talking about water-related risk as an emerging threat to businesses.

If we manage water badly, nature also suffers from a lack of water security. Indeed, the evidence is that freshwater biodiversity is already suffering acutely from over-abstraction of water, from pollution of rivers, lakes and groundwater and from poorly-planned water infrastructure. WWF's Living Planet Report shows that declines in freshwater biodiversity are probably the steepest amongst all habitat types.

As the global population grows and demand for food and energy increases, the pressure on freshwater ecosystems will intensify. To add to this, the main effects of climate change are likely to be felt through changes to the hydrological cycle.

WWF has been working for many years in many parts of the world to improve water management. Ensuring water security remains one of our key priorities.

Acknowledgements

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Jay O'Keeffe, Tom Le Quesne

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Summary: Environmental flows and their assessment

Increasing global exploitation of water resources has led to significant degradation of freshwater biodiversity and the services that rivers provide. In many places, rivers have completely stopped flowing.

The socio-economic consequences of disruption to and collapse in freshwater systems are often profound: people are much more dependent on natural riverine services than is immediately apparent, and this only becomes obvious when the river is seriously degraded.

In response to this, the concept of environmental flows has been developed over recent decades. An environmental flow is an amount of water that is kept flowing down a river in order to maintain the river in a desired environmental condition. As the concept has evolved, there has been significant development of approaches to the assessment of environmental flows.

From global experience with environmental flow assessment in recent decades, a number of key lessons can be drawn.

1. The characteristics and ecosystems of rivers are controlled in a very significant way by physical processes, in particular flows. An environmental flow regime describes all the different flows (wet season, dry season, floods, droughts etc) that are needed to keep the river and all its aspects functioning in a desired condition.
2. Environmental flow assessment is both a social and a scientific process, with a social choice at its core. There is no one correct environmental flow regime for rivers – the answer will depend on what people want from a river. Different sorts of rivers are likely to have different requirements and priorities, for example differing approaches for a river in a protected area in contrast to a river in a major irrigation or urban area. Choice and judgement, particularly when deciding on environmental objectives, are an essential part of the environmental flow process.
3. Environmental flow assessment is based on the assumption that there is some 'spare' water in rivers that can be used without unacceptably impacting on the ecosystem services that the river provides.
4. Environmental flows are not just about establishing a 'minimum' flow level for rivers. All of the elements of a natural flow regime, including floods and droughts, are important in controlling the characteristics and natural communities in a river. For example rivers with a constant flow regime can quickly become dominated by pest species.
5. Environmental flows don't always require an increase from present flows. In some cases, e.g. where low season flows have been artificially increased by inter-basin transfers or releases from dams for hydropower, the environmental flow recommendations may be for lower flows than present. In other cases, the assessment may identify that some further water can be abstracted without unacceptable impacts.
6. Environmental flow assessments are not just useful on rivers for which the water resources have been/are being developed – it's very useful to know the environmental requirements before any development plans are made, so that these flows can be factored into the planning process at an early stage.

Summary
Environmental flows and their assessment

7. There are now over 200 methods for assessing environmental flows. Some are very quick modelling or extrapolation methods, requiring no or minimal extra work; others require years of fieldwork and specialists from a number of disciplines. The five main categories of assessment are: look-up table approaches; extrapolation approaches; hydraulic rating methodologies; habitat simulation methodologies; and, holistic methodologies. The choice of method will depend on:

- The urgency of the problem
- Resources available for the analysis
- The importance of the river
- Difficulty of implementation
- The complexity of the system.

8. Instead of undertaking extensive prior assessment, an important alternative approach may often be to concentrate immediately on implementation of some flows. This option then requires careful monitoring of the results of trial flows, to see whether they meet objectives. This is likely to be particularly important in situations where there is already an acute problem of over-abstraction.

9. In all contexts, implementing environmental flows should be an adaptive process, in which flows may be successively modified in the light of increased knowledge, changing priorities, and changes in infrastructure (e.g. removal of dams) over time. From this perspective, it may be more appropriate for legislation to require implementation but allow flexibility in the methods of assessment.

10. Lack of information, and lack of resources, should never be a barrier to some implementation of environmental flows. Some attempt to restore some of the natural flow variability is always better than none, and fine-tuning is always possible as more knowledge and resources become available.

11. In almost any context, implementation presents an immeasurably greater challenge than assessing the necessary flows. Conservationists therefore need to ensure that they do not devote a disproportionate amount of effort to discussion and debate over the appropriate environmental flow methodology, neglecting the more important effort of working for implementation.

Introduction: Why do we need environmental flows?

It is becoming increasingly evident that, on regional and global scales, freshwater biodiversity is more severely endangered than that of terrestrial or marine systems. Freshwater systems are home to 40% of all fish species in less than 0.01% of the world's total surface water, and when water-associated amphibians, reptiles and mammals are added to the fish totals, they together account for as much as one third of global vertebrate biodiversity. Even at a conservative estimate, there have been global population declines of freshwater vertebrates averaging 55% between 1970 and 2000.

At the same time, people need to use rivers, lakes and wetlands for many things – water to drink, irrigated food, industrial water supply, water repurification, fishing, boating, recreation and cultural activities. If we are careful, rivers can do all these things for us, but more and more, people only see rivers as suppliers of water and as drainage ditches. So lots of rivers round the world now stop flowing, and others carry only waste water. Like other natural resources, rivers are very useful if they are used sensibly, and useless or dangerous if they are abused. Rivers with little or no flow, and lots of waste water, are likely to become centres of diseases like malaria, cholera, schistosomiasis and dysentary.

Environmental flows are aimed at keeping at least some of the natural flow patterns along the whole length of a river, so that the people, animals and plants downstream can continue to survive and use the river's resources. So environmental flows are really about using water resources fairly.

In order to decide on an environmental flow, people need to decide what they want a river to do for them. Do they want to grow crops, or to generate electricity, or to supply towns with water, or to keep it in a national park? The second decision that people have to make is: what state do they want the river to be in? In most cases they want to make use of the water and other resources of the river, so they don't want to keep it entirely natural. Also, in most cases (all cases hopefully) they don't want to turn it into a dry river bed or a drain for waste. So they have to decide in what state between natural and completely ruined they would like to keep it. This is the role of environmental flow assessment.

PART A: Rivers, flows and environmental requirements

PART A:

Rivers and flows

- River habitats are generally controlled by physical processes (flow, water quality, sediment transport) so we can make big changes to the biodiversity of rivers by managing (or mis-managing) the flow.
- Rivers have all sorts of flow patterns – some flow permanently, some seasonally, and some desert streams only once every few years. The biodiversity of different rivers, and different parts of rivers, varies with these physical patterns

Flows – the main driver of biodiversity in rivers

Rivers, except for a few very large ones, are very variable and unpredictable, so the animals and plants that live in them have to be able to deal with sudden extremes such as floods and droughts. As a result, most river ecologists agree that the communities of animals and plants found in riverine ecosystems are largely controlled by physical rather than biological processes.[1]

So, if we want to maintain freshwater biodiversity, then it is necessary to manage the physical processes in rivers properly. And what are these physical processes? They include water quality, sediment dynamics, and, of course, flow. Flow is the main driver of biodiversity in rivers – it creates the aquatic habitats, it brings the food down from upstream, it covers the floodplain with water during high flows, and it flushes the sediment and poor water quality through the system. Bunn and Arthington (2002) suggest the principles that:

1 Flow is the major determinant of physical habitat in streams;

2 Riverine species have evolved primarily in response to natural flow regimes;

3 Flow connectivity throughout the river and its floodplain are essential to the maintenance of riverine populations; and

4 Altered flow regimes facilitate the growth and spread of introduced species.

A recent World Bank (2008) document has characterised flows as a 'master variable' in freshwater systems:

"During recent decades, scientists have amassed considerable evidence that a river's flow regime – its variable pattern of high and low flows throughout the year, as well as variation across many years – exerts great influence on river ecosystems. Each component of a flow regime – ranging from low flows to floods – plays an important role in shaping a river ecosystem. Due to the strong influence of a flow regime on the other key environmental factors (water chemistry, physical habitat, biological composition, and interactions), river scientists refer to the flow regime as a master variable."

Types of flow regime

It is important to recognise that there are as many types of flow regimes as there are rivers:

- There are rivers that flow all year (perennial rivers), those that flow only during the wet season (seasonal rivers), and those that very rarely flow at all (ephemeral rivers or desert streams)
- There are mountain streams – steep, rocky and clear; there are foothill streams – alternating pools and rapids; there are floodplain rivers – meandering, mud-bottomed, with riparian wetlands
- There are flashy rivers – prone to flood and drought; and there are reliable rivers – spring fed for constant flow.

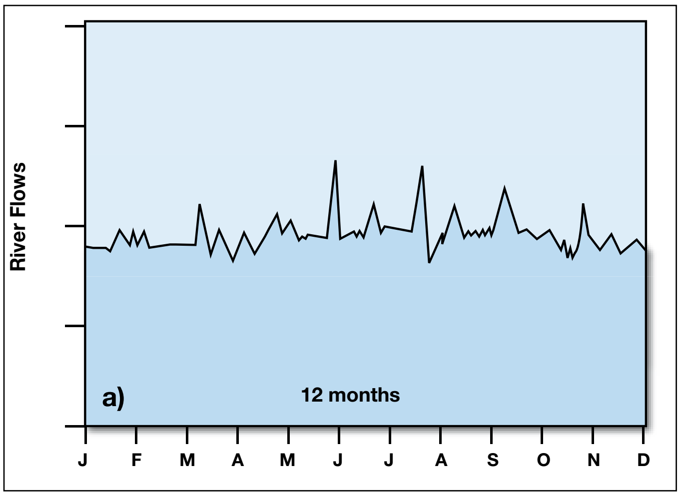
1 Consider, by way of contrast, a tropical forest. Biological communities in such a forest are significantly determined by interaction with each other, for example the trees that create the habitats for mammal and bird species.

PART A:
Rivers and flows

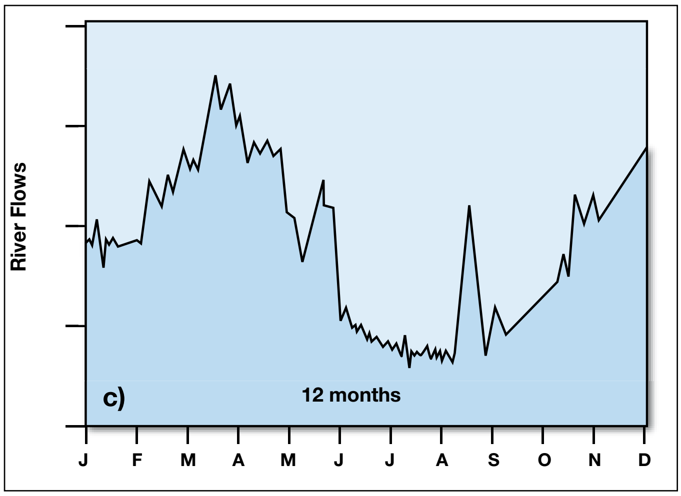
All of these river channels have been formed over geological time by their flow regimes: some have cut deeply through the mountains and some have carved out wide smooth floodplains. It is a long-term function of the flows is to make the shape and texture of the channel that they run in. They do this by eroding the landscape and by carrying the resulting sediment downstream and depositing it somewhere else in the channel. So clear fast-flowing water results in rocky or stony channels, while slow-flowing, sediment laden water results in muddy channels.

The type of channel and floodplain also dictates the physical habitats that will be available for the flora and fauna of the river: mosses and algae, agile insects such as mayflies and stoneflies, and fast-swimming fish like trout predominate in the rocky rapids and clear water of upper streams; lilies, reeds, worms and snails, catfish and carp dominate the slower-flowing turbid lowland rivers. The variety and abundance of life in a river (its biodiversity) will be governed by the diversity of habitats in time and space, and therefore largely by the flow regime.

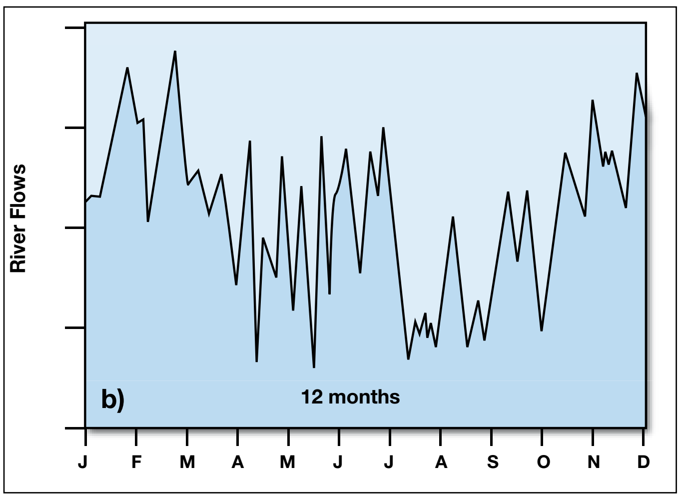
Figure 1 **Different flow patterns charcterised in graphs of daily flows over a number of years.**



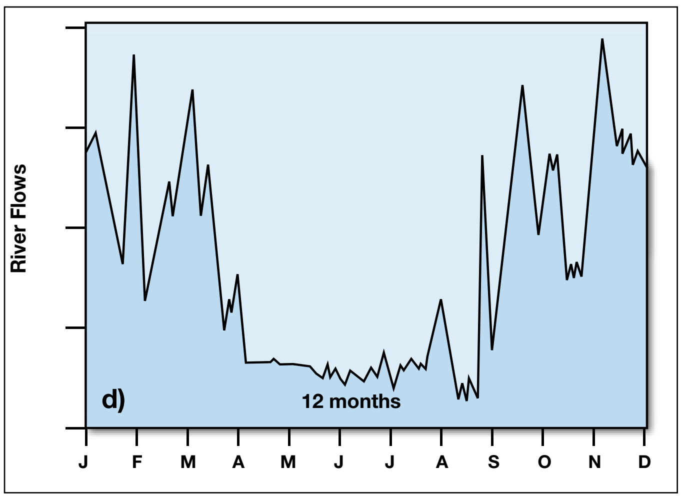
a. Groundwater-fed Creek.



c. Snowmelt River



b. Flashy River.



d. Winter rain.

Contrasting Case studies of modified flow regimes from South Africa

Environmental flow regimes attempt to mimic as much as possible of the natural variability of the flow regime in rivers. These two case studies show the contrasting effects of reducing the flow in a permanently-flowing river, and increasing the flow in a seasonal river, As these cases demonstrate, environmental flows are not just about maintaining minimum flow levels in rivers.

The Letaba River:

The Letaba River rises on the Drakensberg escarpment and flows through the "lowveld" region of north-eastern South Africa, into the Kruger National Park, where it joins the Olifants River flowing into Mozambique. Until the late 1960's the river flowed permanently, but gradually it stopped flowing during the dry season, due to upstream impoundment and irrigation. In the 1980's and 90's the river stopped flowing every year, and during the worst droughts of 1982/83 and 1991/92 there was no surface water at all in long stretches of the river. Studies of the biodiversity of the river in the Kruger National Park showed that the number of fish in the river was considerably lower than in the neighbouring Sabie River, and that the invertebrate diversity comprised only 60% of that in the Sabie – made up of the most common and hardy species. Habitat for hippos and crocodiles in the Park was also drastically reduced. Apart from these indicators of environmental degradation, the river no longer provided a reliable water supply for the rural communities living next to the river, many of whom relied entirely on the river for their water. The river also failed for much of the time, to provide any flow into the Olifants River, itself highly polluted by mining activities. This further reduced the volume and quality of water flowing downstream into Mozambique.

The Great Fish River:

The Great Fish River rises in the Karoo region of the Eastern Cape in South Africa, and flows into the sea some 200 km east of Port Elizabeth. A naturally seasonal river, it stopped flowing during the dry season in most years. That was until 1975, when a pipeline and canal system brought water from the Orange River into its upper reaches, to provide irrigation water and to augment the water supply in Port Elizabeth. Since then, the river has flowed permanently at between 3 and 5 m^3s^{-1}, apart from occasional higher floods.

River ecologists in the early 1970's who were worried about the possible effects of the water transfer took samples of fish, water quality and invertebrates, so that it was possible to repeat these after the transfer had begun. Sampling in the 1980's showed that a number of non-native fish species had been introduced into the river, probably via the water transfer scheme, and were significantly affecting the natural fish community. The invertebrate species had also changed: one species, which had been very rare in the river prior to the transfer, had become so dominant that it constituted more than 98% of the total invertebrate community in the middle reaches of the river. This species, a blackfly called *Simulium chutteri,* has a similar life cycle to mosquitoes, with the larvae and pupae growing in the water, and the adult females requiring a blood meal to facilitate egg development. During Spring, millions of these flies emerge from the river, and settle on the local farm animals, causing millions of dollars worth of damage and disturbance.

This is a classic example of the effect of removing the natural variability, or disturbance regime, of a river. The water transfer has created homogenous habitat conditions throughout the year, and these happen to favour the blackfly, and the introduced fish species, over the rest of the natural biodiversity.

PART A:

What are environmental flows?

- Rivers are being used for many purposes, and dams, canals etc are built in rivers to change the flow regime. These changes affect the natural goods and services that we get from rivers, often to our detriment
- So, we have to decide how much we want to change them, and how much of the natural services we would like to keep. The emerging science of environmental flows aims to provide the balance between the use and the protection of natural water resources for people
- Environmental flow scientists use ecological components and processes (fish, plants, water quality etc) as the most sensitive indicators of the state of the river.

There is a growing recognition of the importance of the natural functions that rivers provide, and the value of the biodiversity that lives in or is dependent on them. The natural functions and biodiversity of rivers provide goods and services that we can take for granted: a reliable water supply, fish and other foods, water purification, transport of nutrients downstream and onto fertile floodplains and deltas, and significant cultural and recreational values. If we wish to maintain these vital functions and the biodiversity associated with freshwater, then it is necessary to maintain the flow regime that fundamentally supports them.

If we accept that water resources have to be developed to provide for human needs, then we also have to accept that we are not going to be able to maintain completely natural flows, and this will have consequences for the functions and biodiversity of river systems. The questions then are: how much change are we prepared to accept? How much can the flow regime be modified before we create conditions that we don't want to live with? How much water does a river need?

The emerging science of environmental flows has developed to assess the consequences of changing flow regimes on aquatic ecosystems. These assessments require an understanding of the chain of events which result from altered flows – from climate change to hydrology, hydraulics, geomorphology and water chemistry, to ecological and socio-economic consequences. Environmental flow assessment examines different scenarios of water resource development, and predicts the chain of consequences. Environmental flow assessment can also assist in developing modified flow regimes that are custom-designed to achieve or maintain a particular suite of ecological conditions, for example flows to maintain river channels or allow for migration of particular species.

Environmental flows scientists use ecological and social indicators to measure the state of the river. Very often a fish which is sensitive to flow conditions, insects which lay eggs in the river, or water chemistry will give the first indication that the river is changing. This doesn't mean that these indicators are the exclusive, or even the main reason for managing the river in a particular way. Like coal miners used to take canaries down the mine, because they are particularly sensitive to low oxygen levels, ecological components of a river can be used to indicate incipient problems, before they reach the stage of endangering people and their livelihoods.

Rivers can do many things for people: but they can't do all these things, all the time, for everybody. People have to choose. So, for communities that are not content to see their natural resources over-controlled and over-exploited, but want to get the best out of the artificial uses and the natural goods and services, environmental flows are becoming an integral part of a sustainable management plan for water resources.

PART B:
The basis of environmental flows

PART B:

The ecological assumptions for environmental flows

- The current approach to the assessment and implementation of environmental flows is based on two key overarching assumptions:
    - Some water can be taken out of a river without unacceptably reducing the services which the river provides
    - The flow variability (high flows, low flows, floods etc) provides a range of conditions which maintain the biodiversity of rivers, and prevent the dominance of individual species (which are often pests). All the elements of the natural flow regime, including droughts, are important in controlling the natural communities of a river.

Assumption 1: There is spare water in rivers

If the water resources of a river are used, then there will by definition be less water left in the river, and this will, to a greater or lesser extent, affect the character of the river ecosystem. However, rivers are variable systems, and the species that live in them are resilient to changes. Annual flows in rivers may vary by orders of magnitude from year to year – very large floods in some years, and extreme droughts in others. By implication, any species which persists in such a river must be able to survive during years when there is much less water than average. Providing conditions do not drastically depart from those that have occurred in the past, the animals and plant populations in the river will fluctuate around some common condition. As a consequence a lower than normal flow regime which still incorporates all the major features of the natural regime may not significantly change the biota.

In addition all rivers do not necessarily need to be maintained in a near pristine condition. In fact, most have already been modified in many ways. The recognition that most rivers are no longer pristine, and the setting of achievable conservation goals tailored to specific rivers, allows an assessment of the amount of water that can be abstracted without compromising the chosen objective.

Assumption 2: Flow variability and the natural disturbance regime of a river is important for the maintenance of its biodiversity

The old notion of a 'minimum flow' necessary to keep the biota alive has fallen away, and in its place is the recognition that elements of all types of flow are necessary to provide the dynamic ecological equilibrium of a river. This flow variability is an important part of what ecologists recognise as the "disturbance regime" of rivers, which is considered to be an important process that maintains biodiversity. Different flows are responsible for creating varying habitat conditions in time and space (stream patchiness). These habitat conditions in turn provide for a diversity of niches and refugia under all conditions. The maintenance of such a diversity of habitats 'spreads the risk' for different species at the community and population level.

Such is the importance of the disturbance regime in rivers, that Resh et al. (1988) conclude: " ... disturbance is not only the most important feature of streams to be studied, it is the dominant organising factor in stream ecology."

These are some of the most widespread effects of different types of flows in rivers:

- Base flows in the river maintain the in-channel habitats – the rapids, stony riffles, pools, marginal areas of tree roots and reeds, backwaters, chutes, runs and waterfalls that are all inhabited by different animals and plants. It's very important that these base flows vary from season to season, allowing new and different species to flourish and breed.

PART B:

The ecological assumptions for environmental flows

- Contrary to popular perception, droughts are equally important for biodiversity – limiting the fast-swimming predators and allowing more sedentary plant and animal species to have their turn.
- Higher flows and floods have different functions: they scour out the old sediments and bring in fresh nutrient-laden supplies; they maintain the channel shape, and inundate the floodplains, replenishing the wetlands which carry their own unique flora and fauna. Small floods at the beginning of the wet season provide cues for fish to begin upstream migrations, and for insects to pupate and emerge as aerial adults. The very large floods which may occur on average once every century can act as 'resetting' mechanisms – carving out new channels and sweeping away the debris of decades. The result may be almost a new river, and the flows that follow will gradually repeat the processes of encroachment and accumulation before the next big flood.

So, rivers are extremely dynamic systems at a whole range of spatial and temporal scales – upstream and downstream; within a river reach; across the floodplain or riparian zone; seasonally, between wet and dry years and, between the occurrence of major floods.

A regulated river which flows at the same rate all the time will soon create the same habitats throughout its length, and a few species suited to the unchanging conditions will multiply at the expense of others. We usually call these pest species – like mosquitoes, blackfly, floating plants such as water hyacinth etc. So the full range of flows are important to maintain the habitats and biodiversity that ultimately provide the goods and services that we value from the river.

Assessments of the flows necessary to keep the river in the desired conditions have to take account of all this diversity. The main lesson for environmental flows is that their effect can only be judged against the natural flow regime of the river – the worst changes can be to stop a perennial river flowing or to regulate a seasonal river so that it flows all the time (see the South African examples described in the box above).

PART B:

Limitations of environmental flows

- **Flows control many, but not all, processes in rivers. Environmental flows can only achieve their objectives if land-use, effluent disposal and other non-flow related processes are also controlled.**

Although flows are a dominant governing process in rivers, there are many problems which are not related to the flow regime, and which need to be solved by methods other than flow manipulation. It is important to recognise that environmental flows can only help to maintain or improve conditions in a river if the other non-flow related aspects are also looked after.

Pollution problems caused by poor land management should be addressed at source by improving land management, and not by flow allocation; similarly, problems caused by introduced species (fish or plants) cannot be solved by changing flows, although a healthy flow regime will usually favour indigenous species over invasives.

The River Kennet, England. The river suffers from both overabstraction for public water supply, and industrial and agricultural pollution.

PART B:
Limitations of environmental flows

Here are a number of different but typical types of environmental problems, with comments about the role of environmental flows:

- Loss of riparian vegetation due to over-grazing: This should be addressed at source, by reducing grazing pressure. High level environmental flows to over-top the banks could encourage the regeneration of riparian plants, but these would not survive if over-grazing continued
- Water quality problems due to sewage effluent: These should ideally be addressed at source, by improving/diverting the sewage effluent. Separately, management decisions may be taken to prevent reduced flows from exacerbating the pollution problem (see water quality box)
- Increased sediment input to the river due to catchment erosion: This should be addressed at source, by improving vegetation cover, and/or other anti-erosion measures. Higher flows could be used to transport the sediment, but this would not be considered an environmental flow, it would simply be a management decision to allocate water for channel flushing

Water quality and environmental flows

There are two views of the role of water quality in environmental flows. One is that water quality issues are an integral part of the environmental flow assessment process. In this view, environmental flows must take account of all water quality issues, so that flows may have to be maintained to prevent existing pollution from irrigation return flows, from industrial effluent or from treated or untreated sewage from having an unacceptable impact. Allowing increased abstraction will lead to unacceptable impacts because of the consequent increased concentration of pollution.

The second view is that water quality deterioration may be affected by flow modifications, but are ultimately caused by other non-flow-related activities, such as sewage outflows. Accordingly, environmental flow assessment should only be used to address those issues which are ultimately caused by the flow regime: sources of water quality problems should be addressed at source – by improving irrigation methods or sewage treatment. Environmental flows, in this view, should not be set to allow for the artificial dilution of effluents. Under this view, a management decision may be taken to dilute effluents, but this is not seen as part of the 'environmental flow process'.

In reality, both these views have their place: it is obviously better to improve management practices to reduce pollutants at source. But where water quality problems are intractable, or prohibitively expensive to deal with at source, dilution flows may be the best option for ecosystem protection in the immediate future. Under these latter circumstances, flow recommendations that ignore pollution issues can lead to recommendations with highly damaging social and environmental impacts.

PART C: Environmental flows: key issues

PART C:

Implementation

- **Implementing environmental flows is about getting water flowing down the river. This may often require difficult decisions about reducing present uses, and depends on social and political will, and economic priorities**
- **There has been enormous development of environmental flow assessment methods, but relatively little implementation.**

Assessment of environmental flows is about predicting what sort of flow regime will be necessary to achieve any particular ecological state in a river. Implementation is actually getting the required water down the river at the appropriate time. In any context, implementation presents an immeasurably greater challenge than assessing the necessary flows. Conservationists need to ensure that they do not devote a disproportionate amount of effort to discussion and debate over the appropriate environmental flow methodology, neglecting the more important effort of working for implementation.

Throughout the countries in the world that have set policies for environmental flows, it's probably fair to say that the assessment of flow requirements has always run far ahead of the implementation. Especially in over-allocated rivers, this requires difficult decisions and actions, such as reducing water use, or building additional storage. In addition to significant problems of political will or finance to implement environmental flows, there can also be practical problems. For example, dam outlets may not have the capacity to deliver necessary flow volumes.

The consequences of this mismatch between ambition and reality can be seen in the fact that several hundreds of environmental flow assessments have been undertaken, compared with only a handful of successful implementations world-wide.

Strategies and actions to implement environmental flows will always be very case specific – there's no recipe for making them happen. If the river is over-allocated then it will require regulations or compensation to persuade users to reduce water use. Often the pressure from downstream users (particularly in trans-boundary rivers) can be a powerful pressure to provide flows. Over the last few years, there has been an increasing understanding among most people that over-exploitation of natural resources is not a sensible strategy in the long-term, and this new appreciation of sustainable use of resources can be harnessed to lobby for environmental flows. In rivers that are not yet fully allocated or over-allocated (like the Mara River in Kenya and Tanzania), environmental flows don't have to be implemented – they are already there, and water allocation plans must then factor in the need to reserve enough water to meet the environmental needs. This may be politically more achievable.

Further information on measures that can help to implement environmental flows is set out in 'Allocating Scarce Water' (WWF 2007).

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Lesotho. **Lesotho has abundant supplies of freshwater, some of which is stored and transferred to neigbouring South Africa.**

A case study of environmental flow implementation
The Lesotho Highlands water project, Lesotho and South Africa

(Summarised from the IUCN Water and Nature Initiative Report)

The Lesotho Highlands Water Project was established by Treaty in 1986 between the governments of Lesotho and Southern Africa, to transfer water from Lesotho to South Africa and generate hydropower for Lesotho. Twenty-five specialists from 23 disciplines took part in the three-year environmental flow study, using the holistic DRIFT approach. Four scenarios of likely consequences of dam-induced flow and sediment changes were produced, predicting in detail how the downstream river ecosystems could change and how this could affect users of the river's natural resources.

Guided by the DRIFT outputs, the two governments negotiated releases that were higher, more varied and closer to natural conditions than the 1986 Treaty required. Lessons learnt were that the environmental flow assessment should have been completed in the early scoping phase of the development, to inform structure location, design and desirability. Several major assumptions made in the 1970s and 1980s that guided the content of the 1986 Treaty were shown by the environmental flow study to be erroneous:

- **Assumption:** Removal of 95% of the flow would have little impact on the downstream rivers other than close to the dams. The environmental flow assessment showed there would be significant hydrological, biophysical and socio-economic impacts all the way to the Lesotho border.
- **Assumption:** People downstream of the proposed Lesotho Highlands Water Project structures made very little use of riverine and riparian resources. The environmental flow assessment showed that there were extensive and sometimes complex relationships between the local communities and the rivers.
- **Assumption:** The major impacts of the dams would be on upstream communities who lost land through inundation by the reservoirs. The EFA showed extensive existing and potential future economic and social impacts downstream of the structures.

PART C:

A scientific and social process

- Environmental flow assessment is a combination of scientific and social elements – scientists can do the best assessment of flow needs, but they won't be implemented unless people know why the flows should be left in the river, and think that it is important to do so
- The most effective way of getting the science accepted is to embed the environmental flows process in an overall basin management process, which combines the use of the river with its protection.

Environmental flows ultimately depend on the social, economic and political will of the stakeholders to make them work. You can have the best hydrology, the best ecology, the best geomorphology in the world, but if people aren't convinced of the need for environmental flows they are unlikely to be implemented. Of course, the better the scientific understanding, the more likely people are to be convinced. This makes the process of assessing and implementing environmental flows an interesting combination of science and societal judgement.

Because it was developed as an eco-hydrological process in the 1970's and 80's, it took some years for the early proponents of environmental flows to realise this. There was a gradual realisation in the 1980's that there needed to be a social component to the process – that the stakeholders needed to have a say in the uses and consequent condition of the resource. But, it wasn't until the 1990's and the new millennium that there has been a full realisation that environmental flow assessment is a social process with an eco-hydrological core, rather than an eco-hydrological process with a social add-on.

Setting environmental flows in an isolated scientific process is unlikely to be successful, because the crucial key to acceptance is the understanding and buy-in of the stakeholders and those who will need to implement any changes. Stakeholder groups may include local communities, municipalities, industries reliant on water, agriculture, local and national government agencies, international NGO's, scientific institutions, nature conservation bodies and others. These groups will inevitably represent a wide variety of viewpoints, and are unlikely to come to a consensus when presented with an isolated demand to accept that a proportion of the water in a river will be unavailable for their consumption.

An example to illustrate the difference between the scientific aspects of environmental flows, and those which involve choice and judgement

In terms of the environmental flows process, the important prerequisite is for the practitioners to recognise which aspects of that process are scientific and which aren't. The box below provides a simple illustration:

- The question 'How many and what species of fish are there in a river?' is open to a scientific investigation – zone the river and quantify the habitats, get the nets and the electro-fisher, go and sample, calculate the catch per unit effort, do mark-recapture estimates, model the densities etc. The results may be accurate or inaccurate, but this is a question that a competent fish biologist can tackle with confidence.
- The question 'How many and what sort of fish should be in the river?' may be informed by science, but is in the end a question of societal judgement – does society want to use all the water for irrigated agriculture, so there will be no fish; or, do they want to protect the river as a national park, to maximise the biodiversity? More often, the answer will be somewhere in between – we want some irrigation, but also to keep the river in a healthy state for fish and people downstream. The final setting of environmental flows is a decision based on these values, and without that decision, there is no basis for setting any flows.

PART C:

Choosing a suitable assessment method

- **There are several methods for assessing environmental flows. Some are very quick modelling or extrapolation methods, requiring no or minimal extra work. Some require years of fieldwork and specialists from a number of disciplines**
- **The choice of method will depend on: the urgency of the problem; the resources available for the analysis; the importance of the river; the difficulty of implementation; the complexity of the system**
- **In some cases, rather than conducting an expensive analysis, it will be best simply to let some water down the river and see if it achieves the objectives, then monitor and adjust the flows accordingly.**

There is no one method or approach for assessing environmental flows. The 200 different methods that have been developed globally seem an awful lot, but, apart from reflecting the endless ingenuity of water scientists, this variey of methods is also a consequence of the endless variety of water resources and their socio-economic contexts. These range from wild and scenic rivers in developed countries, with abundant public concern and money for environmental issues, to degraded and polluted urban rivers in third world slums.

Assessments can take several years, and cost millions of dollars, or they can be done in a matter of hours using extrapolation models. Generally, you can have a high-confidence, very explanatory, easily-defensible assessment if you spend the time and money; or you can have a quick and easy, inexpensive, lower-confidence estimate that may need to be monitored and revised. You can also start with a quick and easy method, and simply move on to a more comprehensive assessment if anyone challenges it. There is no one right way to assess environmental flows, and the context is everything.

How should one therefore go about choosing the appropriate method? Deciding on the type, complexity and duration of the assessment depends on a lot of variables.

- How urgent is it to get the flows down the river? If the river is relatively unexploited, and the assessment is being done for future planning and allocation, it may be worthwhile spending some time to collect the relevant data before any decision is made. On the other hand, if the river has been reduced to stagnant pools due to over-abstraction upstream, then getting some water flowing immediately might be the best option, doing the detailed work to figure out the right amounts and timings later.
- What resources are available? If you don't have reliable hydrological information, then you won't know how much water is available. Under these circumstances there is no point in elaborate studies of the ecology of the system, because the flow assessment will be highly uncertain. Similarly, if you are using scientists unfamiliar with the assessment process, or you haven't got or can't afford highly trained specialists, then there's no point in trying to use complex procedures.
- How important is the river? Where there are particularly important biodiversity sites, or socio-economic issues, it may be sensible to conduct a more rigorous assessment.

- How difficult will it be to implement the environmental flows? In the face of management or stakeholders who are dubious and critical of the value of environmental flows, it may be necessary to spend time and money to build a defensible case for the assessment. If this isn't done, the recommendations won't be accepted. But, if everyone agrees in principle, the best kind of assessment is to get some flow down the river and monitor to see if it is achieving the desired objectives
- Are complex ecosystems such as deltas or wetlands involved? Some of the quicker and more basic methods for assessing environmental flows are likely to be more adequate for assessing flow needs in simple river channels. However, more complex freshwater ecosystems such as wetlands and deltas typically have more complex environmental water needs, for example pulses of water at particular times of year to inundate wetlands or maintain delta channel structure. Under these circumstances, a more sophisticated analysis may be required.

The adaptive approach

Instead of starting out by conducting a predictive assessment of environmental water needs, the adaptive approach instead proposes that some water is allowed to flow down the river, accompanied by an effective monitoring operation that allows for the response of the river to the flows to be assessed. The information that is developed in this way will be real information about the impact of flows on the river, more valuable than the more uncertain information yielded by any modelling exercise.

An adaptive management approach may prove to be a quicker and more accurate method of assessing flow needs than extended assessment methods. 'Adaptive' management approaches may be particularly appropriate in contexts of extreme water stress, where over-exploited rivers run dry for some or all of the year. Under these conditions of dry or nearly-dry rivers, it does not require much insight to understand that insufficient water is being allocated to environmental needs. Spending extended periods of time looking for some kind of certainty over the precise ecosystem needs for water, while the river continues to run dry, is clearly not in the best interests of the river, and may not be the most appropriate way to increase understanding of the environmental water needs of the river.

The philosophy behind the adaptive approach is important even where extensive environmental flow assessment methods have been used. It's always important to continue to monitor the state of the river, and if necessary adjust environmental flow allocations. Of course, such an approach will be a necessary part of any climate change adaptation strategy.

PART C:

Setting objectives

- **There's no one correct set of environmental flows for a river – the answer will depend on what people want the river to do for them**
- **Different sorts of rivers will have different requirements. For example, more natural flows may be required for a river in a protected area than in an urban or industrial catchment.**

There is no single 'correct' environmental flow for any given river. Removing water from rivers is always likely to have some impact on the ecology of rivers. The question is how much impact is acceptable, and what objectives are we trying to achieve with management of the river? Much environmental legislation globally incorporates classification systems that recognise that society will wish to conserve some rivers to a higher quality than others.[2] For example, it is likely that we will want to conserve rivers that run through national parks, or with particularly important fisheries, to a higher level than rivers in extensively developed urban areas. In other contexts, there may be vital hydrological processes that we need to conserve – commonly, flows may be necessary to prevent saline intrusion into farmland and groundwater supplies at the mouth of rivers (e.g. Yangtze River in China), or to maintain the structure of important delta ecosystems (e.g. Indus River in Pakistan).

Setting the objectives for the management of the river is therefore a vital requirement for any assessment of environmental flow needs. Some environmental flow methodologies provide a menu of the environmental consequences of different levels of flow modification, but ultimately there has to be a choice: what level of flows, for what purposes?

A common challenge is how to express these consequences and objectives in terms which are comprehensible to people who may be unfamiliar with environmental science, ecosystem functioning, hydrology, and all the other ologies involved in flows for the environment. One solution that has proved very successful is the 'Objectives Hierarchy' *[see Annex A]*.

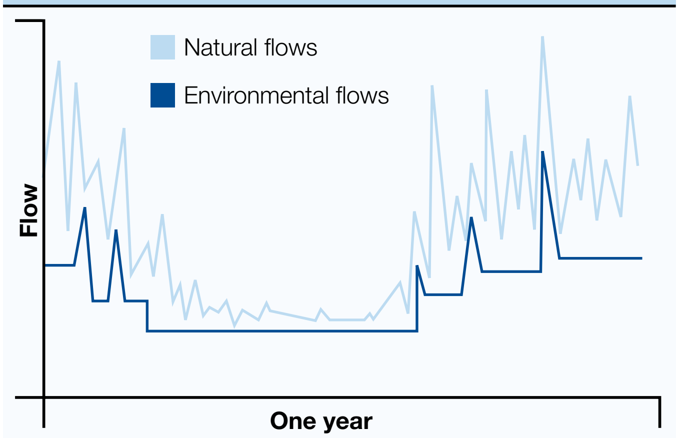
The graphs in Figure 2 show hypothetical time series of flows in rivers over one year, and differing objectives that have been set for differing conditions. Natural flows *(in light blue)* compared to environmental flows *(dark blue)* designed to maintain elements of the dry and wet season base flows, and occasional floods, while allowing a proportion of the flow (between the lines) to be harvested for off-stream uses such as domestic and industrial supply, power generation, or irrigation.

2 These management classes and objectives are variously known as the Desired Future State (DFS) or more recently as the desired Ecological Management Class (EMC),

PART C:
Setting objectives

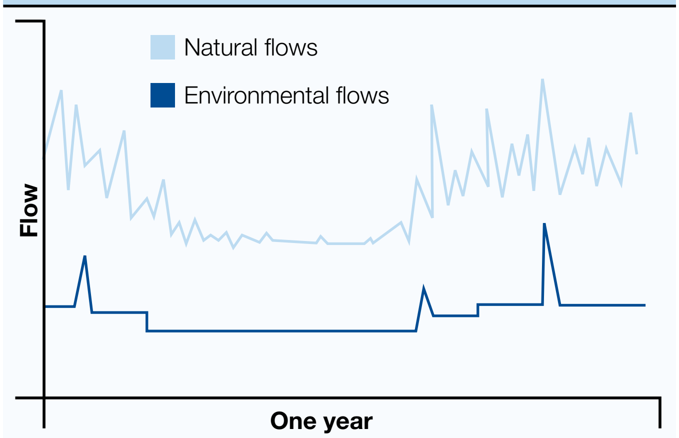
Figure 2 **Differing objectives for different rivers.**

a) River flowing through a conservation area



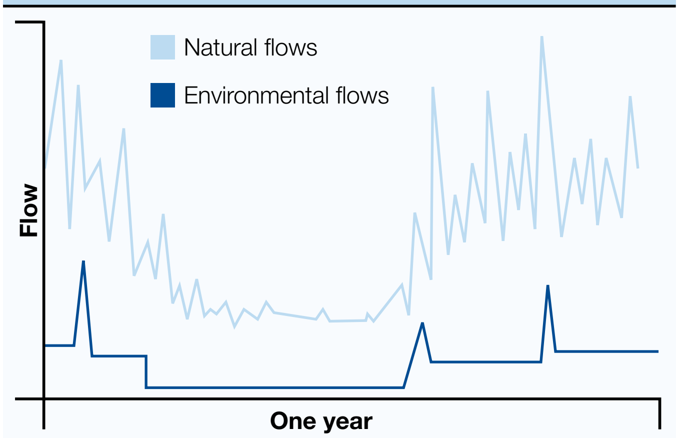
A) For the river flowing through a conservation area the emphasis is on maintaining as much of the natural flow regime as possible, so as to minimise biodiversity loss due to the effects of human water use.

c) A spring-fed river (less variable flow)



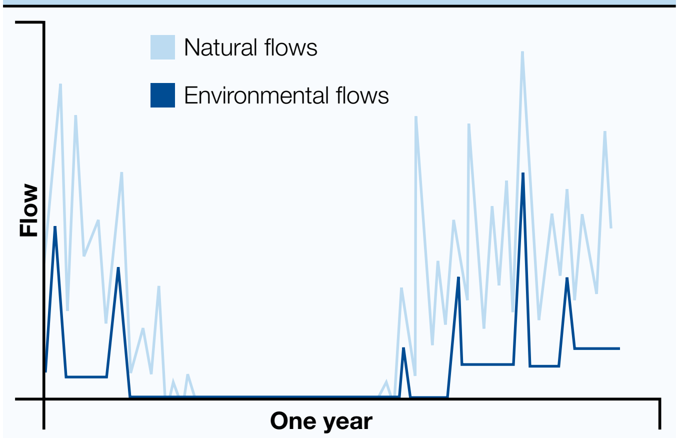
C) For a constantly-flowing spring-fed river, the emphasis is more on maintaining strong base flows, and less on floods.

b) River flowing through an urban area



B) For the urban river, the aim might be simply to maintain reasonable water quality and some recreational fishing, so the base flows can be reduced and less floods are needed.

d) A temporary river (no flow in the dry season)



D) The opposite is true of a flashy seasonal river, in which the biodiversity depends more on sporadic high flow events than on the lower flows.

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Wildebeest crossing the Mara River, Masai Mara National Reserve. Kenya. **Flows in the Mara River through the Reserve are threatened by upstream abstraction.**

Environmental flows for a river flowing through protected areas

The Mara River, Kenya and Tanzania

The Mara River rises in the Mau escarpment of Kenya and flows south through agricultural land, into the Masai Mara Game Reserve, from which it crosses the border into the Serengeti National Park in Tanzania, turns westward out of the Park, flows through the extensive Mara wetlands, and then into Lake Victoria. It is the only constantly–flowing river of the Serengeti ecosystem, and is essential to the functioning of the massive annual wild animal migration – 1.5 million wildebeest and another million zebra, antelope and associated predators. Forestry clearance, and irrigated agriculture in the upper catchment outside the protected areas, threaten dry season flows in the Mara, and the consequences of flow reduction will be severe – during the intense drought of 1993, nearly 400,000 wildebeests perished, and if the river stops flowing during the dry season, the migration could be permanently disrupted.

In 2003, WWF initiated an Integrated River Basin Management project to address the deteriorating environmental conditions of the basin. A major part of this project has been to train a group of Kenyan and Tanzanian specialists in environmental flow techniques, with help of the Global Water for Sustainability Programme (GLOWS) and UNESCO-IHE. In October 2007 an initial assessment of environmental flows was made using the Building Block holistic Methodology (BBM) for 3 sites in the river – 2 upstream of the Masai Mara Game Reserve, and one on the Kenya/Tanzania border in the protected area. The specialists agreed on draft objectives to maintain the river in a near-natural state, and recommended flows were set out for base and flood flows, both in normal and dry years. Extrapolating over the long term, these recommendations would amount to an annual average of just over 50% of present flows.

The Mara example illustrates the great advantage of assessing environmental flows before the river has already become over-abstracted. Far from requiring a decrease in water abstractions, the project has demonstrated that there is some water available for further development: the objectives of the protected areas can be met with just over half of the total water flowing down the river in average years. The other outcome of the assessment is to pin-point that water shortages will only arise, under the present abstraction regime, during the dry season of particularly dry years. This happened in the drought of 2005, when irrigation demands, and the faster run-off from deforested areas, reduced the base flows to less that 0.5 m^3s^{-1} in the protected areas. Stakeholders and government agencies can now concentrate on ways to mitigate the effects of drought, (for example storage in the upper catchment; on-farm storage for irrigation, or compensation for reduced irrigation during droughts).

PART C:

Policy and legislation on environmental flow assessment[3]

- **Many countries now have legal requirements for environmental flows**
- **But, legal protection of environmental flows represents an anomaly in the field environmental protection policy and legislation: it's the only aspect of environmental assessment in which the onus is on to making a case for protection of the resource, rather than the potential user making a case that use of the resource is the best option**
- **It may be effective to confine laws to the principles, and set detailed requirements in policy, which can be more flexibly applied.**

Too often, environmental flows are in an invidious position compared to many other aspects of environmental assessment and protection – it is the only one in which the environment is expected to justify its own protection. This unique concept probably arose by default, as a result of the dam-building bonanza of the 1950's and 60's. At that time, there was a general perception that any freshwater 'escaping' to the sea down a river would be wasted, and that every drop should be intercepted if possible. The concept of environmental flows was developed to make a case for some water to be left in rivers.

Now, most countries have moved on to a recognition of the need to look after their natural resources, and many countries have an explicit requirement for environmental flows as part of their national, provincial or state strategies. Many others have an implicit requirement – prominent among these are the countries of the European Union, for which the EU Water Framework Directive requires the achievement of 'good' ecological conditions for all water bodies by 2015, but no specific requirement for environmental flows.

Such legislation rarely provides careful instructions on how the environmental flows are to be calculated or achieved. The pioneering South African Water Act of 1998 requires water to be 'reserved' for basic human needs and for the environment, and for a classification system to be developed. The Act and its associated parliamentary white papers mention the need for 'sustainability', 'sustainable management', 'sustainable ecosystems' etc. 14 times, but without any operational definition of what this means or how managers should measure whether they are achieving this. Similarly, the US Water Pollution Control (Clean Water) Act of 1972 requires water managers to 'evaluate, maintain and restore the chemical, physical and biological integrity of the nation's waters', but without a quantifiable methodology, managers are often at a loss to know whether or not they are in contravention of the law. The EU Water Framework Directive makes an attempt to define the limits of its classes 'high, good, moderate, and poor', but ultimately the definition has to be developed on a water-body by water-body basis, in relation to the natural range of conditions for each.

3 For a more extended discussion of the policy aspects of environmental flows and water allocation, see the WWF publication 'Allocating Scarce Water' (2007).

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Orange River, South Africa. **South Africa's 1998 Water Act is one of the most ambitious attempts undertaken to protect and restore environmental flows.**

Lessons from South Africa's Water Act

South Africa's 1998 Water Act provides one of the world's most progressive attempts to address social and environmental needs for water. The Act requires that a social and environmental 'reserve' of water be assessed, recognised and protected; once this has been done, the remaining water can be allocated among users.

Despite the progressive legislation, there have been significant teething problems, with important lessons learned. Firstly, the Act requires that the environmental 'reserve' (flow allocation) be accepted by the Minister once assessed. It then becomes a legal obligation. While this provides strong protection for environmental flows, it provides a deterrent to implementation, and can militate against an 'adaptive' approach. Hence, there may be a balance between the strength of legal recognition of a particular flow requirement, and implementation.

Secondly, even sophisticated flow assessments don't stop the arguments raging. Many water managers in South Africa now consider that the assessment methods currently in use are over-complicated and too expensive. However, the original directive from South Africa's Department of Water Affairs and Forestry was for "methods that are scientifically acceptable and legally defensible". The rule of thumb is that you can have complex and expensive methods that are scientifically acceptable and legally defensible, or you can have quick and inexpensive methods that allow for implementation, but require on-going monitoring and may be hard to defend if subject to robust legal challenge. You can't have both.

PART D: Assessing environmental flows

PART D:

Methods for the assessment of environmental flows

- The 200 EFA methods can be grouped into five commonly-used generic types which require variable time and resources, from instant look-up tables to multi-year field investigations
- In addition, there are two approaches which could be highly effective and most appropriate in some situations:
  - Letting down some water flow downstream, without a prior assessment, and monitoring to see the effects
  - Changing the onus to the potential user, who is required to show that the use will not unacceptably degrade the river.

Because rivers are so diverse, and the ecological, social, cultural and economic contexts are also so different for each case, there has been a proliferation of methodologies for the assessment of environmental flows. There are now over 200 different ways to come up with the flows required to maintain riverine ecosystems. The different approaches can be grouped into five generic types, described below, with two additional alternative approaches.

THE FIVE MAIN APPROACHES

Hydrology-based/look-up table approaches

This is the original, and simplest, of the types. Hydrology-based methods are confined to the use of existing, or modeled flow data, on the assumption that maintaining some percentage of the natural flow will provide for the environmental issues of interest. An example is the Range of Variability Approach of Richter et al (1997), which describes the natural range of hydrological variation using 32 different hydrological indices, which together describe the magnitude, timing, duration, frequency and rate of change that characterize the flow regime of the study river. Flow management targets are then set as ranges of variation for each parameter.

Look-up tables are typified by the Montana Approach *(see Figure 3)*, perhaps the original of all the methods, developed by Tennant in 1976. This provides a table which indicates the % of the average (natural) flow required in the wet and dry season, to maintain conditions described as: "Optimum (60 to 100%), outstanding, excellent, good, fair or degrading, poor or minimal, and severe degradation (less than 10%)".

This table, and other similar approaches are typically based on the results of a number of detailed assessments.

As a general rule of thumb, these approaches suggest that about 50 – 70% of the annual flow is needed to keep the river in an excellent environmental condition, about 20 – 50% for reasonable conditions, and 10 – 20% will keep it in a poor condition – impoverished but still flowing. Taking out more than 90% of the flow will more or less guarantee that the river and its biodiversity is seriously damaged or destroyed. The precise amount, and very importantly, the seasonal and yearly patterns of flow, will depend on what sort of river, where it is, and what lives in it.[4]

Figure 3 **The Montana Look-up table of Tennant (1976)**

"Montana Method" for prescribing Instream Flow Regimens for Fish, Wildlife, Recreation and Related Environmental Resources.

Narrative Description of Flows /1	Recommended Base Flow Regimens Oct – Mar	: Apr – Sept
Flushing or Max	200% of the average flow	
Optimum Range	60% – 100% of the average flow	
Outstanding	40%	60%
Excellent	30%	50%
Good	20%	40%
Fair or Degrading	10%	30%
Poor or Minimum	10%	10%
Severe Degradation	10% of average flow to 0 flow	

1/ Most appropriate description of the streamflow for all the parameters in the title.

4 Most importantly, more than 50 – 70% of the dry season flow is likely to be required to maintain excellent environmental conditions.

Extrapolation approach

This approach uses results of existing studies to model a relationship between flow levels and environmental outcomes. This method was developed in South Africa, using the results of a large number of detailed studies, and correlating the results to: the level of environmental objective (A = natural, to D = largely modified); a regional characterization of the hydrology; and a hydrological index which generally describes the reliability or 'flashiness' of the flow regime. The method provides a recommended percentage of the natural flow, and this is broken down into monthly duration curves for normal and drought years.

This method is only possible for regions in which numerous existing environmental flow assessments have been done using more comprehensive methods, to provide the data set for the extrapolation.

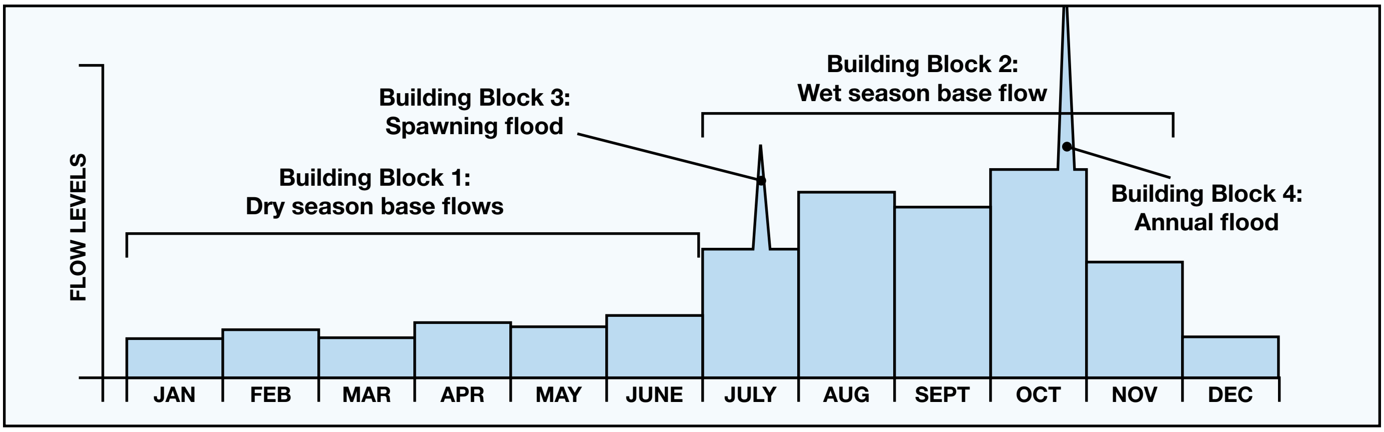
Hydraulic rating methodologies

These methods measure changes in the hydraulic habitat available (wetted perimeter, depth, velocity etc.) based on a single cross-section of the river that measures the shape of the channel. This cross-section is used as a surrogate for biological habitat, and allows for a rough assessment of changes to that habitat with changing flows. The required flows can be inferred from an assessment of the habitat available for indicator species.

Habitat simulation methodologies

These are a development of the hydraulic rating methodologies. With these methods, multiple rated cross-sections are used in a hydraulic model to simulate the conditions in a river reach, again based on wetted perimeter, depth and velocity. Biological sampling of indicator species, combined with measurements of the hydraulic characteristics where they are caught, are used to populate the habitat part of the model.

Figure 4 **Flow Building Blocks of the type used in the Building Block Methodology (BBM). The blocks are basically those elements of the flow variability that are considered to have particular ecological functions**



PART D:

Methods for the assessment of environmental flows

The combined hydraulic/biological model then calculates the area of preferred habitat available for the indicator species at different flows, and can be used to infer the required flows.

This method, and particularly the Instream Flow Incremental Methodology (IFIM), has been used extensively, especially in the United States, and flow recommendations based on it have been successfully defended in court.

Holistic methodologies

These are based on the use of multiple specialists in different fields to provide a consensus view of the appropriate flows to meet a pre-defined set of environmental objectives, or to describe the consequences of different levels of modification to the flow regime. Most of these methods make use of a hydrologist and a hydraulics engineer to provide the baseline data on flows and hydraulic conditions, freshwater biologists for fish, invertebrates, and riparian vegetation to characterize the requirements of the biotic communities, a geomorphologist to predict the changes in sediment transport and channel maintenance at different flows, a water quality specialist, and a socio-economist. A number of different specific methodologies exist (eg Building Block Methodology, DRIFT), and these provide structured frameworks for the collection, analysis and integration of the data to provide an expert prediction of the effects of flow modifications.

This group of methodologies has become very widely used over the past decade, since they are robust, can be used with different objectives and levels of data availability, and have the credibility of the joint expertise of a number of specialists in different fields.

ALTERNATIVE APPROACHES

Adaptive approach or ‘see what happens’ method

The ‘adaptive approach’ is not so much an assessment method, more of an action plan. This approach is to let water down the river, and monitor the results to see if they meet objectives. This has the advantage that it does not require any sophisticated predictions of the effects of flow, and can provide feedback based on real experience. However, it does require that either some form of storage is available, from which the experimental flows can be released, or that users are prepared to forego allocated water in order that it be allowed downstream. There also needs to be a willingness to release the flows without any more detailed justification, often problematic in contested environments.

‘Upside down’ approach

In this approach, the burden of proof is reversed, and the user or potential user is required to demonstrate that the proposed use of the river’s resources will not unacceptably degrade the resource, or ‘impair the public trust’, in the legal sense in the United States, where this approach has been pioneered. This would probably be the long-term goal for the protection of water resources, since it is aligned with the other Environmental Impact Assessment (EIA) methods, in which the onus is on the potential user to demonstrate that the proposed development is not unacceptably damaging.

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The Indus River, Pakistan. Low flows have had devastating impacts on the river.

Assessing environmental flows for people's livelihoods. The Lower Indus River, Pakistan

The Indus River originates on the Tibetan Plateau and flows 3,000 km to its delta in the Arabian Sea. It is the primary source of water for Pakistan and its irrigation – dependent agricultural economy. The Indus delta covers an area of some 5,000 km^2, of which 2,000 km^2 is a protected area. The fan-shaped delta is the sixth largest in the world and supports a population of over 130,000 people, whose livelihoods are directly or indirectly dependent on flow down the Indus River.

As a result of abstraction for irigration the amount of water in the Lower Indus River has decreased dramatically from around 85,000 million m^3 per annum in 1892 to 12,300 million m^3 per annum in the 1990s. In some years, the lower river has almost completely ceased flowing. The reduction in freshwater inflow has led to severe encroachment of the sea into the Delta area. Saline water has intruded 64 km inland and half a million hectares of farmland have thus far been lost, and water supplies contaminated. Furthermore, the abundant freshwater discharges and nutrient-rich sediment load historically supported a highly productive coastal ecosystem, including mangrove forests and fisheries, on which local communities depended for their livelihood. The decline in freshwater flows to the delta has led to a general reduction in the health of the floodplain and delta ecosystems.

Following the 1994 Water Accord apportioning available waters in the river between the provinces of Pakistan, an environmental flow assessment was undertaken for the river, in particular focused on the water needs of the delta. An initial recommendation has been made for a continuous base flow of 140 m^{3}s^{-1}) together with intermittent floods amounting to just over 30,000 million m^3 in 5 years, sufficient to maintain delta channel structure. This flow is significantly less than 10% of the naturalized flow to the delta. This assessment has been reviewed by an international panel, and some shortcomings were identified. Concerns were also raised about the transparency of the process.

Significant controversy has followed the conclusions of the study, and the recommendations are yet to be implemented. Many stakeholders have legitimate concerns over using a flawed study as the basis for longer term management decisions for the river. However, despite the limitations of the study, in a situation in which there is presently virtually no flow in the lower river for extended periods, it may be best to accept and implement the recommendations as an initial option – it's better to have some water in the river rather than none. At the same time, it will be very important to monitor the results of the recommended flows, to see whether they achieve the objectives set, and to revisit the assessment, in the light of improved knowledge of the system. This would be an example of the good use of an adaptive, 'see what happens' approach.

PART D:

Indicators

- It would seldom be possible to measure all the aspects throughout all the river before assessing the environmental flows. So, most methods rely on flow indicators at selected sites to give clues to the flow characteristics required to maintain the desired characteristics
- These indicators should ideally be those which react strongly to flow changes, and which can be investigated to measure their responses to different flow velocities, volumes, depths and/or habitat availability
- Typically, representatives of the following groups are used: fish; benthic (bottom-dwelling) invertebrates; riparian (river-bank) vegetation; water quality; sediment transport; socio-cultural indicators.

Environmental flows are intended to ensure some predetermined ecological stare for a river. People have to decide what that ecological state should be in relation to the goods and services that they value and that the river provides naturally. This means maintaining all the aspects of the riverine ecosystem that go to make up a balanced sustainable system: the biodiversity; the water quality; the sediment dynamics; the microbial processes. But, we can't measure all those things unless we have unlimited time and resources. So we use indicators which we judge will provide the best reflection of the ecosystem as a whole. Because it is flow that we are primarily interested in managing, this means the indicators should be those species and components that are most sensitive to flow conditions, either in terms of the current velocity, the depth, the width of the river, the frequency of flooding etc.

The most commonly used indicators are the fish, the benthic (bottom-dwelling) invertebrates (insects, crustaceans, worms, and snails), the riparian vegetation, the water chemistry, and the sediments.

Using a variety of indicators, the group of environmental flow specialists can build up a picture of the flow requirements for the river, from the low flows to the large floods. Of course, many other indicators may be used, if the resources and expertise are available. Birds and amphibians (frogs and toads) are particularly useful in floodplains and wetlands; algae, bacteria and fungi can add important dimensions to the understanding of all flow requirements.

Fish

These are usually the best known of the biota in the river, and are also of interest to lay people, because of fishing. They provide a variety of lifestyles, and life-stages (breeding, egg-laying, juveniles, and adults) all requiring different habitats and conditions. They normally require at least some water (in pools), some base flow to inundate habitats, some higher flows (to initiate breeding migrations), and, in the case of floodplain dwellers or breeders, floods to lift them onto the floodplain and fill the wetlands. By sampling the selected fish species, and characterising their habitat preferences, it is possible to predict the flows that will maintain these habitats. If a particular flow provides abundant habitat for the most sensitive species, then we can assume that less sensitive species will also be catered for.

Invertebrates

These are the most diverse group of animals in the river, but they are small and difficult to identify unless you've been trained. Like the fish, different groups inhabit different habitats, and the hydraulic conditions can be characterised in the same way as for fish. But invertebrates at least are much easier to catch – put a net in the current, stand upstream and kick the substrate down into the net. They are usually there in hundreds per sample, and as tens of different species, so the information content of a sample can be considerable. The invertebrates are, like the fish, most useful for indicating the base flow requirements – the low flows that keep the water tumbling over the rapids and seeping in amongst the marginal roots and plants that provide refuge habitat.

PART D:
Indicators

Riparian vegetation

These are the plants that inhabit the river banks. Rivers can usually be identified from the air by the bright green highway that snakes through the landscape, indicating the plants that keep their roots in the groundwater that seeps from the river. These plants often grow in characteristic bands or zones, at varying distances from the river: the reeds, sedges and rushes that live in the water's edge; the shrubs that sprout a little way from the water; and the larger trees that grow further up the banks, the roots of which help to stabilise those banks. This succession is an indication of the availability of water and the frequency with which floods reach to different levels. An experienced botanist can tell by the distribution of the species and their seedlings, how frequent and how large the floods should be, and how much base flow is needed to keep the roots wet.

Water quality/ chemistry

Water chemistry is affected by the geology and soils of the catchment, by temperature, by the flow which dilutes or concentrates the elements, and of course by human activities. The natural chemistry changes down the river, as salts accumulate and nutrients flow in. A river also has its natural self-purification capacity, as turbulent flows aerate the water, and microbial and algal processes take up the nutrients. So the job of the water chemist in an environmental flow assessment is to characterise the natural range of concentrations in the river, and to analyse how these concentrations are likely to change as the flows are modified.

Sediments

Erosion is a natural process, but is often accelerated by human land-uses. Sediments are transported down the river, flushed out from some areas and deposited in others, depending on the flows and type of soils. These processes build or erode the river banks, which are then stabilised by the vegetation. So the fluvial geomorphologist (a specialist in sediment transport in rivers) has to analyse the sediments in the river, and judge the effects (net erosion or sedimentation) that will result from different flow regimes. One thing is sure – a modification of the flow regime will result in a change in the sediment transport dynamics, so the channel will change in the long term. The geomorphologist has to determine how rapid and extensive those changes will be, and set flows that will keep the river channel forms in a state that will continue to provide the habitats needed.

Socio-cultural indicators

In some parts of the world, rivers can have a range of important social, cultural and religious values. For example, in South Asia, rivers play a vital role in a range of religious ceremonies, and this may require the river to have certain flows at certain times of year.

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The ecology of the spectacular Kafue flats in Zambia depends on seasonal flood inundation, which also supports aquifer recharge and grazing for local pastoralists. Since the construction of major hydropower dams on the Kafue River, this vital flood is dependent on the operation of these dams.

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ANNEX A:

Objectives hierarchy
– a method for setting measurable indicators to achieve a vision

One process which has been found to be very effective in setting objectives for environmental flows (and other environmental issues) is the objectives hierarchy. One of the great strengths of the process is that it connects the (often vague) environmental aspirations of non-specialist stakeholders with the (often highly technical) requirements of the scientists, and therefore allows both groups to connect in the objective setting process. An objectives hierarchy starts with a generic vision for the river, which can be expressed by the stakeholders, and which is generally inspiring but unmeasurable.

An example could be as follows:

"To maintain as much of the natural biodiversity as possible, while supplying the needs of people, and minimising health risks".

To be useful, this overall objective has to be unpacked into its components, so that the resource managers can know what to manage for, and how to measure whether they are achieving the objectives. A hierarchy of increasingly detailed objectives can provide a link between the measurable indicators, which may not be readily understood by many stakeholders, and the vision. The box provides a hypothetical example, using the vision above.

In the example, anyone can understand the vision and the high-level objective, but there is no way of directly measuring compliance. The sub-objectives are still comprehensible, and connect to the high level, but are still open to different interpretations. The measurable indicators are quantifiable and unequivocal, but objectives dealing with Hydropsychid caddis larvae, and Soluble Reactive Phosphate are obscure to most non-specialists. The objectives hierarchy therefore, is intended to connect the inspiring but unmeasurable vision, to a set of measurable but obscure indicators. Of course, there may be several levels of intermediate objectives, and literally hundreds of indicators, which will form the basis of a monitoring system, linked to appropriate management responses.

An example of an objectives hierarchy

Vision:

"To maintain as much of the natural biodiversity as possible, while supplying the needs of people, and minimising health risks".

High level objective:

"To provide all homes in the catchment with piped clean water, without compromising downstream water availability, environmental health, or natural goods and services".

Sub-objectives:

- To minimise mosquito breeding habitat
- To maintain a subsistence fishery
- To maintain good water quality.

Measurable indicators:

- To ensure flows greater than 1.5 m^3 sec^{-1} at downstream sites during the dry season
- To maintain a benthic invertebrate index of >100 during the dry season, with Hydropsychid caddis larvae as indicators in all riffle samples
- To maintain catch per unit effort (CPUE) at more than 2 Cichlid fish of mass >250g, per hand-line per hour
- To avoid salinity increasing above 50 mS m^{-1} for more than 5% of the dry season
- To maintain pH between 6.8 and 8.0
- To keep Soluble Reactive Phosphates below concentrations of 1 mgl^{-1} for more than 95% of the year.

ANNEX B:

Definitions of some of the terms used in this document

Disturbance Regime:

The pattern of events in an ecosystem which that removes organisms and opens up space or other resources. Such disturbances are seen as providing the mosaic of different conditions that allows different animals and plants to thrive in different places and at different times. The disturbance regime is therefore a very important determinant of the biodiversity in any ecosystem.

Geomorphology:

The study of landforms and the processes that shape them. Geomorphologists seek to understand why landscapes look the way they do: They try to understand landform history and dynamics, and predict future changes through a combination of field observation, physical experiment, and numerical modeling. Fluvial geomorphology looks at the processes that transport sediment from the catchment through the river channel, the erosion and deposition that shapes the river channel and results in

the physical form of the different habitats in rivers.

Hydrology:

The study of the movement and distribution of water throughout the Earth. Hydrologists address both the hydrologic cycle – the processes of evaporation, precipitation, runoff, and groundwater infiltration; and water resources – the amount and distribution of water available.

Hydraulics:

A topic of science and engineering dealing with the mechanical properties of liquids. Stream or river hydraulics deals with the properties of flowing water in the channel – how deep it is, how fast it flows, how wide it will spread, and what it will do in terms of moving materials down the river. For ecologists (and fishermen), the hydraulic conditions describe the types of habitats in a river in which different species will be found.

Riparian zone:

A riparian zone is the interface between land and a river. Riparian vegetation is made up of plant communities along the river banks, characterized by plants that use the water seeping into the banks from the river. Riparian vegetation is important in terms of biodiversity and in its role in stabilising river banks. Riparian zones occur in many forms including grassland, woodland, and wetlands, and require periodic wetting from high flows and floods, to flush away sediments, and to promote seed germination and growth.

Wetted perimeter:

In a cross section of a river, the wetted perimeter is the width (measured across the river bed) that is covered with water. This will enlarge with increasing flows, creating additional aquatic habitat.

ANNEX C:
Further reading

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WWF's Freshwater Programme in numbers

100% RECYCLED

10

WWF is one of 10 organisations which has established the Alliance for Water Stewardship to establish an international certification programme for water managers and users

35%

the Freshwater Living Planet Index (a global measure of more than 700 vertebrate animals) declined by 35% between 1970 and 2007

100 MILLION

WWF has helped establish over 100 million hectares of freshwater protected areas in the last 10 years

12

our global freshwater priorities are the rivers and lakes in 12 critical places across 5 continents

WWF

Why we are here
To stop the degradation of the planet's natural environment and to build a future in which humans live in harmony with nature.

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HSBC
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The HSBC Climate Partnership is a 5 year global partnership between HSBC, The Climate Group, Earthwatch Institute, The Smithsonian Tropical Research Institute and WWF to reduce the impacts of climate change for people, forests, water and cities. For more information visit **hsbc.com/climatepartnership**

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