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Environmental Flows

State-of-the-Art with special reference to Rivers in the Ganga River Basin

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GRB EMP : Ganga River Basin Environment Management Plan

by

Indian Institutes of Technology

IIT Bombay | IIT Delhi | IIT Guwahati | IIT Kanpur | IIT Kharagpur | IIT Madras | IIT Roorkee

Preface

In exercise of the powers conferred by sub-sections (1) and (3) of Section 3 of the Environment (Protection) Act, 1986 (29 of 1986), the Central Government has constituted National Ganga River Basin Authority (NGRBA) as a planning, financing, monitoring and coordinating authority for strengthening the collective efforts of the Central and State Government for effective abatement of pollution and conservation of the river Ganga. One of the important functions of the NGRBA is to prepare and implement a Ganga River Basin: Environment Management Plan (GRB EMP).

A Consortium of 7 Indian Institute of Technology (IIT) has been given the responsibility of preparing Ganga River Basin: Environment Management Plan (GRB EMP) by the Ministry of Environment and Forests (MoEF), GOI, New Delhi. Memorandum of Agreement (MoA) has been signed between 7 IITs (Bombay, Delhi, Guwahati, Kanpur, Kharagpur, Madras and Roorkee) and MoEF for this purpose on July 6, 2010.

Estimates on Environmental Flows or simply E-Flows are a critical input in preparation of the GRB EMP. Not much work has been done on E-Flows in Indian rivers, particularly the rivers in the Ganga Basin. Also, E-Flows assessment is both a social and a scientific process requiring expert knowledge of various fields including, but not limited to hydrology, hydraulics, geomorphology, ecology and biodiversity, socio-cultural, livelihood, and water quality and pollution. Keeping this in view, IIT Consortia has constituted an E-Flows Group with experts within and outside the IIT system.

This report is one of the many reports prepared by IITs to describe the strategy, information, methodology, analysis and suggestions and recommendations in developing Ganga River Basin: Environment Management Plan (GRB EMP). The overall Frame Work for documentation of GRBMP and Indexing of Reports is presented on the inside cover page.

Many of the E-Flows group members participated in a two year long study on estimation of E-Flows in selected stretch of the river Ganga sponsored by WWF – India as part of Living Ganga Project. This study provided opportunity for experts within and outside India to exchange knowledge and experience on the subject and help in selection and adoption of an appropriate methodology. This report heavily draws from the knowledge gained from such pioneering multi-institutional and interdisciplinary study. Many people contributed to the preparation of this report directly or indirectly. A list of persons who have contributed directly and names of those who have taken lead in preparing this report is given on the reverse side.

Dr Vinod Tare
Professor and Coordinator
Development of GRB EMP
IIT Kanpur

The Team

1.	A K Gosain, IIT Delhi	gosain@civil.iitd.ac.in
2.	B S Murthy, IIT Madras	bsm@iitm.ac.in
3.	M D Behara, IIT Kharagpur	mdbehera@coral.iitkgp.ernet.in
4.	N Balaji, IIT Madras	nbalaji@iitm.ac.in
5.	Nitin Kaushal, WWF-India, Delhi	nkaushal@wwfindia.net
6.	P M Prasad, IIT Kanpur	pmprasad@iitk.ac.in
7.	Paritosh Tyagi, Formet Chairman, CPCB Delhi	paritoshtyagi@gmail.com
8.	R H Sidduqui, NGRBA Expert Member	rashidsiddiqi202@hotmail.com
9.	R P Mathur, IIT Kanpur	rpm_2k1@yahoo.com
10.	Rajiv Sinha, IIT Kanpur	rsinha@iitk.ac.in
11.	Ravi Chopra, NGRBA Expert Member	psiddoon@gmail.com
12.	Ravindra Kumar, SWaRA-UP	ravindra53@yahoo.co.in
13.	S K Jain, IIT Roorkee	jainsfwt@iitr.ernet.in
14.	Sandeep Behera, WWF-India, Delhi	sbehera@wwfindia.net
15.	Shivam Tripathi, IIT Kanpur	shiva@iitk.ac.in
16.	Shyam Asolekar, IIT Bombay	asolekar@iitb.ac.in
17.	Vikrant Jain, Delhi University	vjain@geology.du.ac.in
18.	Vinod Tare, IIT Kanpur	vinod@iitk.ac.in

Lead Persons

1. Nitin Kaushal, WWF-India
2. Vinod Tare, IIT Kanpur

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1. Introduction

The modern governance of river basins has shifted towards "Integrated River Basin Management (IRBM)"—an approach that looks at both water and land management to ensure that river systems can be used and developed in a sustainable manner. A critical part of this approach is the assessment and maintenance of Environmental Flows – 'sufficient water to sustain the integrity and functioning of aquatic ecosystems and the associated socio-economic and cultural functions' (UN, 2005).

It is becoming increasingly evident that on regional and global scales, freshwater biodiversity is more severely endangered than that of terrestrial or marine systems (O'Keeffe and Le Quesne, 2009). Freshwater systems are home to 40% of all fish species in less than 0.01% of the world's total surface water, and when water-associated amphibians, reptiles and mammals are added to the fish totals, they together account for as much as one third of global vertebrate biodiversity (O'Keeffe and Le Quesne, 2009). Even at a conservative estimate, there have been global population declines of freshwater vertebrates averaging 55% between 1970 and 2000 (O'Keeffe and Le Quesne, 2009).

The best recent examples of good legislation about consideration of Environmental Flows are from Australia and South Africa. In South Africa, Environmental Flows (called "ecological reserve") have the priority over other water users (Smakhtin, 2004).

Flows – the main driver of biodiversity in rivers

Most rivers around the world are highly variable and unpredictable; animals and plants species that live in them have adapted to sudden extremes such as floods and droughts. As a result, most river ecologists agree that the communities of animals and plants found in riverine ecosystems are largely controlled by physical rather than biological processes (O'Keeffe and Le Quesne, 2009). Thus to maintain freshwater biodiversity, it is necessary to manage the physical and physicochemical processes in rivers. These processes mainly influence water quality, sediment dynamics, and, of course, flow. Flow is the main driver of biodiversity in rivers – it creates the aquatic habitats, brings the food down from upstream, covers the floodplain with water during high flows, and flushes the sediment and poor quality water through the system (O'Keeffe and Le Quesne, 2009).

A recent World Bank document (World Bank, 2008) states that river scientists refer to the flow regime in freshwater systems as a "*Master Variable*" due to the strong influence it has on the other key environmental factors (water chemistry, physical habitat, biological composition, and interactions). During recent decades, scientists have amassed considerable evidence that a river's flow regime – its variable pattern of high and low flows throughout the year, as well as variation across many years – exerts great influence on river ecosystems. Each component of a flow regime – ranging from low flows to floods – plays an important role in shaping a river ecosystem.

2. Environmental Flows – The Concept and its Rationale

Recognition of the escalating hydrological alterations of rivers on a global scale and resultant environmental degradation, has led to the establishment of the science of Environmental Flows (E-Flows) Assessment, whereby the quantity and quality of water required for ecosystem conservation and resources protection are determined. Several attempts have been made to define E-Flows in rivers.

The 3rd World Water Forum held at Kyoto in 2003 defined E-Flows as the provision of water within rivers and ground water systems to maintain downstream ecosystems and their benefits, where the river and underground system is subject to competitive uses and flow regulations. The E-Flows are thus considered as an amount of water that is kept flowing down a river in order to maintain the river in a desired environmental condition. All of the elements of a natural flow regime, including floods and droughts, are important in controlling the characteristics and natural communities in a river.

The 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 IUCN makes a clear conceptual distinction between the water needed to maintain the ecosystem in near pristine condition, and that which is eventually allocated to it, following a process of a holistic assessment for E-Flows.

Section 5.2.5 of National Environment Policy (2006) of India on ‘Freshwater Resources’ calls for promotion of ‘integrated approaches to management of river basins by the concerned river authorities, considering upstream and downstream inflows and withdrawals by season, interface between land and water, pollution loads and natural regeneration capacities, to ensure maintenance of adequate flows, in particular for maintenance of in-stream ecological values, and adherence to water quality standards throughout their course in all seasons’. This typically sets attributes for defining E-Flows.

Brisbane Declaration (2007) defines E-Flows as the quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems.

After critical study of various definitions of E-Flows, the consortia of 7 IITs for preparation of Ganga River Basin Management Plan (GRBMP) concludes that environmental flows refer to a regime of flows that mimics the natural pattern of a river’s flow, so that the river can perform its natural functions such as transporting water and solids from its catchment, formation of land, self-purification and sustenance of its myriad systems along with sustaining cultural, spiritual and livelihood activities of the people or associated population. Considering this following definition for E Flows is considered most appropriate and is being adopted.

"Environmental 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"

3. Overview of E-Flows Estimation Methods

From global experience, the assessment and establishment of E-Flows has significantly contributed to the management of natural resources in a judicious manner. O'Keeffe and Le Quesne (2009) have explained this phenomenon in detail. Some salient points are reproduced as follows for ready reference.

1. The characteristics and ecosystems of rivers are controlled in a very significant way by the flows. A good E-Flows regime mimics all flow variations that are needed to keep the river and all its aspects functioning in a desired condition.
2. E-Flows assessment is both a social and a scientific process. There is no one correct E-Flows regime for rivers – the answer will depend on what people want from a river.
3. E-Flows assessment is based on the assumption that there is some 'spare' water in rivers that can be used without unacceptably impacting on the ecosystem and societal services that the river provides.
4. E-Flows are not just about establishing a 'minimum' flow level for rivers; it actually considers all the elements of a natural flow regime, including floods, diurnal variations, and droughts, as they are important with respect to silt transport and in controlling the characteristics and natural communities of a river.
5. E-Flows don't always require an increase from present flows. In some cases, e.g. where low season flows have been artificially increased by inter-basin transfers or releases from dams for hydropower, the E-Flows recommendations may be for lower flows.
6. E-Flows assessments are also very useful to know the environmental requirements before any development plans are made, so that these flows can be factored into the planning process at an early stage.

In order to reach a consensus about E-Flows, people need to have trade-off between river's natural functions and river's uses such as (i) growing more crops using its water, (ii) generate electricity, (iii) supply towns with water for domestic and municipal purposes, (iv) national/cultural heritage, e.g. river Ganga in India or river Thames in England. This guides in deciding the desired state of the river. In most cases people want to make use of the water and other resources of the river, so they do not want to keep it entirely natural. Also, in most cases (all cases hopefully) they do not want to turn it into a dry river bed or a drain for wastes. Thus the decision is to choose the state of the river somewhere between natural and completely ruined. This is the role of E-Flows assessment. Further, it is also aimed at keeping at least some of the natural flow patterns along the whole length of a river, so that the people, animals and plants downstream can continue to survive and use the river's resources. This is essential for sustenance of the river itself as E-Flows are envisaged to sustain various river functions.

Acreman and Dunbar (2004) state that there is no simple figure which can be considered as E-Flows requirement for a river. It is actually related to number of factors: (i) size of the river, (ii) river's natural state, type or perceived sensitivity, and (iii) a combination of desired state of river and in practice, the uses to which it is put. They have classified the E-Flows settings into two distinct categories, where one of them is called the 'Objective Based Flow-Setting' and the other one is 'Scenario Based Flow-Setting'. Both these categories have merits and limitations. The answer to select the appropriate methodology lies in the requirements and aspirations of the people from their rivers. O Keeffe and Le Quesne (2009) also essentially advocate the same concept.

Objective Based Flow-Setting: In certain cases, people intend to have specific pre-defined ecological, economical and social objectives for the river. In such situations objective based flow setting can be adopted. For applying such an approach, the experts have to build a consensus on desired state of river. An example of such an application is from central valley of Senegal River basin, where the objective is to spare 50,000 hectares of floodplain for flood recession agriculture. As approximately, half the flooded area is cultivated, this equates to inundation of 1,00,000 hectares, which require around 7,500 MCM of water to be released from Manantali dam (Acreman, 2003). WWF-India's study on Assessment of E-Flows in the Upper Stretch of river Ganga also considered objective based flow-setting wherein the geomorphologic, ecological, socio-economic and cultural objectives of the river were first established by the expert groups and then river flow regime is established using hydraulic and hydrologic modeling to meet these objectives (WWF-India, 2011).

Scenario Based Flow-Setting: This is basically an alternative to the above one, where the water managers are able to understand and make decision on water allocations and scenarios for trade offs in managing and balancing the water demands/requirements. For instance – Under the Lesotho Highland Water Project, various scenarios of E-Flows releases from dams were considered. For each scenario, the impacts on the downstream river ecosystems and dependent livelihoods were determined (King *et al.*, 2003). These scenarios permitted the Lesotho government to assess the trade-offs presented by different E-Flows options.

Review of various methodologies developed across the world for assessment of E-Flows

As stated earlier, E-Flows are required for (i) maintaining river regimes, (ii) self purification, (iii) maintaining aquatic biodiversity, (iv) groundwater recharge, (v) supporting livelihoods, and (vi) allowing the river to play its role in cultural and spiritual lives of people. In all contexts, determining E-Flows should be an adaptive process, in which flows may be successively modified in the light of increased knowledge/information, changing priorities, and changes in infrastructure over time.

E-Flows assessment is thus a combination of scientific and social aspects. The scientists can do the best assessment of flow needs, but it won't be implemented unless people know why the flows should be left in the river, and think that it is important to do so. The E-Flows assessment was developed as an eco-hydrological process in the 1970's and 80's. There was a gradual realization in the 1980's that there needed to be a social component to the process – that the stakeholders needed to have a say in the uses and consequent condition of the resource (O'Keeffe, Le Quesne, 2009). But, it wasn't until the 1990's that there has been a full realization that E-Flows assessment is social process with an eco-hydrological process as an essential ingredient.

As the concept of E-Flows has evolved, there has been significant development of approaches to the assessment of E-Flows. There is no one correct E-Flows regime for rivers – the answer will depend on what people want from a river and not just about establishing a 'minimum' flow level for rivers. E-Flows assessments are not just useful on rivers for which the water resources have been developed – it's very useful to know the environmental requirements before any development infrastructure plans are made, so that these flows can be factored into the planning process at an early stage.

Assessment of E-Flows can be referred as to how much water can be withdrawn from the river without disturbing essential flow requirements of the river to an extent that, the specified and valued features of the river and its ecosystem are maintained and not depleted to significant level.

A global review of E-Flows Assessment methodologies by Tharme (2003) reveals that there are more than 200 methodologies, some are very quick modeling or extrapolation methods, requiring no or minimal extra work; others require years of fieldwork and specialists from a number of disciplines. Various E-Flows assessment methodologies can be broadly classified into four categories.

Hydrology-based

Hydrology based methods are confined to the use of existing, or modeled flow data, on the assumption that maintaining some percentage of the natural flow will provide for the environmental issues of interest.

Hydrology based methodologies constituted the highest proportion of the overall number of methodologies recorded with a total of over 60 different hydrological indices or techniques applied till date. Many of such methodologies have become obsolete over time, due to the fact that they are monotonous and there were no provision to integrate other associated aspects, for instance – the ecology, biodiversity, etc.

Hydraulic rating

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

Of the 23 hydraulic rating methodologies reported representing roughly 11% of the global total, most of them were developed to recommend in-stream flows for economically important salmonid fisheries in the United States during 1960s and 70s. These methodologies have been superseded by sophisticated habitat simulation and holistic methodologies in the recent years.

Habitat simulation

These are a development of the hydraulic rating methodologies. With these methods, multiple rated cross-sections are used in a hydraulic model to simulate the conditions in a river reach, again based on wetted perimeter, and average depth and velocity of flow. Habitat simulation methodologies ranked second (28%) only to hydrological methodologies at a global scale. There are about 60 such methodologies recorded throughout the world. These methodologies are more popular in the United States.

Holistic methodologies

These are based on the use of multiple specialists in different fields to provide a consensus view of the appropriate flows to meet a pre-defined set of environmental objectives, or to describe the consequences of different levels of modification to the flow regime. Most of these methods make use of (i) a hydrologist and a hydraulics engineer to provide the baseline data on flows and hydraulic conditions, (ii) freshwater biologists for fish, invertebrates, and riparian vegetation to characterize the requirements of the biotic communities, (iii) a geomorphologist to predict the changes in sediment transport and channel maintenance at different flows, (iv) a water quality specialist, and (v) a socio-economist.

Over the period of time, the primitive methodologies are being replaced by more comprehensive holistic methodologies in the UK, Australia and South Africa. While emphasizing the role of multi-disciplinary expert's team in assessment of E-Flows, Acreman and Dunbar (2004) pointed out that, in earlier days, the opinion of one expert was used to assess E-Flows. However, a better alternative that has gradually replaced earlier methodologies is the use of a multi-disciplinary team, which comes out with E-Flows recommendations, after much needed deliberations and brainstorming. It is largely the holistic methodologies which provide the greater opportunity to have a multidisciplinary team of experts.

The choice of method from the list of various holistic methodologies depends on (a) the urgency of the problem, (b) resources available for the analysis, (c) the importance of the river, (d) difficulty of implementation, and (e) the complexity of the system.

Acreman and Dunbar (2004) state that no single methodology can be considered as the best and all the methods would benefit from further development and refinement. Moreover, the science of E-Flows is still young and much is still to be learnt.

Historically the United States has been at the forefront to develop, experiment and exercise various methodologies for assessment of E-Flows. However, in the recent times, other countries like Australia, South Africa, China, England, New Zealand, Brazil, Japan, Portugal, Latin America, Czech Republic, etc. are also involved in E-Flows assessment and establishment. Geographical distribution of application of various methodologies is presented in Figure 1.

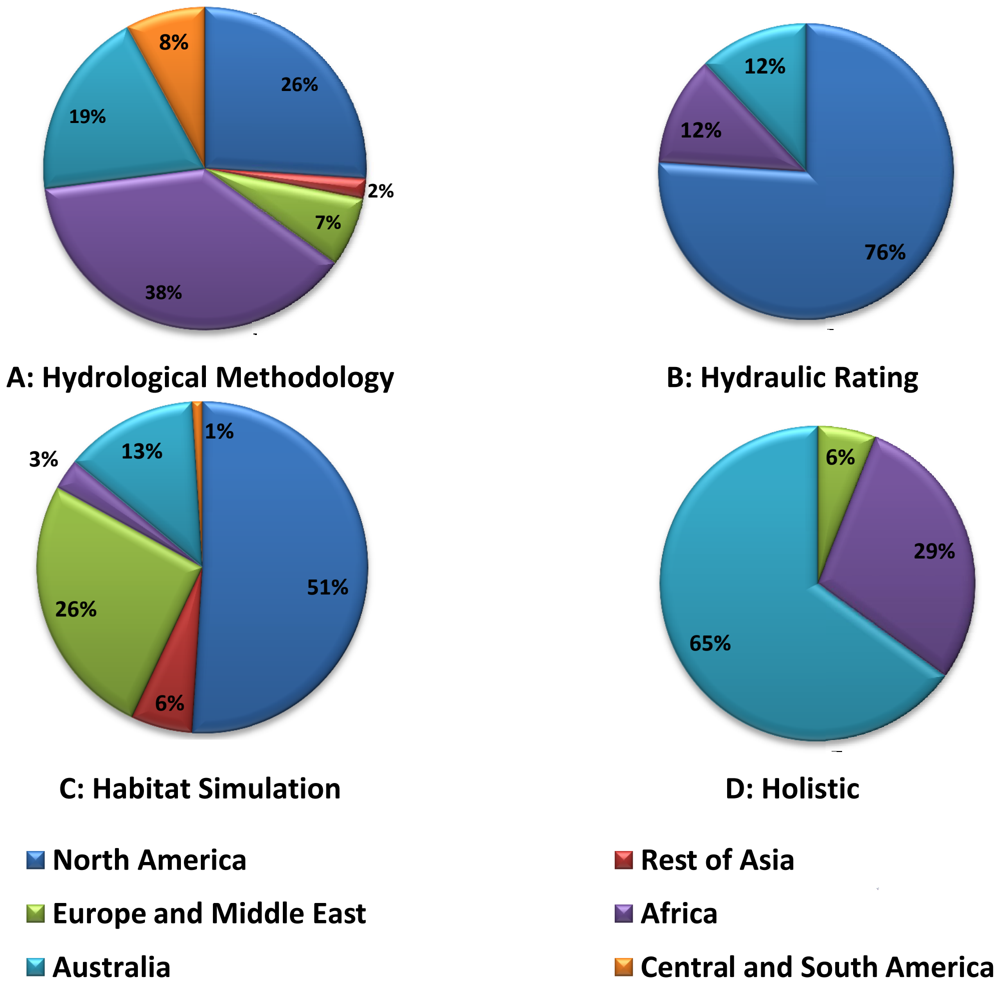

Figure 1: Geographical Distribution of Application of Various E-Flows Estimation Methodologies

A closer analysis of various methodologies for assessment of E-Flows suggests that the simpler and primitive methodologies including hydrology based, hydraulic rating and habitat simulation are getting outdated and various holistic methodologies are replacing them as a comprehensive tool for assessment of E-Flows. An investigation of the different methodologies involving a team of experts from various institutes/organizations and with variety of expertise conducted by WWF-India about three years back suggested that holistic methodologies are most suitable for the rivers like Ganga. Holistic methods are not only comprehensive, but also allow consideration of socio-economic and environmental aspects along with scientific and technical aspects.

4. Comparative Analysis of various Holistic Methodologies for Assessment of E-Flows

Arthington *et al*. (2004) have given detailed account of various holistic methodologies developed and being applied across the world. For sake of brevity, an attempt has been made to present a comparative analysis of various important holistic methodologies in Table 1. Much of the information given in Table 1 has been adopted from Arthington *et al*. (2004).

Table 1: Comparative Assessment of Various Holistic E Flow Estimation Methods

S No	Name of Methodology and its origin	Features and Strengths	Limitations
1	**Expert Panel Assessment Method (EPAM)** (Swales and Harris, 1995). First multidisciplinary panel based E-Flows Methodology developed and used by Department of Water Resources & Fisheries in New South Wales, Australia.	- Low resource intensive - Bottom-up, reconnaissance-level approach - Rapid, inexpensive and site-specific - Requires limited field data - Suitable for sites where dam releases are possible - Aim to address river ecosystem health - Relies on field based ecological interpretations	- Recommendations purely based on opinion of experts and no role of other stakeholders, mainly users - Focused on fish species - No explicit guidelines for application - Subjective scoring approach, so poor congruence in opinion of different panel experts

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S No	Name of Methodology and its origin	Features and Strengths	Limitations
2	**Scientific Panel Assessment Method (SPAM)** (Thoms *et al.* 1996; Cottingham *et al., 2002*) Developed during E-Flows assessment for Barwon-Darwin River system, Australia	- Bottom-up, mixed approach i.e. includes field and desktop - Evolved from EPAM as more sophisticated and transparent expert panel approach - Considers other biodiversity actors like – fish, trees, macro-phytes, invertebrates and geo-morphology - Incorporates systemic hydro-logical variability and elements of ecosystem functioning - Includes stakeholders panel workshop - Moderately rapid, flexible and resource intensive - Simpler, less rigorous in compared to DRIFT and BBM	- appears limited to single application in Australia in its original form - Highly generalized approach - Requires significant modifications before adopting in other river basins
3	**Habitat Analysis Method** (Walter *et al.* 1994; Burgess and Vanderbyl 1996; Arthington, 1998) Developed by former Queensland's Dept. of Primary Industries and Water Resources (now called Department of Natural Resources [DNR]) in Australia, as part of water allocation and management planning initiative.	- Relatively rapid and inexpensive - Basin-wide reconnaissance method for determining preliminary E-Flows requirements at multiple points in catchment - Superior to simple hydrological methodologies - Bottom-up approach, field data requirement is limited or absent - Identifies generic aquatic habitat types existing in the catchment - Determines flow related ecological requirement of each habitat	- Inadequate for comprehensive E-Flows assessment - Little consideration of specific flow needs of individual ecological compo-nents - Requires standard-ization of process - Represents simpli-fied version of holistic approach and largely super-seded by Bench-marking Methodology

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S No	Name of Methodology and its origin	Features and Strengths	Limitations
4	**Benchmarking Methodology** (Brizga *et al.* 2001, 2002) Developed in Queensland by local researchers and DNR in Australia, to provide a framework for assessing risk of environmental impacts due to water resources development at basin level	- Rigorous and comprehensive - Scenario based, top-down approach for application at basin level - Uses field and desktop data for multiple river sites - Assesses ecological conditions and trends - Includes formation of multi-disciplinary expert team and development of hydrological model for catchment - Defines link between flow regime components and ecological processes - Presents a comprehensive benchmarking process and transparent reporting system	- No explicit consi-deration of social aspects - Requires evaluation of several aspects including – (i) applicability and sensitivity of key flow statistics, (ii) degree to which benchmarks from other basins/ sites within basins are valid consi-dering differences in river hydrology and biota - Doesn't provide the room to integrate other local signi-ficant aspects like cultural and spiritual ones
5	**Environmental Flow Mana-gement Plan Method (FMP)** (Muller 1997; DWAF 1999) Developed in South Africa by the Institute for Water Research, for use for intensively regulated river systems	- Simplified bottom-up approach - Applicable in highly regulated and managed river systems with considerable operational limi-tations - Workshop based - Multidisciplinary assessment in-cluding ecologists and system operators - Determines current ecological status and desired future state	- Limited scope for applicability as stru-cture and proce-dures for application are not formalized and well docu-mented - No provision of evaluation, so limi-ted applicability - Not replicable as the methodology is marred with un-certainties

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S No	Name of Methodology and its origin	Features and Strengths	Limitations
6	**Downstream Response to Imposed Flow Trans-formations (DRIFT)** (King *et al*. 2003; Arthington *and Pusey,* 2003) Developed in South Africa with inputs from Australian researchers as an interactive scenario based holistic methodology	- Rigorous, top-down, well-documented approach - Scenario based approach with interactive scenario development - Appropriate for comprehensive exercises for assessment of E-Flows - Mix of biophysical, economical and sociological approach - High potential for application in other aquatic ecosystems - Amendable to simplification for more rapid assessments	- Provides limited consideration for synergetic interact-tions among diff-erent ecosystem components - Requires significant documentation of generic procedures - Limited inclusion of flow indices des-cribing system vari-ability
7	**Flow Restoration Metho-dology (FLOWRESM):** (Arthington *et al*. 1999; Arthington *et al.* 2000) Developed in a study of the Brisbane river in Queen-sland, Australia.	- Suitable for river systems exhibiting a long history of flow regulations and requiring flow restoration - Preliminary bottom-up, field and desktop approach - Emphasize on identification of the essential features that need to be built back into the hydrological regime to shift the regulated system towards the pre-regulation state - More rigorous than expert panel methods - Include flexible top-down process for assessing ecological impli-cations of alternate modified flow regimes	- Risk of inadvertent omissions of critical flow events - Requires significant documentation of generic procedures - Single application in Australia till date

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S No	Name of Methodology and its origin	Features and Strengths	Limitations
8	**Flow Events Method (FEM):** (Stewardson and Cottingham, 2002) Developed in 'Australian Cooperative Research Centre for Catchment Hydrology' to provide state agencies with a standard approach	- Top-down method for regulated rivers - Based on empirical data and expert judgment - Integrates existing analytical techniques and expert opinion to identify vital aspects of flow regime - Assesses ecological impacts of changes in flow regimes - Specifies E-Flows rules and targets - Optimizes flow management rules to maximize ecological benefits within the constraints of existing WRD schemes	- Limited application in other river basins, so far applied in Australia only - No consideration of an associated expert panel
9	**River Babingley (Wissey) Method:** (Petts *et al.* 1999) Developed for application in groundwater dominated rivers in Anglian region of England	- Bottom-up field and desktop approach - Uses hydro-ecological, habitat and hydrological simulation tools to assist in identification of E-Flows - Allows for flexible examination of alternate E-Flows scenarios - Includes provision for both drought and wet year conditions - Considers biota	- loosely structured approach with limited explanation of procedures for integration of multidisciplinary inputs - Specific to base E-Flows dominated rivers - Requires further research in intricate basins - Wider application is very limited

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S No	Name of Methodology and its origin	Features and Strengths	Limitations
10	**Building Block Methodology (BBM)** (King and Louw 1998; King *et al.* 2002) Developed in South Africa by local researchers through applications in numerous water resources development projects to address E-Flows requirements for entire riverine ecosystems under conditions of variable resources. Adapted for intermediate and comprehensive determinations of the ecological Reserves under the new South Africa Water law.	- Rigorous and extensively documented - Manual and case studies available - Perspective bottom-up approach with interactive scenario development - Takes account of number of sites within the critical stretch of the river - Well established socio-economic component - Flexible to accommodate other local aspects, like religious and spiritual requirements (hence applicable for Indian rivers) - Functions well in data-rich and data-poor situations - Multidisciplinary approach with continuous deliberations/ workshops among various experts - Designed to provide specific pre-defined river condition - High potential for application to other aquatic ecosystems - Links to external stakeholders and public participation processes - Less time and cost intensive in comparison to DRIFT methodology - Applicable to regulated and non-regulated river regimes - Globally, most frequently used methodology - Adopted as a standard methodology for South African Reserve determinations	- Moderate to highly resource intensive

In the recent times, as the science of E-Flows has gained significant impetus, the viability and acceptability of various methodologies is being contested. Therefore, there has been changing pattern in the preferences for adoption of methodologies for E-Flows assessment. As a result of this, the researchers, practitioners, academicians and people from the civil society has apparent inclination towards various methodologies falling under the category of 'holistic' ones, for the simple reason that, the methodologies under this category have a comprehensive approach and takes into consideration various associated aspects of a river regime and not only the hydrology and hydraulics. In a nutshell, the process of development of various E-Flows assessment methodologies is an evolutionary one, where a specific methodology takes lesson from previous methodologies and in the process the methodology under consideration gets refined.

Out of the different holistic methodologies, the E-Flows group constituted by the IIT Consortia considers Building Block Methodology (BBM) to be one of the most advanced and refined methodology. Its suitability and applicability with flexibility gives it an edge over other methodologies. The complexity and interests of multi-stakeholders can be handled by the BBM in estimation of E-Flows. Further details on BBM are presented in Appendix I for ready reference.

5. Importance of E-Flows Assessment for Rivers in the Ganga Basin

The spiritual significance of most rivers in the Ganga basin is well known and beyond any doubt. Imperial Gazetteer of India described the Ganga saying: "There is not a river in the world which has influenced humanity or contributed to the growth of material civilization, or of social ethics, to such an extent as the Ganges. The wealth of India has been concentrated on its valley, and beneath the shade of trees whose roots have been nourished by its waters, the profoundest doctrines of moral philosophy have been conceived, to be promulgated afar for the guidance of the world".

The diverse and conflicting demands of the Ganga river system pose challenges in estimating E Flows. Some of these are briefly described as follows.

- The cultural and religious community (saints) in India holds the view that, "there is no dearth of faith for Ganga among the Indians, but it's actually the conservation and preservation of river which is paramount and needs immediate attention".
- Demography has an important bearing on the state of river Ganga, as it is significantly affected by the population living within the basin. Average population density in the Ganga basin is 520 persons per square km as against 312 for the entire country (2001 census). Further, the cities in the basin have large and ever-growing populations. In fact, from 1991 to 2001, the urban population has increased by 32% within the basin (AHEC, 2009). This alarming trend is likely to continue, which escalates the pressure on already diminishing natural resources, including river Ganga. Moreover, the ever-exploding demographic trends in the basin lead to crumbling of sewage treatment facilities of utility providers.

- There have been major water abstractions from river Ganga for the purpose of irrigation. Canal Systems including the Upper Ganga Canal, Madhya Ganga Canal, Lower Ganga Canal, etc. has been fulfilling irrigation needs of the farmers residing within the upper Ganga river basin, mainly – parts of Uttarakhand and Western and Central Uttar Pradesh. However, this has also led to severe problem of water availability in the stretch from downstream of Haridwar to upstream of Allahabad. In addition there has been significant increase in industrial activities at the banks of river at various points and this has led to diminishing water quality as in most of the cases the river becomes a dumping body for the industrial waste. Further, the Persistent Organic pollutants (POP) and hazardous wastes also find their way to the river Ganga, thus polluting the river for a long time.
- The rising standards of living and exponential growth of industrialization and urbanization have further exposed the water resources of river Ganga.

All these issues have compounded the problem of both water quality and quantity, which make it absolutely vital to assess and maintain the E-Flows for the river Ganga and her tributaries.

6. Review of Information Available on E-Flows Estimation on Rivers in Ganga Basin

There have been very few attempts in regard to E-Flows assessment in the context of Indian rivers. Mohile (2009) has worked out Natural Flow of the Bramhani-Baitarni river in the form of monthly time series. This was worked out from the observed flow, through series of corrections.

The environmental water need of the country is estimated at 5 BCM for 2010 and is projected to increase to 10 BCM in 2025, and 20 BCM in 2050 by National Commission on Integrated Water Resources Development Plan (NCIWRDP, 1999). Further, the National Water Policy (2002) states that: ‘minimum flow should be ensured in the perennial streams for maintaining ecology and social considerations’.

The High Powered Committee (HPC) constituted by the River Conservation Authority (RCA), MOEF, GOI recommended 40 and 10 m^3/s as minimum flow for maintaining ecological system and natural self purification capacity downstream of Narora in river Ganga and in Delhi stretch in Yamuna respectively (Dutta, 2009). The river flow is considered inadequate for Kumbh Bath at Allahabad during Dec-Jan in the lean flow months and the Courts are bound to order more and more releases towards social needs of people. This indicates inadequacies in estimation of E-Flows.

The Working Group constituted by the Water Quality Assessment Authority (WQAA) of Government of India used “modified Tennant Method” to assess the minimum flow requirements in Indian rivers. The tenant method requires very short time for assessment. The relative confidence in output, however, is said to be “low”. The working group made following recommendations for minimum flows based on a classification of rivers into two categories, namely Himalayan and Other Rivers (WQAA, 2007).

- Himalayan Rivers: Minimum flow to be not less than 2.5% of 75% dependable Annual Flow expressed in m^3/s; One flushing flow during monsoon with a peak not less than 250% of 75% dependable Annual flow expressed in m^3/s.
- *Other Rivers:* Minimum flow in any ten daily period to be not less than observed ten daily flow with 99% exceedance. And where 10 daily flow data is not available this may be taken as 0.5% of 75% dependable Annual Flow; One flushing flow during monsoon with a peak not less than 600% of 75% dependable annual flow expressed in m^3/s.

Since the confidence level of the Working Group was 'low', these recommendations were neither tried nor tested, and are not accepted.

Workshop on Environmental Flows organised by the National Institute of Ecology (NIE), jointly with the International Water Management Institute (IWMI), World Wide Fund for Nature – India (WWF-India), Ministry of Environment and Forests (MoEF), Ministry of Water Resources (MoWR), and the Indian Council of Agricultural Research (ICAR) in March 2005 in Delhi made following resolution regarding E-Flows (NIE, 2005):

- The Environmental Flows requirements differ considerably in different rivers and their different reaches, and have therefore to be assessed and prescribed separately for different reaches of the river and its estuary.
- The assessment of Environmental Flows requirements should employ comprehensive holistic (whole ecosystem-focused) methods. The hydrological methods for E-Flows do not adequately account for the ecological requirements and therefore, recommendations based on simple hydrological methods alone, could be merely an immediate step in the right direction.

As can be inferred from the aforementioned information, the concept of E-Flows has been inadequately applied for rivers in the Ganga basin. At most E-Flows have been considered as some minimum flow as percentage of annual mean flow or in some cases as percentage of dry weather flow or in some cases as some percentage of 10 daily average flows. A few open access software, with default settings based on data available in public domain, are available for E-Flows estimation. The default settings can be user modified if some specific information about the site at which E-Flows are to be estimated is available. Such tools can possibly be used for estimating E-Flows in rivers in Ganga basin. For example, the Global Environmental Flow Calculator (GEFC) is a software package developed by the International Water Management Institute, Sri Lanka in 2007. It is a desktop assessment of E-Flows incorporating an in-built global database of simulated flow time series. The key objective of this software is to support training and initial quick assessments of E-Flows requirements in river basins. GEFC is supplied with the Global Database of simulated flow time series. These data are provided by the Water Systems Analysis Group of the University of New Hampshire, USA. The GEFC uses a simple approach which has been proposed by Smakhtin and Anputhas (2006) to determine the default Flow Duration Curve representing a summary of E-Flows for each Environmental Management Class (EMC).

The minimum requirement for this desktop Environmental Flow Assessment (EFA) application at any site in a river basin is sufficiently long (at least 20 years) monthly flow time series reflecting, as much as possible, the pattern of 'natural' flow variability. This flow time series is referred to as the 'Reference Hydrological Time Series'. The default flow time series can be replaced by observed/simulated flow time series supplied by the user in a user-defined file as the 'Reference Hydrological Time Series'. However, sites where E-Flows are required are often either un-gauged, or significantly impacted by upstream basin developments. Therefore representative 'unregulated' monthly flow time series, or corresponding aggregated measures of unregulated flow variability, like Flow Duration Curves (FDCs), have to be simulated or derived from available observed source records. The IWMI, in its disclaimer, clearly mentions that this software product is being provided 'as is and with all faults' and without warranty of any kind. Nevertheless, this could be used as one of the preliminary tools towards assessment of E-Flows and thus provides basic information about hydrology-based assessment of E-Flows.

Maintenance of minimum ecological flows in the river Ganga with aim of ensuring water quality and environmentally sustainable development has been assigned second priority after IWRDM Plan for National Ganga River Basin Authority created by an Act of Indian Parliament, February 20, 2009. It is stated that maintaining E-Flows will be at the cost of other requirements, and it is feared that the trade-off will be mostly with agriculture in the context of Ganga Basin (Ravindra Kumar, 2009). A much detailed study on E-Flows estimation at a few selected sites (refer Figure 2) in the stretch Gangotri to Kanpur of the river Ganga was undertaken under the Living Ganga Programme (2007-2011) being run by the World Wide Fund for Nature – India (WWF – India). After some field visits and workshops, an international multi institute team was constituted to develop a framework for estimation of E-Flows on Indian rivers with special emphasis on river Ganga. After extensive debate, some field work, and the fact that socio-cultural aspects are highly significant for river Ganga, it was decided that the Building Block Methodology could be further developed and adopted due to the flexibility that the method offers for incorporating additional factors in estimating E-Flows. Several specialist groups drawing from different institutes within and outside India were setup to study following aspects.

6.1. Hydrology

- Identify and review previous hydrological modeling studies and assessment of their usability
- Set up model and calibrate under existing conditions of land and water use

- Examine the feasibility of different ways of modeling the past 'natural' and present-day flows, using observed flow data

6.2. Fluvial Geomorphology and Hydraulic Modeling

- Analysis of sediments in the river, and the assessment of the effects that will result from different flow regimes
- Analyze the channel and floodplain morphology in terms of the geomorphic features, and their stability
- Generate the cross section and longitudinal profile for hydraulic modeling

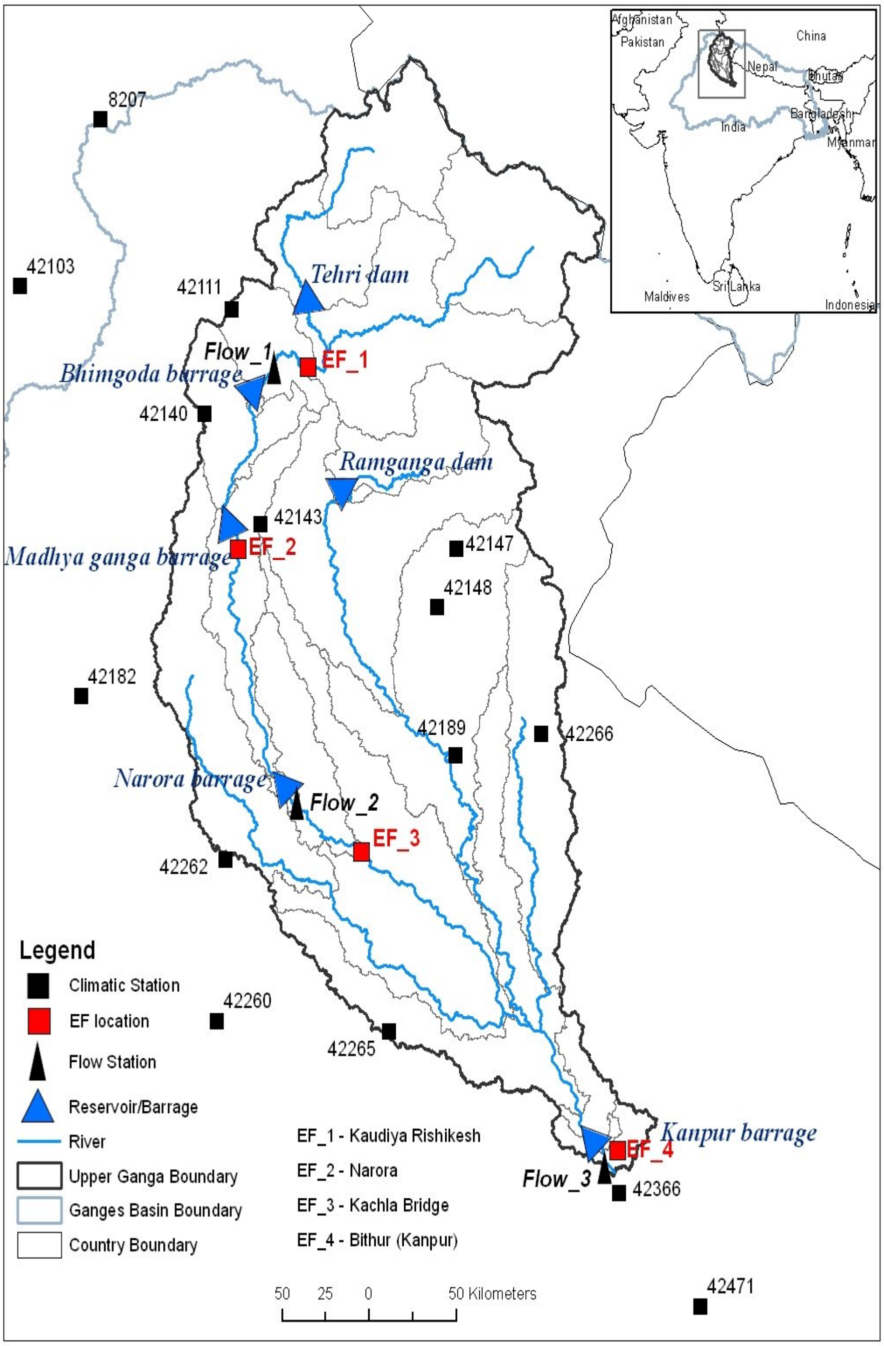

Figure 2: Map Showing Sites for E-Flows Assessment under WWF's Living Ganga Programme

6.3. Establishing the Habitat Preferences of Selected Aquatic Species

- Assess present condition in terms of the difference between the reference condition and survey results
- Describe measured depths, average velocities and substratum types most commonly associated with sensitive species and families, and/or with maximum biodiversity

6.4. Economic and Livelihood Objectives and Assessment of Cultural and Spiritual in Stream flow required

- Evaluate livelihood activities and its implications on E-Flows for the river
- River's representation in mythology, folklore, folk art, popular literature and art
- Historical evidence of civilizations along the river, and its influence on society
- Cultural, religious, spiritual importance of the Ganga, with special focus on rituals and festivals that are linked to the river

6.5. Collation of Water Quality and Pollution Data

- Generation of data on certain water quality parameters that is not likely to be available from any sources and considered essential by the water quality group.
- Assessment of various types of pollution loads in different stretches/sub-stretches

After extensive studies by various expert groups involving hydrological, hydraulic, geomorphologic, ecological, socio-cultural, livelihood and water quality aspects from different institutes/organizations at three sites, namely Kaudiyala, Kachla Bridge and Bithoor, E-Flows assessments were carried out in a five day workshop where all specialty groups participated. Kaudiyala, Kachla Ghat and Bithoor sites were considered to represent Gangotri to Rishikesh, Narora to Farrukhabad, and Kannauj to Kanpur stretches of the river Ganga respectively. Typical results of the E-Flows estimates at three sites for maintenance or normal year are presented in Figures 3 - 5. Details are available elsewhere (WWF-India, 2011). The WWF - India exercise for assessment of E-Flows was pioneering and was a first attempt of its kind in India, whereby the capacity of various experts/teams was strengthened to undertake similar tasks in future for other river basins. Further, the process adopted for this exercise was found to be well accepted and understood among various team members and external experts, and could be applied in future for rivers in the Ganga basin.

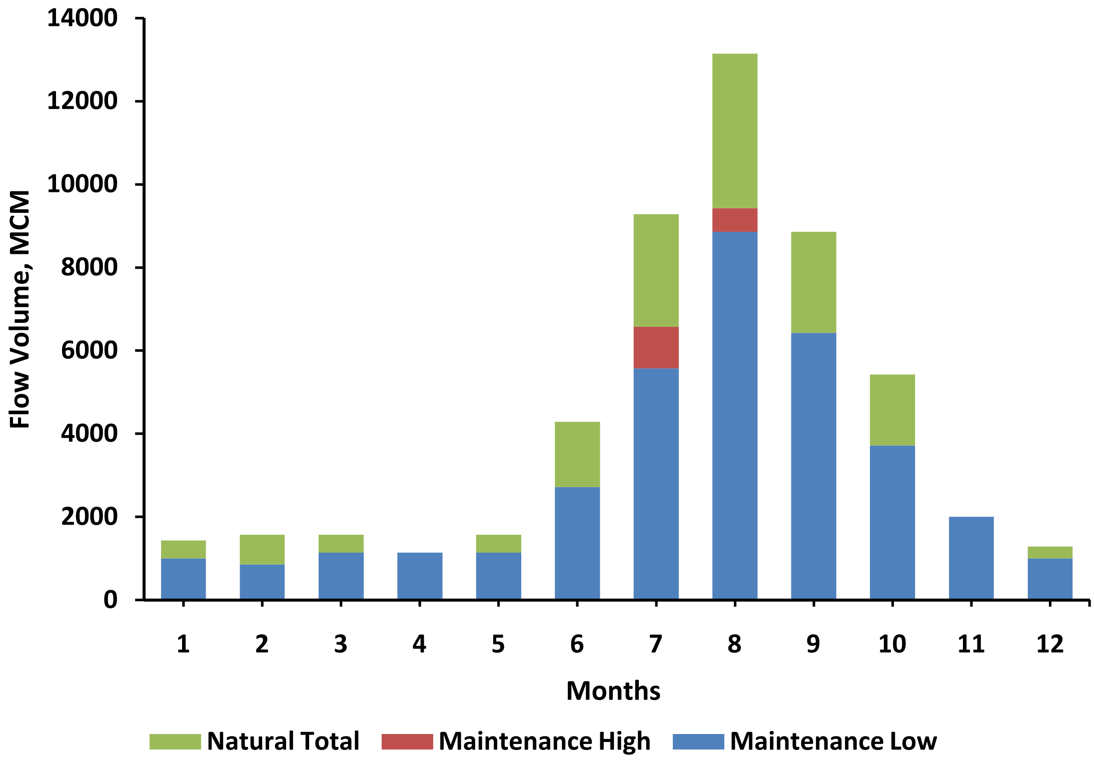

Figure 3: Typical Results of the E-Flows Estimates for Zone I: Gangotri to Risheksh for Maintenance or Normal Year (Adopted from WWF-India, 2011)

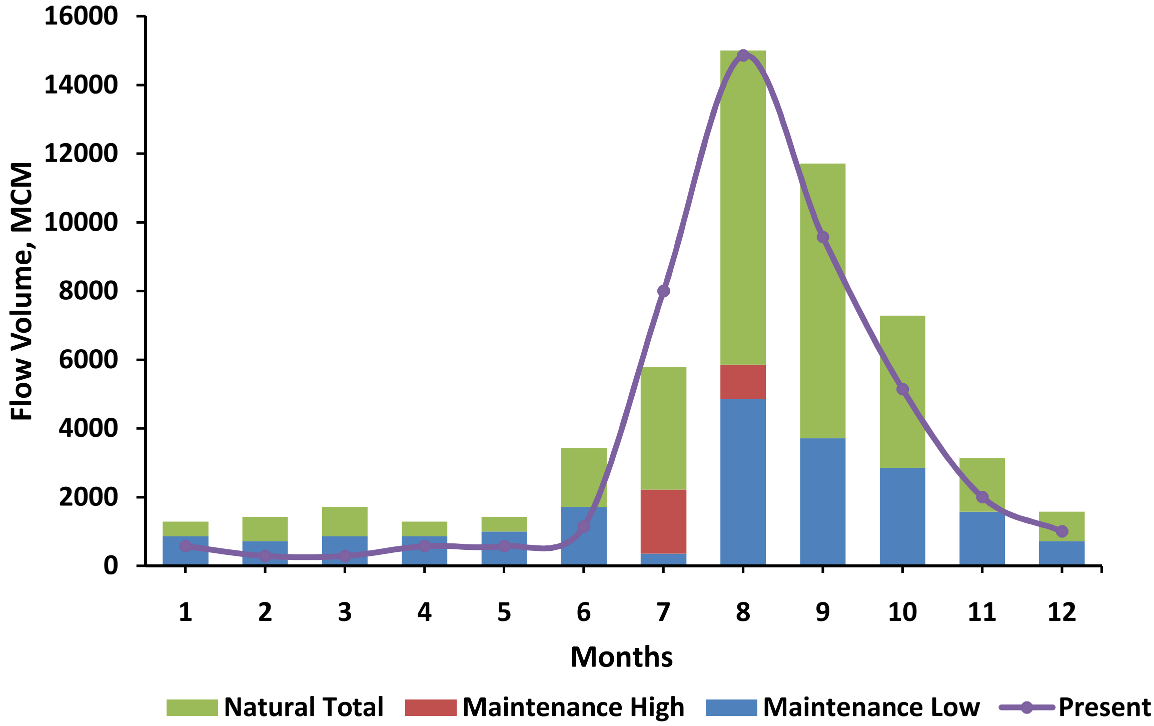

Figure 4: Typical Results of the E-Flows Estimates for Zone II: Narora to Farrukhabad for Maintenance or Normal Year (Adopted from WWF-India, 2011)

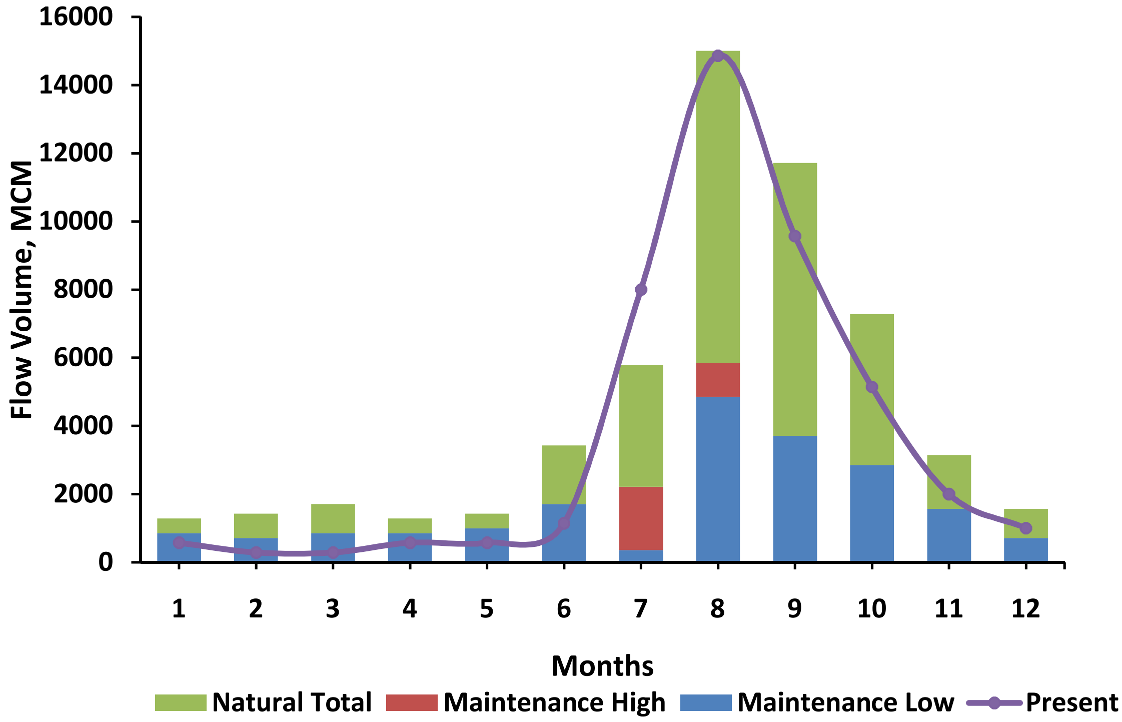

Figure 5: Typical Results of the E-Flows Estimates for Zone III: Kannauj to Kanpur for Maintenance or Normal Year (Adopted from WWF-India, 2011)

In the opinion of the experts who participated in the E-Flows estimation exercise, the BBM methodology was found to be robust with high confidence level. However, the experts were less confident and quite uncertain about the specific flow recommendations presented in Figures 3 - 5.

During this exercise, the specialist groups recommended that the long term Ecological Management Class (EMC) for all three zones should be 'A'. This is with reference to the unique spiritual importance of the river, it being an essential part of the history and culture of the subcontinent. Near-pristine flows will safeguard the spiritual satisfaction that devotees obtain from gazing at the river. In the short term, some augmentation of the flow is required to ensure satisfactory ritual worship. An EMC of 'B' was recommended as an acceptable goal in the short term.

The major uncertainties under this study were centered on the hydrological and hydraulic models due to lack of availability of reliable data. However, the Central Water Commission data on discharge, sediment load and gauge being made available to the IIT Consortia, the confidence level on hydrological modeling should be high. This would be beneficial for the E-Flows estimations.

Based on the aforementioned information and discussion it may be inferred that Building Block Methodology (BBM) appears to be promising and can be adopted by IIT Consortia for E-Flows estimation in rivers of Ganga Basin. However, the estimated E-Flows given in Figures 3-5 need to be revised.

7. Concluding Remarks

- Environmental flows refer to a regime of flows that mimics the natural pattern of a river's flow, so that it can perform its natural functions such as transporting water and solids from its catchment, formation of land, self-purification and sustenance of its myriad systems along with sustaining cultural, spiritual and livelihood activities of the people or associated population.
- E-Flows assessment is based on the assumption that there is some 'spare' water in rivers that can be used without unacceptably impacting on the ecosystem and societal services that the river provides.
- E-Flows assessment is both a social and a scientific process. There is no one correct Environmental Flow regime for rivers – the answer will depend on what people want from a river.
- The fact that socio-cultural and livelihood aspects are highly significant for river Ganga, the Building Block Methodology, having flexibility for incorporating additional factors in estimating E-Flows, could be further developed and adopted.
- The WWF - India exercise for assessment of E-Flows was pioneering and first of its kind in India, whereby the capacity of various experts/teams was strengthened to undertake similar tasks in future for other river basins. Further, the process adopted for this exercise was found to be well accepted and understood among various team members and external experts, and could be applied in future for rivers in the Ganga basin.
- The BBM methodology is found to be robust with high confidence level. However, specific flow recommendations are difficult to justify at this stage, and will have to worked out afresh. The major uncertainties centered on the hydrological and hydraulic models due to lack of availability of reliable data.

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Appendix I

The Building Block Methodology and Its Process

The Building Block Methodology (BBM) is a flexible participatory and robust multi-disciplinary methodology that can be applied for differing levels of information and data availability. It allows the user to focus on key issues of local importance, for instance –in case of River Ganga – the spiritual and cultural aspects which are of immense importance. The BBM is found to be the most appropriate process for large river basins with multiple user and interest groups. As with other assessment methodologies, it is based on the principle that some water can be used from rivers without unacceptably degrading them. The BBM is based on the following steps.

1. Using a stakeholder consultation process to set objectives for the environmental condition of the river.
2. Assessing a modified flow regime that will meet those objectives.
3. Using flow-dependent indicators (e.g. river dolphins, gharial, turtles, fish, invertebrates, floodplain plants) and non-consumptive human requirements, as well as water quality metrics and sediment transport, to identify water depths, velocities, river widths, and substrate types that will provide the required habitats and conditions. Such hydraulic requirements can then be converted to hydrological (flow) requirements.
4. Identifying the critical components (building blocks) of the flow regime that govern environmental conditions (e.g. dry and wet season base flows, and different-sized high flows and floods).

This methodology has been extensively applied in South Africa, Mexico, Brazil, Kenya, Tanzania and Australia. Salient features of this methodology include:

- Bottom up approach, with each recommended flow carefully motivated.
- Multi-disciplinary approach means that each recommended flow is carefully analyzed by a group of specialists from different fields (ecology, geomorphology, water quality, sociology).
- Flexible - can be tailored to suit local conditions as required, for instance – in case of rivers in Ganga Basin cultural and spiritual aspects can be integrated.
- Most frequently used holistic methodology around the world
- Process is driven by baseline data
- Rigorous and well documented, with an explicit user manual.

The overall process chart of Building Block Methodology for assessment of E-Flows is very comprehensive and complex, therefore for the sake of brevity and clarity the same is simplified and presented in Figure AI.1

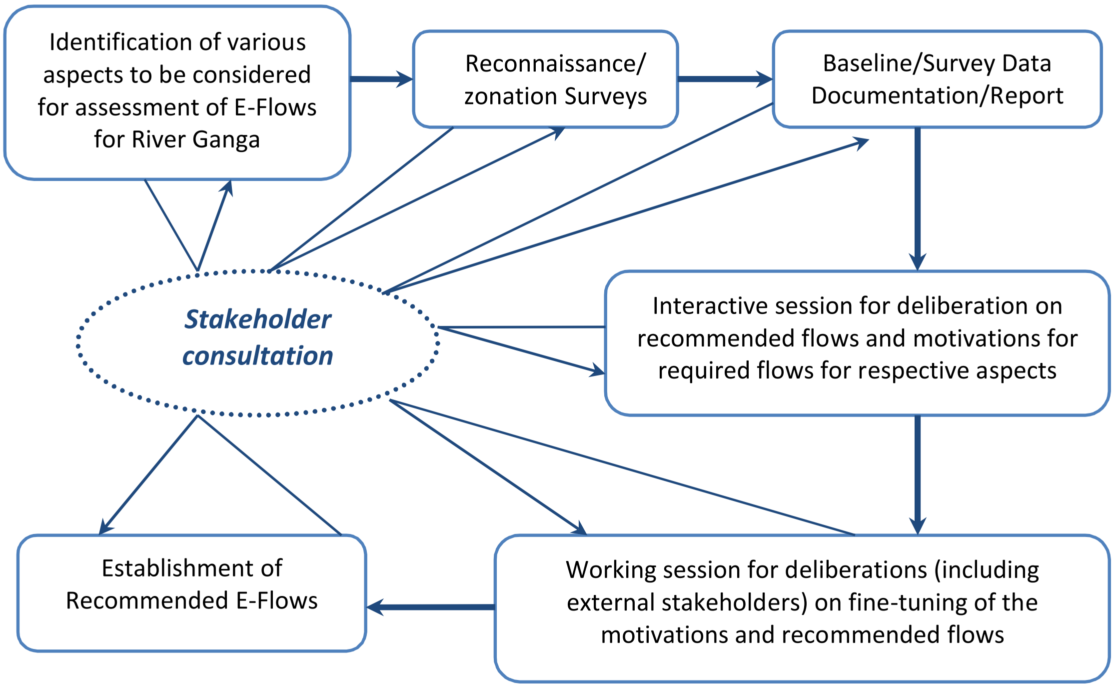

Figure AI.1: Block Diagram Illustrating Various Steps of Building Block Methodology

<u>Note</u>: Much of the information given in this Appendix has been reproduced from WWF – India (2011) report.