



ENVIRONMENTAL FLOWS TECHNICAL GUIDANCE MANUAL

October 2018

This publication is made possible by the generous support of the American people through the United States Agency for International Development (USAID), under the terms of the Sustainable Water Partnership (SWP) Leader with Associates Cooperative Agreement No. AID-OAA-L-16-00006 to Winrock International. The SWP is a partnership of Winrock International, Tetra Tech, International Union for the Conservation of Nature, World Resources Institute, and Stockholm Environment Institute. The contents are the responsibility of the SWP consortium partners and do not necessarily reflect the view of USAID or the United States Government.



EXECUTIVE SUMMARY

This technical guidance manual was developed to assist Missions and partners in understanding the importance of environmental flow (E-flow) regimes and their benefits to water security and sustainable development outcomes. Recognizing that there is a vast body of literature exploring the environmental dimensions and practical assessments of E-flows, we explore and emphasize the broader community and societal benefits of E-flow regimes.

This guidance manual is designed as a complement to the series of guidance documents related to sustainable water management and water security produced by the Sustainable Water Partnership (SWP) consortium.

MAJOR ASSUMPTIONS

- Project managers and stakeholders know a lot more about the local water management context than we will (or than a generic tool can anticipate).
- The provision of methods and information for environmental flow assessments examples of their implementation in a wide range of contexts allows the end-users of this guide to recognize opportunities for implementation in the context of their projects.
- E-flows are an integral tool for sustainable Integrated Water Resource Management (IWRM).

E-flows form a critical component of water security, supporting:

- Water Supply
- Risk Management
- Energy
- Food Security
- Livelihoods
- Economic Development
- Sanitation
- Community Resilience and Climate Adaptation

The E-Flows Assessment and Implementation Process

Step 1: Define context

Step 2: Assess water availability and level of alteration

Step 3: Determine environmental water demands

Step 4: Evaluate trade-offs and cost-benefit

Step 5: Negotiate water allocation between competing users

Step 6: Monitor and report

Approaches to understanding E-flows gained in prominence in the mid-twentieth century in response to rapid and often unsustainable development of water management infrastructure and its detrimental impacts to freshwater and coastal ecosystems. Over recent decades, the benefits of E-flows to people are becoming increasingly recognized as an essential part of sustainable development. The most recent definition of E-flows, formulated in Brisbane, 2017 is below:

Environmental flows and wetland water regimes describe the volumes, timing, and quality of surface and groundwater flows needed to sustain river, wetland and estuarine ecosystems and the human cultures, economies, livelihoods and well-being that depend on these ecosystems.



This more recent definition has been broadened since its initial formulation in 2007 to include the role of wetlands and linkages between surface and ground water.

KEY CONSIDERATIONS

- Healthy rivers, lakes, wetlands and estuaries provide ecosystem services that underpin economies, cultures and livelihoods.
- Many of the Sustainable Development Goals (SDGs) cannot be met if the freshwater regimes that sustain and connect all life are further degraded.
- E-flows can help communities prepare for and adapt to climate change.
- E-flows are an important building block for water security

Recognizing that E-flow requirements within each river basin and watershed are highly context-specific, this guidance manual:

- Describes the importance of E-flows to water security and sustainable development;
- Brings together a set of basic guiding principles and approaches for implementation of E-flows in a development context;
- Provides case studies across a variety of river basin contexts;
- Emphasizes the economic importance of E-flows; and
- Provides references to resources relevant for practitioners interested in E-flow implementation.



TABLE OF CONTENTS

Executive Summary	ii
Major Assumptions	ii
Key Considerations	iii
Table of contents	iv
What are Environmental Flows?	5
E-flows and Water Security	9
Public health	9
Economic growth	10
Environmental sustainability	11
Political stability	11
Disaster Risk Reduction	11
Assessing and implementing E-flows	12
Step 1: Definition of context	12
Step 2: Assess water availability and level of alteration	13
Step 3: Determine Environmental water demands	16
Step 4: Evaluate trade-offs and cost-benefit	18
Step 5: Negotiate water allocation between competing users	19
Step 6: Monitoring and reporting	19
Case studies	20
Environmental Flows in Tanzania and Kenya: How experience in numerous basins led to national and international E-flow policies	20
Environmental Flows in Mexico: National Environmental Water Reserves	25
Conclusions and next steps	28
References	29



I. WHAT ARE ENVIRONMENTAL FLOWS?

Water is fundamental to the existence of all life on earth. Availability of clean and reliable supplies of water is central to many development challenges. Through water management infrastructure, such as dams and reservoirs, irrigation canals, and levees, we secure water supplies and manage risks to communities from excess (floods) and shortage (drought). As water management infrastructure is built in river basins, flow regimes are modified to accommodate human needs and reduce uncertainty in water availability.

Historically, water has been managed with emphasis on enhancing supply, minimizing risk and maximizing short-term economic growth. While modification of river flows is beneficial in terms of managing risk for specific purposes (e.g. water supply for an irrigation district or hydropower generation) it also results in often poorly understood trade-offs in availability for other uses (e.g. water supply for downstream users or ecosystems).

The concept of environmental flows emerged in the mid-twentieth century in response to rapid development of water management infrastructure and its impacts to freshwater and coastal ecosystems. Over the past decades we have witnessed an increasing recognition that while we talk about environmental flows, people, as an integral part of interconnected socioeconomic and ecological systems, are the main beneficiaries of the wide range of benefits that environmental flows provide.

HEALTHY RIVERS, LAKES, WETLANDS AND ESTUARIES PROVIDE ECOSYSTEM SERVICES THAT UNDERPIN ECONOMIES, CULTURES AND LIVELIHOODS.

As illustrated in Table 1, E-flows sustain Provisioning, Regulating, Supporting and Cultural ecosystem services. While some of these services are hard, if not impossible to quantify economically, their economic, ecological and societal benefits are often self-evident.

Table 1: Examples of the Provisioning, Regulation, Supporting, and Cultural Ecosystem services of E-flow dependent ecosystems (adapted from SWH, 2009)

Provisioning		
Ecosystems, which depend on E-flows, provide basic materials of direct value and use to people.	<ul style="list-style-type: none"> • Water • Food • Fiber and fuel • Biochemical • Genetic 	<ul style="list-style-type: none"> • Supply of clean water • Recharge of aquifers • Fish, game, fruits, fodder etc. • Firewood, peat, construction • Pharmaceutical materials • Resistance to pathogens
Regulating		
E-flows regulate adverse conditions and environmental risks.	<ul style="list-style-type: none"> • Water • Climate • Biodiversity 	<ul style="list-style-type: none"> • Flood Control • Flushing of waste water and pollutants • Sink for Greenhouse Gasses • Regulation of local climate • Prevention of invasive species



Cultural		
E-flows sustain diverse and unique environments of cultural importance.	<ul style="list-style-type: none"> • Recreation • Aesthetics and inspiration • Ceremonies and rituals • Education 	<ul style="list-style-type: none"> • Outdoor activities, tourism • Natural beauty • Spiritual values • Opportunities for learning
Supporting		
E-flows support bio- and geochemical cycles and processes.	<ul style="list-style-type: none"> • Nutrient cycling • Sediment cycling • Soil formation • Biodiversity 	<ul style="list-style-type: none"> • Transportation, storage, recycling of nutrients • Transportation, storage, weathering of sediment • Retention and accumulation of organic matter • Habitat for species

MANY OF THE SUSTAINABLE DEVELOPMENT GOALS CANNOT BE MET IF THE FRESHWATER REGIMES THAT SUSTAIN AND CONNECT ALL LIFE ARE FURTHER DEGRADED.

Many of the 17 Sustainable Development Goals (SDGs), adopted by world leaders in 2015, cannot be met if the freshwater regimes that sustain and connect all life are further degraded. E-flows are thought to be especially critical to meeting SDG 6 (Water), SDG 13 (Climate Change), SDG 14 (Oceans) and SDG 15 (Ecosystems).

E-FLOWS COULD HELP COMMUNITIES PREPARE FOR AND ADAPT TO CLIMATE CHANGE.

Since many impacts of climate change are felt through changes in the hydrological cycle, E-flows can form an important tool for water managers to build and sustain resilience. By improving our understanding of the inherent uncertainties in (natural) flow regimes, and by integrating this knowledge in basin level decision-making tools and frameworks, E-flows could help communities prepare for and adapt to the impacts of climate change. It is important to realize, though, that as novel climate conditions emerge, these future E-flow requirements may differ from historical conditions. While potentially forming an important component of climate adaptation strategies, environmental water goals and targets must be adaptive in response to non-stationary ecosystem and climate conditions and emerging novel climate conditions.

E-FLOWS ARE AN IMPORTANT BUILDING BLOCK FOR WATER SECURITY.

Water security is *the adaptive capacity to safeguard the sustainable availability of, access to, and safe use of an adequate, reliable and resilient quantity and quality of water for health, livelihoods, ecosystems and productive economies*¹.

¹ SWP Toolkit #1, 2017



This definition indicates that our ability to sustain ecosystem health through allocation of sufficient water of acceptable quality is an integral component of achieving water security. In reality, however, the preservation of (freshwater) ecosystems and the role of E-flows in ensuring water security are often ignored. All dimensions of water security described in Section II (p. 9) directly or indirectly benefit from E-flows, which as a result can be seen as the foundation of water *and* food security. In fact, the benefits of E-flows are many; Section II enumerates the major ones.

THE HYDROLOGICAL CYCLE DETERMINES HOW MUCH WATER IS NATURALLY AVAILABLE.

The hydrological cycle of a river basin – driven by dynamic climate conditions and complex interactions with land cover, soils and geology – determines how much water is naturally available. Sustainable management and allocation of these water resources requires a robust understanding of the hydrologic cycle of a river basin, as well as knowledge of current and future human and ecosystem water demands.

While E-flows are now recognized as important for ecosystem health, they have the potential to provide communities with an essential reserve or buffer against natural variability in water availability, climate change and shifting human needs. Characterizing and preserving E-flows are essential components of water allocation plans to preserve water for ecosystems, and to provide a reserve of water that can accommodate numerous human needs. Framed properly, E-flows can be implemented in such a way that competing needs between multiple water users, such as farmers and hydropower generators, can be met.

As competition for water resources increases along with basin development, water tends to be allocated towards uses with higher economic value (see Figure 1, Molle, 2009), leaving less water for less obvious economic benefits, such as poorer and often voiceless communities, or the environment. Over-abstraction and mismanagement of water resources (often in water-limited and/or highly developed basins such as the Murray-Darling in Australia, the Orange River in South Africa, the Chapala-Lerma of Central Mexico, and the Columbia River in the U.S.) have led to programs aimed at conserving E-flows. These programs have generally focused almost exclusively on preserving in-stream flows for preservation of ecosystem health and biodiversity. A critical hurdle for implementing E-flows programs in much of the developing world is building the understanding that **natural flows support not only environmental objectives, but also many additional objectives that provide important benefits for the poor and underserved.**

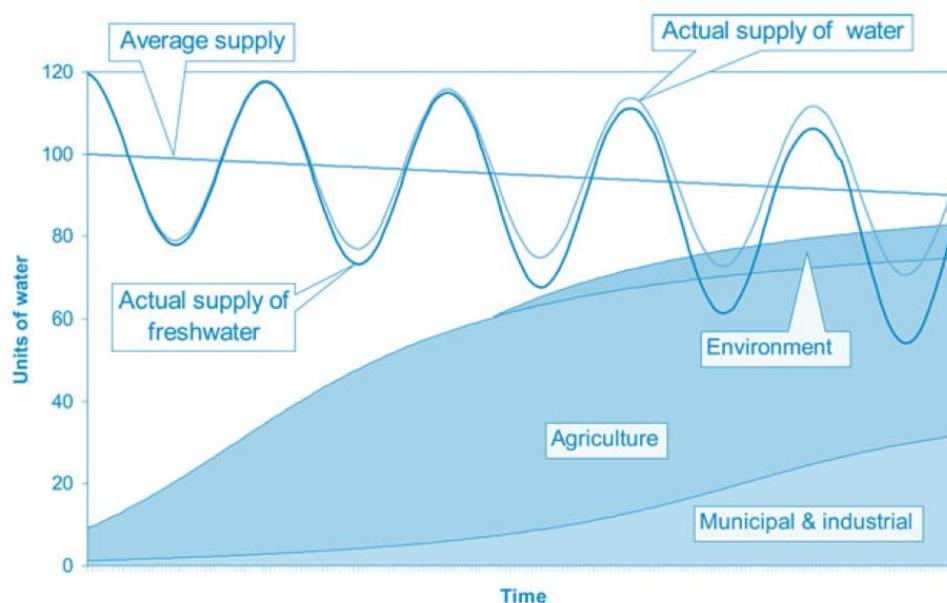




Figure 1: Basin Double squeeze due to increasing demand under decreasing supply (from Molle, 2009)

Recognizing that E-flow requirements within each river basin and watershed are highly context-specific, this guidance manual:

1. Describes the importance of E-flows to water security and sustainable development;
2. Brings together a set of basic guiding principles and approaches for implementation of E-flows in a development context;
3. Provides case studies across a variety of river basin contexts;
4. Emphasizes the economic importance of E-flows; and
5. Provides references to resources relevant for practitioners interested in E-flow implementation.

SUMMARY OF KEY RESOURCES

- USAID SWP Toolkit #1
- Millennium Ecosystem Assessment, 2005
<https://www.millenniumassessment.org/>
- Transforming our world: the 2030 Agenda for Sustainable Development
<https://sustainabledevelopment.un.org/>
- Securing Water for Ecosystems and Human Well-being: The Importance of Environmental Flows. Forslund, A., et al. 2009. *Swedish Water House* Report 24. SIWI
<http://www.siwi.org/publications/securing-water-for-ecosystems-and-human-well-being-the-importance-of-environmental-flows/>
- Flow: The essentials of Environmental Flows
Dyson, M. et al., 2003. IUCN. Gland Switzerland and Cambridge, UK. Xiv +118 pp
<https://www.iucn.org/content/flow-essentials-environmental-flows-0>
- River Basin Trajectories: Societies, Environment, Development
Molle, F, IWMI, 2009
http://www.iwmi.cgiar.org/Publications/CABI_Publications/CA_CABI_Series/River_Basin_Trajectories/9781845935382.pdf



II. E-FLOWS AND WATER SECURITY

Management of E-flows and wetland water regimes is a fundamental component of water security. Environmental water frameworks can integrate ecosystem and biodiversity values into national and local planning, development processes, and poverty reduction strategies. Sound environmental water management hedges against potentially serious and irreversible impacts of climate change.

As illustrated below, water security is essential to life and humankind, by supporting public health, economic growth, environmental sustainability, political stability and disaster reduction (USAID, 2017).

Water Security Is Essential to Life and Humankind, by Supporting:



Public health: Safe water, sanitation, and hygiene (WASH) are the most fundamental human needs.



Economic growth: Income generation and poverty alleviation heavily rely on water availability for agriculture, energy production, transportation and other livelihood activities.



Environmental sustainability: Natural ecosystems rely on water; they rapidly deteriorate when deprived of natural flows, directly affecting public health and livelihoods.



Political stability: When basic health and livelihood needs are not met, the strain on populations affects the legitimacy and sustainability of governing authorities and can lead to civil unrest.



Disaster risk reduction: Floods, landslides, droughts, tsunamis, and oil/chemical spills can be catastrophic events that claim lives, affect local economies, and may multiply due to weather variability and climate change.

These dimensions of water security can be linked to E-flows:

PUBLIC HEALTH

E-flows maintain raw water supply for domestic use, irrigation and other needs. Modification of river systems for hydropower, for example, can restrict equitable access to drinking and irrigation water for downstream users. E-flows can sustain base levels of discharge important to sanitation and hygiene as well as prevention of salt water intrusion. The latter problem is prominent in coastal and delta systems where fresh water supplies are threatened by irreversible salt water intrusion. While the discharge of wastewater function of E-flows is not regarded as good practice, it has been a motivation for implementation. Restricting natural flows has the potential to reduce the only natural flushing that exists in many places (e.g. Bagmati River Kathmandu). E-flows are therefore important for basic sanitation and discharging residual waters as well as nutrient cycling.

E-flow to improve habitat and dilute wastewater in the Bagmati River, Nepal (from ADB 2013)

The Bagmati River Basin (BRB) is culturally and economically important for the people of Nepal. The river's flow is considered holy and is used for ceremonies at the many temples along its banks. The river passes through the capital, Kathmandu, and provides most of the city's drinking water and hydropower and it is also used for large-scale irrigation in the lower basin. Water resources in the basin are in decline as water demands of an expanding population and industrial sector increasingly divert available freshwater. The combination of rapid and unplanned growth of Kathmandu and a lack of solid waste management and waste water treatment, has led to a situation where wastewater is the main flow to the



river in the dry season. This set of conditions sets the stage for human health hazards as well as the degradation of the riverine ecosystem. The Asian Development Bank is currently in the process of implementing the Bagmati River Basin Improvement Project. One of the outputs from the project will be provision of dry-season flow to support both the dilution of wastewater in the river and improvement of conditions for the badly degraded aquatic ecosystem.

ECONOMIC GROWTH

While the short-term economic benefits of modifying natural flow, e.g. for hydropower, are clear and easy to quantify, the costs to downstream users are not. Although it is difficult to assess the many economic losses experienced when the flow regime is modified, these costs are real, and need to be considered in long-term water allocation planning. A full accounting of costs and benefits of river modification can be done to prioritize water decision-making. It is moreover important to consider that proactive planning is generally much cheaper than the cost of restoration or inaction. It is therefore imperative that comprehensive water development plans that consider the many uses of natural flows be developed early.

Fisheries in Tonle Sap Lake, Cambodia (from Rafik and Davis 2009)

Environmental flows from the Mekong River are necessary to sustain fishery resources in Tonle Sap lake, Cambodia. Tonle Sap, a large and shallow lake located in the middle of the Cambodian plain, is filled by the Mekong's wet season flow and, depending on the year, the lake can cover between 2,500 and 16,000 square kilometers. Wet season flooding periodically carries sediment-rich water from the River to the lake, sustaining a complex system including extensive wetlands, flooded forests critical for fish breeding, and a complex food web. Around 75 percent of Cambodia's inland fisheries come from the lake as does about 60 percent of the protein consumed by some three million people. Fish from Tonle Sap are also important for restocking Mekong River fisheries.

Hydropower development is one of the leading reasons for modifying natural flows. While human demands for energy are undeniably important, managing hydropower facilities for multiple needs offers the opportunity for win-win management strategies that can balance energy demand with environmental and downstream human demands. An example of sustainable energy production, though context specific, could be run of the river hydropower or pumped storage solutions in conjunction with other renewable energy sources such as wind and solar.

Many Benefits of E-flow in the Kafue Floodplains, Zambia (from Schelle and Pittock 2005)

The Kafue Flats are a large group of wetlands and floodplains along the Kafue River comprising some 6,500 square kilometers. The flats have an extremely small gradient, and consequently, water passes through them over a period of about two months. These floodplains are extremely important ecosystems, home to numerous rare species. The system also maintains important socio-economic systems, including animal grazing, agriculture and fisheries. In natural flow conditions, the Flats would flood beginning in December, with a peak flow between March and May, and dry conditions beginning by October. Modification of the Kafue River for Hydropower has had both positive and negative impacts on the area. Pros have included energy and water supply for urban populations and commercial farmers. Cons have been mainly felt by downstream users of water who depend on the Flats for livelihoods. Among the cons are the loss of grazing lands due to changing vegetation patterns, the loss of arable land for agriculture, reduced fishery productivity, and declines in endemic species populations, including the Kafue Lechwe, an endemic species of antelope. WWF, working with the Zambia Electricity Supply Corporation (ZESCO) and other stakeholders, developed plans to implement E-flow to restore the lost benefits of the Kafue Floodplains while maintaining electrical and water supply and revenue for the utilities. The experience in Kafue shows the potential for negotiating management strategies that can balance the needs of large utilities with the needs of smaller, in-stream users.



ENVIRONMENTAL SUSTAINABILITY

Freshwater and coastal ecosystems that depend on E-flows provide habitat necessary for numerous species, many of which are critical for food and nutrition security. Restricting flows through dam construction, for example, can degrade habitats and severely impact river and lake fisheries (e.g. Tonle Sap, Lake Malawi). Additionally, natural flows carry sediment and nutrients to both inland floodplain-based food systems (e.g. Madagascar or Kafue) and marine Fisheries (e.g. Gulf of Japan, Nile). An estimated 472 million people live downstream of large-dams around the globe, for whom the restriction of water, sediment and nutrients through flow modification has enormous implications for floodplain-based agricultural production (Richter et al. 2011).

Biodiversity of the wetlands of the Okavango Delta, Botswana (from Mosepele et al. 2009)

The Okavango Delta in Botswana is an extremely important wetland surrounded by the Kalahari Desert, supporting diverse fish species that rely on seasonal flooding from surrounding rivers and actions of fauna, such as hippos, elephants, and termites, for habitat creation and maintenance. Growing human demand for resources, including water, are expected to affect fish and other ecosystem components in the Okavango. Mosepele et al. (2009) developed conceptual models of the Okavango Delta relative to fish and fisheries in a pro-active attempt to guide research and conservation of this important ecosystem. An understanding of the E-flow necessary for sustenance of the Okavango Delta is essential to allocate water in the watershed to meet demands of people while preserving the ecosystem.

POLITICAL STABILITY

River flows provide sustainable livelihoods to communities situated near rivers – these vary from place to place, but include fisheries, agriculture, recreation, and transportation. Restricting natural flows can threaten these ways of life, and implementing E-flows has the potential to maintain flows for these livelihood needs while meeting upstream demands of flow modification.

DISASTER RISK REDUCTION

A major motivation for flow modification is managing environmental extremes, such as floods and droughts. Although dams and reservoirs have been employed successfully in many places around the world to mitigate flood risk in times of excessive flow and store water for use during times of low flow, flow modification can lead to numerous unintended consequences that can exacerbate risk, for example by concentrating flood pulses and removing the natural ability of floodplains to attenuate floods. In addition to preserving ecosystems, E-flows play an essential role in reducing current and future risk to communities for the reasons discussed above. Additionally, E-flows can reduce community vulnerability and uncertainty due to weather extremes and climate vulnerability (e.g. water supply and ecosystem services during dry periods or years). E-flows should be incorporated in adaptation plans, as they offer the potential to mitigate climate impacts and build community resilience, buffer against sea level rise (e.g. Brahmaputra, Bangladesh) and form part of national Adaptation Plans (e.g. Mexico).

SUMMARY OF KEY RESOURCES

- USAID SWP Toolkit #1
- E-flow to improve habitat and dilute wastewater in the Bagmati River, Nepal, ADB, 2013. <https://www.adb.org/sites/default/files/project-document/77118/43448-013-nep-eia.pdf>
- Fisheries in Tonle Sap Lake, Cambodia. Hijri, R. and Davis, R., World Bank, 2009 <https://openknowledge.worldbank.org/handle/10986/18381>
- Mosepele, K., et al. 2009. Fish, floods, and ecosystem engineers: aquatic conservation in the Okavango Delta, Botswana. *BioScience* 59.1. 53-64.



ASSESSING AND IMPLEMENTING E-FLOWS

In recent decades, numerous E-flows programs have been developed to rehabilitate or sustain ecosystem functions and services of rivers around the globe. The assessment of E-flows requires consideration of physical, biological, water quality, socio-cultural and livelihood aspects of riverine ecosystems. In general, assessments must be guided by consultations with experts and local communities to generate negotiated management strategies that meet the needs of as many stakeholders as possible (Gopal et al. 2016).

Although the concepts behind E-flows are generally accepted, their practical implementation often proves challenging for a variety of reasons. First and foremost, the social, legal and physical context as well as the scale at which one aims to implement E-flows all determine which approach might be most appropriate and to what extent an E-flows assessment is feasible. Technical capacity, gaps in baseline knowledge and data availability, and available financial resources further determine appropriate approaches to and feasibility of E-flows assessments. By embedding E-flows into a broader water security framework, requirements and trade-offs can be evaluated in the wider management system.

This section proposes a general framework for understanding E-Flows considerations, recognizing that actual assessment approaches and implementation contexts will vary greatly from basin to basin.

- Step 1: Define context
- Step 2: Assess water availability and level of alteration
- Step 3: Determine environmental water demands
- Step 4: Evaluate trade-offs and cost-benefit
- Step 5: Negotiate water allocation between competing users
- Step 6: Monitoring and evaluation

STEP 1: DEFINE CONTEXT

Scale

A river basin is defined by natural physical boundaries which generally also define the hydrological limits of the basin's water balance. This balance of water entering in the form of precipitation, temporary storage in rivers and lakes, soils, groundwater and vegetation through time, determines how much water we have available for human development. Natural drainage units can be identified within basins, watersheds or sub-basins (all of these terms are commonly interchanged) which allow for sub-dividing water management and allocation decisions. The size of a river basin or watershed and the location of an E-flows target (e.g. wetland system or river reach) within the basin determines the scope of technical knowledge required as well as the potential complexity of implementation. E-flows may be implemented at the scale of an individual project (e.g. operational rules of a single dam) and may not require a review of the full river basin.

Legal context

A major enabling factor for the implementation of E-flows is the presence or absence of water laws, whether they explicitly recognize the environment as a water user and whether they enable the legal implementation of E-flows programs. Additionally, it is necessary to enumerate any international agreements that may exist regarding water allocation.

Water governance

Decision about water resources are made at many governance levels, for which jurisdictional boundaries often may not coincide with physical river basin and sub-basin boundaries. Assessment of governance



structures around water management need to identify whether clear jurisdictions exist. An apolitical river basin authority, or similar entity, usually provides a logical governance body for water resource decision making, which may facilitate the bridging of political boundaries – national to municipal scale – to a river basin level. Any adaptive management frameworks in place should be enumerated as should any trans-boundary dimensions to water management problems in the implementation location.

Stakeholders

Implementation of E-flows requires acceptance by- and broad inclusion of- sectors and stakeholders, including agriculture, industry, urban, environment, recreation, and others. Perceptions of water and its importance for broader societal and environmental functioning may vary heavily based on general perceptions and knowledge as well as cultural relations to this resource. Perceptions may range from highly utilitarian to spiritual.

Data availability

Availability of information is a persistent challenge and care should be taken to identify both availability and quality of meteorological, hydrological, and biological data in addition to estimates of current water use.

Technical capacity

Potential to implement E-flows programs depends, in part, on the technical capacity available to assess human and environmental water demands, explore management options and negotiate management strategies, and implement flow recommendations.

STEP 2: ASSESS WATER AVAILABILITY AND LEVEL OF ALTERATION

One of the chief considerations in developing an approach to E-flows assessment and program implementation is the current level of basin development (Molle et al. 2007). Following the concept of the biological gradient, the assumption is that with increasing hydrologic alteration, the number and complexity of hydrological processes is reduced in exchange for a more stable and predictable flow regime which benefits particular uses such as storage for water supply purposes for hydropower generation. As a result the general biological condition and complexity of the aquatic systems is reduced (See Figure 2, p. 12).

Understand natural water balance

Natural availability determines the amount of water that enters a river system and how much water is eventually available for allocation. Basins in arid regions may have very limited amounts of naturally available water resources.

The critical step in developing E-flows programs is to develop an understanding of the natural water balance of a river basin. As discussed in “Step 4: Determine Environmental Water Demands” below, many methods exist for doing this and the approach selected will depend on the implementation context. In principle, though, it is necessary to develop a rigorous understanding of how much water would be flowing in the absence of flow modification. Then, depending on management context, it is important to understand how much water is necessary to maintain ecosystem function. Flow levels should be developed with respect to priority species or ecosystems – and best practice should include multiple flow targets that can be negotiated in Steps 6 and 7 (e.g. full natural flow, functional flows necessary to maintain habitat/ecosystem, and minimum acceptable flow requirements).



Level of basin alteration

Approach and content of an E-flows assessment depends on a clear understanding of where an implementation site is on a trajectory of development, including a consideration of biological conditions and the level of hydrologic alteration in the system. Figure 2 below illustrates a theoretical spectrum of biological conditions and levels of hydrologic alterations. Boxes underscore the fact that a given level of biological conditions can exist at different stages of hydrologic alteration. However, in general, biological conditions decline at higher levels of hydrologic alterations.

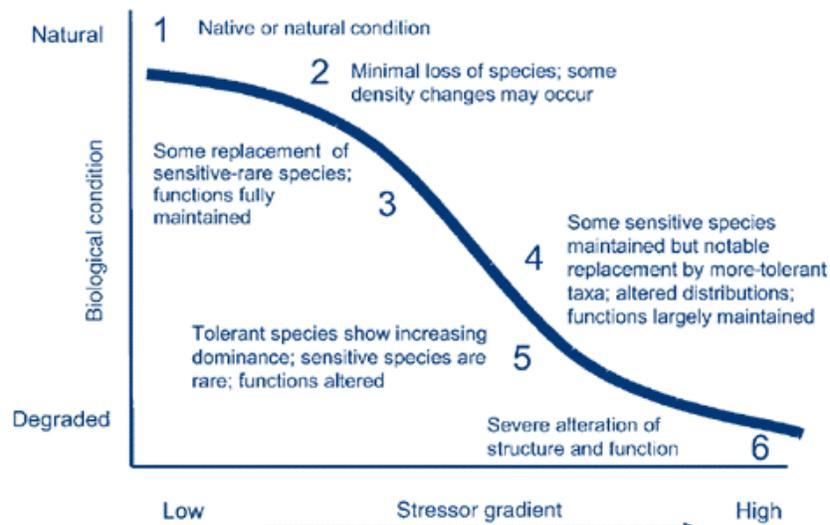


Figure 2: Conceptual relationship between biological conditions and hydrologic alterations (Davies and Jackson, 2006)

Table 1 below, adapted from a USAID-funded E-flows activity in Tanzania (USAID 2011), elaborates six categories of basin conditions, generally corresponding to levels of biological condition and hydrologic alteration.

Table 1. Categories of basin conditions

A	Unmodified/natural	Reaches that are minimally affected by human interference
		<ul style="list-style-type: none"> • Even the most sensitive species are present in natural abundance • All biophysical processes are operational • Minimal artificial erosion and sedimentation • Largely unmodified channel morphology with natural riparian vegetation cover • Floodplains natural, with no or insignificant agriculture, unmodified wetlands, and flooding regime • High water quality
B	Largely natural with few modifications	Reaches that have some evidence of human interference but are still functionally intact
		<ul style="list-style-type: none"> • There may be some reduction in the abundance of sensitive species, but they are not at risk of extinction even during drought periods • Some artificial erosion and sedimentation may be evident but with slight or negligible effects on biodiversity and biophysical processes



		<ul style="list-style-type: none"> • Slight or insignificant modifications to channel morphology, with largely natural riparian vegetation • There may be some introduced or exotic riparian plant species, but natural species are still dominant • Floodplains largely natural, possibly with some agriculture, but most wetlands largely unmodified and natural flooding regime • Water quality clean or only slightly modified, with zero industrial waste, possibly some agricultural runoff, but insignificant, and insignificant domestic waste
C	Moderately modified	Reaches that have clear evidence of human interference but are still largely functionally intact
		<ul style="list-style-type: none"> • Reduction in the abundance of sensitive species and possible risk of local temporary extinction for the most sensitive during stressful periods (e.g. drought or pollution events) • Significant artificial erosion and sedimentation may be evident, with observable effects on biodiversity and biophysical processes, but natural biodiversity and processes are still largely intact • Significant modifications to channel morphology may be present, possibly with introduced or exotic riparian plant species, which may be common • Floodplains often used mainly for agriculture but with some wetlands, which may be modified, flooding regime mostly natural • Water quality may be moderately modified, with the possibility of industrial waste, agricultural runoff, and/or domestic waste, which may affect the natural biodiversity in terms of relative abundance of and risk to sensitive species
D	Largely modified	Reaches that have major evidence of human interference and are marginally functionally intact
		<ul style="list-style-type: none"> • Large reduction in the abundance of sensitive species and local extinction of the most sensitive • Extensive artificial erosion and sedimentation may be evident, with significant effects on biodiversity and biophysical processes, but most species still present and processes are marginally intact • Extensive modifications to channel morphology may be present, often with introduced or exotic riparian plant species, which may be common • Floodplains mostly drained and used mainly for agriculture or urban settlement. Occasional modified wetlands still existing; flooding regime may be modified • Water quality may be significantly modified, with the probability of industrial waste, agricultural runoff, and/or domestic waste, which significantly affects the natural biodiversity in terms of relative abundance, and disappearance, of sensitive species
E	Seriously modified	Reaches that have serious evidence of human interference and are at most only partially functionally intact
		<ul style="list-style-type: none"> • Sensitive species will be absent (except during rare improved flow and/or water quality conditions). Biodiversity dominated by common/generalist species, with many hardy species • Serious artificial erosion and sedimentation may be evident, with significant loss of biodiversity and biophysical processes, which will at most be partially intact



		<ul style="list-style-type: none"> • Serious modifications to channel morphology may be present, with extensive introduced or exotic riparian plant species, which may be invasive and dominant • Floodplains usually completely modified for agriculture and/or urban development, possibly isolated surviving modified wetlands, and flooding regime may have been significantly reduced • Water quality may be seriously modified, with one or more of industrial waste, agricultural runoff and/or domestic waste, which will have seriously reduced the natural biodiversity in terms of the absence of sensitive species, and increased abundance of hardy species
F	Critically/extremely modified	Reaches that are dominated by human interference, with little or no natural functionality
		<ul style="list-style-type: none"> • Sensitive species will be permanently absent, and communities will be dominated by hardy species, some of which may be pests or disease vectors • Very little natural biodiversity will be apparent (except for hardy species) • Serious artificial erosion and sedimentation may be evident to the extent that channel morphology will have permanently altered (possibly channelized) • Riparian vegetation, if present, will be dominated by introduced or exotic invasive species • Floodplains may have been drained and disconnected from the river but will be completely modified for agriculture or industrial uses; no surviving wetlands and flooding regime may have been significantly reduced, diverted, or intercepted • Water quality will probably be completely modified, with flow usually dominated by industrial, agricultural and/or domestic effluents

In heavily modified river systems, the focus of E-flows programs is typically on restoration of ecosystem health and related services. The concept of E-flows is often developed in a reactive manner in the context of heavily modified basins once the detrimental impacts of development have become evident. An emerging body of work is promoting proactive consideration of E-flow in largely unmodified river systems. Proactive development of water resources is substantially cheaper and effective than finding retroactive solutions to problems created by flow alteration, as is the current situation in much of North America and Europe.

STEP 3: DETERMINE ENVIRONMENTAL WATER DEMANDS

Since the 1970s, a progressive evolution of methodologies for assessing the water needs of aquatic ecosystems has taken place (Dunbar et al, 1998; Acreman and Dunbar, 2004; Tharme, 2003). Four groups of methodologies are generally used: hydrological methods, hydraulic methods, habitat simulation methods and holistic methodologies (see for example King et al, 1998; Tharme, 2003, King et al. 2008). Many methods have been developed to derive ‘environmental flows’ (Tharme, 2003; Arthington et al. 2006) and no single E-flows assessment technique suits all social, economic, hydrological, and ecological contexts within a country (Hirji and Davis, 2009; Annear, 2003; Dyson et al, 2008). Complicating the variety of methods available is the fact that most of these methods are based on historic observations and may therefore be poorly suited for consideration of changes in hydrological regimes that are changing due to climate change. Categories of methods are described below, although E-flows assessments are moving toward Holistic methods and we focus principally on these.



Hydrological methods

These methods use the natural flow regime as the key variable that drives aquatic ecosystem structure and functioning. The range of historical flows over past decades are set as a template for contemporary ecological processes, evolutionary adaptations and native biodiversity maintenance (Resh et al., 1988; Doyle et al., 2005; Lytle & Poff, 2004; Bunn & Arthington, 2002). E-flow recommendations based on this approach presume that conservation of these conditions will maintain habitats and species. Originally, hydrological methods focused on minimum flow conditions (Gippel, 2001), but are currently trending towards more holistic methods with an emphasis on covering natural variability and disturbance regimes.

Hydraulic methods

Hydraulic methods focus on approaches that capture relationships between stream geometry and discharge, and are typically used as a proxy for factors that sustain aquatic species and habitat. Tharme (1996) reviewed commonly applied hydraulic rating methodologies and many associated hydraulic simulation models used to derive environmental flow recommendations. Minimum or optimal flows, usually for fish spawning or maximum production by benthic invertebrates, are generally identified from a discharge near the breakpoint of the wetted perimeter-discharge curve (e.g. Collings 1974, cited in Stalnaker & Amette 1976; Prewitt & Carlson 1980).

Biological methods

Biological methods are an extension of the hydraulic methods where flow requirements are linked to specific habitat requirements of species. Habitat features are linked to be directly and indirectly related to flow. Ranges of preferences of individual species regarding physical habitat (current velocity, depth or substrate type, etc.) are related to flows and integrated in hydraulic methods.

Holistic methods

While the previous three methods are applied in single purpose contexts, holistic approaches aim to integrate all major interacting components of aquatic systems which are described in terms of duration, timing, magnitude and frequency. Holistic approaches are inherently interdisciplinary and depend on expert input to reach consensus on recommended E-flows. Below is a generalized description of the Building Block Method of assessing E-flows, as articulated in a USAID-funded E-flows assessment from Tanzania (USAID 2011) and Georgia (USAID 2017). The focus of the method is to identify major flow components and recommended flows that support specific ecological processes. Recommendations are developed for both wet and dry years.

Building Block method (Adapted from USAID 2011 and USAID 2017)

The required EF regime is comprised of three main components (see Figure 3 below):

1. Survival Flow – The critical, extreme low flow recommended during a designated drought period;
2. Low Flow – Low flows related to specific periods of ecological importance for indicator assemblages, species and life stages, ecological processes, and flows for important social and cultural features. The periods defined are generally one to six months each, and together result in a continuous low flow regime during the year;
3. High Flow – High flow pulses and flood events of defined magnitudes extending over a specified number of days and intended for specific purposes, such as maintaining channel morphology or cueing ecological responses (e.g., fish spawning or migration). Additional criteria to describe a flow event may be used, including frequency or rate of the receding limb of the hydrograph.

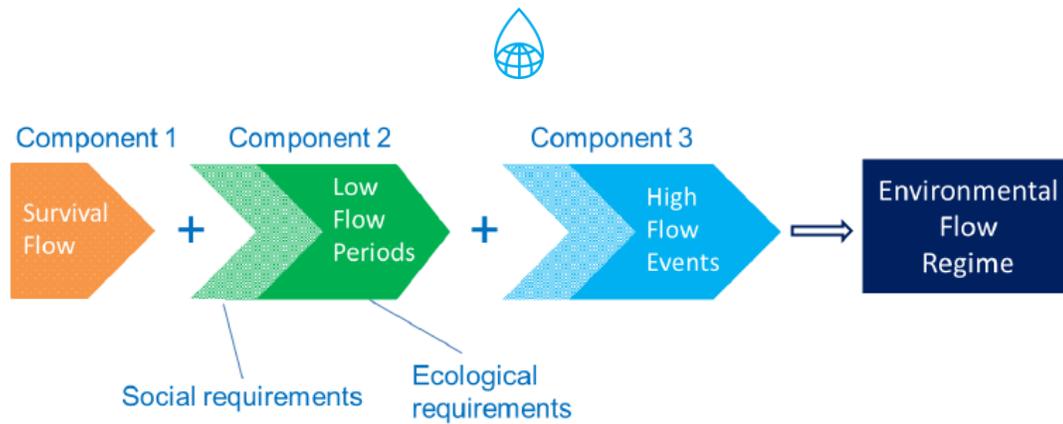


Figure 3 Three flow components that, in combination, represent the recommended EF regimes for a river or stream site, (from USAID 2017).

Environmental flow is expressed as a schedule specifying recommended discharges required for each of the components to meet a series of designated ecological and social requirements in normal years (and under drought conditions). The EF schedule must be detailed enough so that recommended flow regime can be drawn up for implementation.

All components must be calculated for the Environmental Flow requirements to be met, either through rules for the operation of the existing or proposed water resources infrastructure and/or standards limiting the withdrawal of water from a river or stream.

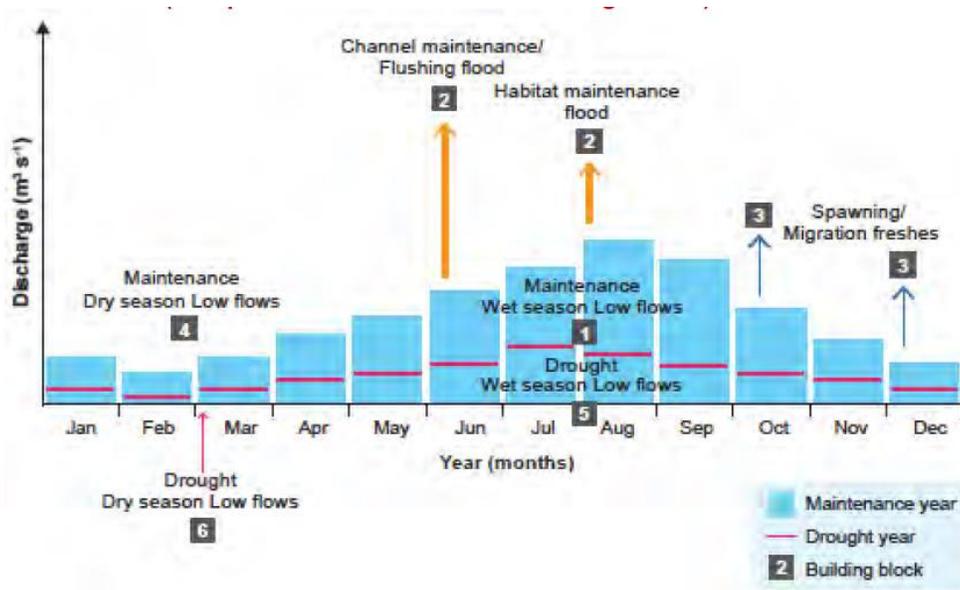


Figure 4 A conceptual representation of E-flows over the course of a year, with recommended flows for drought seasons and low flow years as well as typical years and high flow conditions (from USAID 2017).

STEP 4: EVALUATE TRADE-OFFS AND COST-BENEFIT

Ideally, a formal cost-benefit analysis should be conducted to understand the all impacts of a proposed water management scheme. This analysis should be conducted with due consideration to the sustainability triple bottom line and properly consider economic, social and environmental impacts of water development plans. Such a formal analysis is complicated by several barriers. Chief among them is that social and environmental benefits and costs are often extremely difficult to quantify in clear economic terms (as are the small-scale economic benefits to poor in-stream water users). Additionally, large-scale



infrastructure projects tend to be prioritized over environmental and social costs (partly because quantifying environmental and social costs is so difficult). To address this, Gopal et al (2016) recommend weighting environmental and social costs and benefits to overcome conventional biases toward large-scale and economically profitable water development projects. Consequently, a full cost-benefit analysis in the conventional sense may be impossible and water resources managers should develop a comprehensive accounting of the various users of water, including large and small-scale in addition to environmental water “use”. In the absence of formal cost-benefit analysis, an evaluation of trade-offs in various water allocation decision scenarios is necessary to explore the potential management space available for basin development.

Although many tools exist for assessing the hydrological and biological parts of assessing E-flows, these assessments have value primarily as tools to develop management strategies that balance the needs of multiple human stakeholders with environmental needs. In the past, water development asked the question – “How much water can we take out of the river to meet human needs?” E-flows programs aim to ask the question – “How much water can we leave in the river and still meet human needs?” To approach this goal, managers and stakeholders should use the assessed E-flows to allocate water to the various end-users, beginning with environmental water requirements and then to other users.

STEP 5: NEGOTIATE WATER ALLOCATION BETWEEN COMPETING USERS

Real and potential conflict over water is at the heart of the motivation to conduct E-flows assessments. Inevitably, the goal of E-flows programs is to allocate more water to the environment and to in-stream users who might not receive adequate water if only large-scale diversions are prioritized. Limiting allocations to large-scale diversions will only happen if multiple stakeholders are able to negotiate water allocation plans or negotiate changes to water allocations based on win-win management strategies developed in Step 6 – strategies that will have to show clear co-benefits to all water users and stakeholders. Identifying multiple possible E-flows scenarios in Step 4 is therefore essential as negotiations require flexibility among all involved stakeholders.

STEP 6: MONITORING AND REPORTING

In order to evaluate the effectiveness of E-flow programs, periodic review of emerging conditions versus baseline condition needs to take place. As part of Step 7, one could imagine identifying a set of metrics, targets and reporting at regular intervals (e.g. annual, every 5 years) and allowing for integration of lessons learned. If these periodic evaluations indicate lack of progress, the program needs to be evaluated and adjusted in an adaptive manner.

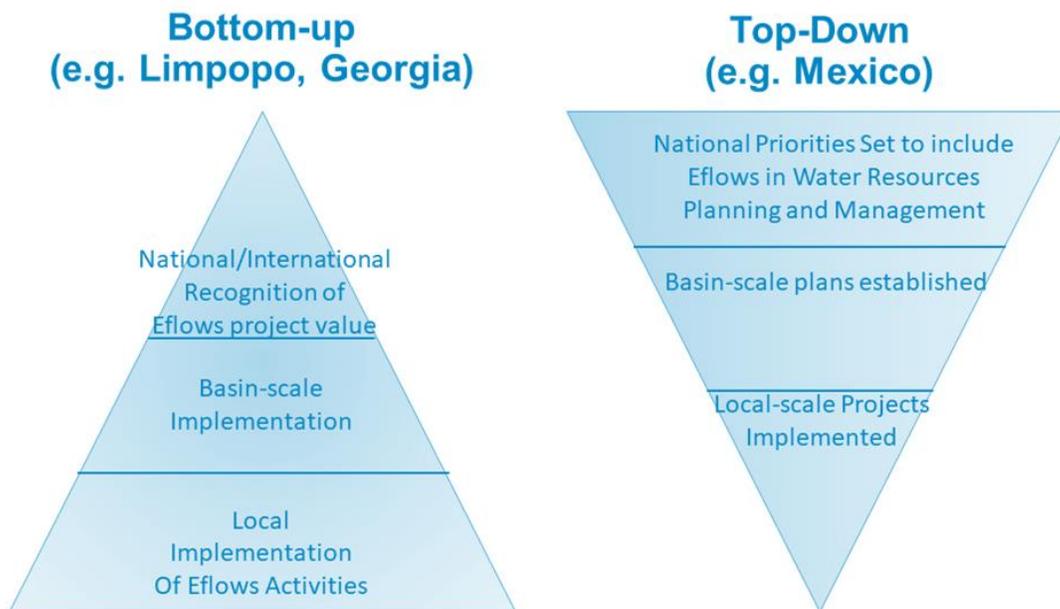
It is particularly important to emphasize potential impacts of climate change and design strategies that are climate adaptive. In some cases, this might mean targets based on past conditions are no longer valid due to emerging conditions. Robust review and evaluation of the sensitivity of water allocation systems to climate change can be performed with systems modelling tools like Water Evaluation and Planning (WEAP) tool (and others) and can help identify modifications.



CASE STUDIES

E-flow programs have been developed in many countries around the world. Although each program is unique, and reflects local environmental conditions as well as social, economic and political realities, programs have generally developed in one of two ways.

In some countries and basins, successful implementation of E-flow activities at the local or watershed scale have led to basin or national scale approaches and policies to guide broader implementation of E-flow interventions. In other countries, national or international policies have set the guidelines under which E-flow assessments and programs can be undertaken and implemented.



Below, we present and discuss general characteristics and outcomes for a set of local ecosystem level E-flow programs, 1) The Rufiji Basin in Tanzania and 2) The Mara Basin in Kenya and Tanzania and National level E-flow programs in 3) Mexico and 4) the Republic of Georgia

The selected case studies are intended to highlight E-flow interventions, for the most part supported by USAID, with the ultimate goal of guiding USAID Missions, Implementing Partners, and relevant stakeholders in the design and implementation of future E-flow programs and activities.

E-FLOWS IN TANZANIA AND KENYA: HOW EXPERIENCE IN NUMEROUS BASINS LED TO NATIONAL AND INTERNATIONAL E-FLOW POLICIES

One of the most complete sets of E-flow program experiences in the world includes four Environmental Flow Assessments conducted by USAID and partners and one conducted by IUCN and partners, in Tanzania and Kenya (see Resources below for relevant reports). These five assessments were conducted for the Kilombero and Lower Rufiji River Basin, the Mara River Basin, the Wami River Basin, the Ruvu River Basin and the Pangani River Basin. Each of these activities was conducted for specific objectives and the information generated through the assessments became fundamental to achieve the development goals specified in each case. In the Kilombero, the assessment supported USAID Feed the Future efforts



and was motivated by proposed irrigation diversions in a sensitive ecosystem. In the Mara the motivation was for meeting water, sanitation and hygiene needs while conserving biodiversity. Assessments in the Wami, Ruvu, and the Pangani were basically proactive, providing the necessary scientific information for future water allocation planning and environmental conservation. This collection of experiences taken together has led to the development of both national-scale and transboundary policy toward E-flow in East Africa.

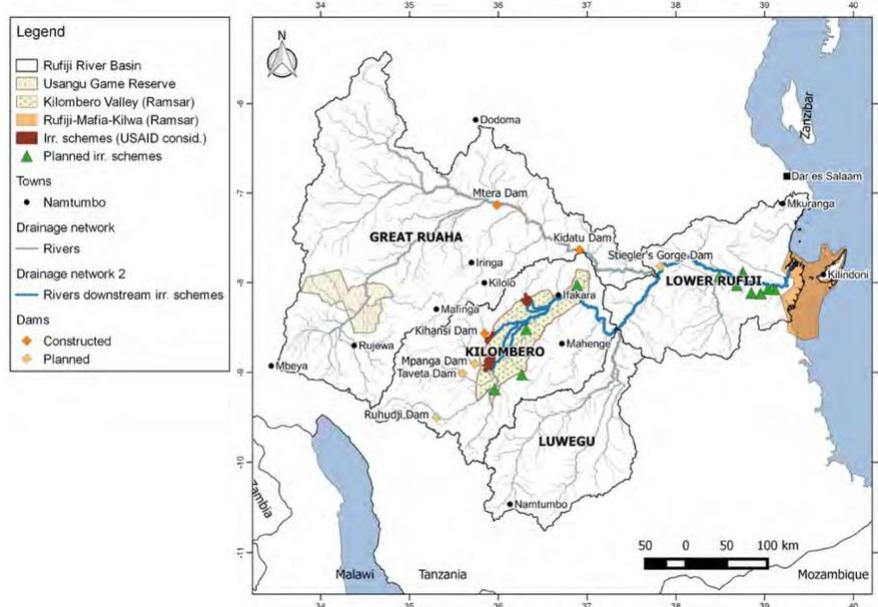
Kilombero and Lower Rufiji (from USAID 2011)

The Government of Tanzania is currently targeting the Kilombero and Lower Rufiji River Basins for dramatic development over the next twenty years as part of the Southern Agricultural Growth Corridor of Tanzania (SAGCOT). Central to this planned development is the diversion of water from the Lower Rufiji for large-scale irrigation, currently projected to increase demand by 7 billion cubic meters per year, and the addition of hydropower facilities.

These basins contain some of Tanzania's most valued landscapes and ecosystems, including important wetlands, floodplains, and protected coastal zones, all of which provide many ecosystem services which sustain the welfare and livelihoods of hundreds of thousands of people. These systems are dependent on seasonal variable river flows for habitat maintenance and biological processes like fish spawning. In order to protect the long-term sustainability of social, economic and environmental components of the basin, development plans for the basin recognize system vulnerabilities and require a reserve of water for the environment, mandated under the Water Resources Management Act of 2009.

According to the 2009 Act, the water reserve is the quantity and quality of water required for: *Satisfying basic human needs by securing a basic water supply for people who are now or shall in the reasonably near future be a) relying upon, b) taking water from c) being supplied from the relevant water resources.*

The USAID-led environmental flow assessment aimed to recommend river flows required to meet the reserve and protect ecological conditions and river function to protect the ecosystem services these systems deliver to human communities. The results of the assessment for the five study sites in the basin is shown below and consists of recommended flow requirements necessary to support river structure and function for both wet and dry years and for all seasons.



Notes: Planned irrigation (IRR) schemes, existing and planned dams, and Ramsar sites are highlighted.



Figure xx: Map of Kilombero and Lower Rufiji Basins (from USAID 2011)

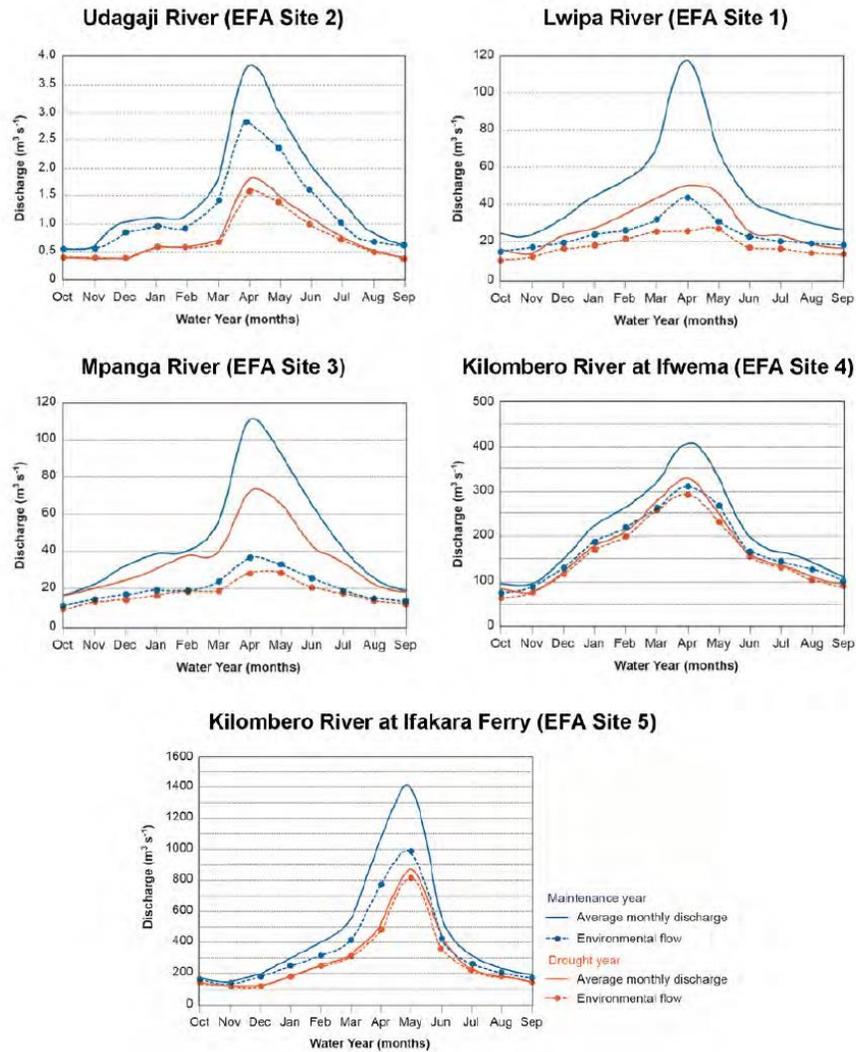


Figure xx: Recommended E-flows for five sites in Kilombero and Lower Rufiji Basins (from USAID 2011)

Wami/Ruvu

A USAID-funded E-flows Assessment was carried out in 2007 and repeated in 2011 in the Wami/Ruvu basins through the Wami/Ruvu Basin Water Office (WRBWO), with partners from the University of Dar es Salaam (UDSM) and Florida International University (FIU). These assessments were proactive in nature, filling knowledge gaps in the flows necessary to sustain river and ecosystem health – knowledge that is essential in any water allocation planning exercise. An example of recommended monthly flow for the Wami River, Site #4 is included below (from USAID 2014a, b).



Month	Driest year			Maintenance year			Wettest year		
	RAD	AAD	RIP	RAD	AAD	RIP	RAD	AAD	RIP
Oct	3.0	4.3		13.3	13.3		23.0	65.0	
Nov	3.0	5.9		14.0	26.0		23.0	265.9	
Dec	7.7	15.9		27.3	54.6		59.8	503.9	
Jan	7.7	10.1		32.8	65.7		96.5	412.9	
Feb	7.7	12.3		24.6	49.2		133.3	325.1	
Mar	5.6	5.6		52.4	69.9		170.0	466.6	
Apr	21.7	102.1	48 (T < 1 yr)	65.0	192.9	53 (T < 1 yr)	170.0	1240.5	170 (T = 1.1 yr)
May	21.7	261.7		65.0	145.4		170.0	465.9	
Jun	15.5	42.6		37.5	49.9		91.4	182.8	
Jul	9.2	27.9		20.8	27.7		30.1	60.3	
Aug	3.0	15.4		14.0	21.1		23.0	51.3	
Sep	3.0	10.4		14.0	15.5		23.0	61.5	

(RAD = recommended average discharge; AAD = available average discharge;
RIP = recommended instantaneous peak (pulse) discharge)

Pangani

IUCN and the Pangani Basin Water Office led an E-flows Assessment for the Pangani River from 2005-2009 to generate baseline information about the Pangani River system to provide guidance around water-related decision-making in the future. Like the assessments of the Wami/Ruvu, this exercise was largely proactive, anticipating the need for baseline data against which trade-offs could be assessed in the future with respect to water allocation planning.

National and International Policy (from USAID 2012)

A proactive agenda focused on Integrated Water Resources Management and the combined experiences from the Environmental Flow Assessment cases mentioned above have led to a robust set of National and International policies around water management in Tanzania and Kenya. Below are the major policies enacted in both countries focused on mandating water resources management and environmental flow considerations.



Both Kenya and Tanzania have passed legislation aimed towards ensuring access to safe water resources for all people, as well as sustaining the valuable ecosystems upon which these people depend. The principle of environmental flows is evident in the wording of water resources policy from both Kenya and Tanzania. Through scientific studies and a consortium approach, the TWB-MRB project supported the development of recommendations for an environmental flow regime for the Mara River as a whole. The respective water policies in each country therefore provided a legal framework for this initiative.

Kenya Water Resources Management Act (2002)

Defines the “reserve, in relation to a water source, [as] that quantity and quality of water required (a) to satisfy basic human needs for all people who are or may be supplied from the water resource; and (b) to protect aquatic ecosystems in order to secure ecologically sustainable development and use of the water resource.” The Water Act further states that “the Minister, the Authority and all public bodies shall, when exercising any statutory power or performing any statutory function in relation to the water resource concerned, take into account and give effect to the requirements of the reserve (Part III, 13 (3)).”

Draft versions of the new Kenya Water Resources Management Act include very similar wording in regards to determination and protection of the reserve.

Kenya Water Resources Management Rules (2007)

Calls for the Authority to establish the reserve based on a) Water resource records and reserve water demand, *or* b) 1) ecological vulnerability, 2) human vulnerability, 3) local observations of historic drought flows, 4) maintenance of perennial flows, and 5) consultations with WUAs.

Tanzania National Water Policy (2002)

Recognizes the importance of environmental flows and prioritizes water use such that “Water for basic human needs in adequate quantity and acceptable quality will receive highest priority. Water for the environment to protect the eco-systems that underpin our water resources, now and in the future will attain second priority and will be reserved (Section 4.1.2).”

Tanzania Water Resources Management Act (2009)

Defines the reserve as “the quantity and quality of water required for (a) satisfying basic human needs... and (b) protecting aquatic ecosystems” and states that “the Minister shall...determine the reserve for the whole or part of each water resource which has been classified...and the Minister, the National Water Board, Basin Water Boards and all public bodies shall, when exercising any statutory power or performing any statutory duty, take into account and give effect to the requirements of the reserve (Section 37, 1-3).”



E-FLOWS IN MEXICO: NATIONAL ENVIRONMENTAL WATER RESERVES

Surface water resources in Mexico are managed through administrative units shaped around 731 river basins, located in 13 hydrological regions throughout the country (CONAGUA, 2015). The most populated and most developed basins in terms of agricultural and industrial productions are experiencing periods of severe water stress, while many basins have a relative abundance of water resources (CONAGUA, 2015). Mexico is one of the most megadiverse countries of the world. Although the Mexican territory represents only one percent of the earth's surface, it hosts more than 10 percent of the world's biological diversity in part due to its unique freshwater ecosystems (CONABIO, 2014). Mexico has a system of 177 protected areas and has 142 wetland systems (4.4 percent of the national territory) that are recognized under the Ramsar Convention on Wetlands of International Importance.

Under Mexican water law, 100 percent of the mean available volume of water as officially established by the National Water Commission (CONAGUA) must be allocated for use. Over the past decade this has led to a severe over-allocation of water resources and periods of shortages, as the flow regime of many rivers is highly variable. While Mexico is one of the few countries in the world where the environment is clearly recognized as a legitimate water user under a National Water Law, a process for determining and securing E-flows was largely absent.

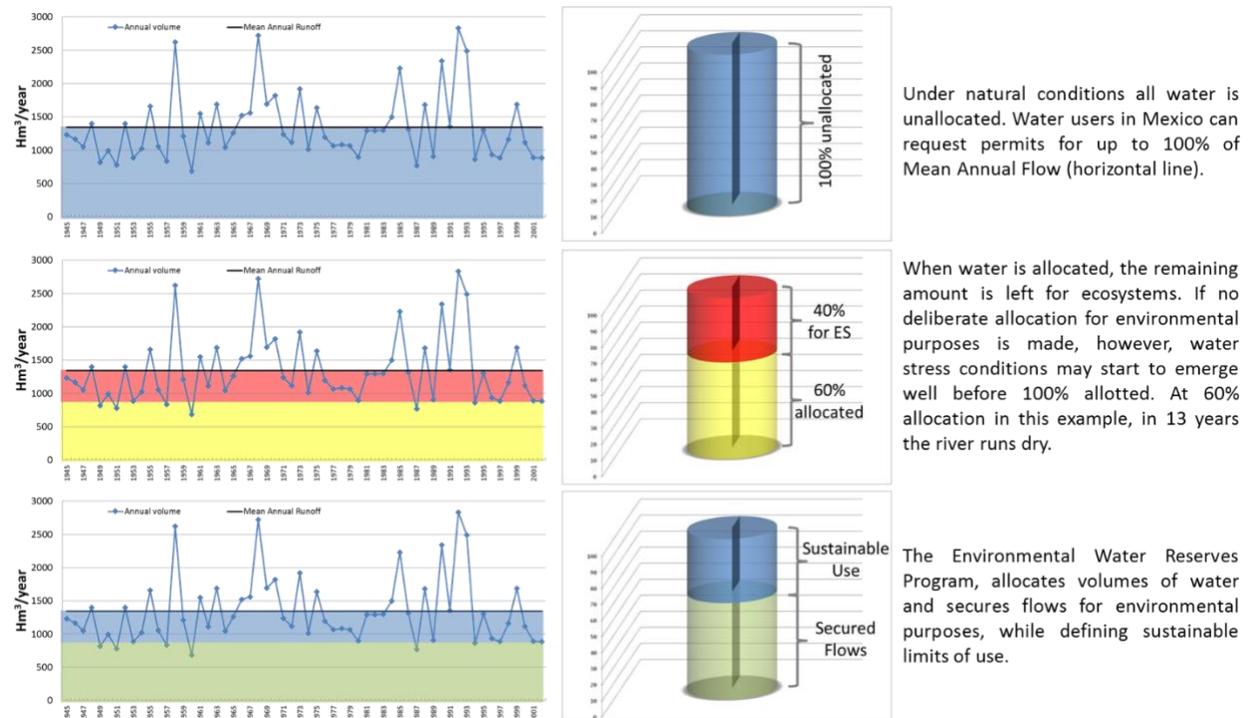


Figure 5 Shifting from treating E-flows as residual flows that are left after all other demands are met to proactive environmental allocation that and secures flows for people and ecosystems

In 2012, the government of Mexico published a standard for the implementation of E-flows at a national level. This Mexican standard (NMX-AA-159-SCFI-2012 or “eFlowsNMx” in this text) is a regulatory instrument that establishes the procedure and technical aspects for defining E-flows of hydrological basins (Secretaría de Economía, 2012). The eFlowsNMx aims to balance water use and conservation of flows, and provides a standardized strategic approach for determining e-flows. It is mainly based on the concepts of *The Natural Flow Paradigm* (Poff et al., 1997) and *The Biological Condition Gradient* (Davies & Jackson, 2006), and defines corresponding methodologies for the definition of e-flows as a measure to balance water allocation for people and nature. In the same year, CONAGUA launched the



National Water Reserves for the Environment Program, focusing the initial implementation of the E-flows standard in 189 of the 731 basins to demonstrate the benefits of environmental water reserves, while building a community of practice around the implementation of the eFlowsNMx. These priority basins were selected based on their close to natural water balance, low levels of water demand and allocation and high biological richness and conservation value (CONAGUA, 2011; Barrios-Ordóñez *et al.*, 2015).

By providing guidelines for determining environmental objectives (desired ecological state) in relation to the river basin's pressure on water resources (water pressure = ratio of allocated water over water availability at an annual scale) the eFlowsNMx provides an independent variable for allocating water to the environment with more natural integrity; and relates its ecological importance (very high, high, medium or low) to the level of hydrological alteration of the basin as a dependent variable.

Environmental objectives are conceptually represented in a matrix with four classes (A, B, C and D) set according to a combination of water pressure and ecological importance levels. The extremes of these classes imply, on one hand, a very good desired or optimal ecological state ("A"), which means that the river basin of study has the lowest water pressure and the highest levels of ecological importance. Therefore, under this scenario the objective would be to conserve as much as possible the integrity of the natural flow regime, its ecological functions and ecosystem services. The class above A (blue) indicates pristine and close to unaltered conditions. On the other hand, a deficient ecological state (class "D") means a river basin with the highest water pressure and the lowest ecological importance levels. In this case the goal will be to restore, at to the maximum extent possible, flow regime components, basic ecological functions and ecosystem services that the flow regime used to provide.

The eFlowsNMx provides a set of appendices which allow users to employ a range of methods for the determination of E-flows, ranging from Hydrologic Methods for data sparse basins to Holistic methods where information is more abundant. The hydrological method is at a level of analysis that provides quick science-based functional proposals from the water planning and management perspective, and eco-hydrologically meaningful approach to protect the e-flow components and associated functions. However, the holistic approach produces detailed flow-ecology relationships that allow testing of eco-hydrological working hypotheses in the field. Since its inception, the Water Reserves Program has implemented 25 Environmental Water Reserves through application of the hydrological and holistic methods at the basin scale.

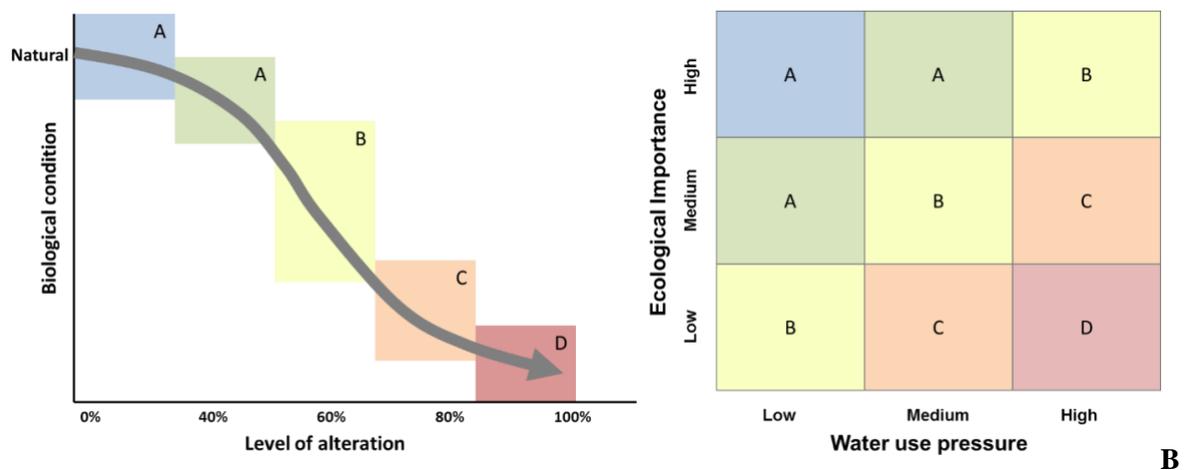


Figure 6 A) Conceptual representation of the biological gradient as a function of level of basin alteration (adapted from Davies and Jackson, 2006); B) environmental objectives expressed as a combination of ecological importance and water demand pressure (CONAGUA, 2012)

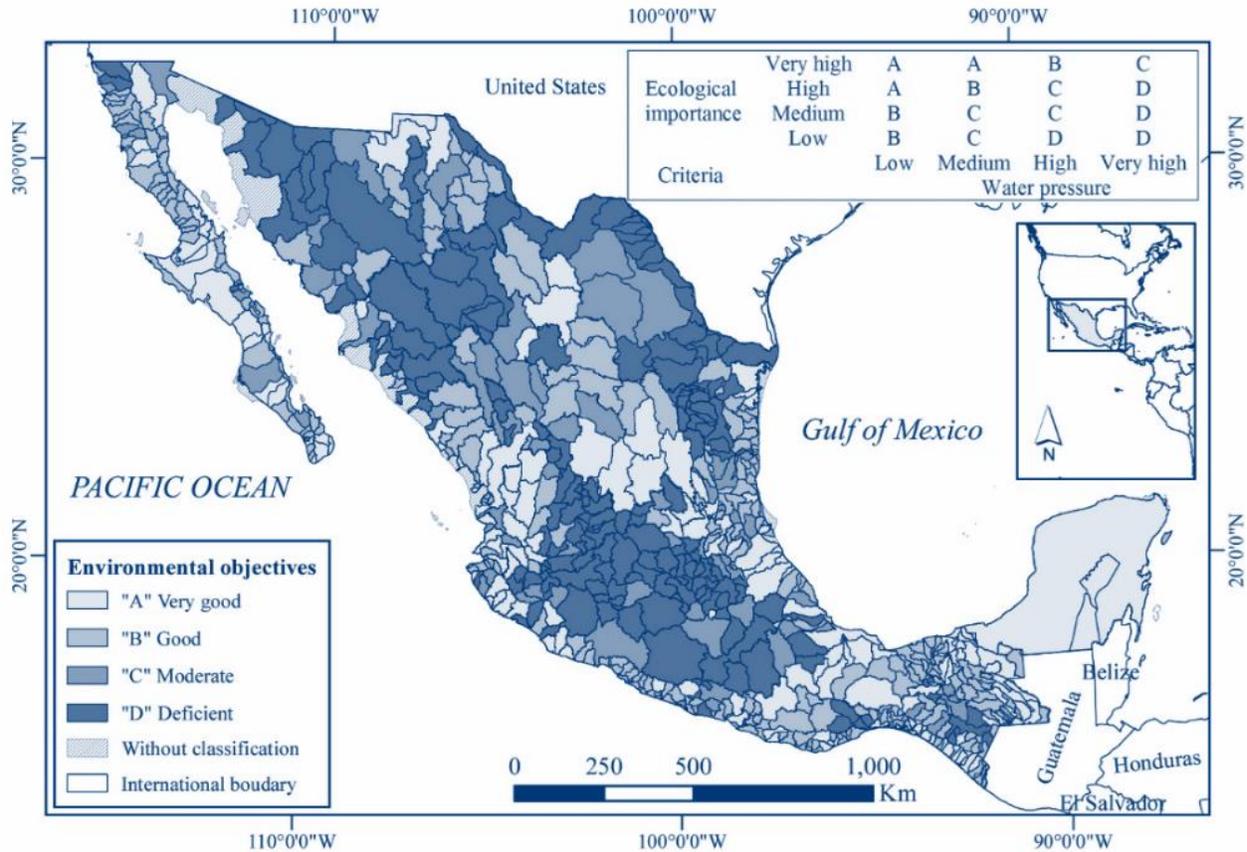


Figure 7 Spatial representation of environmental objectives for 731 basins in Mexico used to guide E-flow implementation at a national level (Salinas et al, in press)

SUMMARY OF KEY RESOURCES

- Cross-Border Project Balances Human, Ecosystem Water Needs in East Africa
<https://www.usaid.gov/global-waters/september-2010/cross-border-project> (Global Waters Link no longer works)
- Risk, Vulnerability & Resilience in the Limpopo River Basin
<https://www.usaid.gov/sites/default/files/documents/1860/Risk%20Vulnerability%20and%20Resilience%20in%20the%20Limpopo%20River%20Basin%20-%20A%20Synthesis%20%281%29.pdf>
- Environmental Flows in Rufiji River Basin Assessed from the Perspective of Planned Development in Kilombero and Lower Rufiji Sub-Basins
http://pdf.usaid.gov/pdf_docs/PA00MKK4.pdf
- The assessment of environmental flows for the rivers and streams of Georgia methodology
http://pdf.usaid.gov/pdf_docs/PA00MRW1.pdf
- Environmental flows in water resources policies, plans, and projects: findings and recommendations. Hirji, R., and Davis, R. World Bank Publications, 2009.
- Mosepele, Ketlhatlogile, et al. "Fish, floods, and ecosystem engineers: aquatic conservation in the Okavango Delta, Botswana." *BioScience* 59.1 (2009): 53-64.
- ADB. Bagmati river basin improvement project. Project Administration Manual. Oct. 2013.



CONCLUSIONS AND NEXT STEPS

- E-flows form the foundation for healthy rivers, lakes, wetlands and estuaries
- The ecosystem services these waters provide underpin economies, cultures and livelihoods
- Achieving many SDGs requires preservation of freshwater flow regimes
- E-flows can help communities prepare for and adapt to climate change
- E-flows are an important building block for water security
- A wealth of information about E-flows is available in the academic literature and from the many agencies and organizations that implement E-flows activities



REFERENCES

- Acreman, M. C., and Michael J. Dunbar. "Defining environmental river flow requirements? A review." *Hydrology and Earth System Sciences Discussions* 8.5 (2004): 861-876.
- ADB. 2013. E-flow to improve habitat and dilute wastewater in the Bagmati River, Nepal. <https://www.adb.org/sites/default/files/project-document/77118/43448-013-nep-eia.pdf>
- Arthington, Angela H., et al. "The challenge of providing environmental flow rules to sustain river ecosystems." *Ecological Applications* 16.4 (2006): 1311-1318. Annear, 2003
- Arthington, Angela H., et al. *Comparative evaluation of environmental flow assessment techniques: review of methods*. Canberra: Land and Water Resources Research and Development Corporation, 1998.
- Barrios Ordóñez, J. Eugenio, et al. *Programa Nacional de Reservas de Agua en México: experiencias de caudal ecológico y la asignación de agua al ambiente*. Inter-American Development Bank, 2015.
- Bunn, Stuart E., and Angela H. Arthington. "Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity." *Environmental management* 30.4 (2002): 492-507.
- Collings, M.R. 1974. 'Generalisation of spawning and rearing discharges for several Pacific salmon species in western Washington', USGS Open File Report. 39 pp.
- Doyle, Martin W., et al. "Effective discharge analysis of ecological processes in streams." *Water Resources Research* 41.11 (2005).
- Dunbar, M.J., Acreman, M.C., Gustard, A. and Elliott, C.R.N. 1998. *Overseas Approaches of Setting River Flow Objectives. Phase 1 Report to the Environment Agency. Environment Agency R&D Technical Report W6-161*. 82pp.
- Dyson, Megan, Ger Bergkamp, and John Scanlon. "Flow: the essentials of environmental flows." IUCN, Gland, Switzerland and Cambridge, UK (2003): 20-87.
- Edmond, J., Sorto, C., Davidson, S., Sauer, J., Warner, D., Dettman, M. and Platt, J. 2013. *Freshwater Conservation and WASH Integration Guidelines: A Framework for Implementation in sub-Saharan Africa*. Washington, D.C., USA: Africa Biodiversity Collaborative Group, Conservation International, and The Nature Conservancy
- Forslund, Anna, et al. "Securing water for ecosystems and human well-being: The importance of environmental flows." *Swedish Water House Report* 24 (2009).
- Gippel, C. J. "Australia's environmental flow initiative: Filling some knowledge gaps and exposing others." *Water Science and Technology* 43.9 (2001): 73-88.
- Gopal, Brij. "A conceptual framework for environmental flows assessment based on ecosystem services and their economic valuation." *Ecosystem Services* 21 (2016): 53-58.
- Hirji, R. and Davis, R. *Environmental flows in water resources policies, plans, and projects: findings and recommendations*. World Bank Publications, 2009.
- King J., Cambray J.A. & Impson N.D. (1998) Linked effects of dam-released floods and water temperature on spawning of the Clanwilliam yellowfish *Barbus capensis*. *Hydrobiologia*, 384, 245–265.
- Millennium Ecosystem Assessment – *Ecosystems and Human Well-being*. 2005.



Molle, François, and Philippus Wester, eds. River basin trajectories: societies, environments and development. No. 8. IWMI, 2009.

Mosepele, K., et al. 2009. Fish, floods, and ecosystem engineers: aquatic conservation in the Okavango Delta, Botswana. *BioScience* 59.1. 53-64.

Poff N.L., Allan J.D., Bain M.B., Karr J.R., Prestegard K.L., Richter B.D., Sparks R.E. & Stromberg J.C. (1997) The natural flow regime: a paradigm for river conservation and restoration. *BioScience*, 47, 769–784.

Prewitt, C.G. and Carlson, C.A. 1977. 'Evaluation of four instream flow methodologies used on the Yampa and White Rivers, Colorado', Report to US Fisheries and Wildlife Service, Colorado State University. p. 96.

Resh V.H., Brown A.V., Covich A.P., Gurtz M.E., Li H.W., Minshall G.W., Reice S.R., Sheldon A.L., Wallace J.B. & Wissmar R. (1988) The role of disturbance in stream ecology. *Journal of the North American Benthological Society*, 7, 433–455.

Schelle, P., and J. Pittock. "Restoring the Kafue Flats: A partnership approach to environmental flows in Zambia." Eighth International River Symposium, Brisbane, Australia. 2005.

Stalnaker, C. B., and J. L. Arnette. "Methodologies for determining instream flows for fish and other aquatic life." Methodologies for the determination of stream resource flow requirements. Report FWS/OBS-76-03. US Fish and Wildlife Service, Washington, DC (1976): 89-138.

Tharme RE. 1996. Review of International Methodologies for the Quantification of the Instream Flow Requirements of Rivers. Water law review final report for policy development for the Department of Water Affairs and Forestry, Pretoria. Freshwater Research Unit, University of Cape Town, South Africa.

Tharme, Rebecca E. "A global perspective on environmental flow assessment: emerging trends in the development and application of environmental flow methodologies for rivers." *River research and applications* 19.5-6 (2003): 397-441.

Transforming our world: the 2030 Agenda for Sustainable Development

<https://sustainabledevelopment.un.org/>

USAID. 2010. Cross-Border Project Balances Human, Ecosystem Water Needs in East Africa <https://www.usaid.gov/global-waters/september-2010/cross-border-project> (Global Waters Link no longer works)

USAID. 2012. Trans-boundary Water for Biodiversity and Human Health in the Mara River Basin PROJECT SUMMARY REPORT October 1, 2005 – September 30, 2012.

http://pdf.usaid.gov/pdf_docs/PA00HVKZ.pdf

USAID. 2014a. Wami River Basin, Tanzania. Environmental Flow Assessment Phase II.

http://www.tzdp.org.tz/fileadmin/documents/dpg_internal/dpg_working_groups_clusters/cluster_2/water/WSDP/WRM - Component 1/WamiRiverBasinEFA_Aug18_FINAL.pdf

USAID. 2014b. Environmental Flow Recommendations for the Ruvu River Basin, Tanzania.

<http://dpanther.fiu.edu/sobek/content/FI/14/10/31/37/00001/RuvuRiverBasinEFA.pdf>

USAID. 2015. Risk, Vulnerability & Resilience in the Limpopo River Basin

<https://www.usaid.gov/sites/default/files/documents/1860/Risk%20Vulnerability%20and%20Resilience%20in%20the%20Limpopo%20River%20Basin%20-%20A%20Synthesis%20%281%29.pdf>



USAID. 2016. Environmental Flows in Rufiji River Basin Assessed from the Perspective of Planned Development in Kilombero and Lower Rufiji Sub-Basins

http://pdf.usaid.gov/pdf_docs/PA00MKK4.pdf

USAID. 2017. The assessment of environmental flows for the rivers and streams of Georgia methodology

http://pdf.usaid.gov/pdf_docs/PA00MRW1.pdf

USAID SWP Water Security guidance. TBD.

World Bank. 2009. Fisheries in Tonle Sap Lake, Cambodia. Hijri, R. and Davis, R.

<https://openknowledge.worldbank.org/handle/10986/18381>