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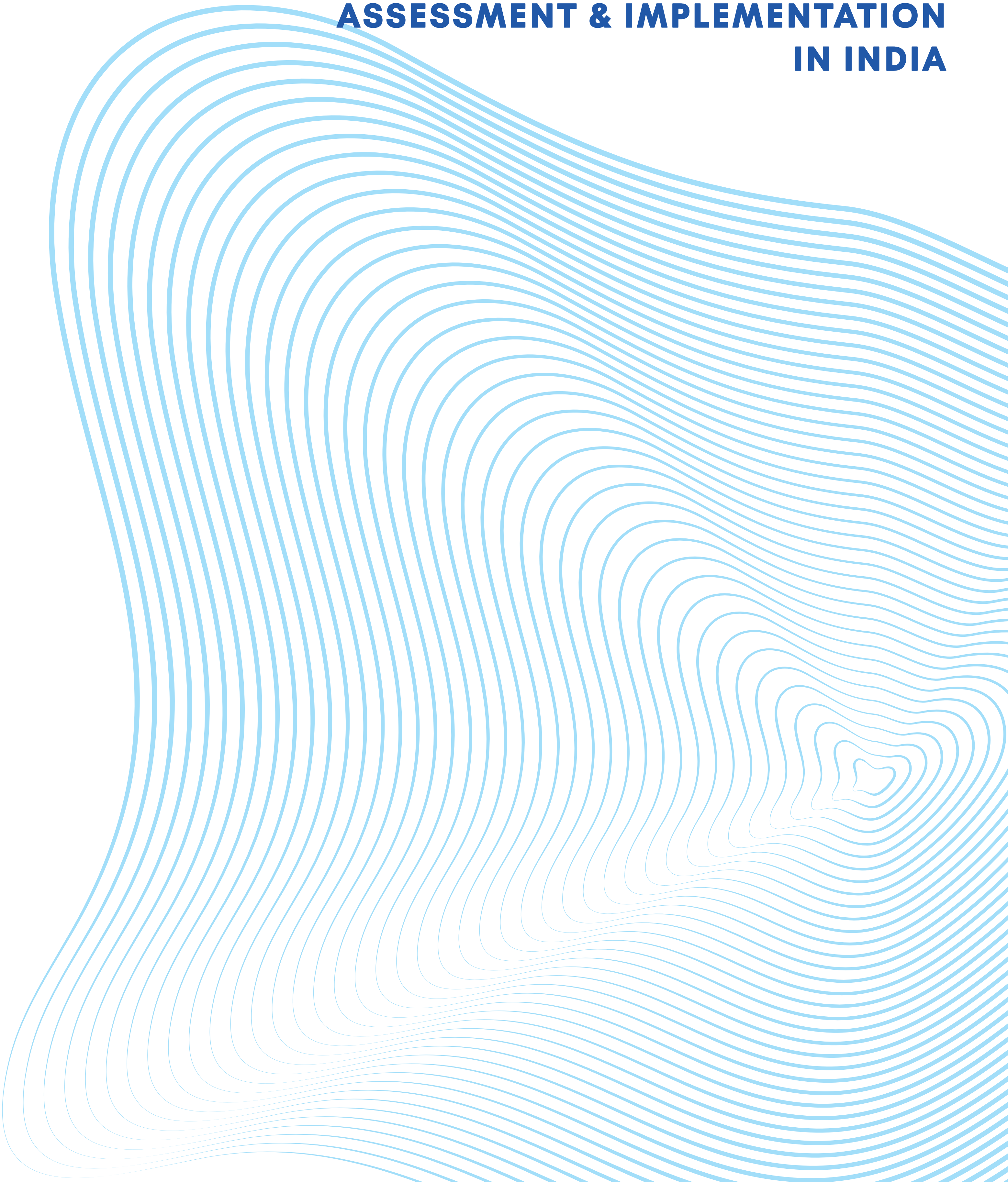

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ABBREVIATIONS

AMBER	Adaptive Management of Barriers in European Rivers
BBM	Building Block Methodology
BiOp	Biological Opinion
CIFRI	Central Inland Fisheries Research Institute (ICAR-CIFRI)
cumecs	Cubic Meters Per Second
CWC	Central Water Commission
DRIFT	Downstream Response to Imposed Flow Transformation
EAC	Expert Appraisal Committee
E-Flows	Environmental Flows
ELOHA	Ecological Limits of Hydrological Alteration
EMC	Environmental Management Class
ESA	Endangered Species Act
eSWIS	E-Surface Water Information System
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FCMacHT	Fish Community Macrohabitat types
FDC	Flow Duration Curve
GEFC	Global Environmental Flow Calculator
GIZ	The Deutsche Gesellschaft für Internationale Zusammenarbeit
HEP	Hydro-Electric Project
HMU	Hydro-Morphological Unit
HSC	Habitat Suitability Criteria
IEWP	India-EU Water Partnership
IHA	Indicators of Hydrologic Alteration
MoEF&CC	Ministry of Environment, Forest and Climate Change
MoJS	Ministry of Jal Shakti
MoWR	Ministry of Water Resources
NGT	National Green Tribunal
NMCG	National Mission for Clean Ganga
NIH	National Institute of Hydrology (Roorkee)
PHABSIM	Physical Habitat Simulation
PMU	Project Management Unit
POF	Percent of Flow
PR	Priority Area
RBMP	River Basin Management Plan
RBO	River Basin Organizations
RVA	Range of Variability Approach
SRTM	Shuttle Radar Topographic Mission
SGR	Support to Ganga Rejuvenation
UCUT	Uniform Continuous Under Threshold
WFD	Water Framework Directive
WII	Wildlife Institute of India
WQAA	Water Quality Assessment Authority
WSL	Water Surface Level
WUA	Weighted Usable Area
WWF	World-Wide Fund for Nature (India)

01

INTRODUCTION

Chilika Lake, Odisha

1.1 Background

Water is an essential natural resource that sustains human life and enables social prosperity and economic growth, and as economic growth and social prosperity advance, the demand for this resource increases. Population growth, coupled with rapid urbanization and industrialization, require more and especially multi-purposed utilization of water (Steffen et al., 2015). Consequently, rivers and their ecosystems come under immense pressure due to storage, diversion and abstraction of water for human uses (Shumilova et al., 2018).

Since earliest times, Indian society has been intensively involved in agriculture, and continues so today. However, most of the country's rainfall occurs during the monsoon season, which extends from June to September. Up to 80% of the total annual river runoff occurs within these four months (Soni and Shekhar, 2013; IWMI,2004). In order to use these water volumes more evenly throughout the year for agricultural and other purposes, historical water resources development targeted the storage and diversion of river flows. For example, one prominent irrigation project is the Upper Ganga Canal system. Completed in 1854, this canal system in Western Uttar Pradesh was one of the world's largest irrigation systems at the time, and the development of many more of such systems followed in the last century. Aside from irrigation channels, many storage reservoirs have been created to regulate river flows to safeguard the water needs of all stakeholders, such as farmers, particularly during the lean season that extends usually from November to May. Nowadays in India, agriculture accounts for around 80% of the entire consumptive water abstractions (CWC-MoWR, 2014). All stages of food production, starting from irrigation to final processing, require water and energy. In order to secure this water-food-energy nexus (FAO,2014; Rasul, 2015) in India, the number of megaprojects is rising. Water is also diverted for domestic and industrial uses. Furthermore, water is diverted from many rivers for hydropower production (non-consumptive use). In comparison to irrigation dams, which are widespread throughout India (WCD, 2000), the number of hydropower dams in the country is still low but is expected to increase in the next decades as India expands its energy generation capacity, especially renewable energies (Thomas, 2017; Hydropower Policy, 2008).

These anthropogenic interventions for development and water security are prone to have adverse effects on the ecological health and integrity of river systems. Dams, barrages, and their associated reservoirs lead to changes in natural river flows, thereby affecting plants and animals and the people that depend on them. During the dry season, discharges in rivers are mainly base flows originating from hydrologically connected aquifers. The uncontrolled abstraction of groundwater, which lowers the groundwater table, has in many cases further reduced base flows. Return flows to rivers (if existing at all) may carry a heavy load of fertilizers, pesticides, etc., from agricultural land. In addition, uncontrolled discharge of industrial effluents and domestic wastes diminish water quality in many riverine ecosystems throughout India, which may have negative impacts on fauna, flora and the human population.

In short, freshwater ecosystems and especially rivers are under pressure (Tickner et al., 2020). So far, we have exploited river basins for various uses, mostly without considering the water requirements of the living systems themselves. Therefore, it is critical to balance the requirements of various human uses and ecological needs in a river system from a basin-wide perspective. In this regard, river flows, so-called "environmental flows" or just "E-Flows" of a certain quantity, timing, and quality are needed ***"to retain the integrity and resilience of riverine ecosystems inclusive of all their related components (river, floodplain, groundwater) as well as associated ecosystem"*** (Hayes et al., 2018). Another recent definition specifies the objectives of E-Flows ***"to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems"*** (Arthington et al., 2018). The International Union for Conservation of Nature (IUCN, 2003) defines ***"E-Flows as the water regime provided within a river, wetland or coastal zone to maintain ecosystems and their benefits where there are competing water uses and where flows are regulated".*** The Indian Institute of Technology Consortium that worked on the development of the Ganga River Basin Management Plan, suggested the E-Flows definition that includes the functions of the river systems apart from providing basic ecological services. It states that ***"E-Flows are a regime of flow in a river or stream that describes the temporal and spatial variation in quantity and quality of water required for freshwater as well as estuarine systems to perform their natural ecological functions (including sediment transport) and support the spiritual, cultural and livelihood activities that depend on these ecosystems"*** (GRBMP, 2011).

1.2 Provisions in the National Water Policy and Current Practices

E-Flows must ensure river health and should be capable of sustaining the full range of goods and services provided by riverine ecosystems. This aspect has been duly recognized in the National Water Policy (2012), the Ganga River Basin Management Plan (GRBMP, 2011) and The River Ganga Authorities Order 2016 (MoWR, 2016).

The National Water Policy (2012) recognized the ecological needs of riverine ecosystems. In the Preamble of the policy, it is stated that ***"water is essential for sustenance of eco-system, and therefore, minimum ecological needs should be given due consideration".*** Clause 3.3 specifies that ***"a portion of river flows should be kept aside to meet ecological needs ensuring that the low and high releases are proportional to the natural flow regime, including base flow contribution in the low flow season through regulated ground water uses".*** Section 8.4 states that ***"environmental needs of aquatic ecosystem, wetlands and embanked flood plains need to be recognized and taken into consideration while planning".***

The Ganga River Basin Management Plan (IIT – Indian Institutes of Technology, 2011) and The River Ganga Authorities Order of 2016 underline the urgency of maintaining ecological flows in the River Ganga.

An environmental management plan is an integral part of any water resources development project in a country. In India, an Expert Appraisal Committee (EAC) for River Valley and Hydroelectric Projects, constituted by the Ministry of Environment, Forest and Climate Change (MoEF&CC), examines the project (planning) reports and recommends the required E-Flows in the affected river reach. Cumulative Impact Assessment studies are also suggested for some river basins.

The National Green Tribunal (NGT) order of August 2017 specified that for all rivers in the country a minimum 15 % to 20% of the average lean season flow of that river shall be maintained.The Ganga E-Flows Notification of 2018 (amended in Sept 2019) is so far the strongest E-Flows implementation action, demanding and specifying the continuous release and monitoring of E-Flows from the Upper Ganga until the middle/lower reaches at Unnao, Uttar Pradesh (NMCG, 2018). Central Water Commission (CWC) is responsible for the supervision and monitoring of E-Flows.

As such, the current policy and practices duly emphasize the assessment and provision of E-Flows in river reaches affected by storage, diversion or abstraction of river water. However, due to various reasons summarized below in Chapter 1.3, it remains challenging to assess E-Flows requirements rationally, particularly in over exploited basins.

1.3 Key Challenges Regarding Environmental Flows

Defining Management Objectives for Environmental Flows

In India, demand for water is ever increasing due to the rapid population growth, urbanization and industrialization. Rivers being the main source of fresh water, the abstraction of water from rivers has considerably increased. About 80% of the consumptive water is used for irrigation to ensure the food security of the large population in India. For water allocated to domestic needs, energy generation, and agriculture, etc., management objectives are clear and the consequences of not meeting them are easily understood by water users and sectors. But what comprises essential and legitimate environmental needs still remains a question. River ecosystems, like human systems, may exist across a range of conditions from healthy and thriving to poor and degraded. Increasing levels of human intervention are correlated with increasing levels of degradation, so what condition (or level of health) should be set as objective of E-Flows allocations? Environmental flows may also support additional instream values and services, such as recreation, bathing, and other spiritual practices. It should be clear if these functions should also be considered in environment flow allocations.

In the European Union, the Water Framework Directive (WFD; European Commission, 2000)sets a common goal across all EU member states of maintaining or achieving a “good ecological status” in all water bodies (rivers, lakes transitional- and coastal waters as well as in ground waters). The definition of good ecological status allows for low levels of distortion in biological quality elements (which are fish, benthic macroinvertebrates, macroalgae and phytoplankton), but these distortions may only deviate “slightly” from natural conditions. The meaning and means of measuring subjective terms like “slightly” have been addressed through inter-calibration exercises among countries.

Environmental flows are understood to be necessary in meeting the goal of a good ecological status in European river reaches affected by water diversion/ abstraction. In fact, the definition of E-Flows (termed ecological flows) applied in the context of the WFD is ***“a hydrological regime consistent with the achievement of the environmental objectives of the WFD in natural surface water bodies as mentioned in Article 4(1)”***. The objectives set in Article 4(1) of the WFD are i) non-deterioration of the existing status, ii) achievement of good ecological status in natural surface water body, and iii) compliance with standards and objectives for protected areas. Moreover, Article 4(3) defines heavily modified water bodies (HMWB), natural or artificial bodies of water which, as a result of physical alterations by human activity, are substantially changed in character and cannot, therefore, meet “good ecological status”, but “good ecological potential” instead, which is the best ecology that can be achieved in a water body whilst still enabling uses such as water abstraction, hydropower and flood protection. The establishment of such specific environmental objectives and linking E-Flows to those objectives has helped to clarify E-Flows science and practice in Europe. However, such stringent environmental objectives are currently challenging to be achieved in India and would need to be adapted to the country’s hydrometeorological variability, socio-economic conditions and water demand including agriculture.

In India, the issue of E-Flows has been deliberated widely for the past 10-15 years. The broad thinking that has emerged so far is that the flows required for the sustenance of biotic life should be maintained. A clear ecological target state (e.g. target/key species, organism-based multi-metric index, overall ecological status etc.) is needed to decide how much flows to allocate.

Also, more water than a minimum should be released to maintain ecological functioning and integrity, as it adds more socio-economic value to the society. However, as of now, there is little (quantitative) understanding about the socio-economic benefits of river ecosystems and their services as well as related impacts linked to E-Flows. Therefore, it is necessary to (1) understand and highlight the ecological and socio-economic implications of water abstraction and flow releases, and (2) to determine which socio-economic benefits should especially be targeted to assess the required E-Flows regime. Without such a quantitative understanding, it is difficult to visualize the importance of allocation and maintenance of these scarce water resources for ecosystem integrity and thus human well-being.

Lack of Standardisation in Assessment and Availability of Data

Several studies have been carried out over the past years in India, suggesting required minimum flows for the maintenance of ecological integrity of rivers, particularly in Himalayan rivers (Rajvanshi et al. 2012; AHEC-IITR 2012, also see Section 2.3). These studies show wide variations in assessment techniques and recommended E-Flows. Also, there is a lack of both the understanding and the availability of data on flow-ecology relationships. For proper application in E-Flows assessments, knowledge of habitat needs of indicator or target species should be embedded in frameworks that take into consideration a broader scope of processes and objectives. This should include those linked to river geomorphology, water quality, and particular ecosystem services benefiting communities using or living near the rivers. In Europe, this broader context is generally provided by the Water Framework Directive and related European and National regulations and management structures.

Both, governmental and non-governmental organizations in India, such as the Central Inland Fisheries Research Institute (CIFRI), the Wildlife Institute of India (WII), the National Bureau of Fish Genetic Research (NBFGR) and the World Wide Fund for Nature-India (WWF India)assessed ecological data and hydro-ecological links in the past, in the context of their individual objectives and mandates. Nale et al. (2017) also emphasized that the studies incorporating knowledge of river hydrology and hydrodynamic transport phenomena coupled with a knowledge of ecological preferences of indigenous species can provide robust and more realistic solutions in Indian context.

However, a framework and strategy for such data collection and integrated assessments is still widely lacking. The recent data collection mainly focuses on certain species, their life history traits, population dynamics and conservation measures, etc. Information on flows/water level dependencies of various species during distinct life-stages are rarely reported, making it difficult to draw meaningful flow-ecology relationships. Furthermore, also other relevant data such as the effects of dams/reservoirs on fish migration and population dynamics are not consistently reported. Also, not many studies or data are available on the socio-economic values of ecosystem services provided by rivers ***vis-à-vis*** other competing users like irrigation, hydropower, industry, households and others.

Therefore, similar to the extensive gathering of hydro-meteorological data, which need to be done at the river basin scale, it is necessary to (1) assess ecological data in multiple (impacted and non-impacted) sites throughout the basin, (2) link the data to river flows in order to draw meaningful conclusions on flow-ecology relationships, and (3) make data publicly available. Also, there is a strong and urgent need to standardize the assessment methods - at least based on various hydro-climatic zones in India and to develop and maintain a data collection strategy based on identified data requirements.

Lack of Integrated Planning and Management

Limited water resources in India have to cater to water demands of various sectors which often compete with each other. Assessing the demand of each sector rationally and then allocating optimal quantity of water to each sector is extremely challenging. There is a multiplicity of agencies working in the water sector, each having different goals, motivations and dynamics. Most of the large rivers in the country are interstate and water allocations between states have been regulated through Tribunal Awards. Efforts to achieve optimal and sustainable utilization of limited water resources of a basin, duly safeguarding the river ecology, are often neglected if not set aside. The mechanism for integrated water resources planning and for optimal and sustainable management of a river basin is still evolving in the country. Without such an integrated water resources management (IWRM) mechanism in place for each river basin backed by a sound institutional framework, balancing the development of water use and environmental needs of ecosystems will always be a challenge. It is highly important to develop such mechanism based on existing best-practices in India and elsewhere and to adapt and improve that with progressive and integrative solutions in the future.

Over Exploited River Reaches/Basins

India is an agrarian society with nearly 60 % of its population dependent on agriculture. Considering the monsoonal nature of rainfall, where annual rainfall is limited to a period of 3-4 months, the support of irrigation to agriculture is very critical for food security of the country. In some arid and semi-arid regions, where, on average, less than 50 rainy days are counted every year (Kumar and Jain, 2011; Dash et al., 2009), the availability of water is especially critical. Hence, drought proofing and livelihood support of the vast population are one of the country's top priorities.

The focus on water for agriculture has led to the overexploitation of many river reaches and entire river basins, in particular the peninsular ones. In the Himalayan region, the impact can predominantly be seen in some of the river reaches. Further, the Indian government is increasing efforts to extend irrigation coverage, but also aims to improve water use efficiency at the farm level. Recovering environmental flows from other sectors would also be very challenging in the over-exploited river reaches. Finding suitable trade-offs and ensuring that they are embraced by the stakeholders is a key to successful E-Flows implementation in India.

Monitoring Mechanism

Though the willingness for assessing and providing required E-Flows in affected river reaches is already in place, a sound mechanism for regulating and monitoring required E-Flows by an independent agency is not yet in place. As a first of its kind, implementation efforts are being made to monitor the recommended E-Flows in the Upper Ganga Region by NMCG and CWC. Now, there is a strong need to capacitate and strengthen such organizations in technical, administrative and financial aspects, in order to establish a comprehensive monitoring framework. These organizations may have to be identified as custodian/regulatory organizations and need to be backed-up with legal and authoritarian powers. It will also be important to standardize monitoring methods and formulate a mechanism for monitoring including time plans, etc.

1.4 Objectives and Structure of this Guidance Document

This guidance document has been developed for all stakeholders involved in the processes of E-Flows assessment, their notifications and implementation in India. This guidance shall help Indian researchers and the scientific communities, decision makers, implementing authorities and other important stakeholders like hydropower and irrigation facilities to understand the science and administration of E-Flows along with their roles in achieving E-Flows objectives. The specific objectives of this document are:

- To provide an overview on the background and current status of E-Flows assessments in India, as well as of methods and data used.
- To suggest how assessments can be improved by outlining steps to enhance data collection (specifically ecological data) and the use of more robust methods.
- To provide a standardized and most appropriate methodology/methodologies based on actual assessment experiences and lessons learnt under the pilot assessments.
- To present key benefits and a Road Map of a gradual advancement of E-Flows assessment in India within the next few years towards full strategic planning and management.
- To outline key points for the long-term implementation of E-Flows in India.

Chapter 1 provides the background of the process leading to this guidance, including provisions in the Indian National Water Policy and other legislations (for example, pertaining to Ganga River Basin) within current practice. Additionally, it reviews the key challenges regarding E-Flows, which are not only limited to India but are being faced by countries around the world.

Chapter 2 goes into additional depth regarding available international assessment methodologies, complemented by the description of four case studies of E-Flows assessments and implementation in the Annex. It also examines the background and experiences of E-Flows assessments in India.

Chapter 3 presents the current Indian method of the E-Flows assessment along with details on each step.

Chapter 4 presents the necessary steps for advancing methods in India. It introduces the so-called E-Flows Pyramid, a hierarchical concept for method selection by assigning the dimension of the problems to the available methods. After this introduction, Chapter 4 presents first staging actions and preparatory work needed to advance individual E-Flows assessments. These include defining the objectives of the E-Flows assessment, selection of a suitable method, and development of a comprehensive data framework for the long-term E-Flows assessments in the country. As a core element, Chapter 4 also describes the recommended habitat analysis methodologies step-by-step. This begins with the establishment of biological targets, indicators and criteria. Next, representative and critical reaches must be identified, and a schedule determined. Field and historical data are then collected and fed into the possible habitat suitability models, resulting in quantitative recommendations for E-Flows during different periods of the year.

Chapter 5 presents benefits and a Road Map for a gradual adaptation of the current E-Flows assessment method over the next few years to enable comprehensive strategic planning.

Chapter 6 concludes the guidance by laying out a longer-term perspective for implementing and adapting E-Flows assessment methodologies and taking necessary steps towards nation-wide implementation.

02

INTERNATIONAL EXPERIENCE IN THE ASSESSMENT OF E-FLOWS

Kolhu River, Uttarakhand

2.1 Available Methods for E-Flows Assessment

International experience in the assessment, provision, and implementation of E-Flows dates back more than 60 years. The first detailed E-Flows assessments began in the late 1940's in the western USA and included multi-objective assessments of the flow requirements to maintain river ecosystems as well as the economic benefits derived from them (USFWS 1951).Over subsequent decades and to the present day, major advances in E-Flows have occurred in countries with similar hydro-climatic conditions to India and similar water management challenges. These include the semi-arid western mountain States of the USA, Australia, South Africa, and the Mediterranean countries of Europe. In fact, it is the combination of strongly seasonal climate, abundant built infrastructure, large water demands, and measurably degraded river ecosystems that stimulated and propelled the advancements in E-Flows science and practice. Consequently, there is much for India to learn from these international experiences and to apply when developing its own custom guidelines.

Current best practice strategies and methodologies for E-Flows assessment around the world fall into two main groups: top-down and bottom-up. Top-down approaches address E-Flows objectives through statistical analyses of the natural hydrograph informed by ecological knowledge to preserve ecologically relevant components of the natural flow regime. Bottom-up approaches address E-Flows objectives through systematic steps and procedures to design reach-scale hydrographs based on empirical and expert knowledge of ecosystem flow requirements. Both approaches include methods applicable in data-rich and data-poor conditions and at various spatial scales, and both approaches provide recommendations that can be applied in the operation of water infrastructure or the restriction of water withdrawals in basin scale water allocation.

2.1.1 Top-Down Approaches

Top-down approaches are classified as range-of-variability (RVA) or percent-of-flow (POF) methodologies. They are conceptually based on the natural flow paradigm, which holds that ***"the full range of natural intra-and inter-annual variation in hydrologic regimes, and associated characteristics of timing, duration, frequency, and rate of change, are critical in sustaining the full native biodiversity and integrity of aquatic ecosystems"*** (Poff et al. 1997). The RVA-method (Richter et al. 1997) is an example of this approach making use of the free software-Indicators of Hydrologic Alteration, which is used to quantify the ecologically relevant components of natural flow regimes and the degree to which natural flow regimes are altered in regulated rivers. RVA is intended for application in rivers where protection of native biodiversity and ecosystem functions are primary management objectives. E-Flows are recommended to preserve the full range of hydrological variability within ranges determined to minimize the risk of ecological degradation. This approach has subsequently been embedded in a holistic framework for ecologically sustainable water management that takes account of multiple water use needs (Richter et al. 2003).

In addition to basing E-Flows recommendations on the long-term natural variability of river flow regimes, a POF approach has also been proposed based on real-time daily to weekly natural flow variability either measured in free-flowing reaches upstream of infrastructure or simulated using rainfall-runoff models (Mierau et al., 2018). Applying this approach calls for maintaining downstream flows within a band of variability (a sustainability boundary) around the baseline condition, which is the naturalized flow (Figure1). This approach has also been proposed as a presumptive standard for application in ecologically important river reaches where detailed E-Flows assessments cannot or will not be made in the near future (Richter et al. 2012). RVA and POF approaches have seen limited implementation in water and infrastructure management around the world but are being tested by the US Army Corps of Engineers in the operation of its dams.

Other top-down POF approaches such as the Tennant Method (Tennant 1976), Modified Tennant Method (Tessman 1980), Flow Duration Curve method (Annear et al. 2004), and various low-flow statistical indices like Q95 and 7Q10 are still widely applied around the world but are not considered best practice as they may have limited applicability outside the geographic and hydro-climatic settings in which they were developed or they do not give required attention to the multiple flow levels needed to meet ecological objectives.

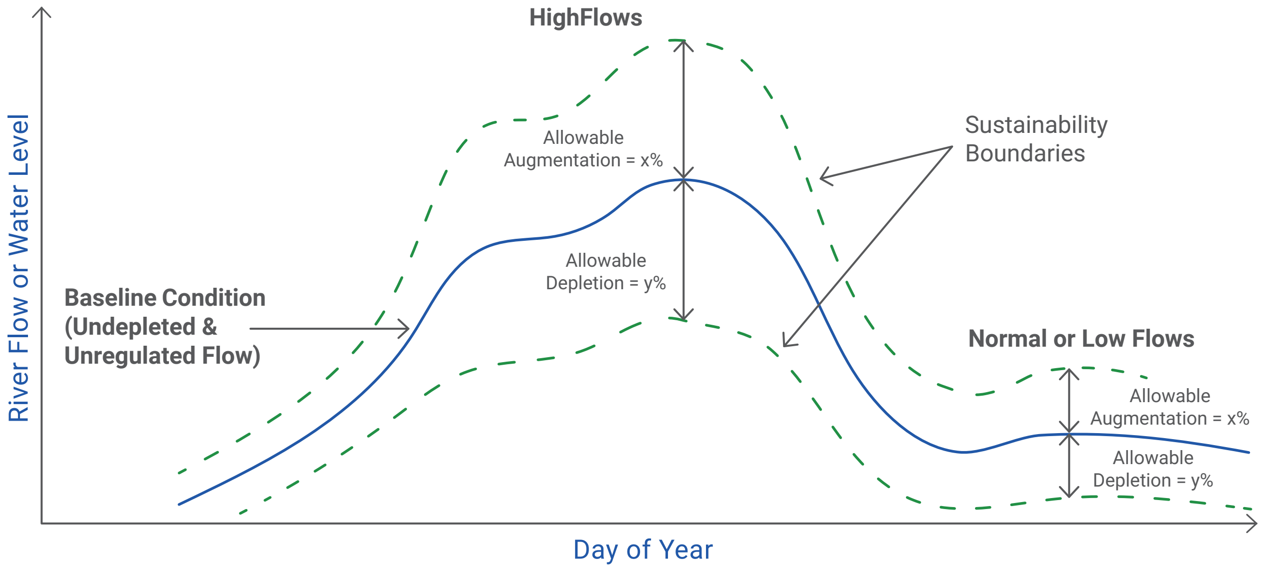


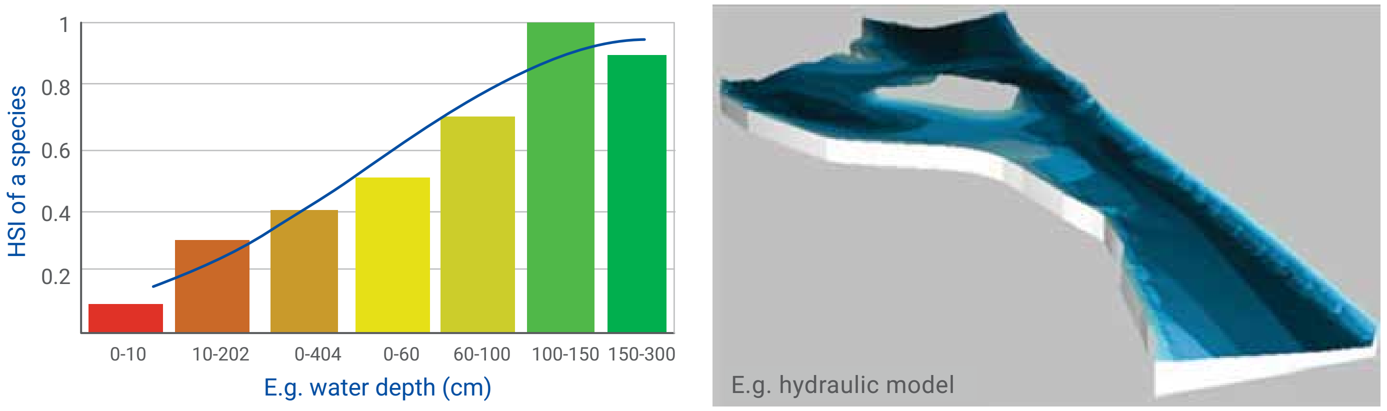
Figure 1. Illustration of the percent of flow approach with sustainability boundaries (Richter et al. 2012).

2.1.2 Bottom-Up Approaches

Best practice bottom-up approaches apply a range of methodologies in structured frameworks to quantify the individual components (e.g. base flows, floods etc.) of a river flow regime necessary to meet specific environmental, social, and economic objectives. They are conceptually based on the designer paradigm, which accepts that significant change in natural flow regimes is inevitable to meet the multiple objectives of water and river management and holds that E-Flows regimes can be 'designed' to meet set objectives (Acreman et al. 2014). Bottom-up approaches provide for the greatest level of water resource use by other sectors (energy, agriculture, domestic, etc.) while still meeting E-Flows-related objectives, but their application requires significant knowledge (empirical or expert) of the relationships between flow components and ecological, geomorphic, and biogeochemical processes.

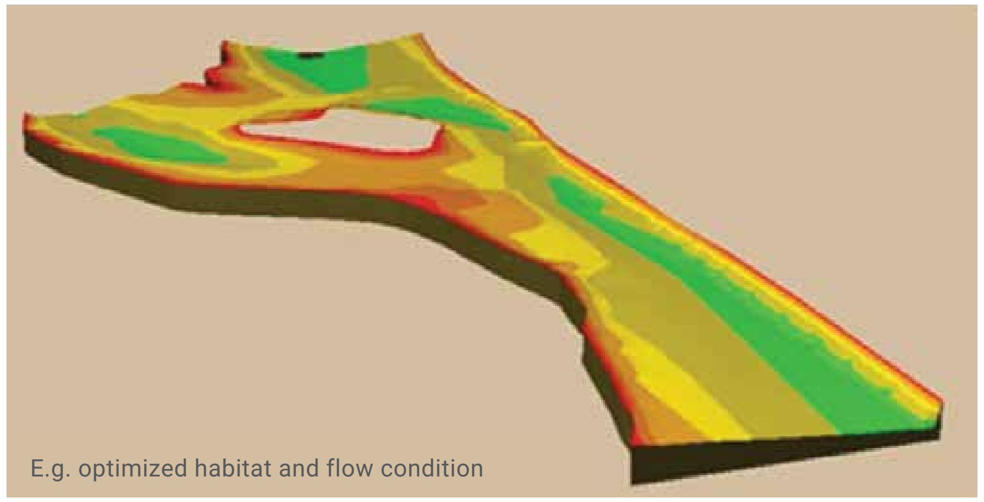
At the heart of bottom-up approaches is the determination of habitat requirements of indicator and target species and the quantification of flows supporting and providing these habitats. For fish, aquatic insects, mussels, crustaceans, and plants, the main micro-habitat variables examined tend to be water depth, velocity, substrate (river-bed grain size) and cover (shading of riparian vegetation and shelter within the river from large woody debris, etc.). For these variables, habitat requirements are defined in terms of Habitat Suitability Criteria (HSC) curves that assign the suitability ranging from zero (non-suitability) to one (optimal) to these variables (Figure 2 shows the HSC curve for Depth variable). Micro-habitat needs are also defined for different life stages and seasons in life history (Hudson et al., 2003; Milhous and Waddle, 2012). Habitats are also commonly delineated at a meso-scale composed of river geomorphic units such as riffles, pools, glides, etc. (Schwartz, 2016). Relationships between habitat variables and its suitability to indicator or target species may be simulated and expressed in the form of Habitat Suitability Criteria (HSC) mapped in one, two, or three dimensions in stream and river reaches (Figure 2). Most applied software for micro-habitat suitability simulation is Physical Habitat Simulation (PHABSIM) developed in the USA as part of Instream Flow Incremental Methodology - IFIM (Waddle 2001). Other models developed on the similar lines include RHABSIM developed in USA, RYHABSIM developed in New Zealand, EVHA developed in France, RSS developed in Norway etc. (Payne and Jowett, 2013). Habitat assessment models like River-2D and CCHE-2D involve 2D hydrodynamic modelling to establish the flow and hydraulic parameter relationships. For mesoscale simulation of habitat suitability, the MesoHABSIM (Parasiewicz 2001, 2007a&b, 2008a&b), Mesohabitat Evaluation Model (MEM)-(Hauer et al. 2008); MesoCASiMiR (Eisner et al. 2005); Norwegian Mesohabitat Classification Method (NMCM) (Borsanyi 2005), etc. are available. Application of each of these approaches requires detailed knowledge of habitat preferences of species living in the rivers under study, and detailed application of these approaches has been concentrated in North America and Europe.

With rapidly growing data acquisition and analytical technology, habitat models (e.g. MesoHABSIM) are applied in broader context of determining E-Flows for entire regions and for entire aquatic communities also taking into account seasonal and life stage variability (see Case Study 4). The widely applied of bottom-up approaches is the Building Block Methodology (BBM) (King et al. 2008), which is also an effective structure for the incorporation of expert knowledge in more data scarce regions. The BBM provides a structure and systematic series of steps to collect, analyze, and synthesize a wide range of data and information needed to construct and implement a modified river E-Flows regime. The approach has been used for approximately 20 years and adapted to local conditions in river basins around the world.



Habitat suitability criteria

Hydro-morphological description



Habitat evaluation

Figure 2. Illustration of habitat suitability criteria- combined with relevant variables (Source: Melcher et al. 2018)

The BBM considers stages in the process of developing, negotiating, and implementing E-Flows in water management programs. The core of the approach, and that applied most widely internationally, is the set of tasks leading to the formulation of E-Flows recommendations. The tasks include assembling a multidisciplinary team of specialists, assessing the current status of the system, selecting appropriate study sites, carrying out detailed assessments (including habitat simulation if feasible and appropriate), defining environmental and social objectives and recommending the E-Flows regime to meet the defined objectives. The level of social and ecological objectives is generally linked to some classification of river condition, ranging from less to more altered. In a European context the classifications generally refer to levels of river condition specified in the EU Water Framework Directive; other classification systems apply outside of Europe.

The constructed E-Flows regime consists of multiple flow components referred to as building blocks. The exact definition of the building blocks may vary depending on the system assessed, but common building blocks include wet and dry season low flows during normal years, wet and dry season low flows during drought years, and floods of differing magnitudes intended for specific purposes such as channel maintenance, habitat maintenance, spawning cues, etc. (Figure 3). The BBM approach generally calls for also assessing the E-Flows related to river classes above and below the target class. These scenarios are tied to greater or lesser levels of exploitation of the water resource. More elaborate scenarios of water resource use and E-Flows protection may be developed using the Downstream Response to Imposed Flow Transformation (DRIFT) (King et al. 2003; King and Brown 2006), which utilizes the outputs of the assessment phase of BBM.

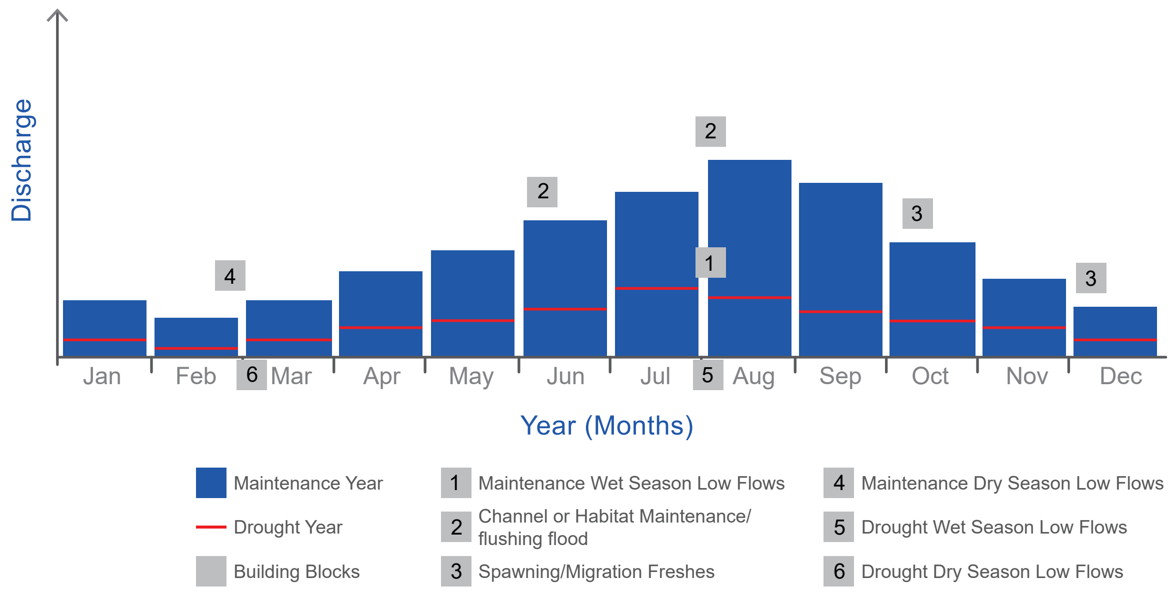


Figure 3. Schematic illustration - A generic flow regime considered in the BBM (USAID-2018).

2.1.3 Strengths and Weaknesses of the Methods

The advantage of top-down RVA and POF approaches is that they are based on the natural (or naturalized) hydrograph and can therefore be applied in their simplest form rapidly and with hydrologic data alone. The level of confidence in applying RVA and POF approaches is highest when flow regimes and bed morphology are near natural conditions. An important weakness is that the underlying biological information is based on qualitative estimates and is therefore imprecise. Hence, as flow regimes and hydro-morphology are increasingly altered the risk of ecological degradation increases and more in-depth knowledge of flow-ecology relationships is required to make reliable recommendations for E-Flows regimes meeting environmental management objectives. Thus, in more heavily modified systems the knowledge requirements for applying RVA and POF approaches will be close to those necessary to apply bottom-up approaches and the earlier advantages (less time and data intensiveness) will be lost. Moreover, RVA calls for basing recommendations on discharge records extending over at least 20-30 years, which limits their applicability in poorly gauged regions. In contrast, POF can be applied using real time measured or simulated naturalized flow.

Bottom-up, habitat suitability approaches like PHABSIM, CASiMiR, and MesoHABSIM have the potential to provide high confidence E-Flows recommendations by establishing quantitative relationships between flow, river morphology and biological response. A particular strength of habitat models is that they take into account channel alterations, which have substantial influence on habitat availability. However, they require extensive fieldwork by specialized scientists to acquire quantitative knowledge of the habitat preferences of aquatic biota across multiple life stages and variable flow levels (seasonally and inter-annually). Where they have been applied successfully over larger regions, they are based on data from long-term and in-depth research efforts and technological advancements. Their application in less studied systems, especially those composed of species significantly different from North America and Europe, is limited and the transfer of knowledge from more studied areas must be verified and supported by monitoring and additional research.

It has to be recognized, though, that physical habitat models are particularly precise in determination of low flow thresholds. Defining other flow components is not what they were designed for. Still these models are excellent complement of holistic frameworks such as BBM or ELOHA.

Application of the full scope of holistic frameworks such as BBM are time and resource intensive, requiring a team of specialists and a minimum of six months to one year of effort. The frameworks like BBM are also flexible and may be adapted and streamlined somewhat to local needs and conditions. An advantage of frameworks like BBM is that empirical and expert knowledge can be used in tandem to fill all required information needs. Moreover, fieldwork carried out as part of the process generates much of the essential information needed. The facilitated, workshop-based approach of BBM also allows for consensus to be built among participating specialists and associated information to be leveraged. Other holistic frameworks such as the Savanna Process (Richter et al. 2006) share similar characteristics.

2.1.4 Applicability at Regional Scales

All approaches vary in their conceptual approaches and the cost, level of technical expertise, and data required to apply them (Zeiringer et al 2018). Consequently, they will vary in their suitability for application in different conditions. Majority are limited to reach scale in their spatial applicability.

Petts (2009) recognized that estimating E-Flows requirements is challenging and requires understanding of direct and indirect interactions between flows and river biota and considerations of different time and space scales. There is a seemingly a tradeoff between the applicability at regional scale and accuracy. This can be avoided by creating a rigorous framework for transferring the information across the scales, specifically with regard to biological response. Arthington et al. (2006) proposed an approach of classifying rivers into groups based on their hydrological regime and using those groups to compare frequency distributions from modified stream flows to reference streams. This allows the development of a flow-response relationship based on the ecological data from reference and modified streams included in the same group (Arthington et al. 2006). The authors also suggest applying this method region-by-region and country-by-country to achieve global E-Flows guidelines. This approach is considered to be the precursor of the ELOHA framework (Linnansaari et al. 2013, Poff et al. 2010, 2017). PROBFLO (O'Brien et al. 2018) is another basin/regional scale methodology created to provide a holistic framework where above the technique can be incorporated.

An alternative approach to hydrological classes is to group rivers based on their habitat and fish community characteristics that it supports, a prime example of such an approach developed for entire Laurentian Great Lakes basin is presented by McKenna et al.(2006, 2011) and Steen et al. (2008). This approach has been adopted and modified during development of a concept of E-Flows for Poland. Instead of proposing hydrological classification of the streams, Parasiewicz et al. (2018) proposed to cluster the rivers based on their macrohabitat characteristics derived from expected fish species abundances and estimated hydromorphic characteristics of already delineated water bodies.

The above approach was adopted during the International EU-funded research project AMBER (Adaptive Management of Barriers in European Rivers – **http://amber.international**), where water bodies in entire Europe were classified into 15 Fish Community Macrohabitat types setting the stage for a continent-wide adoption of the Polish approach (Figure 4).

The applicability of such methods at regional scales in India requires better understanding of habitat and fish diversity within and among river basins. Recent initiatives such as the envisaged development of a "National Habitat Atlas" will be the foundation of a nation-wide data base for E-Flows methodologies. However, this still requires substantial research efforts.

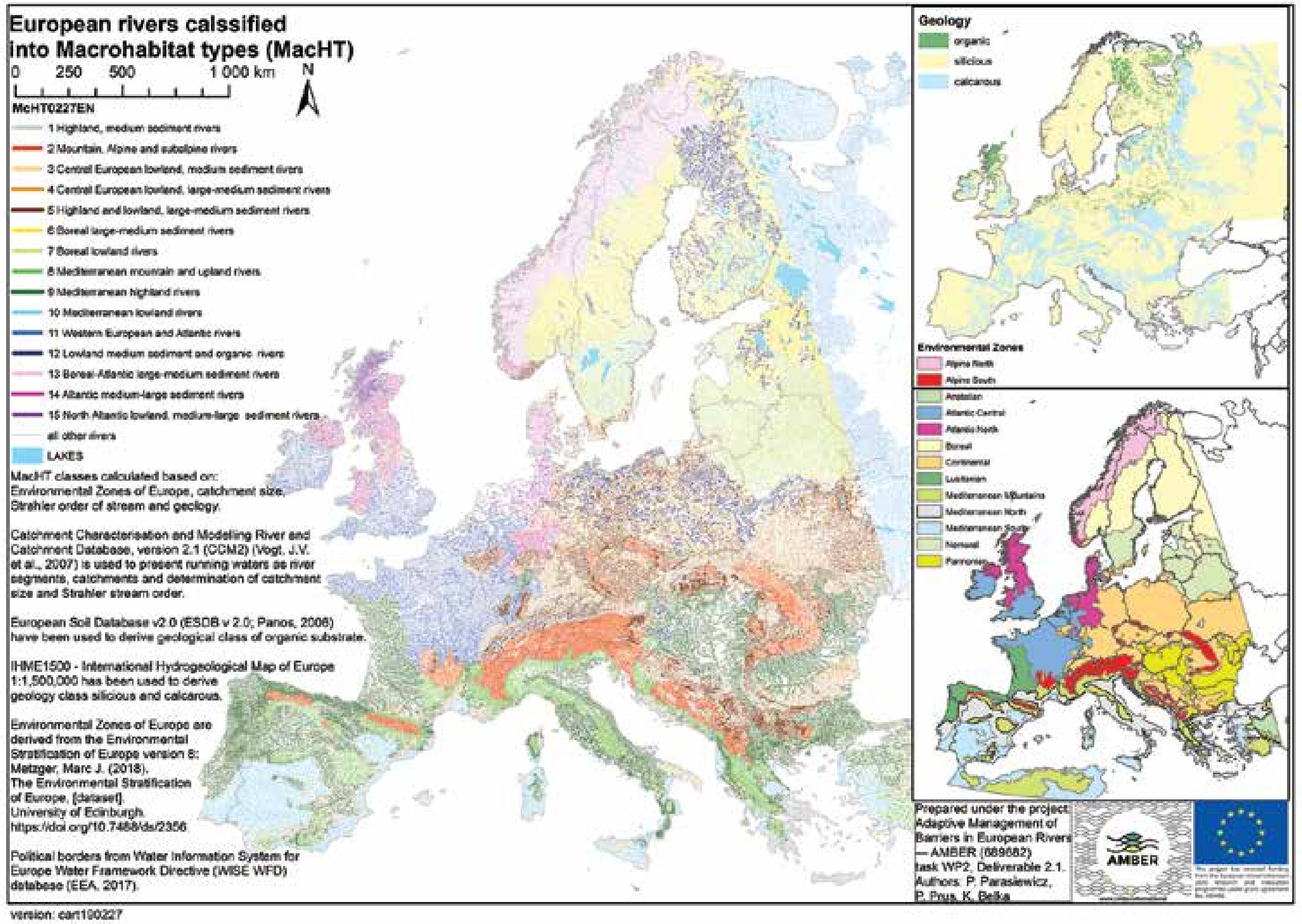


Figure 4. European rivers classified into 15 Fish Community Macrohabitat types (FCMacHT) (AMBER D2.1, version 2.0).

The annex of this document presents a few detailed case studies on the E-Flows assessments undertaken in different countries using different assessment methods. The success stories of implementation and monitoring of these suggested E-Flows have also been reported.

2.2 Background and Experience Regarding E-Flows Assessment in India

The environmental water needs of rivers have been duly recognized in the development and management of water resources in India. This has been clearly spelled out in the National Water Policy of 2012. In the past, attempts have been made from time to time to provide E-Flows in rivers to maintain river health in a reasonable state. Until early 2000, the concept of assessing E-Flows requirements was almost non-existent in the planning and design of water resources projects and the focus was on the utilization of the available potential. A provision of 5-10% of the minimum flow in lean season was considered to be a sufficient E-Flows.

The first initiative on E-Flows was taken by the Government of Himachal Pradesh when they issued a circular during the year 2005 making 10% of minimum lean season flow as a mandatory E-Flows release (This was increased to 15% of average lean season flow in the year 2009).

Also, in 2005, a Working Group was constituted by the Water Quality Assessment Authority (WQAA) to advise on the minimum flows in rivers. Advice is provided for Himalayan and other rivers separately. (1) For Himalayan rivers (a) the minimum flow must not be less than 2.5% of the 75% time dependable (equaled or exceeded) annual flow. (b) One flushing flow is required during the monsoon period, with a peak flow of not less than 250% of the 75% dependable annual flow. (2) For all other rivers, (a) the minimum flow in any 10-day period must not be less than the observed 10-day flow, with 99% exceedance. Where 10-day flow data are not available, this may be taken as 0.5% of the 75% dependable annual flow (b) One flushing flow is required during the monsoon period with a peak flow of not less than 600% of the 75% dependable annual flow (CWC 2007).

During the years 2008-2009, the Expert Appraisal Committee (EAC) for River Valley and Hydropower Projects, Ministry of Environment and Forest, and the Government of India started to emphasize the need for E-Flows releases downstream of diversion structures. The EAC recommended 20% of average lean season discharge (4 leanest months) in a 90% dependable year to be released as E-Flows and since 2008-09 this has almost become the norm during the planning of hydropower projects. This norm was adopted, and a fixed E-Flows was considered to be released throughout the year – irrespective of the inflows or natural dynamics.

During the next 2-3 years, the concept was developed further requiring site specific studies and focus was also shifted to varied E-Flows releases during the year. The lean season E-Flows requirement was kept as 20% of average flow of four leanest months in a 90% dependable year, but the E-Flows requirement for the monsoon season (4 months) was set as 30% of inflows in a 90% dependable year, and the E-Flows requirement for other months i.e. pre-monsoon and post monsoon period was set as 20-30% of inflows in a 90% dependable.

Among the first site/region specific E-Flows assessment studies are the part of cumulative impact assessments done by Alternate Hydro Energy Centre-IIT Roorkee (AHEC-IIR 2012) and WII (Rajvanshi et al 2012) for the Upper Ganga Basin. Both the studies provided seasonal E-Flows suggestions based on different methods ranging from hydrological, hydraulic (mean depth) approaches to ecology-based assessments.

Another important study is from WWF-India in the form of an Upper Ganga report (O'Keeffe et al. 2012) which involved multi-stakeholder engagement. This report provides an outline of the typical thought process, and items to consider, for a team of practitioners setting an E-Flows assessment. It states that to initiate the E-Flows assessment, practitioners need to decide the level of detail and define the methodology to use, which depends on factors like urgency of the problem (which may call for using a fast method), data availability, resources, importance of the river, current and future river use, complexity of the river system, difficulty of implementation, etc. Similarly, they cover the process of selecting study sites, for example, recommending that criteria for site selection could include accessibility, habitat diversity, habitat sensitivity to flow change, suitability for hydraulic and hydrological measurement/modelling, proximity to flow gauging site, etc.

E-Flows assessment studies as a part of the Ganga River Basin Management Plan (GRBMP 2015) involved assessments of minimum flow requirements based on 'flow depths over a riffle' criteria for Upper Ganga Region. Flow depths corresponding to three different types of ecological functions (Figure 5) were identified based on keystone fish species requirements. D1 was identified as 0.5m and D2 was 0.8 m. D3 corresponds to average virgin flows having 20% dependability during monsoons. The E-Flows for non-monsoon season were obtained by mimicking the trend of annual variation of 90% dependable flow using the minimum ecological requirement for non-monsoon season. For the monsoon season, the 90% dependable flow variation was mimicked by first deducting the flows corresponding to D3 and then adding the deducted values on the mimicked hydrograph.

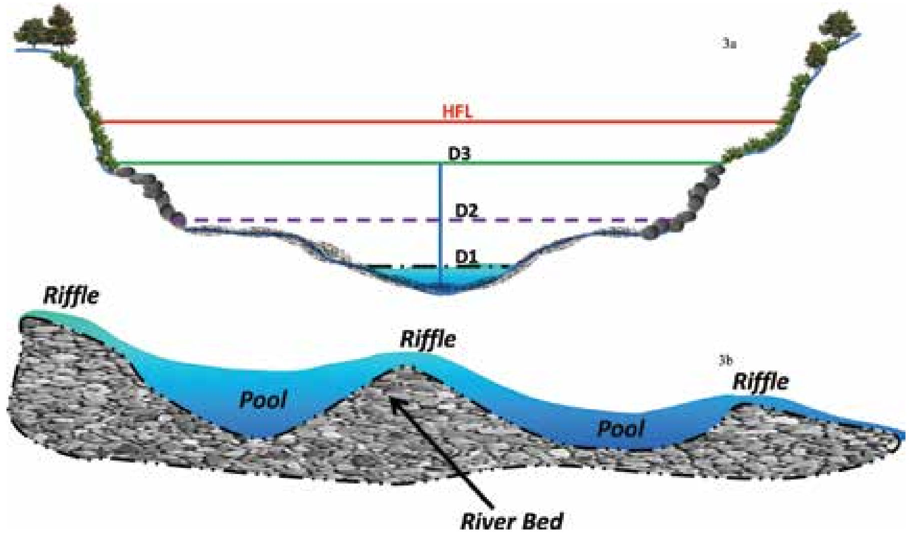


Figure 5. Flow depths corresponding to three different types of ecological functions (GRBMP 2015).

Nale (2018) carried out E-Flows assessments for the Ganga River Basin in her Ph.D. work, integrating ecological concerns within a hydrologic and hydraulic framework. The study followed an interdisciplinary and hierarchical approach involving comparison of (a) hydrologic, (b) hydraulic and (c) habitat analysis methods in order to arrive at E-Flows. In acknowledgement of the scale of spatial and temporal heterogeneity, the basin was spatially divided into 24 sub-systems. For each sub-system, flow ranges corresponding to minimal scale of anthropogenic interventions (unregulated) to the currently prevailing status (present) have been used to assess the performance of various globally prevalent hydrological indices/methods. It was demonstrated that these approaches fail to suggest reasonable E-Flows scenarios, especially for all rainfed tributaries of Ganga, where seasonal variations in flows are predominant. For habitat analysis, ecological preferences of five indigenous Ganga species were coupled with hydraulic prospects of various flow ranges at 13 habitat sites in Ganga Basin to establish flow versus habitat relationships for target species. Finally, spatio-temporally diverse hydrology of the basin was linked with the ecological effects to suggest the most desirable and achievable E-Flows regimes corresponding to classes A, B, C and D, respectively, representing 80, 60, 40 and 20% retention of monthly habitat available under unregulated monthly flow regimes (reference habitat). Finally, the current (altered) status of ecological habitat conditions resulting from present Ganga flows was compared with these classes on a monthly scale to present the current ecological health distribution.

CWC and MoEF&CC have adopted a methodology based on a combination of hydraulic analysis with ecological requirements of the representative species (CWC 2014, MoEF&CC 2016) after perusal of the recommendations of various research studies in India, hydrological characteristics of Indian river and dependence of the society on river water. This methodology, called as "Hydraulic Rating Cum Habitat Simulation Method", has been used by MoEF&CC to estimate the E-Flows releases from river valley projects proposed in Siang, Subansiri, Lohit, Dibang, and Tawang basins, etc. The Expert Appraisal Committee of the MoEF&CC also recommends use of this method by the projects for E-Flows assessments during the development of the project plans. In Upper Ganga sub- basin, E-Flows estimated by CWC using this method have been implemented by NMCG through the October 2018 (amended in Sept 2019) notification and CWC is monitoring its implementation and compliance by various projects in the basin. Detailed overview of this methodology along with steps followed for data collection, modelling and development of E-Flows scenarios has been given in Chapter 3.

In addition to this overview of Indian experience with E-Flows, it is valuable to scrutinize the body of published work on this topic. Table 1 lists references and gives summary information on the context and geographical focus of the studies and the type of method/approach used. Additionally, Jain and Kumar (2014) can be referred for the review.

One of the notable aspects of this short review is that there is a variety of approaches and/or methods applied in India, and a variety of reasons why E-Flows studies are carried out (e.g. hydro-electric Project (HEP), dam, climate change, water resources, irrigation, ecosystem services). In this, India echoes what is typically occurring internationally: there is a range of methods/approaches available depending on the context (e.g. data availability) and objectives (e.g. impact of building a dam, impact of future climate change) of the situation in which E-Flows are to be assessed.

Table 1.Selection of published E-Flows studies in India

REFERENCE	STUDY CONTEXT	STUDY AREA	APPROACH/ METHOD	COMMENT
Smakhtin and Anputhas (2006)	National River Linking Project (NRLP)	National with focus on NRLP i.e. transfer of flood water from Ganga, Brahmaputra and Meghna to south & west	EMC/FDC	Course scale of analysis with limited number of sites. E-Flows assessed for Environmental Management Class A (Natural) to F (Critically modified)
DHI (2006)	HEP	Rampur HEP	hydraulic habitat analysis	Not consulted; cited in Jain and Kumar (2014)
Kumar et al. (2007)	HEP	NathpaJhakri HEP	hydraulic habitat analysis	Not consulted; cited in Jain and Kumar (2014)
Jha, et al. (2008)	Research-Comparative assessment	Brahmani and Baitarani	Two approaches (minimum flow and FDC-based)	Evaluation of Methods and estimation of environmental design flow values
Harish Kumara and Srikantaswamy (2011)	Dam/Abstraction-hydrological alteration	Tungabhadra	Tennant method, IHA and Global Environmental Flow Calculator	Hydrological alterations are observed
Nale et al (2013)	HEP - Effects on downstream habitats	Himalayan Case study	PHABSIM-Habitat Modelling	Monthly Effect of Hydropower diversion on snow trout habitats in three life stages.
Soni et al. (2013)	Indirectly related to traditional E-Flows Assessments.	Yamuna River at Delhi	Hydraulic modelling targeting sediment and algal choking	Defines flow required to address sediment & algal issues and assumes that other ecological aspects are addressed
WWF (2013)	2013 Kumbh Mela bathing festival	Triveni Sangam, Allahabad	BBM	Study specific to one event/ (cultural) service
Amarasinghe, Smakhtin et al. (2013)	Irrigation Impacts of E-Flows	Upper Ganga	Agriculture-related benefits forgone by reducing canal irrigation withdrawals	Indirectly relevant to E-Flows
Dubey et al. (2013)	Research-Comparative assessment	Narmada	Lookup Tables, Tennant and Modified Tennant method applied for four gauging sites.	Comparative assessment-Modified Tennant method is found to be preferable.
Abe and James (2013); Abe and Erinjery Joseph (2015)	HEP-hydrological alterations	Periyar and Muvattupuzha	IHA/RVA (historical data)	hydrologic alterations are observed
Joshi, et al. (2014)	Dam/ abstraction	Sone at Indrapuri barrage	Desktop EMC/FDC approach (using GEFC software)	Ecological data analyzed separately -impact of modification based on historical data
Jain (2015)	HEP and probable economic loss due to E-Flows	Himalayan Case study	FDC	Hydrological approach-FDC lowering to estimate loss of power production
Johnson et al (2017)	Habitat Modelling	Godavari River	PHABSIM-Habitat Modelling	Developed Habitat suitability criteria curves for five economically important fishes and used those in E-Flows assessments.

03

CURRENT E-FLOWS ASSESSMENT METHOD USED BY THE INDIAN GOVERNMENTAL SECTOR

Mahanadi River, Odisha

The Hydraulic Habitat cum Habitat Simulation method adopted by CWC and MoEF&CC is based on hydraulic modelling of the selected reach and integration of ecological requirements with these modeling results. The ecological assessments and related expert judgments are provided by aquatic ecology experts (fish and aquatic macroinvertebrates etc.) from WII and CIFRI. The steps involved in E-Flows assessments using this method are described below (Figure 6).

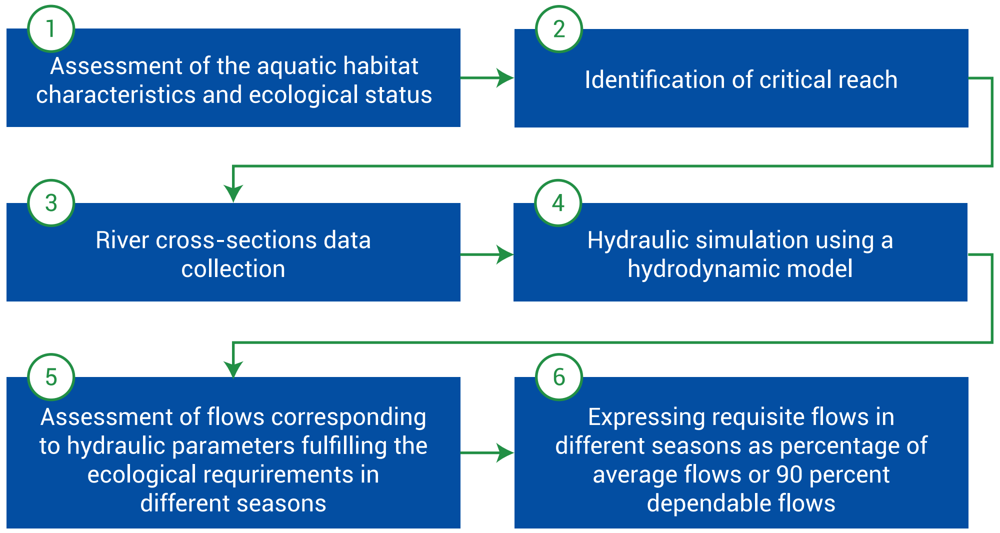


Figure 6. Steps of the Hydraulic Habitat cum Habitat Simulation method adopted by CWC and MoEF&CC.

Step 1:

The first step involves the assessment of the aquatic habitat characteristics and ecological status of the region. This assessment may be carried out by expert agencies such as the WII, CIFRI, etc. A biodiversity survey is necessary to document the baseline ecological status of the region. This survey involves the identification of important aquatic species in the region. Mostly these are fish species of high conservation value, species representative (keystone/indicator) of the region, or species of high socio-economic importance. Based on actual field observations in the study region and expert knowledge on habitat requirements of such species, criteria for E-Flows assessments are defined in the form of hydraulic parameters (for example flow depth, velocity etc.). Experts also determine habitat requirements based on field observations of use of certain hydraulic habitat condition by target fish species in different life stages (Johnson et al 2017). Hydraulic Habitat conditions in which the greatest number of fishes are observed are generally considered as best suitable habitats.

Step 2:

A critical reach is one likely to be impacted by the diversion or impoundment/storage of water due to any project under consideration or operation. In case of a hydropower project, such a critical reach shall be from the point of diversion or dam to the outfall of the tailrace or joining of a downstream tributary. In case of diversions for consumptive uses, like irrigation, the critical reach shall be from the point of diversion or dam until the location where the flow is augmented by a tributary contributing significantly to the river. The concept of selection of critical reach is explained in Figure 7.

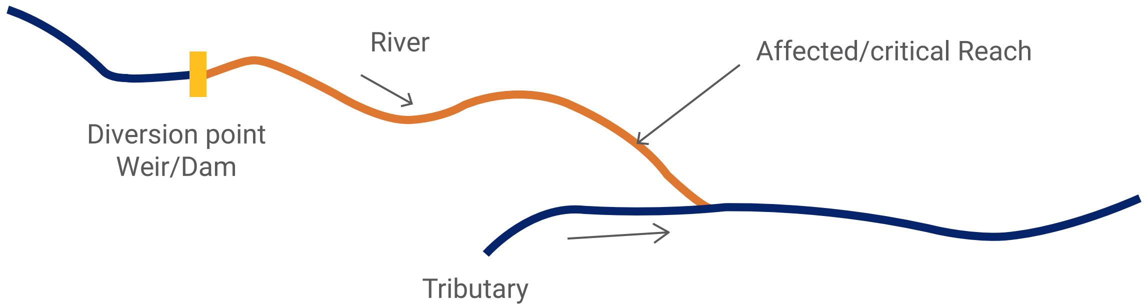


Figure 7. Selection of Critical Reach

Step 3:

Next, river cross-sections are surveyed in the critical reach. This involves surveying four to five cross sections at regular intervals (200–1000 m), depending upon variability in river geomorphology. Sometimes, the nearest hydrological observation site of the CWC is also taken as a reference for the cross-section surveys. The lateral observation points in a cross section are placed at about 5m distance in the bank areas while in the main water channel area, more dense observations are taken to capture the variability in the bed levels. Figure 8 represent the cross-section surveys and actual cross sections of a Ramganga Site.

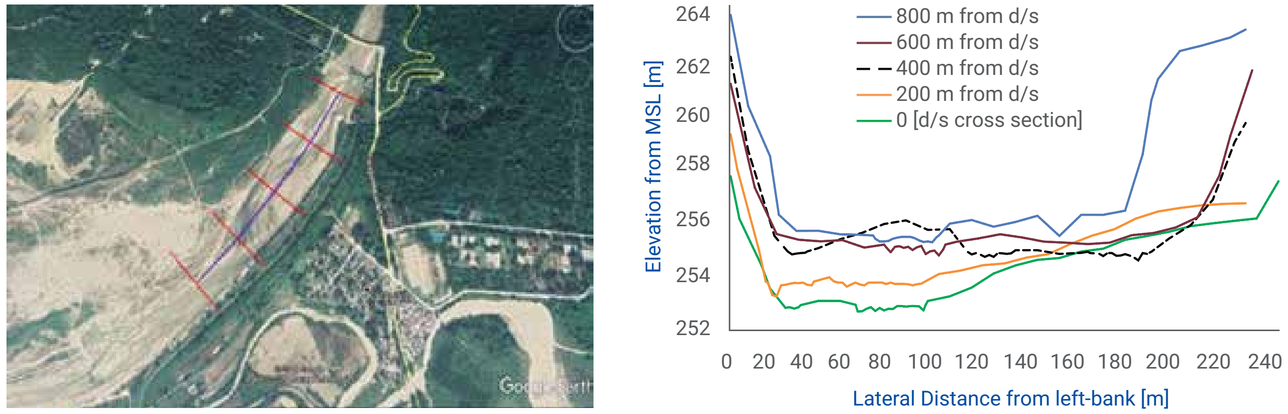


Figure 8. Cross-section surveys (Ramganga Study)

Step 4:

Next, a hydrodynamic model is developed using one-dimensional modeling software such as HEC-RAS or MIKE11. Boundary conditions (e.g., slope) and other model input parameters (e.g., roughness coefficient) are set according to site specific details observed during cross section surveys. Model results are developed in the form of flow versus hydraulic parameter relationships as shown in Figure 9 for water surface elevation

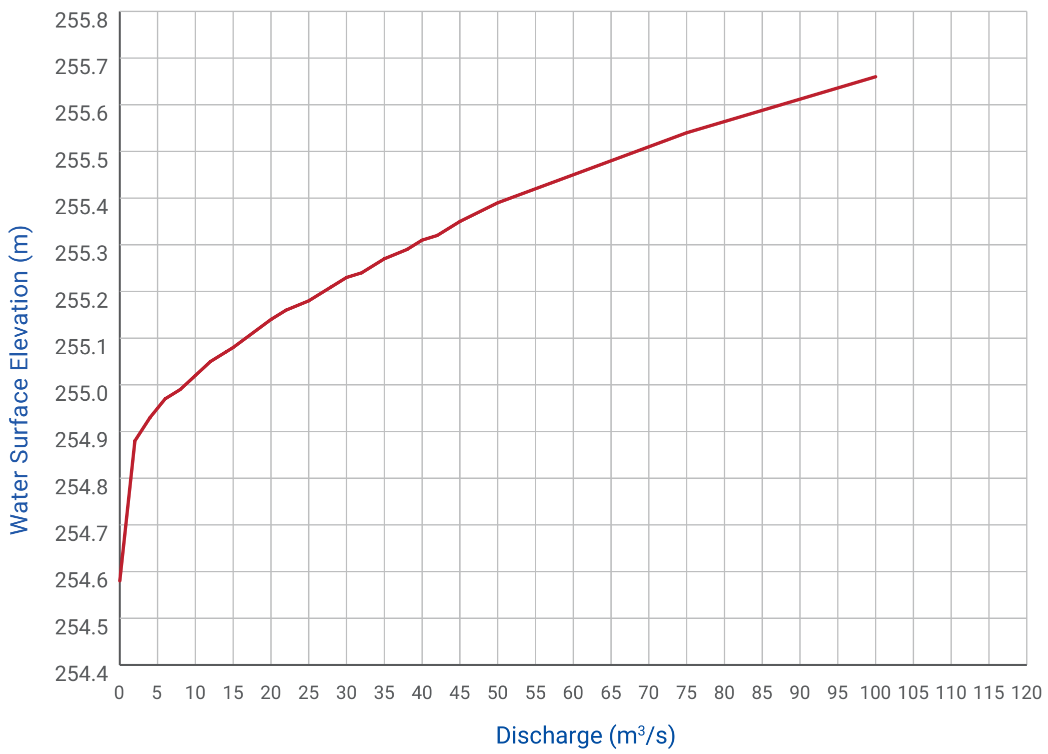


Figure 9. Water level versus flow relationship

The range of flow discharges for which the hydraulic conditions are simulated is selected based on various percentages of average seasonal/ten-day flow observations in the study reach in the 90% dependable year. Generally, simulations may be carried out corresponding to three seasons: high flow period or monsoon season (June to Sep), average flow (Non - monsoon non lean) period (April, May, October and November) and lean or dry period from December to March. For example, in the Lohit Basin study, hydraulic simulations are performed for various percentages of average seasonal flows (in 90% dependable year) in three seasons (M - monsoon season; L - lean season; NMNL - Non-monsoon non lean). The results of hydraulic simulations for these three seasons are shown in below Table 2 (reference MoEF&CC 2016).

Step 5:

In the next step, flows corresponding to hydraulic parameters (e.g., flow depth) fulfilling the ecological requirements in different seasons are identified. For example, in the Lohit Basin study, the following (Table 3) depth requirements were considered, and flows required to attain these depths were assessed.

Table 2. Flow versus hydraulic parameter relationships for various percentages of seasonal flows of 90% dependable year for Kalai HEP stage-I (reference MoEF&CC 2016)

LOCATION	PROFILE	Q TOTAL	DEEPEST BED LEVEL	WATER SURFACE ELEVATION	DEPTH OF FLOW	FLOW AREA	TOP WIDTH
		(m^3/s)	(m)	(m)	(m)	(m^2)	(m)
Kalai-I 50 m D/s of dam axis	M(100%)	772.7	918.32	920.8	2.48	193.17	118.57
	M(30%)	231.8	918.32	919.74	1.42	78.71	90.83
	M(29%)	224.08	918.32	919.72	1.4	76.74	89.86
	M(28%)	216.38	918.32	919.7	1.38	74.8	88.78
	M(27%)	208.63	918.32	919.68	1.36	72.95	87.73
	M(26%)	200.9	918.32	919.65	1.33	70.53	86.33
	M(25%)	193.17	918.32	919.63	1.31	68.62	85.22
	M(24%)	185.45	918.32	919.6	1.28	66.45	83.94
	M(23%)	177.72	918.32	919.57	1.25	64.26	82.62
	M(22%)	169.99	918.32	919.54	1.22	61.76	81.1
	M(21%)	162.27	918.32	919.51	1.19	59.45	79.66
	M(20%)	154.53	918.32	919.49	1.17	57.56	78.46
	L(100%)	233.9	918.32	919.75	1.43	79.36	91.14
	L(20%)	46.8	918.32	919.95	0.63	22.45	51.43
	L(19%)	44.44	918.32	919.93	0.61	21.57	50.57
	L(18%)	42.1	918.32	919.91	0.59	20.62	49.62

LOCATION	PROFILE	Q TOTAL	DEEPEST BED LEVEL	WATER SURFACE ELEVATION	DEPTH OF FLOW	FLOW AREA	TOP WIDTH
		(m^3/s)	(m)	(m)	(m)	(m^2)	(m)
	L(17%)	39.76	918.32	919.9	0.58	19.81	48.79
	L(16%)	37.42	918.32	919.88	0.56	81.83	47.77
	L(15%)	35.1	918.32	919.88	0.54	17.98	46.87
	NMNL1(100%)	566.4	918.32	919.48	2.14	154.32	112.56
	NMNL1(25%)	141.6	918.32	919.44	1.12	53.73	75.98
	NMNL1(24%)	135.94	918.32	919.42	1.1	52.02	74.85
	NMNL1(23%)	130.27	918.32	919.39	1.07	50.11	73.56
	NMNL1(22%)	124.61	918.32	919.37	1.05	48.3	72.32
	NMNL1(21%)	118.94	918.32	919.34	1.02	46.67	71.18
	NMNL1(20%)	113.3	918.32	919.32	1	44.79	89.85
	NMNL2(100%)	390.3	918.32	919.13	1.81	118.27	106.78
	NMNL2(25%)	97.6	918.32	919.25	0.93	39.92	66.27
	NMNL2(24%)	93.67	918.32	919.23	0.91	38.61	65.27
	NMNL2(23%)	89.77	918.32	919.21	0.89	37.34	64.29
	NMNL2(22%)	85.87	918.32	919.19	0.87	36.02	63.26
	NMNL2(21%)	81.96	918.32	919.17	0.85	34.75	62.25
	NMNL2(20%)	78.1	918.32	919.15	0.83	33.48	61.22

Table 3. Seasonal Depth Requirements for Golden Mahseer and Snow Trout

S.NO.	SEASON	DEPTH REQUIREMENT (M)	
		MAHSEER ZONE	TROUT ZONE
1	Monsoon Season	1.2 – 1.4	1.0
2	Lean Season	0.5	0.4
3	Non-Monsoon Non-Lean Season	0.9 – 1.0	0.65 – 0.70

Step 6:

In the final step, for ease of implementation, the assessed E-Flows (requisite discharges for fulfilling the ecological requirements in different seasons) may be expressed as a percentage of average flows of 90% dependable flows in that season. This step is important to represent E-Flows with reference to flow variability in the region rather than defining them as absolute numbers. In case of the Lohit study, E-Flows for three seasons (M- monsoon season; L- lean season; NMNL- Non-monsoon non lean) are suggested as 30, 20 and 25% of average seasonal flow for 90% dependable year respectively. In the case of Upper Ganga basin, it is recommended to calculate E-Flows as suggested percentages (season-wise) of flows observed during the previous ten days.

Though the above approach takes care of assessment of E-Flows requirements in all seasons, it is generally seen that river flows are adequate during monsoon season and ecological needs of the rivers are naturally fulfilled. The issue of E-Flows is critical during the lean period only and thus assessments focus on lean season computations.

04

ADVANCING E-FLOWS ASSESSMENT METHODS IN INDIA

Ramganga River, Uttarakhand

4.1 Guiding the Selection of an Advanced E-Flows Method in India

In order to further develop its water resources without irreversibly degrading its aquatic ecosystems and their services, India must begin using more diversified and advanced methodologies for E-Flows assessment. Science has produced a plethora of E-Flows assessment methods ranging from simple desk-top methods to highly complex and integrative methods (see chapter 2), making it sometimes difficult to select the appropriate methods for specific cases. In general, the choice of method should be related to the dimension of the problem to be solved. The E-Flows Pyramid (Figure 10) represents a hierarchical concept for assigning the dimension of the problems to the appropriate E-Flows methods.

The E-Flows Pyramid consists of ecological and socio-economic criteria assigned to E-Flows methods along continuous gradients from simple/cheap to complex/costly methods. For example, small headwaters represent more “simple” ecosystems compared to large floodplain rivers, the latter requiring multiple biotic indicators and methodologies to fully cover ecosystem complexity. If endangered species are affected, more accurate methods should be applied to ensure long term survival of the species. Ecosystems providing essential services for humans, e.g., fisheries, should receive more attention than others. Furthermore, a small-scale water diversion with local and/or temporal impacts requires less detailed assessments than large dams affecting the flow of a large proportion of a catchment/basin over decades. Indispensable water uses like drinking water may require much more precise methods for optimizing and balancing human uses and E-Flows needs, while less important water uses (e.g., irrigation of golf courses) may be judged based on simple approaches. In cases with multiple competing water uses only very elaborated methods are able to cope with the complex spatio-temporal interactions between users’ demands and ecosystem needs. A key parameter in method selection should be also water scarcity. If more water is available a simpler method for E-Flows settings can be applied, which offers flow safety margins protecting aquatic ecology. The more sophisticated methods allow for precise seasonal or daily flow regulations helping to better manage available resources. The rules may even offer mixed precision depending on the type of flow they address e.g., very low flows are regulated precisely using very accurate data on intra-annual scale, while higher flows are established and operated with simpler rules on inter-annual scale.

Following the E-Flows Pyramid concept supports the selection of cost-efficient methods for case-specific situations by relating E-Flows assessment methods and human/river system requirements.

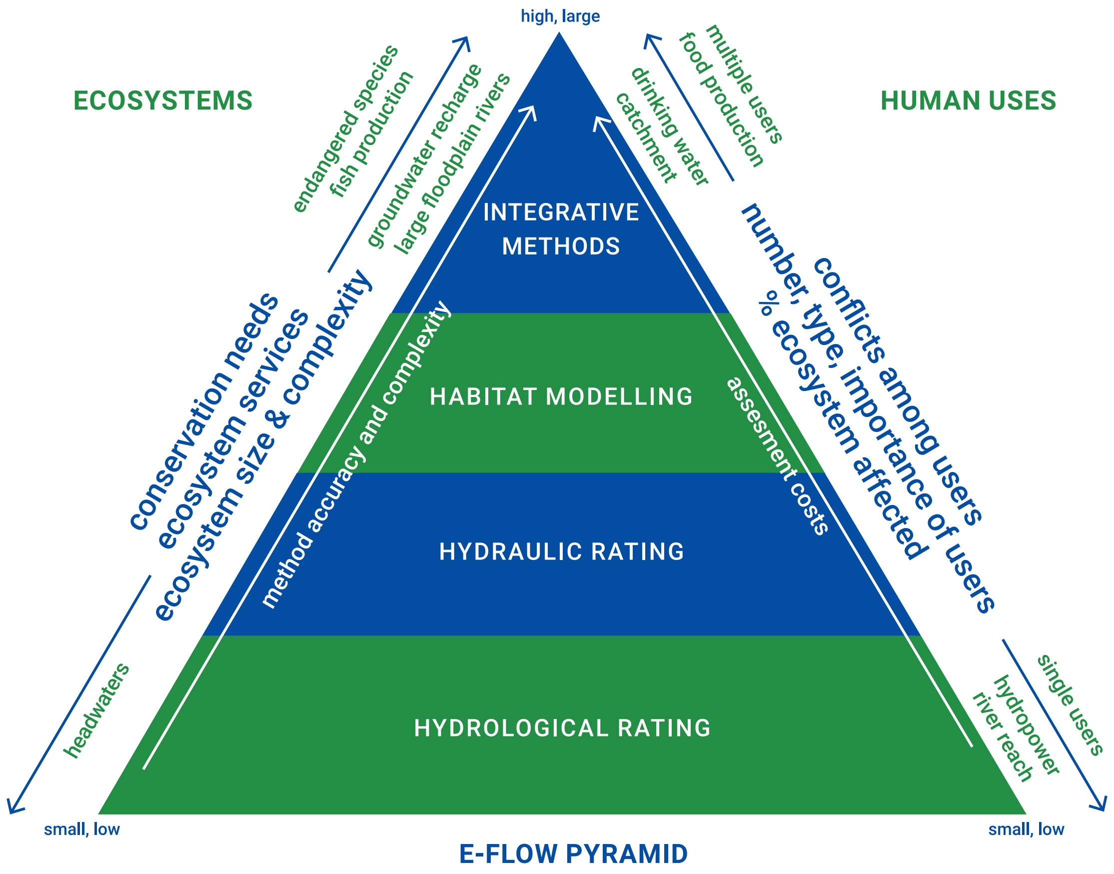


Figure 10. The E-Flows Pyramid guiding the appropriate selection of E-Flows assessment methods

Hydrological and hydraulic rating, as well as habitat modelling, represent the main (bio-) physical E-Flows assessment methods available nowadays. These methods are different in terms of underlying theoretical concept, data requirements, spatial and temporal resolution and involvement of ecological criteria (see Chapter 2.1). According to these criteria they are more or less suitable for covering the complexity of ecosystems and for predicting and optimizing E-Flows. Implementation effort and costs are mainly linked to field data requirements and method complexity (Table 4).

Hydrological rating follows the natural flow paradigm and is solely based on hydrological data. These methods indirectly cover ecological criteria as they are based on the assumption that biota have evolved with the flow regime and the more closely the E-Flows resembles the natural flow regime the less likely the biota are affected. To be properly applied, they require daily records of discharge extending over 20 years or more. The outcome of the methods is a proposed flow regime commonly defined as percentages of the natural flow or other hydrological statistics. The concept is attractive because of its simplicity and relatively low costs but limited in terms of its predictive power to optimize E-Flows. In particular, in socio-economic situations where every drop counts hydrological rating methods lack the theoretical foundation for accurately predicting ecological consequences of different E-Flows scenarios. Hydrological rating methods do not consider the morphology of natural and modified rivers and its consequences for biota. Therefore, these methods are only applied for screening-level assessments or where habitat models have already been established.

Hydraulic rating methods establish a link between the flow and the hydraulic condition in the river. These methods indirectly refer to the habitat as they assume that e.g., deeper water levels or larger wetted width provide more habitat than vice versa. The methods are applied commonly by sampling one or a few river cross sections and linking the morphology to measured or modeled flow conditions. The established flow/water level relationship is used to predict the abiotic conditions of different E-Flows scenarios. If the hydraulic conditions are associated with the habitat requirements of indicator species (e.g., minimum depth for fish migration) a linkage to ecological criteria can be established. However, the ecological relevance of this linkage is limited by the representativeness of the selected cross-sections for the entire available habitat. Hydraulic rating methods do not consider the full variability of the morphology of natural and modified rivers and its consequences for biota. Because of higher costs and still limited ecological relevance, these methods are only applied for screening-level assessments or where habitat models have already been established and can be linked to rating curves.

Habitat models establish a linkage between the flow dependent abiotic habitat conditions and the biotic habitat use. The models assume that the more suitable habitat is available the better the conditions for the biota. Representative habitat conditions (multiple riffle pool sections) are sampled. Besides water depth and flow velocity, other habitat parameters such as substrate and cover are included. The outputs of the models are (weighted) usable habitat areas linked to flow conditions. This enables a very precise prediction of the ecological consequences of different E-Flows scenarios. Habitat models are able to reflect responses of biota to both natural and modified river morphology conditions. While microhabitat models are commonly based on indicator species and sampling multiple cross-sections, mesohabitat models extend the scope to entire communities and organize sampling directly related to mesohabitat types. Especially in cases with very complex habitat conditions, the mesohabitat approach is better able to cover the full diversity of habitats such as (dis) connected side arms and floodplain habitats. Due to the larger habitat units sampled in the mesohabitat approach this method enables cost-efficient E-Flows assessments at larger scales. The effort required makes these methods more expensive, but the higher costs are justified.

Because of the high ecological relevance and predictive power of habitat models these are recommended as standard methods for India, particularly in instances where new (modified) river types have to be assessed or where the pressure of water use is very high.

Currently, E-Flows assessments in India are site/river reach specific. The status of ecosystem services, socio-economic, socio-cultural importance of various river reaches, and the degree of anthropogenic alterations generally define the priority of river reaches selected for E-Flows assessment. With the growing understanding about the importance of hydraulic habitat conditions in rivers, often researchers/agencies involved in the E-Flows assessment undertake physical hydraulic surveys of the selected river reaches (for example CWC 2014; GRBMP 2015). In relation to ecology, the species of high conservation value are widely being studied by ecologists across the country vis-à-vis life-history traits and specific habitat requirements. For example, priority species of the Ganga Basin have been identified by the NMCG and WII (WII-GACMC 2017), and dedicated actions are being undertaken to support conservation of these species, which is believed to restore biodiversity of the Ganga River. **These current developments have already resulted in the availability of initial/surrogate eco-hydraulic data and expertise required to initiate and take forward physical habitat assessments for several river reaches in the country.**

While there has been some development and application of “integrative” E-Flows assessment methods already in India, they are not yet recommended as standard methods. Due to the resource intensiveness of such methods, it may not be currently possible to standardize these methods for broader use in India. When progress is made in the application of ecologically-driven E-Flows assessments methods using the habitat models, other ecosystem functions (such as those fulfilling socio-cultural, economic and livelihood demands and maintaining riverine functions such as sediment transport, floodplain (wetland/ estuarine) connectivity, etc.,) can also be incorporated into E-Flows assessments (as suggested in the latest international definitions of E-Flows) using integrative methods. However, it is advisable to already begin collecting data relevant for application of the integrative methods, when the circumstances allow. Reference to these data needs is made in Table 5.

Based on the recommendation to use habitat modelling for the assessment of E-Flows, the following staging actions and preparatory work related to setting the objectives and development of data framework are suggested for Indian E-Flows science progress.

Table 4.Comparison of E-Flows methods and recommendations for advancing methods in India according to the Road Map (see Chapter 5).

TYPE OF METHOD	PRINCIPLE METHOD	METHOD OUTCOME	DATA TYPE						ECOSYSTEM COMPLEXITY COVERAGE	PREDICTIVE POWER	POTENTIAL FOR E-FLOW OPTIMIZATION	COST	RECOMMENDATIONS
			HYDROLOGY	MORPHOLOGY		OTHER HABITAT FEATURES	BIOTA COVERED	BIOTIC SAMPLING EFFORT					
			Flow and Flow Variability	Habitat Linkage	Sampling Effort								
HYDROLOGICAL RATING													
	Natural Flow paradigm	Percentage of (natural) flow	🟩	🟥	🟥	🟥	🟥	no	low	low	low	₹	applied for screening - level assessments or where habtat models have already been established
HYDRAULIC RATING													
Abiotic habitat	Flow-water level relationship	Wetted, width, depth etc.	▨	🟥	one or few cross sections	🟥	🟥	no	low	medium	medium	₹	applied for screening - level assessments or where habtat models have already been established
Linkage to biotic criteria	Flow - water level-habitat use relationship	Minimum biotic criteria fulfilled	▨	hydraulic para meter linked to biota	one or few cross sections	🟥	indicator speciets	medium	low	medium	medium	₹ ₹	applied currently for a wide range of indian river types
HABITAT MODELLING													
Microhabitat modelling	Flow-microhabitat use relationship	Weighted usable habitat	🟩	micro - habitat	multiple riffle pool sequences	substrate, cover	indicator species	high	medium	high	high	₹ ₹ ₹	applied for natural and modified rivers with low to medium ecosystem complexity at smaller scale
Mesohabitat modelling	Flow - mesohabitat use relationship	Effective available habitat	🟩	meso- habitat	multiple riffle pool sequences	substrate, cover	community	high	high	high	high	₹ ₹ ₹	applied for natural and modified rivers with high ecosystem complexity at larger scale

4.2 Recommended Staging Actions and Preparatory Work

4.2.1 Definition of the Objectives for E-Flows Assessments

As with any measure in water resources management, the assessment of E-Flows must be driven by clear objectives. In the EU, most E-Flows assessments have the objective of providing a flow regime that will support the achievement and maintenance of good ecological status in the target water body. Good ecological status is defined as a slight variation from undisturbed conditions, and specific indicators for what constitutes good ecological status have been established by the member states. However, such stringent environmental objectives for ecological status are currently challenging to be achieved in India due to socio-economic conditions, the large population and related water demand including agriculture.

In India, the National Water Policy 2012 clearly spells out the need for providing E-Flows in rivers, but objectives for the ecological status to be achieved and maintained are not specified.

The assessment methods recommended in this guidance document assess the relationship between flow levels and the availability of habitats needed by target and indicator species. As the availability of needed habitats approach optimal levels, higher levels of potential ecological status are achieved. The choice of what final result to implement requires setting objectives for the levels of habitat availability, and thus potential ecological status, to be achieved. Setting an objective everywhere of “optimal” habitat availability will require significant proportions of flow in the river, which will likely restrict water availability for other purposes and may not be feasible in Indian conditions, where water demands are very high. Objectives for optimal habitat availability are often limited to rivers of unique character and high conservation value where undisturbed conditions are desired. In most rivers, however, sub-optimal habitat availability with the potential of a slight variation from undisturbed conditions is set as the E-Flows objective. In some rivers where other water uses are prioritized (i.e. “heavily modified water bodies”), even greater variations from undisturbed conditions may be the objective.

In the absence of clear objectives for the ecological status of Indian rivers, and given the degree of alteration common to rivers, this guidance document recommends applying the pragmatic approach of Palmer et al. (2005), which argues that restoration objectives“ ***should be to move the river towards the least degraded and most ecologically dynamic state possible, in a given regional context”.*** However, natural conditions give at least the general direction of mitigation pathways. There is, therefore, a need for the assessment team to agree on clear and achievable objectives regarding target conditions, keeping in mind that it may have to be defended (e.g., with stakeholders, public). In India a balanced approach should be adopted that combines the achievement of ecological and socio-economic sustainability. Looking at the present scenario of water requirements for development needs, it is suggested that the requisite flows for ecological needs of rivers to sustain biota must be ensured. However, more water may be allocated to the environment if it adds more socio-economic value to the society vis-à-vis other users like irrigation, hydropower, etc.

4.2.2 Development of a Data Framework for Assessment of E-Flows

CWC maintains the e-Surface Water Information System (e-SWIS) to support its objectives, including to collate, manage, and publish the hydro-meteorological data of all river basins in India, to process the data to provide information required for a range of hydrological, environmental and engineering studies, to manage and maintain the historical data and disseminate data to stakeholders, to communicate flood forecasts in a timely manner, and to standardize recording of hydro-meteorological observations. Data in e-SWIS are organized into static/semi-static characteristics (which include cross-sections) and modules focused on meteorological, hydrological, sediment, water quality, snow, and flood forecast data types. Incorporation of key E-Flows data types into e-SWIS could be done by creating a new module focused on ecohydrological datasets and by creating or distributing new data products, most importantly, including a national classification of river flow regime types based on natural flow regimes and maps of degree of flow alteration. Data relevant to E-Flows assessment is widely distributed across other parts of e-SWIS, so it will also be important to create a special section of the system that links relevant data from multiple sections.

Also, in e-SWIS, data relevant to E-Flows assessments may be grouped in various ways. It is relevant to use operational groups, namely 1) long-term historical data sets, 2) general data products, and 3) project specific data sets.

Historical Datasets

Fundamental datasets for E-Flows assessment include hydro-meteorological data, water quality data, records of engineering developments and water use, fisheries data, aerial photography, and satellite imagery.

Hydro-meteorological data include records of water level (depth), velocity and discharge. The cross-sectional data used in the construction and updating of discharge rating curves are also valuable as a record of changing channel form and geomorphological dynamics of the system. Discharge data are of course essential to the calculation of ecologically relevant long-term statistical properties of flow represented in flow duration curves, the recurrence intervals of floods, and the timing of annual shifts in regime characteristics. Meteorological data such as rainfall, temperature, wind, and relative humidity are important for the construction of hydrological runoff models used to simulate run-off in ungauged sections of river basins or to fill significant gaps in discharge records.

Water quality data are most valuable when they record variations in the concentrations of ecologically relevant parameters such as temperature, dissolved oxygen, suspended sediments, and nutrients. Records of toxic chemical levels linked to pollution sources are also valuable as a measure of stressors on aquatic ecosystem processes. Water quality data are most valuable when collected jointly with discharge data, allowing the analysis of relationships between water quality and flow levels. Water quality data from unimpacted river reaches are also valuable as measures of background water quality, especially when the same flow-water quality relationships can be quantified.

Historical records indicating the timing and magnitude of engineering interventions (such as irrigation schemes) are valuable for calculating the degree of hydrological alteration of river flow regimes. Data on consumptive and non-consumptive water use are both important, as one records permanent reductions in river flow levels while the other records alterations in the distribution of flow throughout the year, or even between years. Information about reservoirs and especially the volume of water stored in relation to annual river flows is another common index relevant for E-Flows assessment. The Degree of Regulation index is calculated as the volume of water stored in the reservoir (or its capacity) divided by the total annual discharge of the river. In case of non-consumptive use, it is important to consider where the water reenters the river system and with what quality.

Historical river fisheries datasets are a valuable source of ecological data over time. Records may include catch data for multiple species over space and time, which can be used as a proxy for the ranges of species and their natural variability in population size. Inferences such as these must of course be made with caution due to multiple other factors influencing catch amounts, such as level of effort and technologies used, but when care is taken useful inferences can be drawn. Any other historical datasets of ecological parameters relevant to E-Flows will also be of high value. These may include survey data related to the implementation of international treaties such as the Ramsar Convention on Wetlands of International Importance or the International Convention on Biodiversity.

Aerial photographs and satellite imagery are valuable data sources for analyses of geomorphic change in large rivers and change in land use and land cover in river basins. Aerial photographs may extend back nearly 100 years, and satellite imagery extends back more than 40 years. Sequences of images can be analyzed to reconstruct channel dynamics that may also be linked to hydrological data when available.

General Data Products

A hydrological classification of Indian rivers would be useful to support E-Flows assessments. Such classifications have been made in the USA and Australia (Kennard et al. 2010;) and are currently under development in other countries (Figure 11). Rivers are classified according to the ecologically relevant characteristics of their flow regimes and serve to highlight and standardize consideration of these features in E-Flows assessments. More details on this can be found in Poff (1996); Poff et al. (2006); Whipple et al. (2017) and Zimmerman et al. (2017). Other important data products to consider in E-Flows assessments are topographic maps, soil maps, geological maps, land use and land cover change maps.

Another important data product can be the classification of Indian rivers based on habitat types. Habitat Atlas should be prepared for perennial rivers in the country. The Habitat Atlas may aim to compile all the related information/data with respect to fish species, plankton and benthic invertebrates, other macro-flora, and to classify aquatic habitats of each umbrella species based on the environment of its existence, throughout the years available in identified river reaches in perennial river systems.

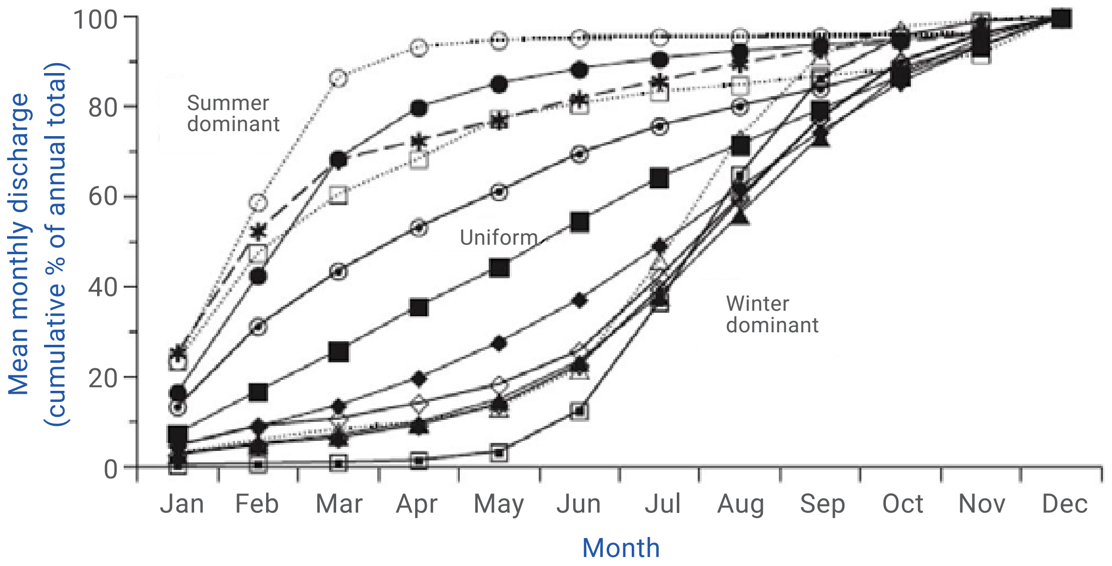


Figure 11. Cumulative mean monthly discharge of 12 different river flow regime classes defined in Australia. Source: Kennard et al. 2010.

This classification can be supported by the bio-geographical classification of the rivers. The ecoregions, catchment area, altitude, geology, and flow regime, etc., are important characteristics that should be considered while delineating the habitat types. An Example of Austrian River Typology based on fish-bioregions is presented in Figure 12. Also, all European rivers have been classified into different macrohabitat types (see Figure 4).

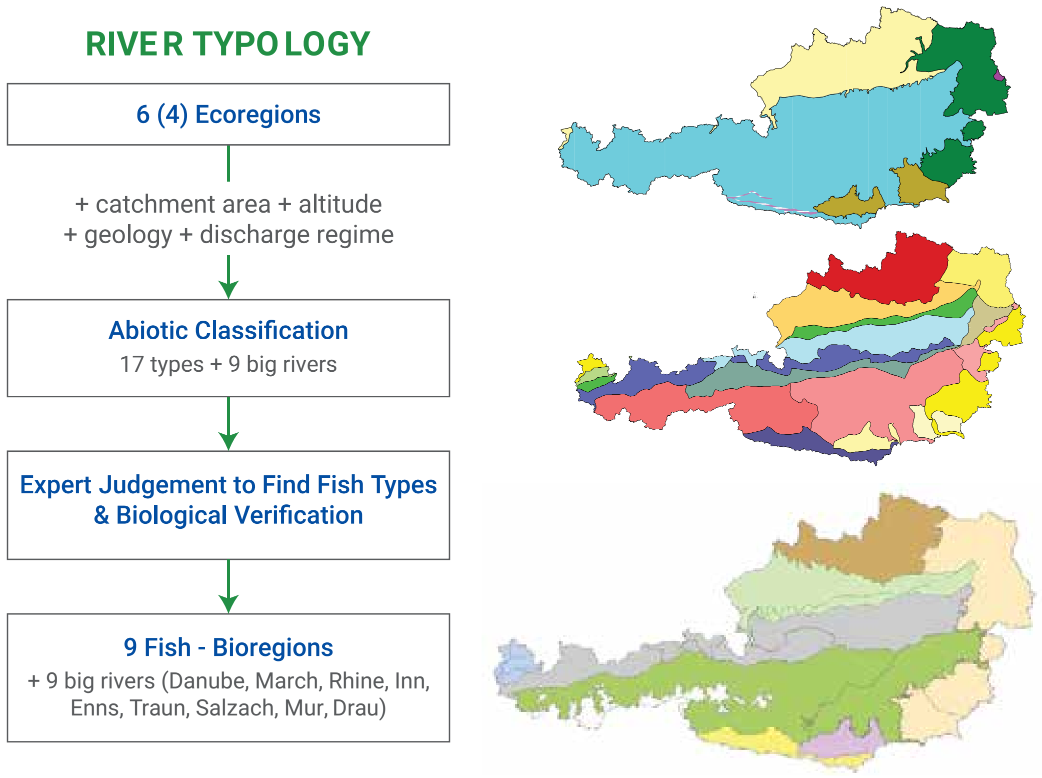


Figure 12. Bioregions of the Austrian Rivers. Modified after Haunschmied et al. (2006).

Project Specific Data

For the E-Flows assessments using the recommended habitat modelling methods, site specific data include the full range of hydrological, hydraulic, geomorphic, ecological data that may be surveyed and collected in the process of an E-Flows assessment of a particular project. It is also advised to seek out scientific literature and technical reports that may contain data relevant to the sites. In addition to these, it will also be useful to collect data related to chemical and socio-economic conditions of the project sites, for future application of integrative assessment methods. The project specific data structure can be formulated based on following components (Table 5). Further specific details on ecological data requirements and data structure etc. are presented in Chapter 4 (section 4.3).

Table 5. Detailed data requirements and methodology for collection

DATA TYPE	REFERENCE/CONTEXT	METHODOLOGY FOR COLLECTION	CURRENT STATUS OF DATA COLLECTION & RECORDS AVAILABILITY
Geographical extent of river basin	These data are needed in large scale context for reconnaissance and critical reaches selection. Information about sources of river and its tributaries, their flow networks, important human settlements dependent on river, locations and of major engineering structures, interstate river networks, etc.	GIS based information may be validated through ground observation	Good
HYDROLOGICAL DATA			
Long term flow discharges	Long terms daily (sub-daily) observations of flow discharges are required for understanding the flow regime of the river (magnitude, frequency, timings, durations), at least over recent past. Seasonal flow variability and extremes can be well described using this data. Sub-daily observations are good to predict effects of releases from upstream structures.	Discharge variations in vertical column and horizontal flow width should be noted with multiple observations.	Good
HYDRAULIC AND GEOMORPHOLOGICAL DATA			
Hydromorphic data	Hydromorphological Units (HMUs) are small river sections with specific hydraulic patterns. Pools for example are slow and deep, while riffle fast and shallow units. These units are associated with specific assemblages of animals (e.g. deep pool – big fish, shallow riffle –small fish).	There are about 11 easily distinguishable HMU types. They are mapped during field survey and annotated on aerial photography. Their area is then estimated in GIS analysis.	Needs Improvement
Depth and velocity	Spatial distribution of depth and velocity is a factor directly influencing behavior of fish and other animals. Measurement of these variables serves determination of biological preferences and description of the site hydraulics. Depth and velocity directly affect species behavior and need to be captured at the scale at which animals perceive their environment. This data is a key descriptor of representative site and measurements need to capture site variability.	The centimeter precision with decimeter accuracy. It can be sampled using cross-sectional or topographic surveys. At mesoscale it serves as a descriptor hydraulic unit area within hydromorphic unit (7-10 measurements per unit).	Needs Improvement
Habitat dressing	Distribution of various types of substrates, woody debris, undercut banks, canopy cover shading, boulders, submerged and overhanging vegetation, shallow margins, bank stabilization are important habitat dressings affecting behavior of many biota. They create refugia, spawning grounds and feeding stations. These attributes need to be captured in the representative site.	At microscale presence these attributes are estimated at every hydraulic measurement location. At meso scale only substrate type is described at hydraulic measurement locations. Cover is defined in terms of absence, presence and abundance (>50% of unit length) for each HMU	Needs Improvement
ECOLOGICAL OBSERVATIONS/DATA			
Selection of target species	Various types of species [belonging to floodplains, forests and wetlands; freshwater as well as marine; aquatic life inclusive of invertebrates and vertebrates as well as riparian species of plants and animals] can be focused for E-Flows assessments based on type of methodology selected. The target species should be selected in such a way that it represents certain spatial stretch of the river for which E-Flows can be suggested based on it. River stretches can be spatially segregated based on their indicator species.	For present selected methodology, aquatic species of high conservation value/ keystone Species (fishes) may be targeted and their life history traits and Habitat Use Guilds may be studied to understand various habitat related requirements that are flow and geomorphology specific.	Good
Life history traits of target species in various life stages, flow related requirements and records of impacts on account of altered flows	Information about water requirements of each of these life forms/ stages in terms of magnitude, frequency, timings, and durations of various flows and water quality can be incorporated in E-Flows assessments. Such requirements are generally season specific. Thus, time of the year should also be considered.	Various aquatic ecology experts need to jointly discuss and define flow related requirements in seasonal context.	Average

DATA TYPE	REFERENCE/CONTEXT	METHODOLOGY FOR COLLECTION	CURRENT STATUS OF DATA COLLECTION AND RECORDS AVAILABILITY
Habitat use criteria	Information of habitat frequently used by selected species is necessary for calculating habitat models. The criteria are established from field observations of animals and circumstances around them. Accuracy of these criteria is key factor in the accuracy of habitat model	The criteria can be established using literature data with expert opinion. However, the developed criteria should be verified through field observations.	Needs Improvement
It is also recommendable to focus on whole communities rather than limited species. An expected proportion of each guild in the aquatic community should serve as a restoration target of E-Flows regulation			
WATER RESOURCES DEVELOPMENT			
Scale of water resource development	Types of interventions, their magnitude, timings of operation, and spatio-temporal effects on downstream flows help in E-Flows assessments and trade-off analyses.	Information about locations and salient features of various water abstraction/ storage/ diversion projects should be tabulated. This information can be later related with alterations in flow regime on account of these projects.	Good
SPATIAL INFORMATION/DATA			
DEMs, Land Use, Soil maps, Toposheets, Satellite images etc.	Spatial information is useful in hydrological rainfall-runoff modelling exercise. Satellite images and toposheets also help in predicting the geomorphological changes in river channels and floodplains.	Spatial information can be obtained from various sources like NRSC, IWMI, FAO, NBSSLUP, Survey of India and USGS datasets (SRTM, LANDSAT) etc.	Good
METEOROLOGICAL DATA			
Precipitation, temperatures, wind speed, solar radiation etc.	Meteorological forcing datasets are useful in rainfall-runoff modelling exercise for estimation of natural/virgin flow scenarios.	India Meteorological Department data as well as other global datasets like Princeton's Global Meteorological Forcing Dataset and APHRODITE precipitation can be used	Good
In addition to above datasets, it is also advisable to collect data related to the following aspects to enable the use of more integrative methods in future.			
SOCIO-CULTURAL DATA			
Anthropology	Historical and present information of population levels, quality of life and religious and cultural activities play an important role in E-Flows analysis and trade-offs.	Census reports for historical and present population dependent on river directly or indirectly. Information on religious cultural activities like number of visitors/pilgrims and their needs in terms of flows.	Average
GROUNDWATER DATA			
Fence Diagrams, Water levels, draw downs,	Fluctuations of groundwater levels in the basin define effluent and influent streams. Thus, it is important to understand the dynamics of surface water-groundwater interactions in the basin.	CGWB data in terms of Fence Diagrams, well-logs, groundwater levels time series, draw downs, etc. as well as district and state reports of groundwater assessments are useful.	Good
WATER QUALITY DATA			
Long term water quality records	Long term water quality assessments [including concentration of sediments and nutrients] are important for understanding the effects of water abstraction and sewage/ effluent discharges on river water quality. These data can be incorporated in water quality modelling for analyzing the flows required for assimilation (dilution).	Total 41 Water quality parameters observed by (CWC): frequency of monitoring according to classification as Base, trend and/or flux stations of monitoring. While extending network, sites critical for ecological purposes should be focused. Data from CPCB sites can also be part of overall data framework	Average
Note: In addition to historical records, real time observations of these parameters are also desirable for successful implementation and monitoring of E-Flows.			

4.3 Key Steps Towards the Application of Advanced Habitat Modeling

Presently in India, the hydraulic rating cum habitat simulation methodology is commonly used to assess the ecological needs for corresponding target/umbrella species in river reaches. Considering, the data availability regarding ecology and other parameters, environmental flow management objectives, the scale of operation, the expertise available in the country, etc., the E-Flows assessment methodology that is applied (see Chapter 3 for details on the method), is currently performing well to meet the objectives. However, for the future, it is advised that India applies any of the internationally established and advanced habitat modeling methods. Two types of habitat models are recommended: A) PHABSIM and B) MesoHABSIM. This recommendation is based on the experiences gained during the pilot assessments under the IEWP (PR2). Physical habitat assessment was undertaken for E-Flows assessments in Ramganga and other pilot cases under the IEWP (PR2) (Ref-IEWP 2020-Draft Ramganga E-Flows Assessments). For this, a one-dimensional PHABSIM model was adopted due to the high degree of flexibility in terms of data and time requirements, etc. It is a pioneer, most widely used and advocated habitat simulation model (Jowett, 1997; Ayllón et al., 2012) available in the form of a freely available software. PHABSIM results obtained in the form of flow versus habitat area (weighted with its quality) curves are especially important in defining E-Flows as they provide qualitative and quantitative estimates of the effects of flow alterations on ecological habitat conditions (Bovee 1982). It has been validated through numerous scientific studies over a long period and utilized for policy formulations across the world (Holzwart et al 2017; Sparling et al 2018).

For one case study in Ramganga Basin, MesoHABSIM (please refer to MesoHABSIM assessment report prepared under PR-2 of IEWP for further details) was also applied. Native fish community structure was developed, and the assessments were carried out to establish flow requirements of various fish guilds. Though the hydrological and hydraulic data collection process was impacted due to the COVID-19 pandemic; the study was supported by use of a hydrological and hydrodynamic modelling results.

From the experiences in Ramganga and other pilots, it can be suggested that habitat assessment models like PHABSIM and MesoHABSIM can be quickly and successfully applied in India as reliable tools for broader and effective decision making. However, it is pertinent to mention here that for the application of any such advanced methodology/tool for the assessment of E-Flows, it is very important to have/collect requisite data as required in these models. The first effort for advancement in the assessment of E-Flows should be on the development of a data framework and the collection of requisite data. The application of these advanced tools without adequate data would be counterproductive as the accuracy of the model output relies on input data quality. As these models are data intensive, their applications may currently be limited to small reaches with high importance of aquatic life or to degraded reaches. For assessments on the basin-wide scale, the applications of these advanced tools are currently challenging and there is a need to enhance the data framework in India.

With application of improved hydro-morphological and other data sets, such models will lead to furthermore confident and robust E-Flows assessments. The decision of which to be used can be determined based on the criteria presented in Table 4. Steps required to be followed for successful applications of these advanced methods are as below.

4.3.1 Step 1: Establish Biological Targets, Indicators and Criteria

The first step is to define biological targets to be achieved through the planned actions. The targets setting can be approached in two ways:

A) maintenance of the habitat conditions for carefully identified target species so that the larger ecosystem in which these species dwell will be protected. (Applicable for PHABSIM)

B) maintenance of a native fish community structure, i.e. a community consisting of expected species occurring in proportions reflecting habitat settings as defined by local geomorphology. (Applicable for MesoHABSIM)

A. Applicable for PHABSIM

For target species, habitat requirements have to be defined by experts in terms of most suitable ranges of flow depths, velocities and substrate-cover conditions for various life stages. For use in microhabitat model (like PHABSIM) habitat suitability criteria curves should be developed (Figure 13)

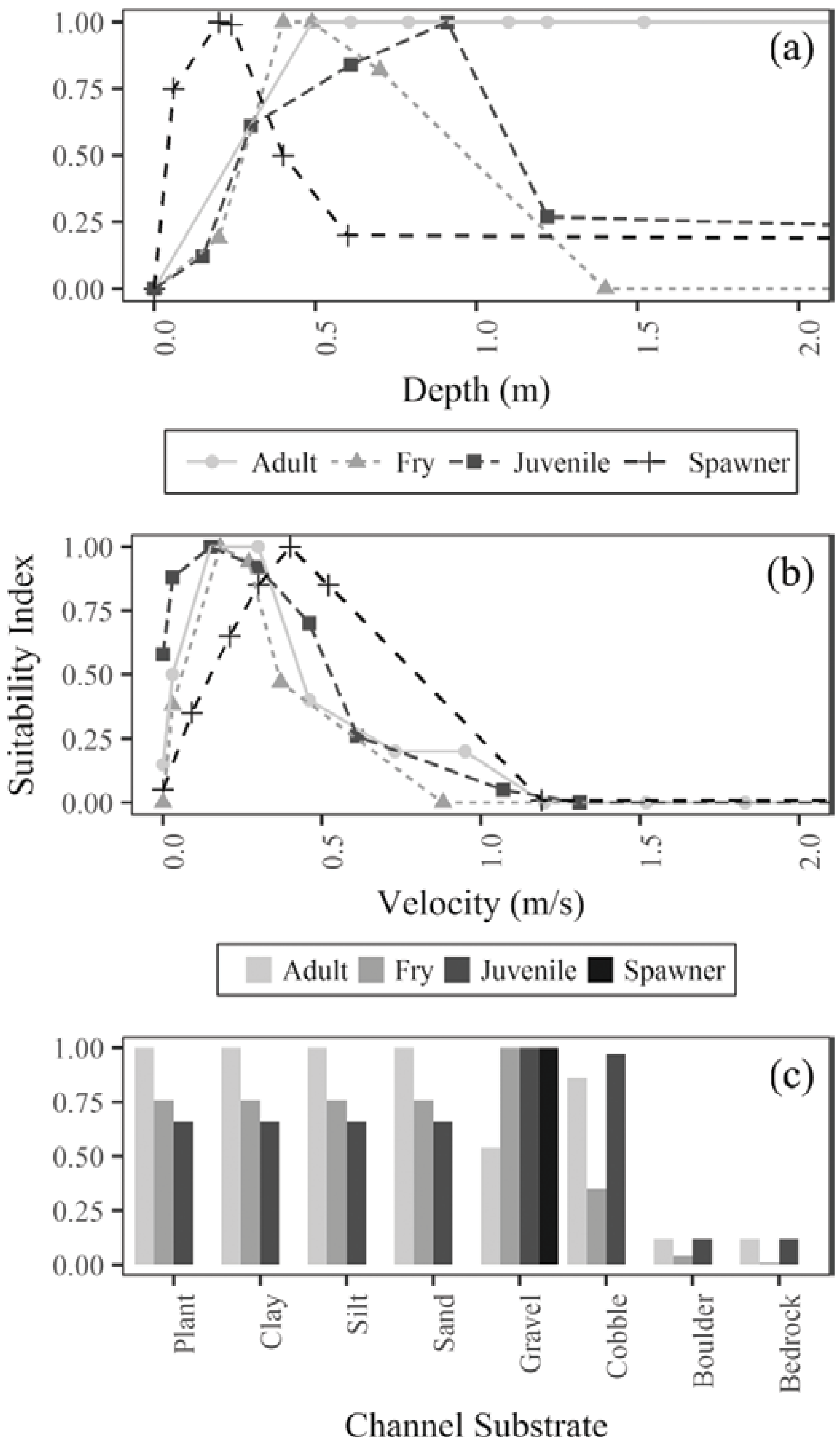


Figure 13. Habitat suitability criteria curves for (a) depth, (b) velocity, and (c)channel substrate for brown trout (Salmo trutta) habitat for adult, fry, juvenile, and spawning stages (Richer et al 2019).

The target species can be identified based on;

- Expert judgement and field surveys (including discussions with local communities),
- Indicator, keystone or umbrella species of the region
- Priority species identified, for example, species identified by WII-GACMC (2017) for Ganga Basin, species of National/state importance
- Species of high conservation value (referring to IUCN Red list), for example Gangetic Dolphin
- Species of high socio-cultural importance etc, e.g. Hilsa

B. Applicable for MesoHABSIM

To build a community model it is necessary to determine what species, in what numbers, can be expected at the location during different times of the year. To establish such biological targets, the following procedure is recommended:

Define the seasons (bioperiods) in which different fish communities and life stages occur in the river. Fish community structure is variable across the seasons due to spawning migrations. The beginning and end of the bioperiods are defined by biological processes (e.g. spawning), as well as by changes in the flow patterns (see also below). Experts identify the fish species that typically occur in the area and group them into habitat use guilds (HUG), i.e. assemblages using similar habitats (Pegg et al 2014, AMBER 2019, Parasiewicz et al. 2019).Separate guilds are for spawning and growth bioperiods. Fish biology experts rank the abundances of expected guilds to define the proportion of appropriate (i.e. spawning or growth) guilds in the target community. The ranks are used to compute a fish community model (Bain and Meixler 2008) presenting the expected proportion of guilds in the community (community structure). Each guild is assigned conditional habitat suitability criteria, which can be applied for all rives in India (Table 6). This step has been completed to a large extent during the Ramganga River pilot study as a modification of criteria developed in the AMBER project.

Table 6.Conditional Habitat Use Criteria of HUGs occurring in Ramganga River.

HABITATUSEGUILDS	DEPTH [m]	VELOCITY $[m\ s^{-1}]$	CHORIOTOPE	HMU TYPE	COVER
Rheophilic benthic species, preferring sandy-gravel bottom substrate	0.3-2.0	0.3-1.5	megalithal>40 cm, makrolithal 20-40 cm, mesolithal 6-20 cm, microlithal 2-6 cm psammal (sand), akal (microgravel <2 cm), xylal, pelal (mud), sapropel	riffle, ruffle, cascade, rapid, fast run, run, glide, plunge-pool, pool,	boulders, undercut banks woody debris, submerged vegetation
Limnophilic benthic species of moderate tolerance	0.25-2.5	0.0-0.5	microlithal psammal, pelal, akal, debris, xylal	run, pool, glide, sidearm	undercut banks woody debris, boulders, submerged vegetation, canopy shading
Limnophilic water column species of moderate tolerance Limnophiliclithophilic species of moderate tolerance	0.5-4.0	0.1-0.7	megalithal, macrolithal, mesolithal, microlithal psammal, akal, debris, xylal	riffle, ruffle, run, glide, plunge-pool, pool, backwater, fast run	boulders, woody debris, submerged vegetation
Limnophilic water column species of moderate tolerance	0.5-4.0	0.0-0.5	microlithal, psammal, pelal, akal, debris, xylal	run, pool, backwater	woody debris, undercut banks, canopy shading
Generalists - tolerant species	0.25-4.0	0.0-0.45	mesolithal, microlithal, psammal, akal, debris, pelal, sapropel, xylal	run, pool, glide, sidearm, backwater	woody debris, undercut banks, canopy shading, overhanging vegetation, detritus, No cover area
Intolerant, rheophilic benthic species, preferring detritus or pelal bottom substrate	0.20- 0.50	0.15-0.5	detritus, pelal, psammal, sapropel	backwater, glide, pool, run	shallow margins, woody debris
Rheophilic water column species, preferring sandy-gravel bottom substrate	0.5-4.0	0.15-0.7	mesolithal, microlithal, psammal, akal, debris, xylal	run, fast run, pool, plunge-pool	undercut banks woody debris, canopy shading, submerged vegetation

4.3.2 Step 2: Define Reference and Critical Reaches, Survey Location and Schedule

Reference sites are river reaches that are under minimal human interferences (headwater streams) need to be selected to understand naturalised situations that can be reference points for other sites, and to be able to anticipate what best can be achieved. E-Flows values should be established on reference sites, then optimized on other reaches.

Critical reaches (study sites) are those hydro-morphologically, ecologically and/or socio-culturally important sites in the river where E-Flows assessments have to be prioritized. Apart from such reaches of importance, E-Flows should also be planned for sections that are significantly affected by abstractions of water resources structures (dams, barrages, etc.). Identification of critical reaches requires extensive surveys and field visits of experts from multiple scientific disciplines. For example, hydraulic engineers and hydrologists prefer river sections with minimal details to be assured in terms of accurate hydraulic/ hydrological measurements while ecologists and geomorphologists prefer complex and heterogeneous sections that incorporate various diverse arrangements important for ecological and geomorphological processes. To identify critical reaches, it is necessary to perform reconnaissance surveys by studying aerial imagery, GIS information (e.g. geological patterns, land use) and if still needed site visits by fluvial geomorphology and biology experts.

The following important points may be assured for careful identification of critical reaches.

- Representation: The reach selected as a critical reach should be a good representative of the river under study (or some section and sub-basin of the river). It should represent important ecological and socio-cultural hotspots and river reaches under severe pressure of water abstraction and pollutant discharges. In addition, one should include critical reaches that are of particular value (e.g. conservation area, important town).
- Data availability and requirements: The reach selected as a critical reach should have temporal data sets in terms of flow records and ecological observations etc. The survey timing and schedules are based on references from hydrological data records. Long term (min 10 years and preferably 20 years) daily mean flow records from a nearby location are best for determining natural and modified flow patterns in the area. To be of biological significance the flows need to represent nature-like (i.e. no withdrawals or other modifications) conditions. Medians of observed daily flows offer an annual flow pattern, which permits to identify bioperiods i.e. seasons where flows trigger specific biological processes such as spawning and rearing. If such flow records are not available, they may be modelled with hydrological model. Even if short natural flow records are available, they can be extrapolated and transferred to ungauged locations as per standard hydrological practices. Number of sites/reaches: Site selection follows two parallel approaches within each catchment aiming to identify: (i) an appropriate number of sites capturing the catchment main river types; (ii) sites that are critical and should be included on their own merit. For standardization of the approach, the Multiscale Hierarchical Framework by Gurnell et al (2015) (see also Belletti et al 2017) can be applied. Select representative sites such that the key geomorphic features (pools, meanders) are captured. The rule of thumb here is the site length equivalent to value between 10 and 30 times wetted river width.
- Number of observations/visit schedules: The habitat distribution in representative sites should be described over multiple site visits in a number of low flow conditions. These flows should capture the range of investigated circumstances, which can be managed (i.e. low flows). The range of investigated low flows can be determined by calculating the low flow threshold with the Indicators of Hydrologic Alteration (IHA) software. With regard to hydro-power schemes, hydro-peaking metrics (e.g. ramping) may be of importance (Greimel et al., 2016; Hayes et al., 2019). Three to four flows need to be chosen from the range from the lowest possible to the low flow threshold.

4.3.3 Step 3: Collect Habitat Data

Data collection at a site should include flow depth, velocity, substrate and cover patterns. The data collection can be done using a combination of remote sensing and on-site surveys.

A. Applicable for PHABSIM

- The PHABSIM methodology requires collection of hydraulic data for the development of a hydraulic model, which calculates the distribution of depth and velocity as a function of flow. The hydraulic survey should ensure that the patterns and sequences in the river channel geometry are covered with precision corresponding to micro scale observations. This can be done either by cross sectional or topographic survey of the river bed in the study site.
- Depending on the river type, the geomorphology of a river consists of a sequence of distinct mesohabitat types such as riffle, pool, run etc. The hydraulic surveys should cover a representative proportion of such mesohabitat types. In this case habitat classification may precede the survey to quantify the proportion of habitat types associated with each hydromorphic unit such as riffles, pools, runs, etc. Subsequently the cross sections are selected to represent each mesohabitat type accordingly. Alternatively, the site is selected to include appropriate proportions of the mesohabitat units and the entire site is sampled. At least one to two sequences of mesohabitat types should be covered in the survey.
- When surveying the cross sections for a one dimensional hydrodynamic model, the guidelines specified in Bovee (1982 and 1997) and Johnson et al (1991); pertaining to total length of the study site, number of cross sections and exact locations of cross-sections within the reach etc. should be followed. The cross sections need to be spaced closely enough to capture hydromorphic variability. For better efficiency the cross section spacing should be irregular and adjusted to riverbed diversity (denser in more variable topography - Parasiewicz 1996). As a rule of thumb, the average cross section spacing should be equivalent to one half of the wetted river width.

- When developing a two dimensional (2D) hydrodynamic model, the survey may follow topographic principles, i.e. measuring break lines in the river-bed rather than cross sections. This is more time and cost efficient, but best performed with Differential GPS equipment.
- For calibration of flow depths and velocities in the microhabitat model, it is recommended to collect three sets of observations of flow depths and velocities at low, mean/median and high flow conditions. Using these surveyed flow observations, flow depths and velocities pertaining to interim flows can be simulated.
- The observations of substrate and cover conditions in the channel sections should be noted at every measured point.

B. Applicable for MesoHABSIM

For the MesoHABSIM method, the procedure varies depending on the size of the river (Figure 14) but generally one site and flow condition can be completely surveyed in one day.

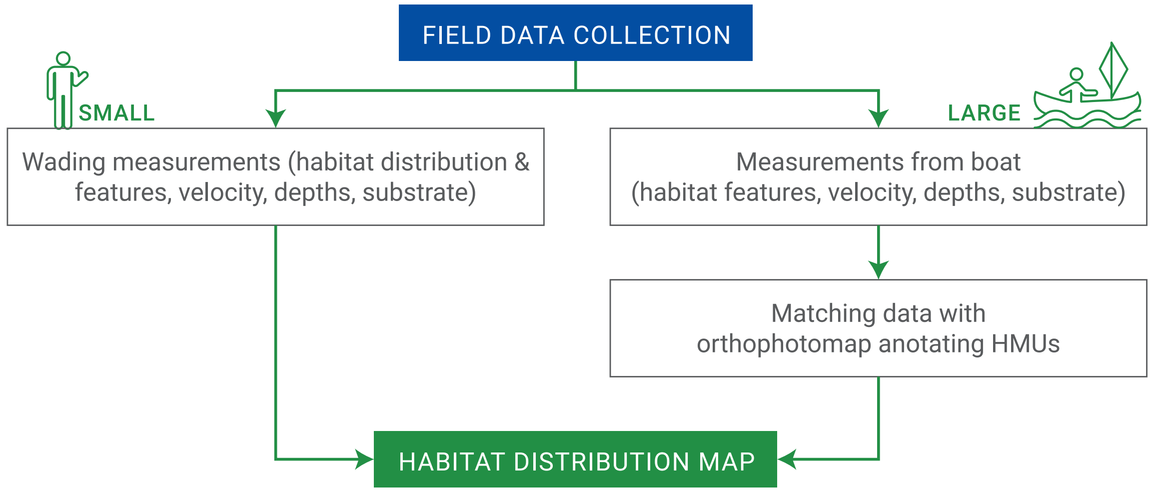


Figure 14. Habitat survey process for small and large rivers (modified from AMBER Field Manual).

Small rivers

The goal of the habitat survey is to determine the spatial proportions of mesohabitat units in selected reaches. Mesohabitat units or Hydromorphological Units (HMUs) are river sections with similar morphologic, hydraulic, and cover attributes (i.e. pools, riffles, runs) (Figure 15). For each HMU, the location and size are determined with a GPS in conjunction with high-resolution aerial photographs. For each HMU, information on habitat features presented in the Table 6 is recorded. This includes measurement of hydraulic patterns (samples of depth and velocity) with handheld flow meters (Parasiewicz 2007a).

The outlines of each HMU are drawn as geo-referenced polygons on the pictures using Android tablet or a smart phone and velocities are measured with a flow meter. Two surveyors one with notepad and second with flow meter) are necessary

Figure 15. Habitat Characterization

Large rivers

Habitat mapping in large rivers needs to be conducted in post processing. The mapping procedure utilizes data collected during the survey consisting of aerial imagery (nadir and oblique), depth and velocity measurements using GPS-positioned ADCP. There are two options for data collection:

1. Perform repeated surveys at different flows each consisting of topographic/hydraulic measurements (depth, velocity) and aerial photography with a UAV (RGB photos with decimeter resolution). Substrate distribution can be calculated with the SubDiSMO model created in AMBER project (AMBER 2020).
2. Perform one topographic/hydraulic survey including substrate estimates and 3 repeated UAV aerial imagery surveys. In this case a 2-D hydrodynamic model is applied to calculate depth and velocity at flow conditions captured by the aerial photographs.
3. Having measured velocities, depths and substrate and plotted the data to an orthophotomap (for example using QGIS), the spatial HMU distribution can be defined in accordance with the rules defined in the MesoHABSIM method (Figure 16 and 17). Nadir and oblique photos support the decision making (Parasiewicz 2001, 2007a, Parasiewicz et al 2013).

Figure 16. Bathymetric survey using acoustic Doppler profiler and sonar trace of depth measurements

(presenting data density necessary for hydrodynamic model)

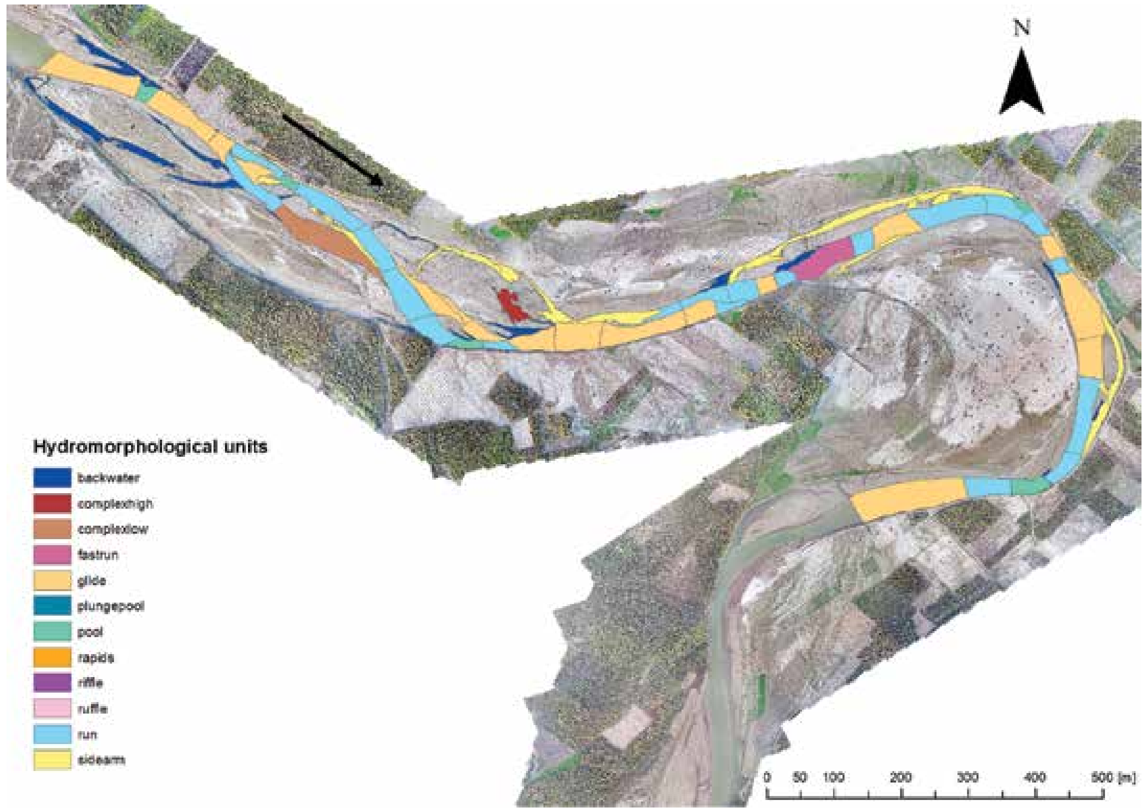


Figure 17. Distribution of HMUs mapped in Ramganga River in data postprocessing.

4.3.4 Step 4: Building the Habitat Model and Interpretation of Results

A. PHABSIM

- PHABSIM set-up starts with incorporation of hydraulic data (cross sections) into the model. Using these data, PHABSIM divides the river reach under the study into a number of habitat cells (based on lateral cross-sectional points and distance between cross sections) (Figure 18).

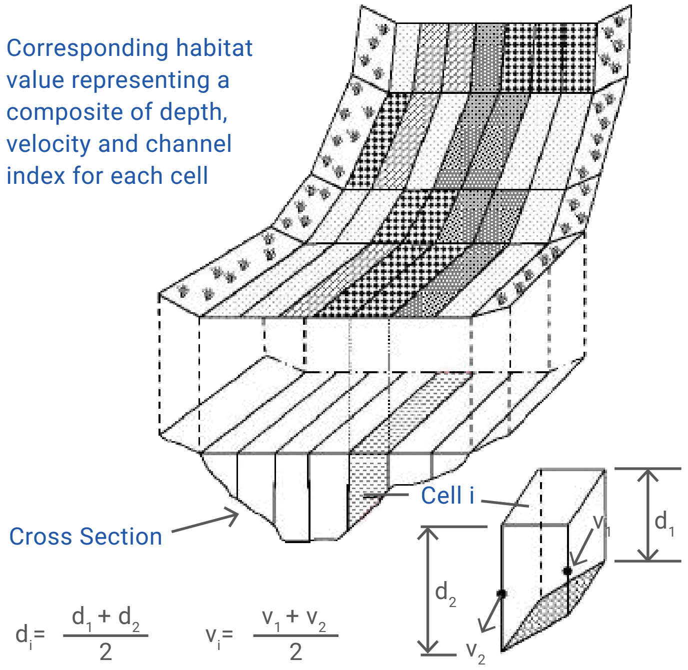


Figure 18. PHABSIM-Habitat cell computations (Waddle 2001)

- For each cross section, water levels and velocities corresponding to different observed/surveyed flow conditions are given as an input for simulations.
- Manning's roughness coefficient (n) and slope of the river section are provided based on the observed substrate and slope conditions.
- Water Surface Level (WSL) Simulation-PHABSIM utilizes the given combinations of flows and water levels to establish the flow-water level relationship for every cross section. (There are different computational options available in PHABSIM to achieve this- Waddle 2001)
- Velocity Simulations- Using flow depths and slopes for each habitat cell, PHABSIM computes the flow velocities for each habitat cell. So, it can be said that PHABSIM works as a 1.5D or pseudo-2D model. The local (transverse) velocities are scaled with the established local depths using uniform flow equations (Bovee 1982) with the assumptions that velocity is a function of local depth and energy slope, and that flow vectors have longitudinal direction only (Benjankar et al, 2015). Figure19 shows the velocity profiles (VELs) at a cross section obtained using PHABSIM for flows of 10, 50, and 100 cumecs along with Water Surface Levels (WSLs) at these flows.

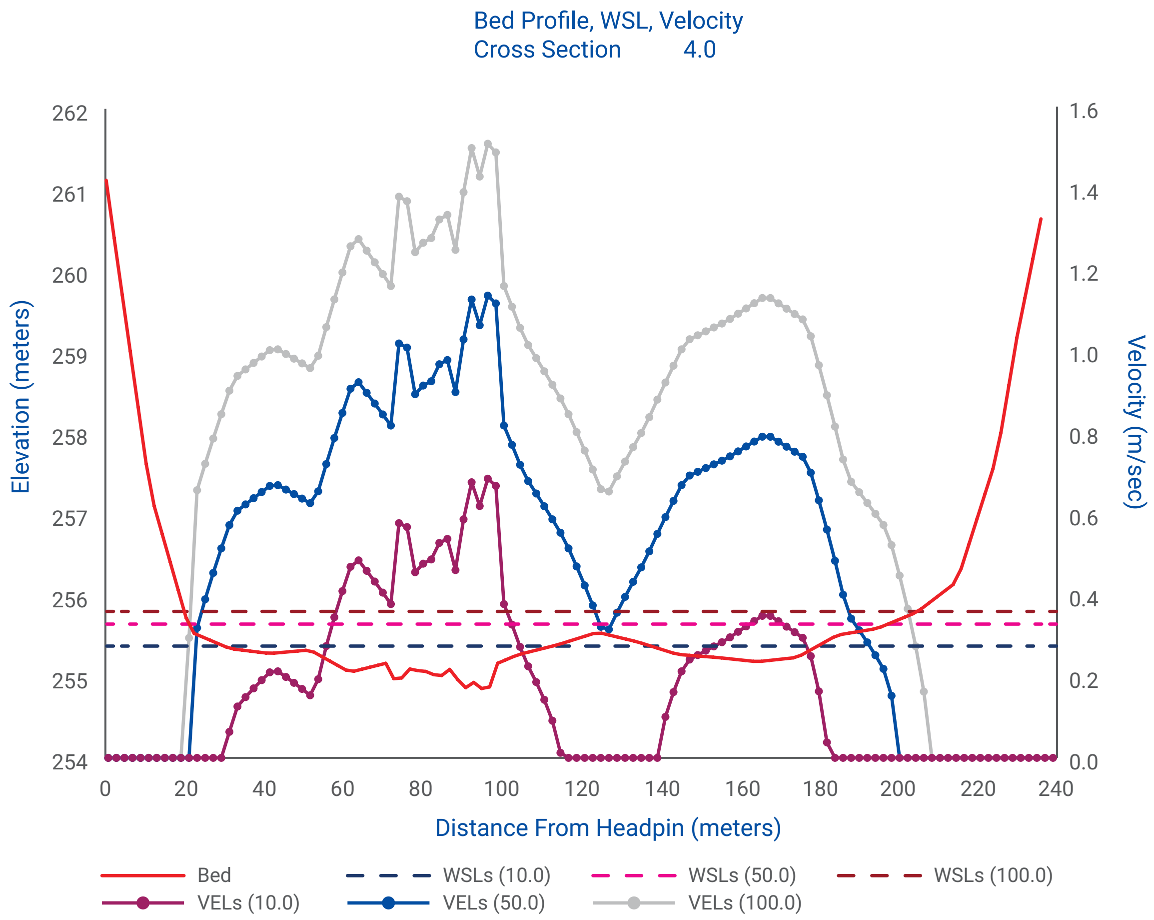


Figure 19. Velocity and WSL profiles generated using PHABSIM

- Habitat Simulations- PHABSIM computes the total habitat cell area (water surface area) for each flow condition. Based on suitability of hydraulic parameters (depth and velocity corresponding to various flows conditions) and channel index, each cell habitat area is multiplied (weighted) by its composite suitability (ranging from 0 to 1) and total Weighted Usable Area (WUA) for each flow condition is obtained. The composite suitability can be obtained by using different aggregation methods-best suitable to the user's requirements (Waddle 2001). Multivariate techniques are recommended. WUA signifies the quantity of habitat area weighted by its quality that makes it usable for the indicator species. PHABSIM also provides a three-dimensional overview of the distribution of WUA.
- The flow versus WUA curves may have different shapes and patterns (linear, non-linear, bell-shaped etc) based on hydraulic settings and fish habitat preferences. Based on these shapes and patterns and an overview of seasonal variations in the flow regime etc, the most optimal combination of flow and habitat condition can be identified as the optimal E-Flows suggestion. Suggesting a flow range in the vicinity of optimal value is more justifiable than a single value. Figure 20 shows the results of PHABSIM analysis for a Ramganga Site. Blue curve in the figure shows that the rate of increase in total surface area of water (sq. m per km length of the reach) with per unit increase in flow decreases significantly after 5 cumecs flow. WUA for Kalabans ***(Bangana dero)*** Adult fish is maximum when the flow is in the range of 10 cumecs (Orange Curve). This suggests that best results on habitat conditions for Kalabans can be obtained when flows are in the range of 5 to 10 cumecs. Grey line in the figure shows that WUA for Reba Carp Fish increases linearly with increase in flow.

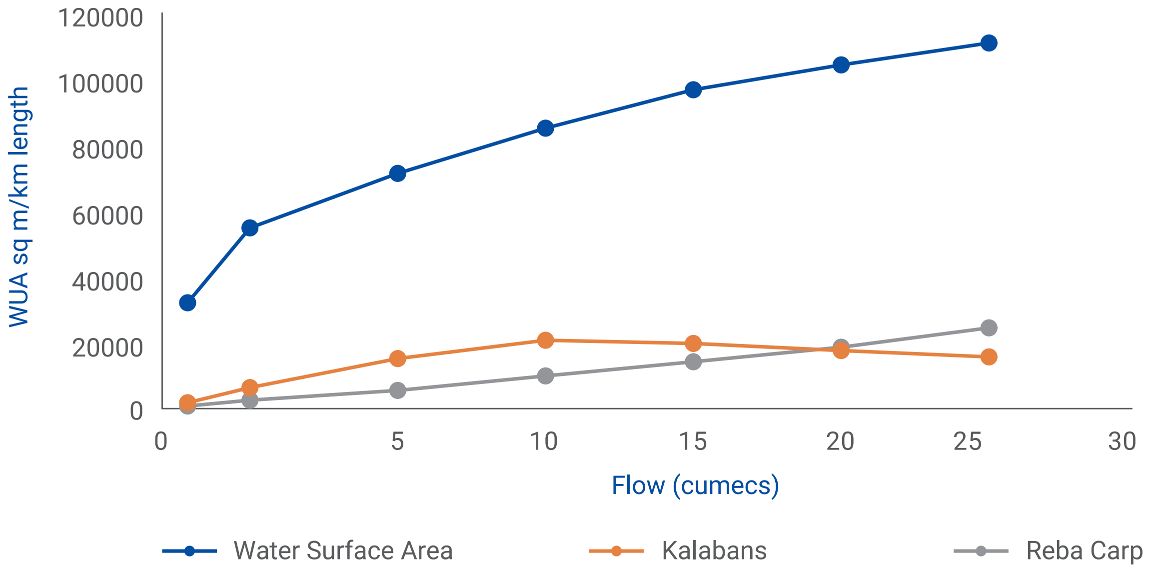


Figure 20. Results of PHABSIM analysis for a Ramganga Site

- **It is recommended to develop the habitat time series and habitat duration curves (Bovee 1982)** referring the natural flow conditions and to recommend seasonal E-Flows scenarios based on natural variability of habitat conditions.
- With data availability, it might also be possible in future to switch to 2D hydrodynamic modelling-based habitat assessment models and to incorporate the fuzzy and multivariate (joint) suitability criteria (for example CASiMiR Model).

B. MesoHABSIM

Field collected data (HMU, depth velocity and cover distribution) are entered into SIM-Stream software. The habitat use criteria are applied to each HMU, which are assigned a suitability category (unsuitable, suitable and optimal) depending on how many criteria are met for the guild (Figure 21).

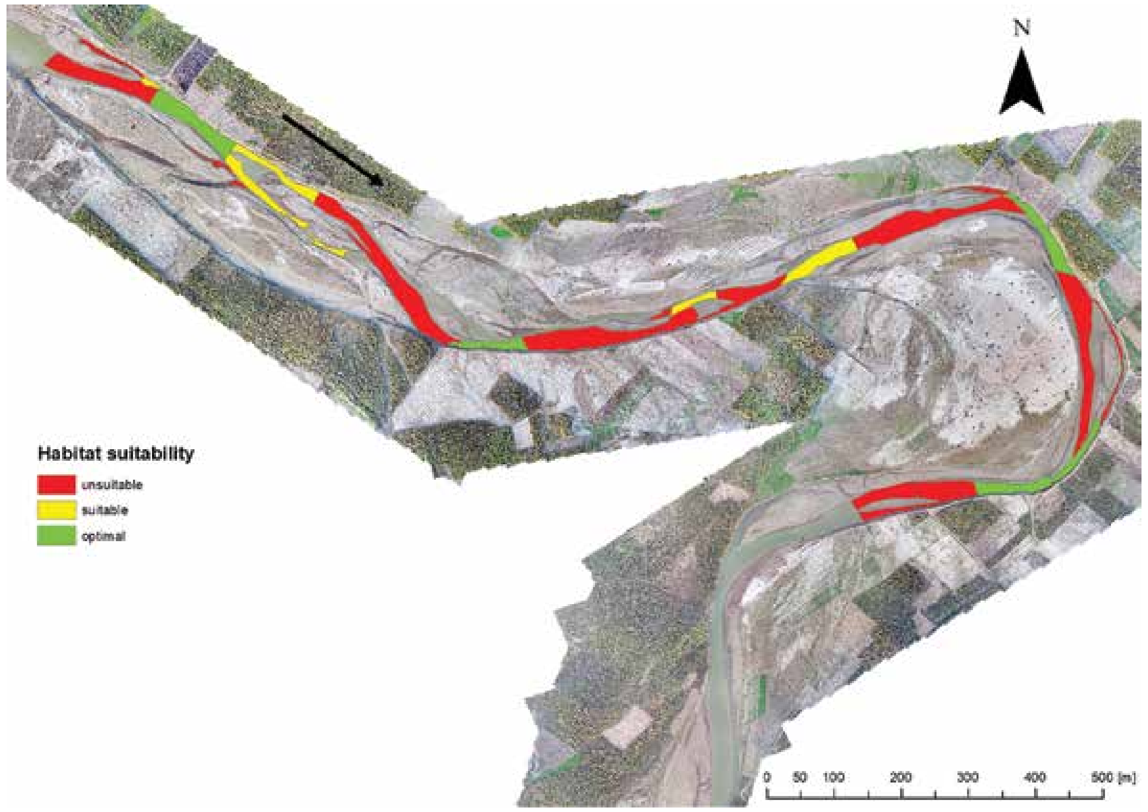


Figure 21. Habitat suitability distribution for Habitat Use Guild of Rheophylic water column preferring sandy-gravel bottom substrate species at flow of 1 m3/s.

The amount of Effective Suitable Area for each species or HUG is calculated for each flow by weighting optimal and suitable habitat with factors .75 and .25, respectively. This assures that not only quantity but also habitat quality is maintained.

The habitat model predictions should be verified though field observations of fish with 100 samples. Habitat model predictions should be compared with fish abundance. More fish should be found in the areas predicted as good habitat than in those predicted unsuitable (Figure 22). **In almost all optimal habitats fish were caught, most often in abundant numbers.**

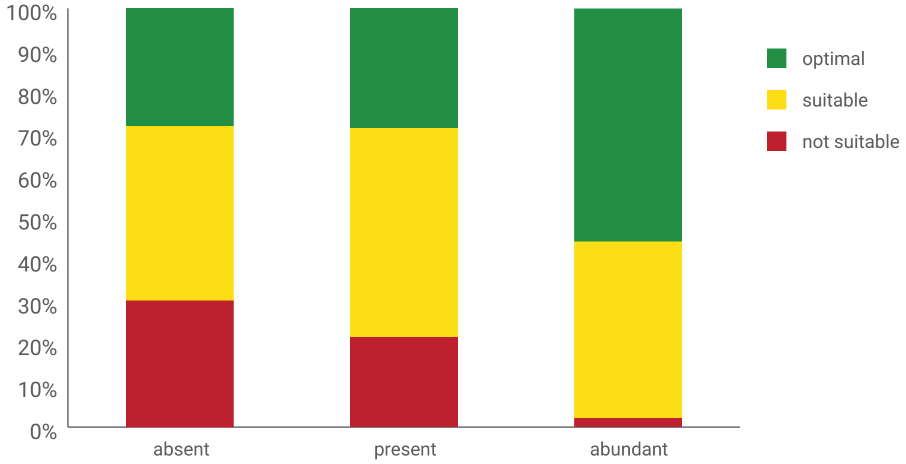


Figure 22. Verification of habitat model predictions by comparing abundance of captured guilds with habitat suitability classes on the Vistula River, Poland

Steps 1 to 4 complete the application of habitat analysis models for the E-Flows assessments. The outcomes of these models can be interpreted in various ways based on their requirements. For example, with given hydraulic settings, channel condition and defined ecological requirements, these model results suggest the best suitable flow range. However, to relate these ranges with hydrological variability of the region, following additional steps can be recommended. With below steps, E-Flows can be defined more intricately to accommodate the hydrological variability and to suggest more clear management objectives for water resources managers/project operators.

4.3.5 Step 5: Analyzing the Static Model

The rating curve plots suitable habitat areas (WUA or Effective Suitable Area) for every species or HUGs life stage present in the bioperiod. Unless single indicator species are used, the rating curves should be generalized to represent a community rating curve for a bioperiod by calculating the sum of the suitable areas for guilds weighted by the expected proportions of guilds (Figure 23).

The flow versus WUA curves may have different shapes and patterns (linear, non-linear, bell-shaped etc) based on hydraulic settings and fish habitat preferences. Based on these shapes and patterns, and an overview of seasonal variations in the flow regime etc, the most optimal combination of flow and habitat condition can be identified as the optimal E-Flows suggestion (see Figure 24).

An additional parameter that can be analysed is similarity of habitat structure to expected fish community structure at different flow conditions. The affinity Index model by Novak and Bodee (1992) calculates the proportion of similarity of two distributions. It can be plotted on the distribution diagram to define at which flow the habitat is best supporting appropriate fish community structure.

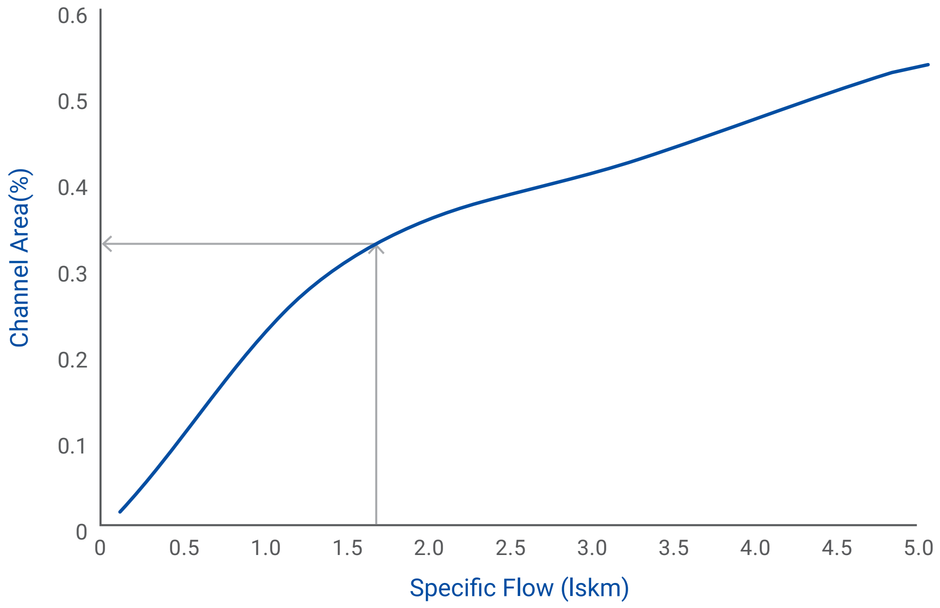


Figure 23. Habitat rating curve for fish communities (example from Vistula River).

The slope inflection point on the curve is at the flows of 1.7 lskm indicating subsistence E-Flows threshold (AMBER 2020).

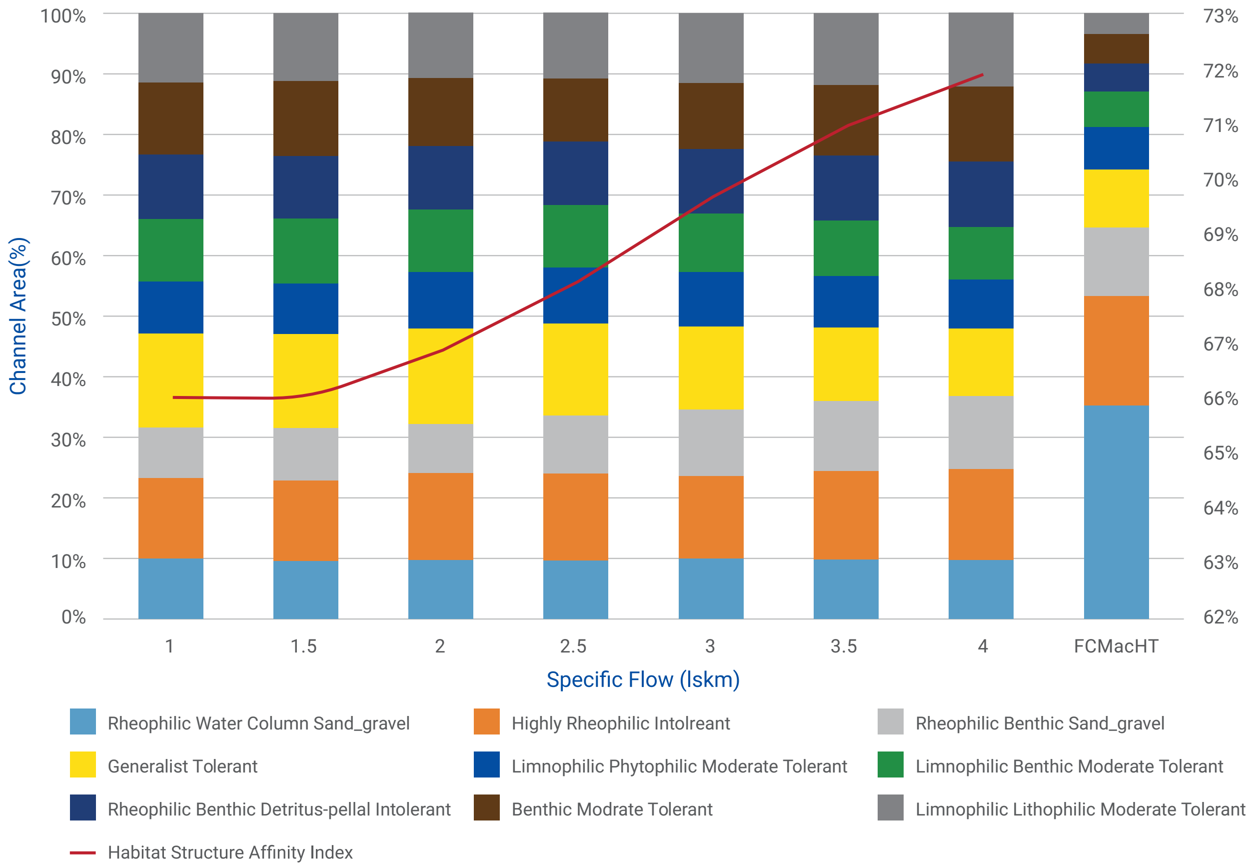


Figure 24. Fish Community Habitat Structure in Vistula River at different flows and its similarity to habitat expectations.

The habitat base flow begins at the inflection point of 3.5 lskm. FCMacHT stands for Fish Community Macro-Habitat Type a standard habitat structure developed for large lowland rivers in central Europe in AMBER project.

4.3.6 Step 6: Establish E-Flows Criteria with Habitat Time Series Analysis

Change in the magnitude, duration and frequency of flows in time is an important feature of rivers. Extreme low and high flows create habitat availability “bottle-necks” that shape the aquatic community. Extreme floods or persistent droughts impact fish fauna composition, but they occur rarely in natural conditions. If such conditions become more frequent the impact may be severe and even irreversible. Water withdrawals for human use increase frequency and duration of droughts and may cause long lasting damage, pushing the populations to the brink of extinction. Hence, ecologically and economically efficient E-Flows management strives to keep naturally rare conditions rare while letting flows fluctuate within natural limits at other times (Parasiewicz 2008a, Parasiewicz et al. 2013).

Quantifying the frequency and continuous durations of naturally occurring droughts allows to identify habitat deficits that shape aquatic communities. Available habitat area associated with infrequent, persistent droughts is assumed to be a limiting factor for fish communities.

Historical flow records and habitat rating curves are used to calculate habitat time series describing habitat availability patterns in the past. Moreover, the analysis allows to define boundaries between rare and common habitat availability conditions.

The Uniform Continuous Under Threshold (UCUT) method is applied to identify thresholds representing bottle-necks in habitat availability (Parasiewicz 2008a). It is a habitat duration analysis, designed to represent how often long continuous events with low habitat availability occurred in the past. UCUT curves are similar to flow duration curves, except that continuous duration of subsidence of habitat magnitude is plotted instead of flow magnitude. The frequency patterns of UCUT curves help to identify thresholds for rare (i.e. subsistence) and common (i.e. habitat base) events. For each threshold, the UCUT analysis indicates the longest **allowable** (before becoming persistent) and shortest **catastrophic** durations. Catastrophic durations, by definition, do not occur more often than every 10 years.

Four E-Flows thresholds are introduced (see Ramganga case study report for biological justification):

- **Subsistence flow** provides survival conditions for the fish community;
- **Habitat base flow** offers stable and sufficient living conditions for the fish community;
- **Trigger flow** alerts for management actions preventing subsistence conditions;
- **Absolute minimum** is the lowest flow on record.

These thresholds are calculated for each bioperiod and presented together with associated habitat area and allowable and catastrophic duration as E-Flows management criteria (see Table 7).

Table 7. An example of E-Flows management criteria calculated for Vistula River, Poland, from UCUT analysis. %CA-(Percent Channel Area) need not sum to 100%.

RIVER	VISTULA
Rearing and growth of the fish community	**July-September**
Watershed area (km^2) at gauging station	172000
Habitat base flow(l/s/km^2)	**3.80**
Common habitat (%CA)	46
Allowable duration under (days)	44
Catastrophic duration (days)	92
Trigger flow (l/s/km^2)	**1.80**
Critical habitat (%CA)	35
Allowable duration under (days)	31
Catastrophic duration (days)	61
Subsistence flow (l/s/km^2)	**1.58**
Rare habitat (%CA)	34
Allowable duration under (days)	7
Catastrophic duration (days)	31
Abs. Minimum (l/s/km^2)	**0.62**

4.3.7 Step 7: Formulation of Management Rules

To aid dynamic E-Flows management, the information from Table 6 is used to develop diagrams for quick assessment of current conditions. So called ACTograms are a graphic representation of the above thresholds (Figure 25). Observed flow conditions can be plotted on this diagram specifying for how long (y-axis) flows were lower than chosen value (x-axis).

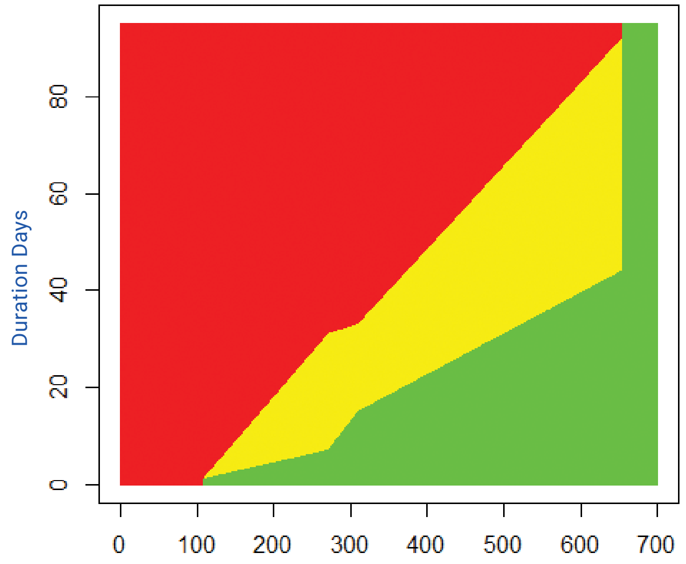


Figure 25. ACTogram for Lower Vistula River during growth season

For example, if flow measured in the river is under a threshold300 l/s for a continuous duration of20 days, it plots the event in the yellow field and defines it as a persistent event. If the event lasts for more than 35 days, it becomes catastrophic. To prevent damage to the fish community, the following rules need to be followed:

1. Catastrophic events cannot happen more often than once in every 10 years.
2. Three persistent events in a year are equivalent to catastrophic duration event.
3. The flows cannot be lower than Absolute Minimum.

To prevent a second catastrophic event in a decade an operator can:

1. Release habitat base flow from an upstream reservoir for two days bringing the reading back into the green field.
2. Stop water withdrawals during persistent duration events.
3. Improve habitat structure to provide low flow refuges, i.e., increase habitats available under lower flow conditions.

This system has been proposed in a number of studies (eg. Ballesterro et al. 2006, Parasiewicz et al 2007, 2008, 2010) and is currently applied for E-Flows management in the State of New Hampshire, USA (Parasiewicz et al 2008). Figure 26 demonstrates the potential implications of such management on the example of Mienia River in Poland. The horizontal lines present all four thresholds such as those in Table 6. The red vertical squares indicate the times when a management action is needed, because the criteria have been violated (e.g. flows were lower than trigger flow for longer than allowable duration). In other times, no action is required.

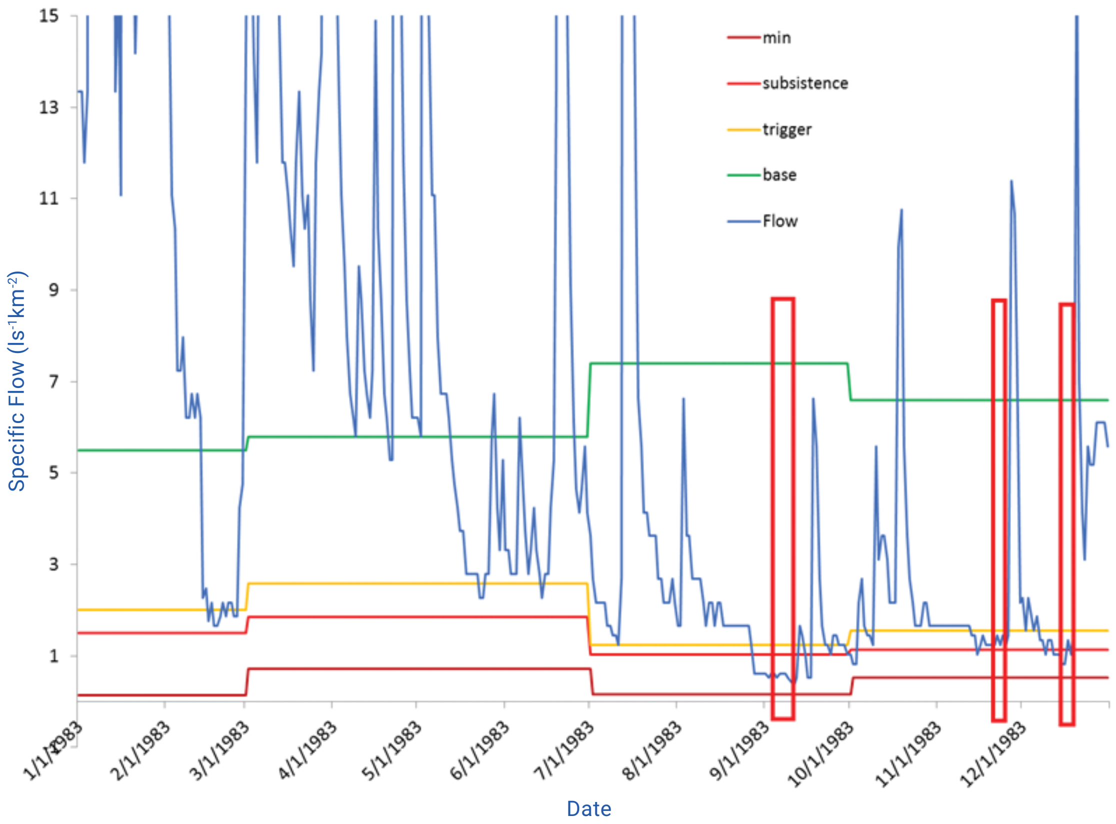


Figure 26. Example of application of dynamic augmentation rules in E-Flows management.

The management actions (indicated by red rectangle) are introduced when flows are below the yellow line for longer than 10 days.

05

ROAD MAP TO FURTHER ADVANCE THE E-FLOWS ASSESSMENT METHOD

Bharathapuzha River, Kerala

5.1. Rationale to Further Advance the Indian E-Flows Method

The assessment of E-Flows has become an implementation priority in Indian water resources management to ensure adequate and continuous flows in rivers as well as to support sustainable management of rivers. As described in **Chapter 3**, the ***Hydraulic Rating cum Habitat Simulation Method*** is currently implemented by the Indian water authorities to assess E-Flows in Indian rivers, including the Ganga. It can be clearly said that a lot of efforts have been invested so far to develop the Indian method in response to the legal requirement regarding E-Flows assessment and to enable its implementation at earliest convenience. A good basis has been successfully established. As discussed in previous chapters and in **Table 4**, any of the three methods namely the Hydraulic Rating cum Habitat Simulation Method, PHABSIM Model and MesoHABSIM Model may be utilized for E-Flows assessment in the Indian conditions depending upon the data availability, type and size of river reach, ecological as well as socio-economic importance, the availability of resources and related costs etc.

Still, as next steps over the upcoming years, it is considered important to invest further efforts to advance the current Indian E-Flows assessment method towards European and international best-practice standards. Table 4 of this guidance document compares different E-Flows assessment approaches including the Indian method as well as international ones. The Hydraulic Rating cum Habitat Simulation Method, currently being commonly used in India, follows a hydraulic rating approach linking abiotic assessment with simplified biotic criteria. It has its strengths and weaknesses. The methodology has low ability to cover the full complexity of ecosystems and biological requirements. However, it is easy to apply at wider scale.

For more complex and sensitive reaches, and to move to implementation, it is recommended to build the capacity and use the advanced E-Flows assessment methods in coming years, moving towards best-practice habitat modelling. This will enable best-possible assessment results, the setting of best-optimized, cost-effective improvement measures with aim to ensure adequate flows in Indian rivers.

This chapter outlines the benefits of advancing the current method and presents a Road Map (**Chapter 5.3** and **Table 8**) with key steps to enable this improvement of the method.

5.2. Benefits to Further Advance the Indian E-Flows Method

Advancing the current E-Flows assessment method also brings along several key benefits:

- **Step-wise alignment to EU and international best practice and implementation in parallel** In addition to using the current E-Flows assessment method, it is recommended to use advanced habitat models for the assessment of E-Flows in ecologically important and complex reaches to align with EU and international best practice. This will not only help in assessment of E-Flows in a more reliable way using best international practices/models but also in capacity building and creating awareness in the collection of habitat data in a systematic and scientific aligned way.
- **Protect and enhance aquatic biodiversity and natural heritage in Indian rivers:** India possesses abundant freshwater ecosystems that are home to a high biodiversity of plants and animals. Healthy aquatic biodiversity and natural heritage are crucial for a functioning environment, ecosystem services and socio-economics. A further advanced E-Flows assessment method, which fully takes into account biological habitat conditions and needs will be helpful to significantly support the protection of biodiversity as well as any restoration and river rejuvenation efforts.
- **More precise E-Flows recommendations, which facilitate stakeholder involvement and alignment to future requests of water users:** The results of E-Flows assessments usually bring along regulatory measures and notifications to ensure adequate flows in rivers. Habitat analysis methods precisely quantify the habitats corresponding to certain flow conditions and, hence, elaborate a more precise discharge schedule to ensure adequate flows. This translates to more precise and reliable figures for water available to other uses. Greater precision and reliability also minimize possible economic impacts for water users. Hence, stakeholder confidence, involvement and consultation will be improved through the development of habitat analysis methods.
- **Integration of E-Flows Assessment into River Basin Management to improve capacities:** As described in the concluding Chapter 6, E-Flows assessment should be integrated into river basin planning and management processes. Adopting a more precise method will help in building confidence in inter- and transdisciplinary exchanges with various stakeholders. In addition, the results of a more advanced E-Flows assessment will support the future development of River Basin Management Plans in India and, hence, significantly support strategic planning and decision-making when it comes to securing water quantity in Indian rivers today and in the future subject to climate change.
- **Available EU and international support to develop the current method and to develop capacities:** Several international programs and projects including the India-EU Water Partnership, the Indo-German Cooperation (Support to Ganga Rejuvenation Project) as well as the World Bank (The Second National Ganga River Basin Project) consider E-Flows assessment as a key topic for support to India. Related activities are supporting the piloting and development of the improved E-Flows assessment method, stakeholder involvement as well as capacity development and training. In summary, these activities will support the stepwise advancing of the current method.

5.3 Road Map to Further Advance the Indian E-Flows Method

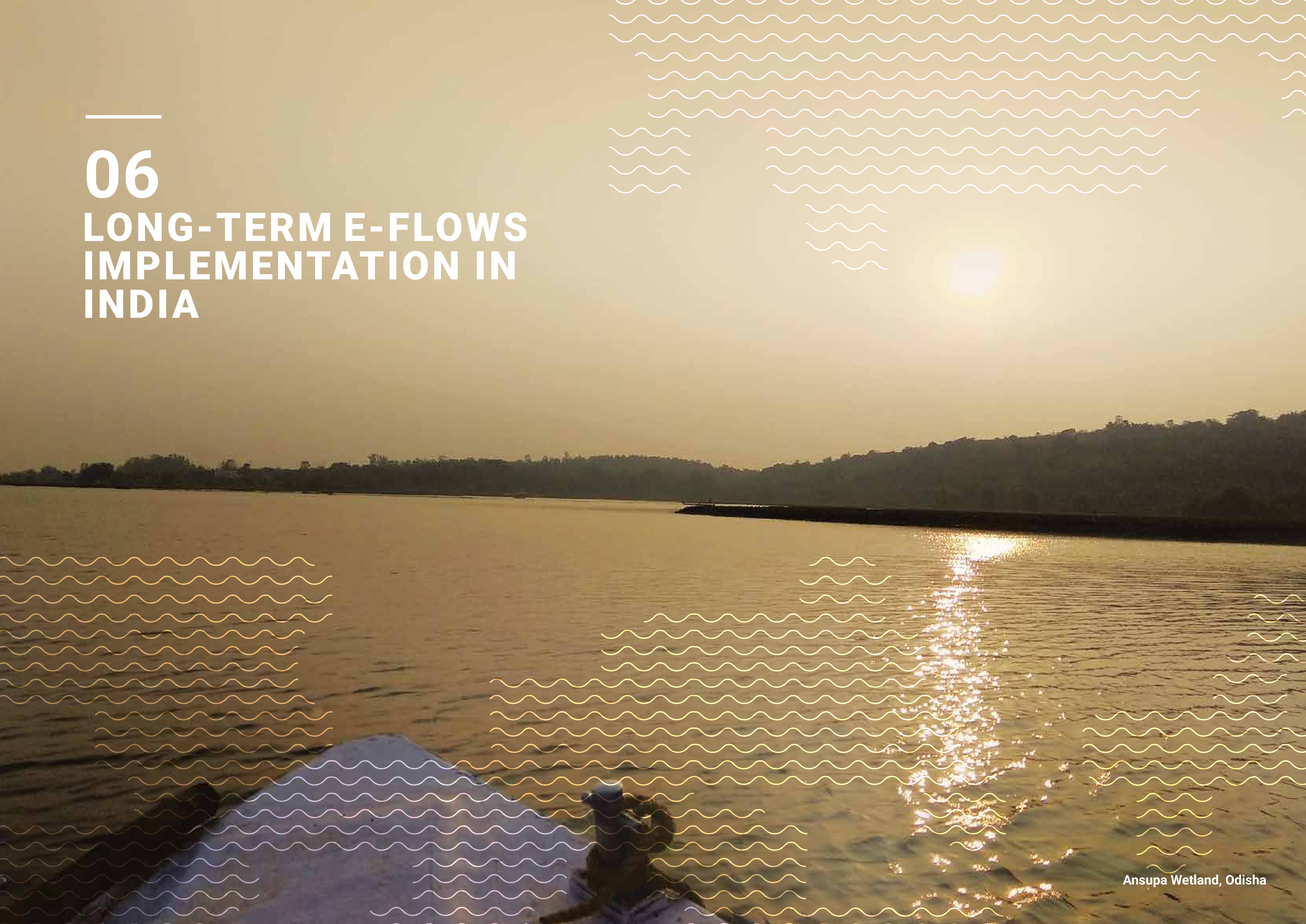
Table 8 presents the Road Map (2020 to October 2023), which outlines activities that will support the improvement of the current E-Flows assessment methods towards European and international best practice. The continuous improvement of the current E-Flows assessment method will be based on pilot testing in a Ganga River sub-basin and be accompanied by stakeholder involvement, capacity analysis, development and trainings. The precise Road Map will be evolved in consultation with the Indian partners under the IEWP Phase 2.

Table 8. Road Map to adapt and advance the current E-Flows method from 2020 to October 2023.

2020	1 JANUARY 2021 - 30 SEPTEMBER 2023	JUNE 2021 - 30 SEPTEMBER 2023
NOVEMBER/ DECEMBER: **Launch** the E-Flows Guidance Document that was developed under the IEWP. **Ensure** a plan to promote the E-Flows Guidance Document **Detail** the Road Map with the Indian IEWP partners towards implementation **Start** discussing and planning the trainings for advanced E-Flows assessment tools.	**JANUARY – MARCH 2021:** **Initiate** new activities under the IEWP Phase 2 and German Cooperation Support to Ganga Rejuvenation Project. **Reconfirm** IEWP nodal officers for joint technical E-Flows Working Group. **MARCH/APRIL 2021:** **Select** a pilot test sub-basin in the Ganga Basin to assess E-Flows towards measure setting (NMCG/CWC). **APRIL/MAY 2021:** **Conceptualise** the pilot testing. **Define** clear joint aims including the improvement of the E-Flows Assessment methods and guidance document. **Conceptualise** and plan the stakeholder involvement in the Ganga sub - basin to ensure joint planning and decision making	**Initiate** the stakeholder involvement **Undertake continuous** stakeholder involvement towards joint planning and decision making
	JUNE 2021: **Start** pilot testing **Perform** continuous pilot testing in Ganga sub-basin involving an interdisciplinary team and present results in regular frequency: **APRIL/MAY 2022:** **Present** and discuss first results from pilot testing involving all stakeholders **JANUARY 2023:** **Present** and discuss draft final results and propose draft measures to implement suggested E-Flows. **MAY 2023:** **Present** and discuss final results & suggest final measures to implement suggested E-Flows.	**Implement** the current Hydraulic Rating cum Habitat Simulation Method and international best-practice habitat modelling methods to assess E-Flows in a Ganga sub-basin. **Document** the learnings and improvement needs. **Continuously adapt and improve** the current Hydraulic Rating cum Habitat Simulation Method towards best practice habitat modelling **Present** the improved method to relevant Indian authorities and institutions
		Capacity analysis and planning for the future implementation of advanced/ improved E-Flows assessment method through Indian authorities **Continuous training and capacity development** for the future implementation of advanced/improved E-Flows assessment

06

LONG-TERM E-FLOWS IMPLEMENTATION IN INDIA



Ansupa Wetland, Odisha

The increasing demand for water due to population growth, rapid urbanization and industrialization is putting rivers, their ecosystems and ecosystem services under immense pressure. Insufficient flows and their impact on water security can also increase the risk of negative economic effects and social tension. Hence, the protection, improvement and management of water quantity are essential to manage sustainable use of water resources, to prevent further deterioration as well as to ensure long-term and safe access to water. The National Green Tribunal calls for a full implementation of E-Flows in Indian rivers. The robust E-Flows assessment is an essential step to achieve the above aims. Strategic planning will be needed to ensure the precise E-Flows assessment and, thereby, adequate amounts of water in the Indian rivers.

The Road Map presented in the previous section lays out several actions for the next three years. The following key points address needs and actions for longer-term implementation of E-Flows in India:

Integration of E-Flows into River Basin Management

The basin level is the most appropriate spatial scale to manage water resources and assess trade-offs between different sectors including environmental needs for the entire basin. Inter- and transdisciplinary expert teams including hydrological, hydraulic, ecological, geomorphological, socio-cultural and economic aspects should work together. The formation of a management authority for the basin-wide level is essential for such multidisciplinary interactions and decision making for the optimal use of water resources in a basin on a sustainable basis. Through integrated planning at the basin level, E-Flows objectives and allocation limits can be set holistically from the very beginning. Moreover, savings options and reallocation of trading mechanisms for E-Flows implementation can be established in the best way.

In the longer-term, E-Flows assessment should be fully integrated into water resources and river basin planning and management processes (River Basin Management Plans - RBMPs) rather than be implemented as a stand-alone approach or included in only selected river basin management plans. Best results can be achieved if the situation of water quantity in the river and its alteration from E-Flows are assessed and understood for entire river basins to address critical E-Flows reaches with the most effective improvement actions in a holistic way. Furthermore, RBMPs provide options for validating implemented E-Flows against ecological and socio-economic objectives. In this regard, RBMPs are an essential tool in basin-wide approaches. These can be adopted and implemented by River Basin Organizations (RBOs).

Integration of E-Flows into a Holistic Data Framework for Well-Informed Management

It is needed to integrate E-Flows into a holistic data framework for well-informed and scientifically-grounded flow management. The framework should include a database containing all the existing and future information needed for the E-Flows assessment process in India. This tool should allow integration of the current datasets of multiple agencies into a single platform accessible by all stakeholders, while also remaining flexible and allowing integration of new relevant data such as satellite images or citizen data. Finally, data should be successful E-Flows implementation.

Capacity Building for E-Flows Implementation

Long term capacity development should be arranged for required personnel. This includes the allocation of financial means to ensure additional expert staffing and technical support needed for E-Flows assessment. E-Flows implementation should be followed by regular flow monitoring and ecological health assessment in impacted and reference conditions to validate or, if necessary, adjust environmental and/or socio-economic objectives.

Responsibilities Regarding Long-term E-Flows Implementation

E-Flows should be implemented step-by-step in all affected rivers based on the level of alterations and priorities in terms of conservation significance, etc. E-Flows implementation requires the strengthening of institutional framework to deal with the new situation. The administrative, institutional, technical and financial means should be provided to make E-Flows implementation effective. This involves clarity of administrative responsibilities at national, state and regional level and capacity building of involved institutions (administration, education, practitioners).

Establish Common E-Flows Objectives, Targets and Goals through Stakeholder Involvement

Stakeholders should be involved in the E-Flows process to develop a mutual understanding on targets and objectives. Experts in communication and transdisciplinary processes may assist in bringing together various disciplines and enhancing the overall understanding of trade-offs on how available water can be used to reach a desired target status. E-Flows targets should be measurable and include economic, social and environmental values. The consensus and understanding of river ecological targets should be strengthened regarding ecological status and reference conditions measured v ia biological quality elements.

07
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ANNEX-I

INTERNATIONAL CASE STUDIES

Gira Falls, Gujarat

Case study 1: Gaiá River, Spain (European Commission, 2014.)

Gaià River is a highly seasonal Mediterranean river with low average annual flows (0.25 m3/s) and small catchment area (422 km2), located in Catalonia, NE Spain. A large dam (Catllar dam) was built in 1976 on the lower Gaià River to store water. Eighty per cent of the stored water is used by an oil refinery owned by Repsol and 20% is used for irrigation. No water was released from the dam after it was built, leaving an 11 km long reach to completely fall dry. Requirements of the new EU WFD, and growing social concern for environmental protection, forced the Catalan Water Agency (ACA) and Repsol, who is also the holder of the Catllar dam, to begin a process to release a suitable E-Flows without significant unsustainable additional costs.

An agreement was reached in 2010. E-Flows were calculated in the whole Catalan River Basin District using hydrological methods. Results were later validated using the Instream Flow Incremental Methodology (IFIM), which included fish habitat modelling. Several E-Flows allocation options were analyzed and assessed, considering technical, economic and administrative issues. The main objective was to establish E-Flows with minimum economic impact on current uses. The study revealed that the Catllar reservoir was highly inefficient when water storage was managed at high water levels or volumes, mainly due to the high local geological permeability. Thus, the conclusion was to manage the reservoir at low water levels, which will allow the release of E-Flows as well as the decrease of water loss due to infiltration. ACA conducted an analysis of the historical management of the reservoir and designed a model to predict the evolution of the reservoir level based on the management carried out so far. This model allowed comparing the evolution of the reservoir with or without E-Flows according to different water level scenarios. After many technical meetings between the water authority and Repsol, a satisfactory agreement was reached to release E-Flows without significant water supply losses or additional costs by managing Catllar reservoir at low water levels. To achieve this, additional purified water from the urban wastewater treatment plant at Tarragonawas used to meet requirements of industrial water (Figure 27).

A technical committee (Repsol–ACA) was created to monitor the compliance and follow the agreement. TheE-Flows regime has been restored and tested in the lower Gaià River, combining minimum in-stream flows together with controlled small released floods according to the natural flow regime upstream. Over 20% of natural discharge has been released downstream the Catllar dam in terms of E-Flows during 2011 to 2013, without any relevant cost and impact on the industrial activity.

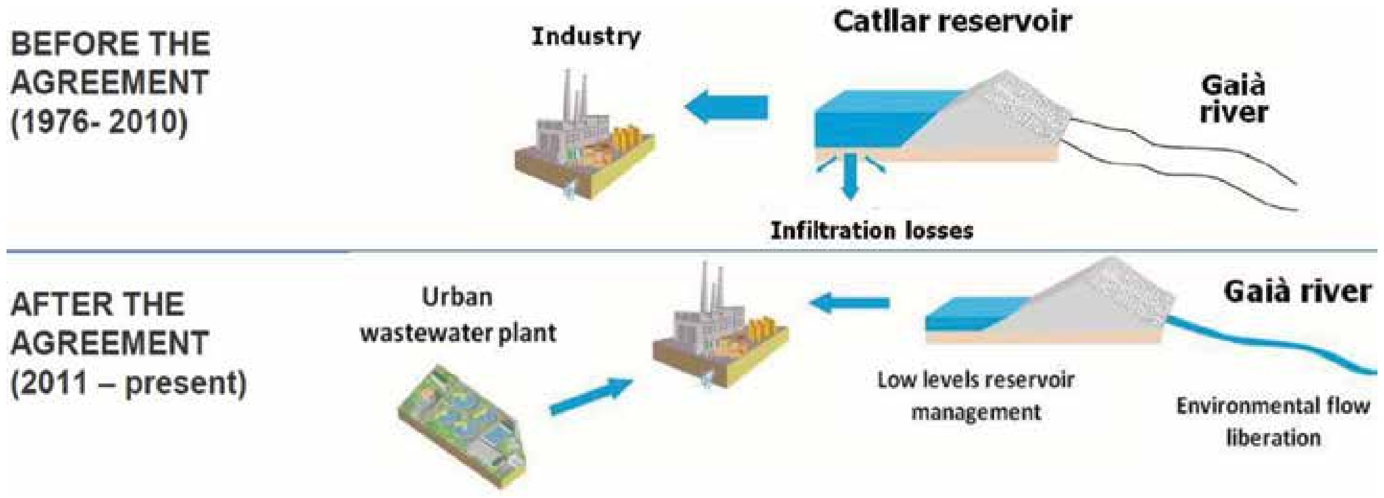

Figure 27. Gaiá River E-Flows implementation strategy (WFD, 2014)

Case study 2: Aabach Reservoir, Germany (European Commission, 2014.)

The security of water supply for millions of inhabitants was the main focus of reservoir operations in mountainous areas of Germany where groundwater extraction is not possible. With the introduction of the German standard specification for dams (DIN 19700) and the Water Framework Directive (2000/60/EC) (WFD), aspects like the ecological status of the downstream reaches also became more important. Therefore, it became necessary to release E-Flows to meet legislated minimum ecological requirements.

In particular, the following two aspects were important: i) The water consumption per capita was already reduced to 120 L per day in Germany, and the total losses in the drinking water networks were reduced to less than 7%. As the reservoir volume is used for E-Flows releases, water allocations can affect the security of the drinking water supply in a whole region. Furthermore, the management of the drinking water reservoirs is also determined by water quality aspects. During the summer period, the reservoir is thermally stratified. The raw water should usually be extracted from the hypolimnion to meet acceptable conditions for water purification. To avoid a collapse of the hypolimnion, typically the reservoir volume should not be lowered under a certain water level. This important boundary condition for providing potable water limits the degree of water release for other purposes.

To overcome these problems, attempts were set up for managing several drinking water reservoirs. One of the most elaborated case studies is the application of E-Flows at the Aabach Reservoir in North-Rhine Westphalia, Germany. A variety of field tests were conducted to find the basic requirements for the E-Flows. During the field tests, the local flow pattern as well as the behaviour and development of fish (trout) and macroinvertebrates(zoobenthos)were analysed. On this basis, a concept for the necessary E-Flows was developed and implementation outcomes of the E-Flows regime was tested, whereby the study reach extended 20 km downstream from the Aabach reservoir. The study started in 1991 and was completed in 2004. Since then, status assessments have been conducted nearly every year.

The entire project had four distinct phases. In phase I, a two-year preparatory study was conducted. In this stage, water releases from the reservoir ranged from 20 l/s up to 3,000 l/s. During this time, the effects of these different water releases on aquatic biota and physicochemical conditions in the downstream sections of the Aabach river were measured. Additionally, the structural quality of the water body was examined.

In phase II, an operational E-Flows model was developed. The aim was that the E-Flows regime should emulate the typical seasonal flow pattern and to estimate the effect of dynamic flow releases on the biota and the hydro-morphology in the downstream river sections. A fixed artificial flush was designed to investigate the large-scale effect of a flood release. The developed concept of E-Flows was tested for a sufficient security of drinking water supply with the help of long-term reservoir simulations.

In phase III, the fixed artificial flush was modified to an artificial flood wave since fish damage can occur if the flood flush is too fast. To avoid this, the shape of the artificial flood wave was adjusted to be more similar to natural flood waves in the Aabach catchment, thereby allowing fish and macroinvertebrates to reach stagnant water zones in time.

In the earlier phases of the project, the important role of local flow diversity on biota was recognized. To quantitatively assess the effect of local flow diversity, deadwood was placed in a 90 m-long river section. The conditions of hydro-morphology, especially the structural quality of the water body, were mapped during nearly half a year after the installation of woody debris. To study the hydraulic effect of the different measures, several approaches (e.g. Gippel et al., 1996) were implemented in the hydraulic model STAU from Braunschweig University. Hydrological reservoir simulations were carried out with the model WinMBM. Also, the status of water quality (saprobic index) and the fish population (electrofishing) were assessed. The results show that the developed E-Flows regime, together with the placement of woody debris, has significantly positive effects: The structural quality of the water body improved by one level. The saprobic index increased from class II (moderately polluted) to class I-II (slightly polluted). And even though the monitoring period was short, a positive effect on the trout population could be detected.

In the last phase, the developed E-Flows continued to be released and further hydro-morphological measures were designed, especially at sites along the downstream river with poor ecological conditions. Also, a final inventory and evaluation of the hydro-morphological and biological state of the river was carried out. Coupling of E-Flows (seasonally variable flows and near-to-nature floods) with hydro-morphological measures helped to reduce the demand of water for the E-Flows to only 10 % of the available mean annual water resources in the Aabach catchment and also, the abundance of trout could be doubled within one decade.

These results show that a monthly varying minimum discharge together with an artificial flood during autumn and accompanying hydro-morphological measures in the downstream river sections can increase the ecological status of the river significantly. The water demand for the necessary E-Flows covers only 10 % of the available water resources in the Aabach catchment and does not endanger the security of water supply in quantity and quality. This example shows how E-Flows can be established without reducing the security of water supply of a drinking water reservoir under the normal spread of hydrological conditions. The developed E-Flows concept for the Aabach Reservoir is in operation since the completion of the study in 2004.

Case study 3: PHABSIM Application-Lemhi River, Idaho, USA

As per the recommendations of the Federal Columbia River Power System Biological Opinion (FCRPS BiOp), the Bureau of Reclamation (Reclamation), U.S. Army Corps of Engineers and Bonneville Power Administration support the implementation of salmonid habitat improvement projects in Columbia River Basin tributaries. This includes a suite of actions to protect salmon and steelhead listed under the Endangered Species Act (ESA).

Among the eight sub-basins of Columbia River Basin, in which a total of 23 fish-habitat improvement projects were completed in 2015, Lemhi sub-basin (Salmon River Tributary) included a total of eight projects (Bureau of Reclamation, 2016). The Lemhi River basin was historically one of the most important spawning areas for migratory salmonids; however, multiple factors that contributed to the significant decline in fish production from historic conditions were reported (Uthe et al 2017). The 2000 BiOp identified it as a priority sub-basin (where addressing flow, passage, and screening problems could produce short term benefits) and the 2004 BiOp restated the objectives in terms of specific metric goals for entrainment (screens), stream flow, and channel morphology (passage and complexity). For determining the E-Flows that will satisfy the Endangered Species Act (ESA) requirement, the PHABSIM methodology was suggested (Morris and Sutton, 2007).

• Study sites

Hawley Creek and Eighteenmile Creek (Tributaries of Lemhi River) were identified as priority streams (based on inventory and assessment needs) to conduct habitat studies to identify stream flow needs to support relevant life history stages of summer steelhead (Oncorhynchusmykiss), spring/summer Chinook salmon (O. tschawytscha), and bull trout (Salvelinusconfluentus) as well as macroinvertebrates. For these two creeks, investigations were performed during the summer and fall of 2006. There were four study sites on Hawley Creek and six study sites on Eighteenmile Creek. For each creek, the most-upstream study site was a reference site, upstream of a major diversion. Other study sites were selected in relation to the locations of diversions. Limiting factors for fishes in these sites were found to be flow, summer temperature, and sedimentation in the lower reaches. In upper reaches (upstream of diversions), self-sustaining fish populations existed, and water was available throughout the year.

• PHABSIM data collection and modelling

PHABSIM requires hydraulic and habitat suitability data to determine the E-Flows requirements for the species and/or life history stage of interest.

Hydraulic data were collected in terms of i) cross sections located based on physical and hydraulic features of each habitat type and ii) the flow depths, velocities, substrate and cover conditions at various points along each cross section.

i. Habitat types (mesohabitats) were classified, mapped and inventoried as i) riffles (slope), ii) glides/runs (slope), and iii) pools (backwater) in the study sites using "cumulative-lengths approach" described by Bovee (1997). Linear distance of each major habitat type was recorded, and the total number of each habitat type and its total length mapped were recorded. The mapped data were used to determine percentages of each habitat type to decide the location of cross-sections. Additional sections were placed at hydraulic controls by professional judgment to aid in hydraulic calibrations.

ii. Depths were measured using a top-setting wading rod. Mean column water velocity was measured using a Marsh McBirney Flo-Mate 2000 velocity meter attached to the wading rod. Velocity calibration sets were collected at three different time periods. Substrate and cover for PHABSIM were visually assessed using a system developed by EA Engineering. Although cover was measured, it was not used in the model.

Habitat suitability data were given in the form of Habitat Suitability Criteria Curves (see section 2.1.2). While it is generally recommended to develop site specific criteria curves, curves developed previously were used due to the limitations in time and resources.

PHABSIM modelling was performed the using above data and application of weighting factors to some cross-sections based on site specific settings. The relationships between flow discharges and Weighted Usable Area (WUA) were obtained for all the species (for adult and spawning life stage) (Figure 28). Apart from this, discharge required for adult fish passage (0.6 foot depth criteria) with >25% of total channel width and >10% of contiguous channel width were computed.

It was found that for Hawley Creek, flows that produced optimal habitat ranged from 5 cubic feet per seconds (cfs) for bull trout adult at Study Site 3 to over 30 cfs for bull trout adult at Study Site 2. Minimum discharge required for adult salmonid passage ranged from 5 to 15 cfs at Study Sites 1 and 2, respectively. For Eighteenmile Creek, flows that produced optimal habitat ranged from 4 cfs for macroinvertebrates at Study Site 4 to over 46 cfs for steelhead, Chinook, and bull trout adults at Study Site 6. The minimum discharges required for adult salmonid passage at Study Sites 1 and 6 were 9 and 16 cfs, respectively.

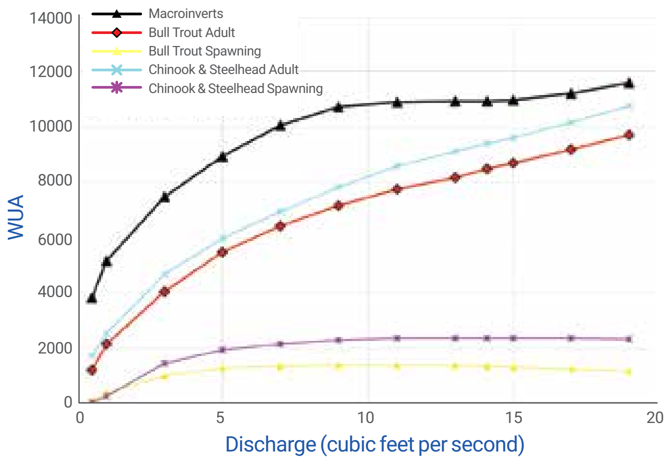

Figure 28. Example of combined Species weighted usable area (WUA) versus discharge relationships in Hawley Creek, Study Site 1.

During the implementation for habitat improvement, various changes in the structures/patterns, locations and flow release patterns of the diversion units have been made to increase the habitat access and water quantity etc. For example, Upper Hawley Creek Water Rights Transfer (LHaC-03) project ensured that 1.5 miles river length was made accessible up to the next upstream barrier and the streamflow of 5.3 cfs has been made available for 0.7 miles downstream to the next diversion. Hawley Eighteenmile Intercept/Irrigation Project ensured that 1.5 miles length is made accessible to the next upstream barrier (LHaC-01 Diversion), the ditch entrainment is eliminated (new point of diversion has been screened) and the streamflow of 1.65 cfs is available for 1.5 miles downstream to the next diversion. (refer to Bureau of Reclamation, 2016, for further details on restoration actions)

A detailed procedure was developed and followed for monitoring the effects of restoration actions from 2008 through 2016 (Uthe et al 2017). It has been found that restoration efforts in the Lemhi River basin are substantial enough to elicit local responses of multiple species and life stages of salmonids, but they have not resulted in a basin-scale response. The most noteworthy responses to restoration actions have been exhibited by juvenile salmonids. Restoration has caused an increase in summer rearing capacity of Chinook salmon. Specific large-scale projects are needed in the lower Lemhi River to increase winter survival. The indication that age-1 Chinook salmon smolts may be increasing as a result of restoration actions in the upper Lemhi River underscores the importance of maintaining the existing monitoring framework into the future. The initial responses to restoration are encouraging, but full understanding of fish population and habitat responses in the Lemhi River will require monitoring for an additional 10 to 15 years.

Case study 4: MesoHABSIM Application-New Hampshire, Nebraska US and Poland

The Niobrara watershed covers approximately 32,600 km^2, mainly within northern Nebraska, USA. The river is of an alluvial type that can be divided into three broadly defined river regions: a braided region, a canyon-restricted region, and a region with wider valleys and increased sinuosity (Alexander, 2009). The Niobrara River's water source is primarily ground water seepage from underlying geological formations, but seasonal precipitation patterns are also a vital component to the hydrography (Istanbulluoglu, 2008). Anthropogenic diversions within the basin include dams and irrig ation reservoirs along with groundwater wells. All of these uses have the ability to change the river and the surrounding ecosystem.

In determining the riverine habitat characteristics and the habitat required for various faunal species within the basin MesoHABSIM was applied (Parasiewicz, 2007). Sixteen sites and sections were chosen after reviewing the extensive USGS data set, and by conducting a reconnaissance survey. Due to expected differences in fish communities, the 16 sections were grouped into three study segments based in part on the similarity of their fish communities.

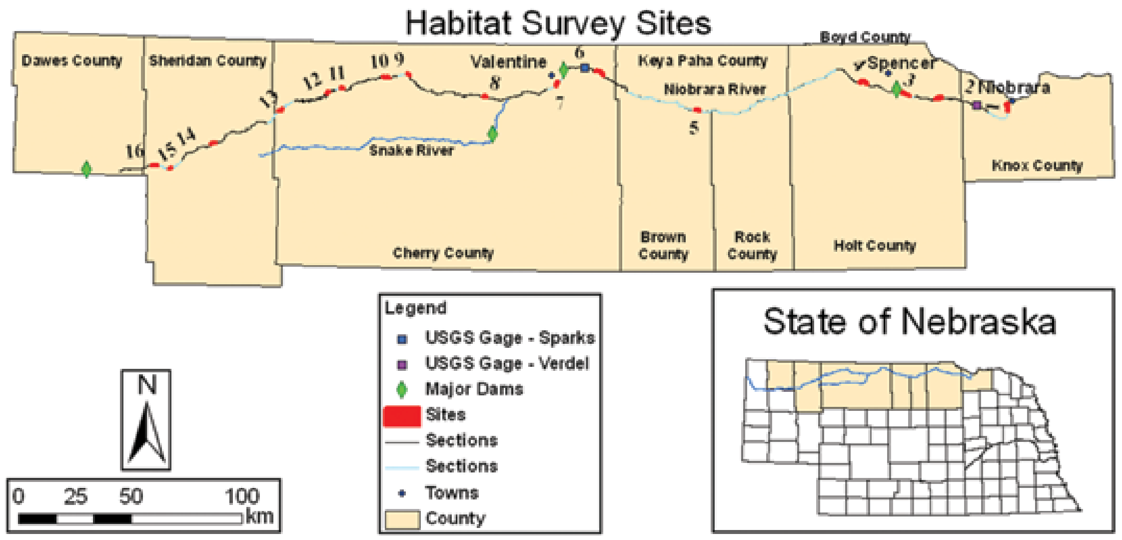

Figure 29. Niobrara River Study area with locations of sites, sections and 3 segments.

Habitat availability was modelled for species of interest, which serve as indicators of habitat conditions necessary for protection of aquatic communities within the Niobrara River Basin. Thirteen of the geologically, hydraulically, and geographically distinct study sites were sampled to develop the Expected Fish Community (XFC) as a starting point to model habitat availability for target species. Five fish guilds were developed (e.g., groupings of similar habitat uses: Lobate Margin, Run, Riffle, Slackwater, and Habitat Generalist.) to further characterize the habitat needs of fish in the Niobrara River. Furthermore, three avian species (Whooping Crane, Piping Plover, and Interior Least Tern) were considered target species. Faunal habitat needs vary seasonally due to different life stages (e.g., spawning or over-wintering) as well as changing environmental conditions. E-Flows can be developed for each of these periods (Parasiewicz, 2008). Table 9 shows the bioperiods for the Niobrara Study area used for the project.

Table 9.Bioperiods of the Niobrara study area

BIOPERIOD	START DATE	END DATE	INDICATOR
Early spawning	March 1st	May 14th	Generic Resident Adult Fish
Late spawning	May 15th	June 30th	Generic Resident Adult Fish
Summer Rearing and Growth	July 1st	September 30th	Generic Resident Adult Fish
Overwintering Early	October 1st	December 31st	Flows
Overwintering Late	January 1st	February 28th	Flows

Habitat suitability criteria used to evaluate the habitat quality in the mapped areas of the river were established from empirical data collected in the Niobrara River, as well as through literature review and the input of expert opinion. The amount of habitat determined to be suitable in the river was quantified for each in habitat rating curves. In addition to curves for individual species, rating curves for Community Habitat, Generic Fish, and Generic Fish Plus were calculated (Parasiewicz, 2007). Rating curves for Community Habitat are constructed by weighing the suitable habitat area of each species by its expected proportion in the community, while Generic Fish Habitat curves represent the total amount of habitat area that is suitable for all of the species in the investigated community (Figure 30). Generic Fish Plus Habitat includes habitat for the additional species of special concern that were not included in the XFC.

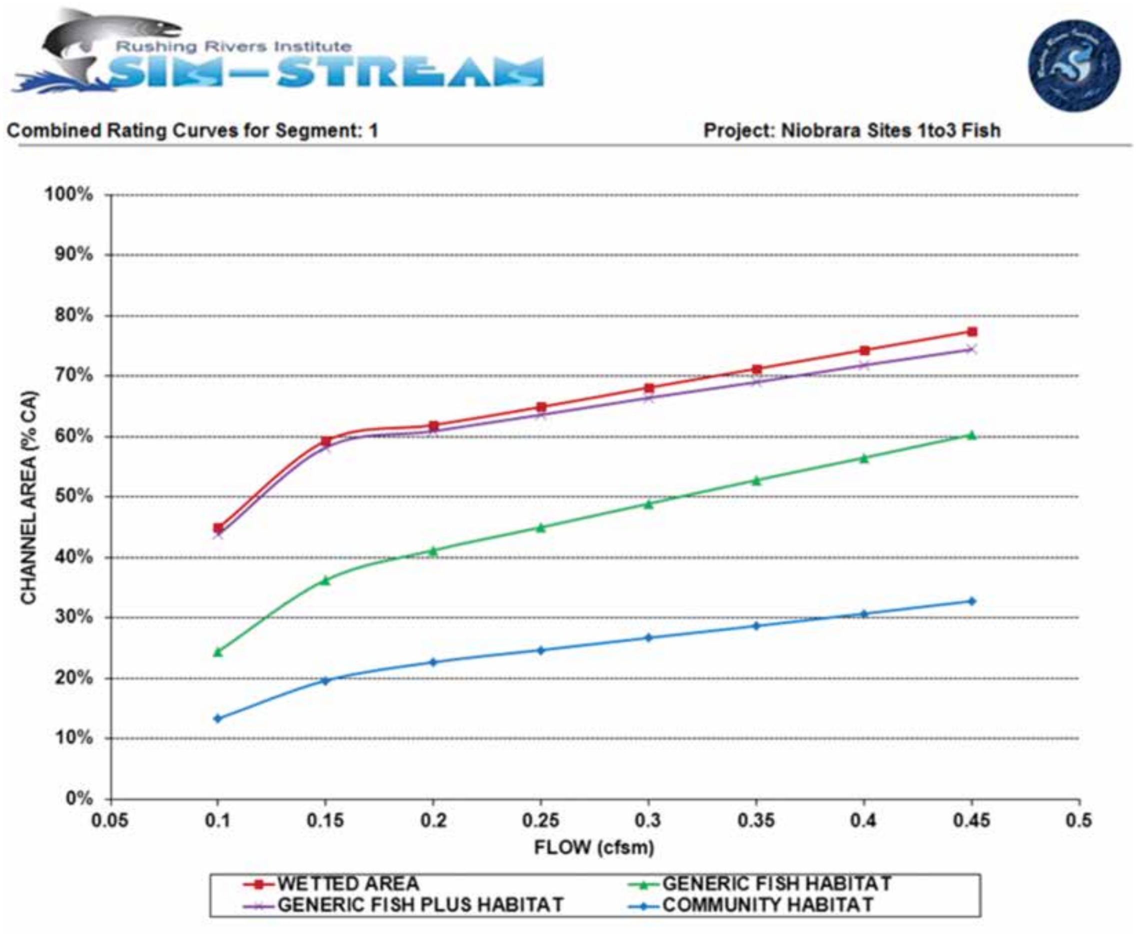

Figure 30. Community rating curves for Segment 1 (Sites 1-3) in the Niobrara River.

The habitat models documented a substantial amount of habitat for aquatic fauna in the Niobrara River. As demonstrated by the habitat rating curves for the Generic Fish Plus community, almost the entire wetted area can be utilized by the extended fish community. However, there are areas in the river that are not used by Generic Fish.

Scientists analysed the correspondence between the distribution of habitat at surveyed flows and the proportions of guilds in the community. The similarity between the habitat structure and the guild community structure is measured with the help of an affinity index (AI) model (Novak and Bode, 1992). The study's affinity index values are mostly high, and AI's above 70% are usually observed in healthy rivers. It was therefore concluded that the overall habitat distribution is appropriate to support the expected fish community.

The determination of E-Flows thresholds comes from comparing the timing and magnitude of the flow needs for fish, riparian vegetation and wildlife and human uses. The selection of the highest flow need as the protected flow magnitudes are tempered by the description of allowable and catastrophic "under threshold" durations keyed to their natural range of occurrence. However, specific interannual flow needs of entities other than fish are incorporated in E-Flows recommendations.

Three flow thresholds, marking significant changes in the frequency of habitat availability, are selected to represent the protected flows. The three flow magnitudes of E-Flows are named: common, critical, and rare (later renamed to habitat base, trigger and subsistence flows).

- **The base flow** is the flow corresponding to the highest habitat magnitude above which the frequency of occurrence begins to decline significantly with incremental increase in habitat magnitude.
- **The critical flow** is the flow corresponding to the second to the lowest habitat magnitude for which the frequency of occurrence increases significantly with incremental increase in habitat magnitude. Critical flow magnitudes describe less habitat availability than that provided by the common flow, but this habitat magnitude is not unusual.
- **The rare flow** is the flow corresponding to the lowest of habitat magnitudes for which the frequency of occurrence increases significantly with incremental increase in habitat magnitude. Rare flow habitat availability is severely reduced and very uncommon.

Analysis of the habitat time series documented typical habitat fluctuations that fish fauna would expect to experience in the river. The seasonal flow thresholds enveloping rare and common conditions for fish and avian species are presented in Tables 10 and 11.

Table 10. Selected flow thresholds for fish in Segments 1 and 2 of the Niobrara River using the Verdel USGS gage

BIOPERIODAPPROXIMATE DATES	REARING & GROWTH JULY 1 - SEPT. 30	R & G GENERIC PLUS JULY 1 - SEPT. 30	OVERWINTERING EARLY OCT.1 - DEC. 31
Location Verdel Gage	Threshold Flows	Threshold Flows	Threshold Flows
Base Flow (cfs)	1725	1806	1969
Allowable duration under (days)	32	32	45
Catastrophic duration (days)	92	92	92
Trigger Flow (cfs)	718	695	1158
Allowable duration under (days)	8	7	9
Catastrophic duration (days)	16	11	18
Subsistence Flow (cfs)	625	637	926
Allowable duration under (days)	5	4	6
Catastrophic duration (days)	8	8	10
Minimum Flow (cfs)	338	338	200
Bioperiod Approximate dates	**Overwintering Late January 1 - February 28**	**Ealy Spawning March 1 - may 14**	**Late Spawning May 15 - June 30**
location Verdel Gage	Threshold Flows	Threshold Flows	Threshold Flows
Base Flow (cfs)	2084	2270	2270
Allowable duration under (days)	21	18	20
Catastrophic duration (days)	59	55	47
Trigger flow (cfs)	926	1390	1204
Allowable duration under (days)	7	7	7
Catastrophic duration (days)	8	11	11
Subsistence flow (cfs)	695	1297	1100
Allowable duration under (days)	4	3	6
Catastrophic duration (days)	5	8	9
Minimum Flow (cfs)	240	430	646

Table 11.Selected flow thresholds for the modeled bird species in the Niobrara River using the Verdel USGS gage.

BIOPERIOD APPROXIMATE DATES	CRANE APRIL 1 - APRIL 30	PLOVER MAY 1 - AUGUST 31	PLOVER MAY 1 - AUGUST 31	CRANE OCT.1 - OCT. 31
Location Verdel Gage	Threshold Flows	Threshold Flows	Threshold Flows	Threshold Flows
Base Flow (cfs)	1806	1424	1818	1714
Allowable duration under (days)	11	24	34	18
Catastrophic duration (days)	17	68	81	31
Trigger Flow (cfs)	1552	961	695	1540
Allowable duration under (days)	6	15	9	5
Catastrophic duration (days)	11	35	11	9
Subsistence Flow (cfs)	1332	903	591	1332
Allowable duration under (days)	3	14	6	4
Catastrophic duration (days)	5	28	8	6
Minimum Flow (cfs)	705	338	338	683

Each flow magnitude is further characterized by two durations: allowable and catastrophic. The durations define limits on the consecutive days when flow is below a protected flow magnitude. Stream flow at levels below a protected magnitude for durations shorter than the allowable duration is acceptable and is a common condition. Flow below a protected magnitude for durations longer than the catastrophic duration is unacceptable and triggers management. Flow below a protected magnitude for more than the allowable duration, but less than the catastrophic duration is a persistent condition. A persistent condition that occurs for three consecutive years within the same bioperiod is a catastrophic condition and triggers management on the inception of an event on that third occurrence. Flow durations are reset by a two-day increase in flow above the next higher flow magnitude threshold. These reset events can be naturally or artificially created increases. Flow durations are reset at the beginning of a new bioperiod.

The proposed flow values served as a foundation for granting Instream Flow Permit to the Nebraska Game and Parks Commission. Appropriation A-19406 was approved for seasonally adjusted flow amounts to coincide with the different life cycle stage needs of the fishery, including overwintering, spawning, rearing and growth. The flows also will meet habitat needs for whooping crane migration in spring and fall, and piping plover and least tern nesting in spring and summer.

The State of New Hampshire, in North-eastern United States, legislature created the **Instream Flow Program in 1990,** applying instream flow protections to the state's 9 Designated Rivers. As a pilot two rivers, the **Lamprey** and **Souhegan,** were selected as the subjects of in-depth pilot studies to determine how best to protect flows so that both human and wildlife needs can be met.

E-Flows were defined in the study for flow-dependent protected entities grouped as fish, riparian wildlife and vegetation, and human uses. Protected instream flows for fish were developed using MesoHABSIM, and those for riparian wildlife and vegetation were developed using a floodplain transect survey method. Flow needs for the human recreational (boating and swimming) and water supply uses of flow were developed using questionnaires and surveys. The flow requirements for fish, riparian wildlife and vegetation were found to be the determinant factors for E-Flows because of their dependence on specific flow magnitude, duration and frequencies to support habitat and life cycle needs. The human recreational uses of flow are considered to be opportunistic, meaning that boating and swimming are seasonal uses supported by recurring natural flows. The use of the Souhegan and Lamprey Rivers as a water supply source is also considered to be flow dependent since sufficient flow must be available to meet public water supply needs.

The calculated and implemented E-Flows values you can find under ***Protected Instream Flows for Fish and Aquatic Life on Lamprey Designated River***

The proposed protected instream flows have been already introduced with the Water Management Plans for both rivers. Management actions are implemented to offset catastrophic conditions. The instream flows defined for Fish and Aquatic Life are assessed on a day to day basis to determine whether flows below thresholds exceed catastrophic durations. Flows that continue below thresholds beyond allowable durations are tracked. Persistent events are tracked on an inter-annual basis and will be deemed catastrophic if they occur in three consecutive years within the same bioperiod, with management actions triggered (such water released from upstream impoundments) at the beginning of the onset of the third event under these flow conditions. Increased frequency of catastrophic events calls for long term measures such as habitat improvement that will reduce the recurrence interval of the catastrophic events.

NHDES adopted the Lamprey River and Souhegan River Water Management Plans in August 2013 and continues to work with affected water users and dam owners to help them comply with the plans. Based on two years of water management plan implementation, NHDES produced the 2015 Report of the Instream Flow Pilot Program, making recommendations on how to apply instream flow protections to all of New Hampshire's Designated Rivers. These recommendations resulted in legislation in 2016 and revised rules in 2018 to allow expansion of the Instream Flow Program to more rivers.

Building on the experience of the Niobrara, Lamprey and Souhegan project the concept of E-Flows for Poland has been developed, also to be implemented in future legal regulations. This study also conducted a test pilot investigation but goes step further to create country wide E-Flows scheme. The work performed in the pilot phase focuses on the method development applying MesoHABSIM approach on 7 water bodies and creating a conceptual framework for upscaling of the results to all rivers in the country. Subsequently the validity of the concept is tested and verified on additional 36 rivers.

Following strategy is created to perform this upscaling task:

Fish inhabiting Polish rivers are separated into several groups with different habitat preferences - habitat use guilds. The basic parameters of differentiating habitats suitable for different groups of species are the flow velocity and water temperature, oxygen conditions and substrate type and size.

To provide E-Flows criteria taking into account the needs of different life stages, the year is divided into 3-4 bioperiods: spring spawning, rearing and growth (R&G), fall spawning (salmonid rivers only) and overwintering. In each bioperiod a guild-based fish community structure has been established for each of the clusters. Based on literature review interpreted by the experts from Stanisław Sakowicz Inland Fisheries Institute a Conditional Habitat Suitability Criteria (CHSC) were developed for each of the guilds.

A non-hierarchical cluster analysis of guilds distribution in data from 406 water bodies produced six fish ecological types of water bodies: 1) upland streams, 2) flysch rivers, 3) lowland streams, 4) lowland rivers, 5) lake connectors with salmonids, 6) rivers connecting lakes, peat bogs and estuaries. The selection of appropriate sites representing water body types was conducted with help of a multi-scale hierarchical framework described in Gunnel et al 2015. E-Flows criteria are developed for each site as described above.

To allow to transfer the values obtained from pilot water bodies it is necessary to correct for regional hydrological variability. Hence, calculated E-Flows are standardized by catchment area and by bioperiod's specific mean low flow (q_{MBLF}). We named the product an index p_b. In this way it is possible to calculate simplified E-Flows in any cross-section k of flow gaged catchments by multiplying p_b by catchment specific q_{MBLF} and the upstream catchment area.

The formula for simplified E-Flows for any cross-section *k* of a catchment is established as:

$$Q_{sef,k} = p_b \cdot q_{MBLF,k} \cdot A_k$$

where

p_b = tabulated value of index obtained from pilot studies specific for bioperiod and fish ecological river type (see table 12)

$q_{MBLF,k}$= specific mean low flow for the bioperiod at the cross-section **k**

A_k = catchment area at the cross-section **k**

In the ungauged catchments, calculation of q_{MBLF} is complicated due to lack of data. As approximation we can use specific mean annual low flow (q_{MBLF}) that can be obtained from runoff maps.

It has to be mentioned here that for application of adaptive E-Flows the subsistence and ecological base flow are calculated following the same formulas hence replacing q_c with corresponding specific flow values. After verification on 36 water bodies and the original p-indices per water body type are revised using all 40 samples.

Table 12. Index p for ecological trigger flows for fish biological water body types, Poland.

P_b Based on mean annual low flow				
FISH BIOLOGICAL WB TYPE	SPRING SPAWNING III - VI	REARING & GROWTH VII - IX (X)	FALL SPAWNING X (XI) - XII	OVER - WINTERING I - II
1	1, 45	1,23	1,38	1,32
2	1, 35	0,93	0,95	1,57
3	1, 38	1,13	1,74	1,70
4	1, 14	0,81	1,56	1,58
5	1, 21	1,11	1,37	1,34
6	0, 93	0,88	1,22	1,42

Sensitivity analysis is also performed by comparing the variability of E-Flows calculated for rivers of the same fish biological type and comparing it with values obtained in the same sites using 3 more methods: Kostrzewa (Kostrzewa 1977), Wetted Perimeter (CDFW, 2013) and Critical Riffle Analysis (CDFG 2012). MesoHABSIM based model have shown very high stability of the results (Figure 31).

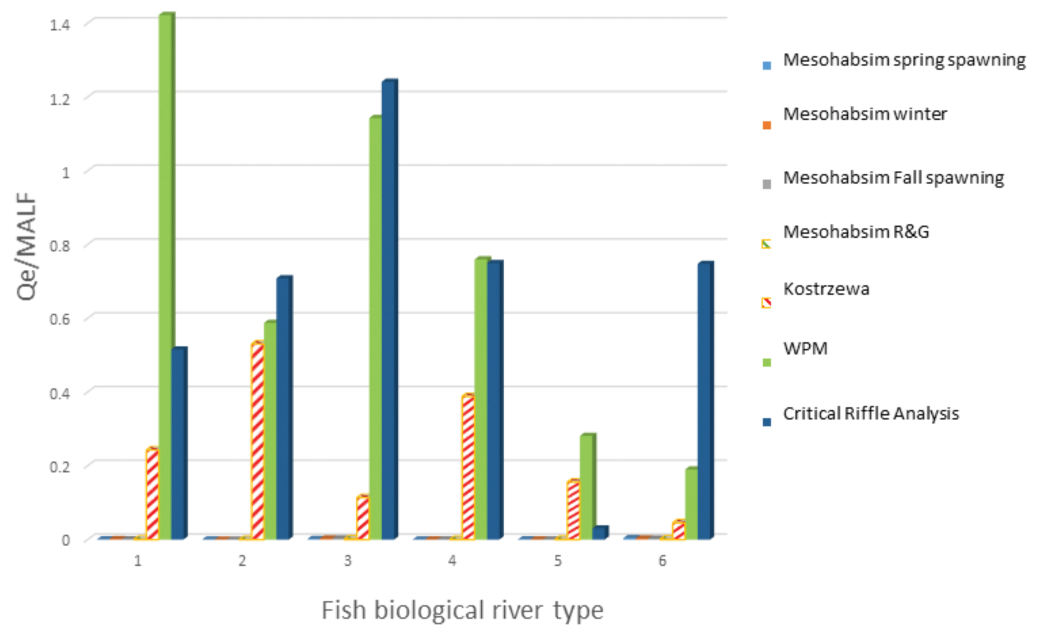

Figure 31. Comparing standard deviation of based E-Flows within each biological type using MesoHABSIM, Kostrzewa, Wetted Perimeter (WPM) and r2 Cross method.

The study also documented that in comparison with an application of simplified E-Flows, an adaptive system will reduce the need to limit water withdrawals. This is due to the fact that at flows lower than trigger flows an intervention would not be necessary until the persistent duration of such event is exceeded. Exceptions are the events of catastrophic duration, which have to be avoided if they appear for the second time in a decade. Adaptive E-Flows management reduces the number of shut-off days by at least three quarters of the time. On the Skawa River it is, for example, 3% instead of 12% of the cumulative duration of interventions occurring for constant E-Flows.

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