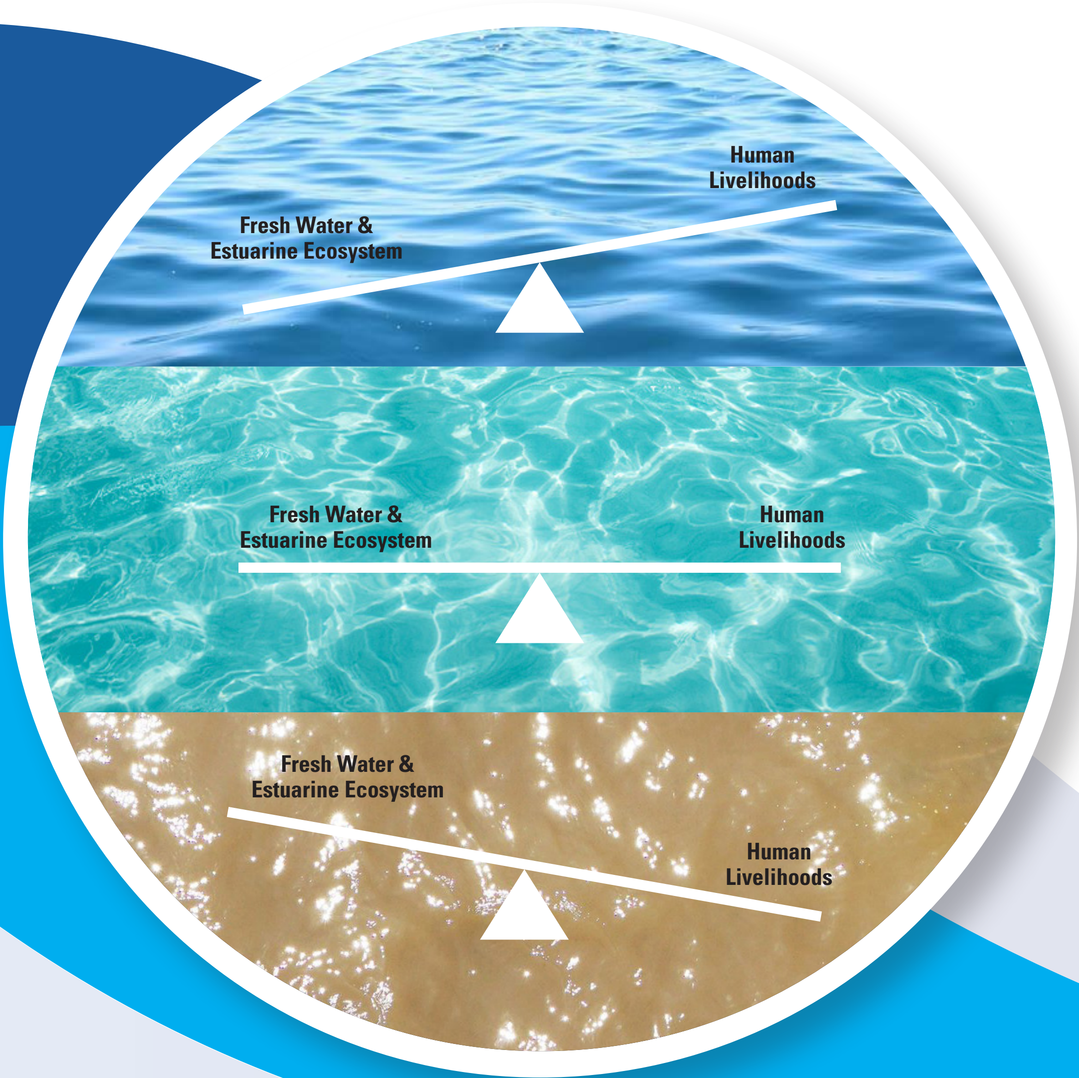
NATIONAL MISSION FOR CLEAN GANGA
Ministry of Water Resources, River Development and Ganga Rejuvenation
GOVERNMENT OF INDIA



FLOW REGIMES AND ENVIRONMENTAL FLOWS IN GANGA RIVER SYSTEM

DECEMBER 2018

Centre for Ganga River Basin Management and Studies

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Free flowing Ganga in her verdant Himalayan setting

The gorgeous Ganga menders in the Upper Himalayas

NATIONAL MISSION FOR CLEAN GANGA (NMCG)

NMCG is the implementation wing of National Ganga Council which was setup in October 2016 under the River Ganga Authority order 2016. Initially NMCG was registered as a society on 12th August 2011 under the Societies Registration Act 1860. It acted as implementation arm of National Ganga River Basin Authority (NGRBA) which was constituted under the provisions of the Environment (Protection) Act (EPA) 1986. NGRBA has since been dissolved with effect from the 7th October 2016, consequent to constitution of National Council for Rejuvenation, Protection and Management of River Ganga (referred to as National Ganga Council).

www.nmcg.in

CENTRE FOR GANGA RIVER BASIN MANAGEMENT AND STUDIES (cGanga)

cGanga is a think tank formed under the aegis of NMCG, and one of its stated objectives is to make India a world leader in river and water science. The Centre is headquartered at IIT Kanpur and has representation from most leading science and technological institutes of the country. cGanga's mandate is to serve as think-tank in implementation and dynamic evolution of Ganga River Basin Management Plan (GRBMP) prepared by the Consortium of 7 IITs. In addition to this it is also responsible for introducing new technologies, innovations and solutions into India.

www.cganga.org

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SUGGESTED CITATION

Flow Regimes and Environmental Flows in Ganga River system by cGanga and NMCG

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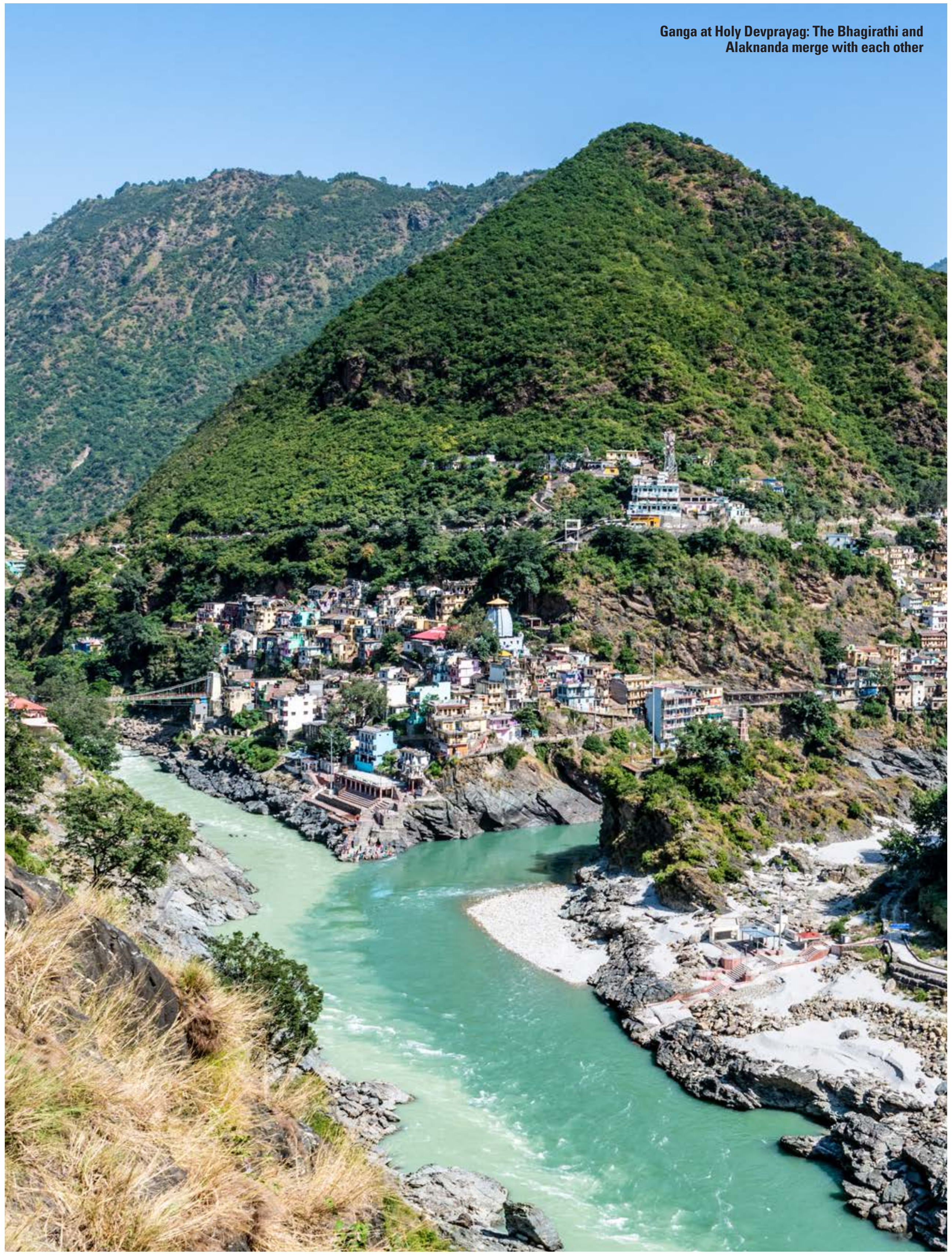

Ganga at Holy Devprayag: The Bhagirathi and Alaknanda merge with each other

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Contents

A headstream of Ganga bubbling
down in her uppermost reach

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1. Introduction

To achieve the objective of "Restoration and Conservation of River Ganga", assessment of Environmental Flows (E-Flows) and its maintenance throughout the river is one of the most important aspects.

Flow is one of the main drivers of biodiversity and morphology in rivers, and a river's flow regime – the variation of high and low flows through the year as well as variation over the years – exerts great influence on its ecosystem. Environmental Flows (or E-Flows) are a regime of flow in a river that mimics the natural pattern of a river's flow variation. E-Flows consider the equitable distribution of river resources between extractable goods and the ecosystem services availed from river systems. E-Flows refer to the quality, quantity, and timing of water flows required to maintain the components, functions, processes, and resilience of aquatic ecosystems that provide goods and services to people [Nature Conservancy, 2006]. Specification of the E-Flows enables the river to at least perform its minimal natural functions such as transporting water and solids received from its catchment and maintaining its structural integrity, functional unity and biodiversity along with sustaining the cultural, spiritual and livelihood activities within the river space. As per the Brisbane Declaration [2007], "Environmental Flows describe 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." In other words, E-Flows describe the temporal and spatial variations in quantity and quality of water required for freshwater and estuarine systems to perform their natural ecological functions (including material transport) and supports the spiritual, cultural and livelihood activities that depend on them [IITC, 2011].

The objective of E-Flows is to recognise the physical limit beyond which a natural water body suffers irreversible damage to its ecosystem functions, and systematically balances the multiple water needs of society in a transparent and informed manner. E-Flows are, therefore, one of the central elements in water resources planning and management for sustainable development.

After reviewing several different holistic methods of estimating E-Flows and in consultation with stakeholders and expert groups, the Building Block Method (BBM) was found to be robust and scientifically most suitable [IITC, 2011]. The method had been developed in South Africa through numerous applications in water resources development to address E-Flows requirements for riverine ecosystems under conditions of variable resources. The Inter Ministerial Group (IMG) chaired by Mr B K Chaturvedi and Expert Body constituted by the Ministry of Environment, Forests and Climate Change (MoEF&CC) had also opined in favour of adopting BBM for E-Flows assessment [IMG, 2013; Expert Body Report, 2014]. But since it was found that the method effectively results in Bigger Block governing E-Flows, BBM was considered to denote Bigger Block Method in GRBMP [IITC, 2015]. Based on this method, E-Flows were computed for different sites of interest in the Ganga River System. It should be noted here that the BBM method quantifies only the lower bound on flows required at different times to sustain the river, and does not specify other conditions to be maintained in the river. One of these conditions is, of course, the connectivity in river flow. However, maintenance of the water-sediment balance is also an essential condition. It is desired that E-Flows should carry suspended load and bed load in approximately the same proportions as present in the virgin flow.

IT SHOULD BE NOTED HERE THAT THE BBM METHOD QUANTIFIES ONLY THE LOWER BOUND ON FLOWS REQUIRED AT DIFFERENT TIMES TO SUSTAIN THE RIVER, AND DOES NOT SPECIFY OTHER CONDITIONS TO BE MAINTAINED IN THE RIVER. ONE OF THESE CONDITIONS IS, OF COURSE, THE CONNECTIVITY IN RIVER FLOW.

The Alaknanda in her tumultuous rush

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2. Concept of Aviral Dhara

Among other factors, the vision for a wholesome Ganga River includes the concept of Aviral Dhara defined in GRBMP as "the flow of water, sediments and other natural constituents of River Ganga and her tributaries are continuous and adequate over the entire length throughout the year". As may be seen from this above definition, a certain quantity of flow is required in the river for it to support its natural processes. However, the increase in anthropogenic activities in the river basin has the potential to alter the flows in the river leading to interference with the natural processes of a river.

In river systems, several processes lead to differentially structured river sections, varying in geomorphology, hydrology, biogeochemistry, and ecosystem variables. In terms of stream habitats, a hierarchical classification based on temporal and spatial scales is a necessary tool to understand biodiversity. Fluvial and ecological processes are correlated at a range of scales and the sensitivity to disturbance and recovery times of communities in river systems differ at various scales. The continuum character of rivers become very clear in the case of construction of dams and embankments (dikes), because these disrupt the longitudinal, lateral and vertical continuum, resulting in shifts in abiotic and biotic parameters and processes (Velde et al., 2004).

ALONG ITS LENGTH, RIVERS OFTEN CHANGE FROM SMALL, ROCKY-BASED, SHADED STREAMS IN UPLAND MOUNTAINOUS REGIONS TO WIDER RIVERS IN VALLEYS TO BROAD, MUDDY RIVERS IN LOWLAND FLOODPLAINS. WHILE MOST MOVEMENT IS DOWNSTREAM, SEVERAL TYPES OF BIOTA ALSO MOVE UPSTREAM AT SOME STAGE IN THEIR LIFE CYCLES.

Given the increase in anthropogenic activities in the Ganga River Basin in the last few decades, it is critical now to understand the drivers that are modifying the flows in the river from their natural conditions spatially and temporally. Further, maintaining river connectivity that allows for energy, nutrients, sediment and organisms exchange between different parts of the river pathway is imperative before establishing the environmental flows for a stretch of a river.

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2.1 River Connectivity

Connectivity is defined as the maintenance of lateral, longitudinal, and vertical pathways for biological, hydrological, and physical processes (Annear et al., 2004). This connectivity refers to the flow, exchange and pathways that move organisms, energy and matter throughout the watershed system. These interactions create complex, interdependent processes that vary over time. As with hydrology, stream connectivity can be described in four dimensions:

1) Longitudinal – linear connectivity: It refers to the pathways along the entire length of a stream. As the physical gradient changes from source to mouth, chemical systems and biological communities shift resulting in change in response. Along its length, rivers often change from small, rocky-based, shaded streams in upland mountainous regions to wider rivers in valleys to broad, muddy rivers in lowland floodplains. While most movement is downstream, several types of biota also move upstream at some stage in their life cycles.

2) Lateral – Floodplain connectivity: Lateral (or sideways) linkages occur between the river, the adjacent riverside land and the floodplain. In the uplands, the riverside zone provides organic matter (e.g. leaf litter) to the river. Organic matter is a major energy source for the in-stream aquatic life. In the lowland floodplain, lateral linkages are more important and come into operation when rivers flow over their banks and inundate the floodplain on a regular basis. Flooding is the key to maintaining the health of both the river and the floodplain. Transfer of sediments, nutrients and organic material between the river and the floodplain is vital to the maintenance of both ecosystems. A flood stimulates a boom in floodplain productivity with the regeneration of floodplain and riverside plants, and the breeding of invertebrates and vertebrates such as water birds, frogs and tortoises. It opens the floodplain as new habitat for fish and macro-invertebrates and is often the cue for breeding for these species. As the flood recedes, it transfers organic matter and nutrients to the river, replenishing in-stream food and energy sources and recruiting fish populations and insect communities.


A glimpse of the Tehri reservoir through pines and oaks

3) Vertical – hyporheic (below the stream bed): A river links vertically with groundwater systems. The base flow in rivers is maintained by groundwater, and rivers can also recharge shallow groundwater aquifers. Groundwater provides organic carbon (an energy source) to the streams, and during high flows the stream bed can provide a refuge for invertebrates as they move down below the stream surface to take shelter. The hyporheic zone itself often teems with micro-organisms, and provides a rich source of microbial exchange with river waters.

4) Temporal (continuity over time) – many scales; seasonal, multiyear, generational: A stream exhibits temporal connectivity of continuous physical, chemical, and biological interactions over time, according to a rather predictable pattern. These patterns and continuity are important to the functioning of the ecosystem. Over time, sediment shifts, meanders form, bends erode, oxbows break off from the main channel, channels shift and braid. A stream also rises and falls according to seasonal patterns, depending on rain and snowmelt.

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2.2 Flow Regime

Flow regime influences the water quality, energy cycles, biotic interactions, and habitat of rivers (Naiman et al., 2002). It is possible to describe flow regime in terms of five states or environmental flow components, each of which supports specific ecological functions. The health and integrity of river systems ultimately depend on these components, which may vary seasonally (Mathews and Richter, 2007):

- **Extreme low flows occur during drought.** Extreme low flows are associated with reduced connectivity and limited species migration. During a period of natural extreme low flows, native species are likely to out-compete exotic species that have not adapted to these very low flows. Maintaining extreme low flows at their natural level can increase the abundance and survival rate of native species, improve habitat during drought, and increase vegetation.

- **Low flows, sometimes called base flows, occur for the major part of the year.** Low flows maintain adequate habitat, temperature, dissolved oxygen, and chemistry for aquatic organisms; drinking water for terrestrial animals; and soil moisture for plants. Stable low flows support feeding and spawning activities of fish, offering both recreational and ecological benefits.

- **High flow pulses occur after periods of precipitation and are contained within the natural banks of the river.** High flows generally lead to decreased water temperature and increased dissolved oxygen. These events also prevent vegetation from invading river channels and can wash out plants, delivering large amounts of sediment and organic matter downstream in the process. High flows also move and scour gravels for native and recreational fish spawning and suppress non-native fish populations, algae, and beaver dams.

- **Small floods occur every two to ten years.** These events enable migration to flood plains, wetlands, and other habitats that act as breeding grounds and provide resources to many species. Small floods also aid the reproduction process of native riparian plants and can decrease the density of non-native species. Increases in native waterfowl, livestock grazing, rice cultivation, and fishery production have also been linked to small floods.

- **Large floods take place infrequently.** They can change the path of the river, form new habitat, and move large amounts of sediment and plant matter. Large floods also disperse plant seeds and provide seedlings with prolonged access to soil moisture. Importantly, large floods inundate connected floodplains, providing safe, warm, nutrient-rich nursery areas for juvenile fish.

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2.3 Geomorphological Processes

Geomorphological processes contribute to the changes that occur to a stream channel in response to alterations in watershed conditions; and, in turn, these changes impact human infrastructure and fish habitat. Stream morphology is dynamic and constantly changes in both space and time. A stable stream channel is in a state of equilibrium and responds physically to the stream flow and sediment it receives from upstream.
Geology and physical geography act as constraints to the level of geomorphic change and determine the nature and quantity of sediment supplied to the system. Stream


Rocks and water: the struggle of Ganga headstreams

Ganga Aarti: Spiritual homage to Maa Ganga

geomorphology is to be studied because it influences flooding patterns, erosion rates, stream flow and sediment movement and deposition. For example, lowered stream depth associated with widening would impact fish communities through loss of cover, and suitable summer and winter habitat. In addition, stream aggradation leads to embedded riffle substrate and the loss of riffle habitat.

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2.4 Socio-Economic, Spiritual and Cultural Aspects of Rivers

Rivers in general, and the river Ganga and some of her tributaries in particular, have significant economic, environmental and cultural values in India. River Ganga is also one of India's holiest rivers whose cultural and spiritual significance transcends the boundaries of the basin. Ganga River resources are unique in nature in promoting cultural, ecological and economic prosperity of India. It provides fertile land for agriculture, it is a perennial source of fresh water and fish, it is an inseparable part of Indian culture, and it has rich bio-diversity. River Ganga occupies a unique place in the hearts of millions of Indians whose faith is intimately connected with her. Rituals from birth to death take place all along the flowing river and at the confluence with her important tributaries in search for salvation.

Due to increasing population in the basin and poor management of urbanization and industrial growth, both river water quantity and quality has significantly deteriorated, particularly in dry season which pose a great threat to the biodiversity and environmental sustainability of the Ganga. The water abstraction at the constructed barrage at many places for irrigation and dams across the river for hydropower have left the main stream of the river almost dry in few stretches, impacting river health and leading to a state where the river may not be able to deliver its social and spiritual services that Ganga has been providing since time immemorial.

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3. Overview of Different River Flow Regimes

Flow regime is a major component of physical river environment. Flow regulation through dam and weir construction and water abstraction has led to severe stress being placed on river ecosystems (e.g. Walker and Thoms, 1993; Thoms and Sheldon, 1997). Hence there is an urgent need to recognize the requirements to allocate water to fulfil the needs of the riverine environments.

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3.1 Virgin Flows

Virgin flows can be referred to as the natural flows, which exist or would exist if the influence of humans such as artificial diversions, impoundments, or channels would not have taken place, on or along the stream or in the drainage basin. Human intervention along the river course has resulted in physical, chemical, hydrological, and biological modifications of its fluvial and estuarine ecosystems. The principal drivers of the physical modifications include rapid population growth, industrialization, urbanaization and lifestyle changes, and the consequent over-exploitation of natural resources.

Factors that have contributed significantly toward these modifications include hydroelectric power generation, water withdrawal for irrigation, waste discharges (point and non-point), deforestation, diking and filling of shallow water and intertidal areas, and navigational development. In order to study the effects of anthropogenic influence and climate effects, the observed daily flow alone does not provide all the information. It is also essential to have an assessment of virgin flow of the river to deliver a historical perspective of water resources development, separate anthropogenic and climate effects, and compare present water use scenarios with those of the past era. Virgin flows are also necessary for hindcasting the sediment transport under natural conditions. Finally, by taking the difference between the virgin flow and the observed flow it is possible to obtain the total change in flow, due both to flow regulation and irrigation depletion (Naik and Jay, 2005).

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3.2 River Flow Health

A biological system can be thought of as "healthy" when its inherent potential is realized, its condition is stable, its capacity for self-repair when perturbed is preserved, and minimal external support for management is needed. To properly understand how healthy a river is, three aspects of the river system need to be considered:

a) The diversity of the habitats, flora and fauna: Rivers and streams support a huge diversity of life. This is to a large extent because they provide a great range of habitats and link aquatic and terrestrial ecosystems. At the broader scale, river habitats include the river channels, the riverside (or riparian) vegetation, the subsurface hyporheic zone, the floodplains, and the connected wetlands and lakes. Sustaining this diverse range of habitats and the species they support is a key component to maintaining the ecological health of a river.

b) The effectiveness of the linkages: Maintaining linkages is essentially about making sure that a river is part of the total landscape and is not just

River rafting in sunlit waters of Ganga

The mighty river leaping across treacherous rocks and boulders

regarded as a channel running through the land. A river links with its catchment in three different dimensions: Along the river, lateral and vertical. Recognition of these important linkages in river functioning is a key part of study of the ecological health of the rivers.

c) **The maintenance of ecological processes:** To maintain river health, in particular to maintain biodiversity, it is essential to maintain the ecological processes operating within the system. They can be grouped into three types: Energy and nutrient dynamics, processes which maintain animal and plant populations, such as "reproduction or regeneration, dispersal, migration, immigration and emigration" & species interactions, which can affect community structure.

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3.3 Ninety Percent Dependable Flows

Dependable flows can be described as the nature of flow in a river based on which human activities such as water supply, irrigation, power generation, etc. can be reliably planned. It gives an estimate of the water availability in the river system at any time of the year. Dependable flows are obtained by studying daily discharge in a stream for a very long time period such as 50 years. Ninety percent dependable flow means that, the observed flow obtained by analyzing historical data, could be expected to be available in the river at least 90% of the time.

ENVIRONMENTAL FLOWS PROVIDE CRITICAL CONTRIBUTIONS TO RIVER HEALTH, ECONOMIC DEVELOPMENT AND POVERTY ALLEVIATION. THEY ENSURE THE CONTINUED AVAILABILITY OF THE MANY BENEFITS THAT HEALTHY RIVER AND GROUNDWATER SYSTEMS BRING TO SOCIETY.

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3.4 Environmental Flows

Environmental flows are the water regime that need to be 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. Environmental Flows provide critical contributions to river health, economic development and poverty alleviation. They ensure the continued availability of the many benefits that healthy river and groundwater systems bring to society.

To determine Environmental Flows, one needs to consider all aspects of the river and drainage system in their context. This means looking at the basin from its headwaters to the estuarine and coastal environments and including its wetlands, floodplains and associated groundwater systems. It also means considering environmental, economic, social and cultural values in relation to the entire system. A wide range of outcomes, from environmental protection to serving the needs of industries and people, are to be considered for assessment of Environmental Flows.

To assess Environmental Flows, one needs to identify clear objectives as well as water-abstraction and water-use scenarios. Objectives should have measurable indicators that can form the basis for water allocations. Objectives and scenarios can best be defined with multi-discipline expert teams and stakeholder representatives.

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4. Recommended Methodology

The basic procedure for assessing E-Flows adopting BBM (referred here in as Bigger Block Method rather than Building Block Method) is summarized as follows.

1. Generation of Stage-Discharge curve at the E-Flows site using river cross section and hydraulic modelling.
2. Identification of keystone species* for the stretch that represents the E-Flows site.
3. Assessment of temporal variations in depth of flow required to ensure survival and natural growth of keystone species.
4. Assessment of temporal variations in depth of flow from geomorphological considerations factoring longitudinal connectivity in all seasons and lateral connectivity of active flood plain for the historically observed number of days per year of such flooding.
5. Assessment of minimum ecological depth of flow (higher of steps 3 and 4 above) and generation of hydrograph for Minimum Ecological Requirements (MER) using Stage-Discharge Curve.
6. Determination of Average Flows and 90% Dependable Flows from historical flow data or hydrological modelling.
7. Applying the trend of variation of 90% Dependable Flows with the estimated Minimum Ecological Requirement (MER) to obtain E-Flows hydrograph for dry and wet seasons subject to the condition that minimum flow in wet season is more than or equal to the highest recommended E-Flows during the dry season.
8. Comparison of E-Flows and MER hydrograph with hydrographs for average and 90% dependable virgin flows.

4.1 Minimum Ecological Requirement

The objective of the E-Flows is the restoration of the river health. However, the river health itself depends on a wide range of variables. Identifying and addressing them individually is a complex and non-linear problem.

For upper Ganga Rivers, keystone fish species, such as Mahseer and Snow Trout, are in danger due to fragmentation and loss of connectivity of the river due to the construction of numerous dams, barrages, and reservoirs. Also these fish species govern the minimum depth of flow required for sustenance of the aquatic species, and hence are given priority for assessing E-Flows. In general, for any specific site the relevant aquatic species in the stretch that represents the E-Flows site and governs the minimum depth of flow is referred as "key-stone species".

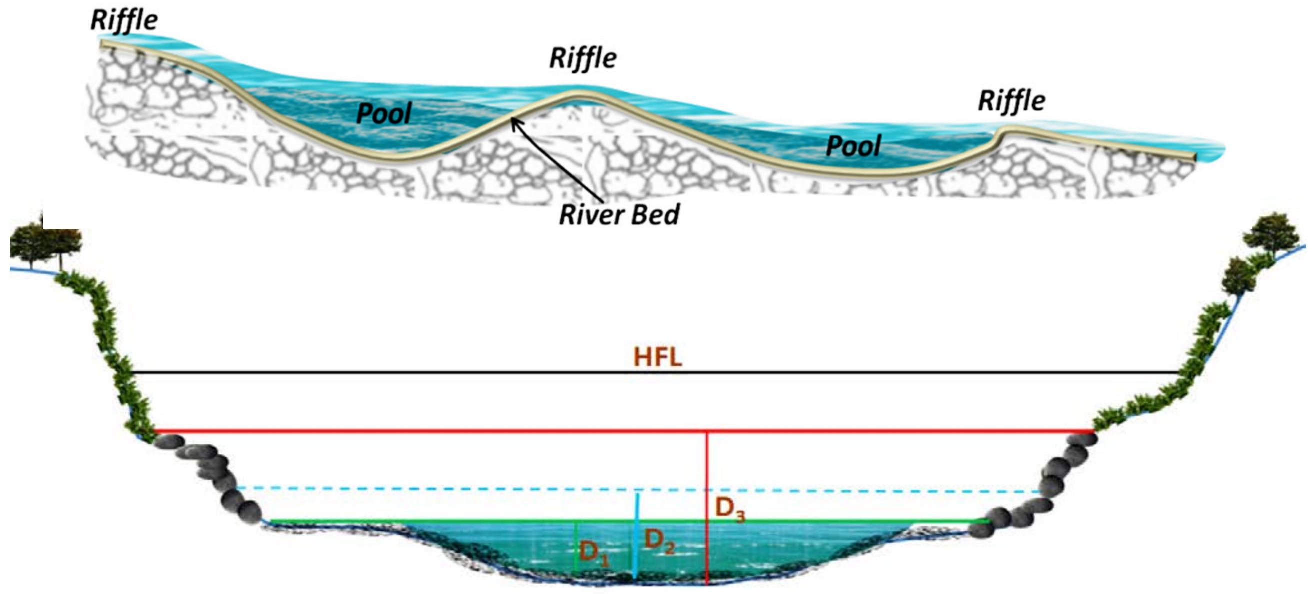
Referring to Figure 1, flows corresponding to minimum depth D_1 are required during all seasons for general mobility of keystone species. For the spawning period of keystone species, flows corresponding to depth D_2 are needed throughout the spawning season for migrations of keystone species.

Assessment of temporal variations in depth of flow from geomorphological considerations factoring longitudinal connectivity in all seasons and lateral connectivity of active flood plain for the historically observed number of days during monsoon season reveals that the increased discharges corresponding to depth D_3 are needed for almost 18 days during the monsoon season in river Ganga (equivalent to 20% of the time during monsoon season of 90 days).

*Keystone species: A species that has disproportionately large effect on the environment relative to its abundance (Paine, 1995). Such species are described as playing a critical role in maintaining the structure of an ecological community, affecting many other organisms in an ecosystem and helping to determine the types and numbers of various other species in the community.

FIGURE 1: E-Flows Assessment – Conceptual Diagram

Riffle and Pool Locations in Longitudinal River Profile



River Cross-Section at E-Flow Site

D_1 – Depth of water required for mobility of keystone species during lean period.
D_2 – Depth of water required for mobility of keystone species during spawning period.
D_3 – Depth of water required to inundate some sand bars, riparian vegetation, etc. for 18 days/year.

To determine these requirements, the keystone species in the given river stretches are identified, and the required depths D_1 and D_2 are determined for these species. Since flow depths at pools are higher than at riffles, hence the critical E-Flows sites are selected at riffle sections, thus ensuring that the flow depths in the entire reach will not be less than D_1 or D_2. The flows corresponding to D_1 and D_2 are then read from the stage-discharge curves for the given sites. To determine D_3, the virgin flows that were exceeded for 18 days (on an average) during the monsoon (i.e. between June and October, but generally between July and September) are computed. This, in concept corresponds to virgin flows having 20% dependability during monsoons.

THE ENVIRONMENTAL FLOWS FOR MONSOON PERIOD ARE OBTAINED BY MIMICKING THE TREND IN DAILY 90% DEPENDABLE FLOW USING THE MINIMUM MONSOONAL FLOW. LATER, THE DEDUCTED FLOW MAGNITUDES ARE ADDED TO THE MIMICKED HYDROGRAPH.

The depth D_3 is then read from the stage-discharge curve and verified against the available river flow depth at the site.

Estimating D_1, D_2 and D_3, and the corresponding discharges from the hydraulic model leads to estimation of minimum ecological requirements (MER) of the river for the corresponding periods (e.g. non-monsoon and monsoon).

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4.2 E-Flows Hydrograph

Environmental Flows are computed based on minimum ecological requirements and is done separately for monsoon (wet) and non-monsoon (dry) periods. Daily Average Flows and 90% Dependable Flows are first computed from historical flow data. The Environmental Flows are obtained by mimicking the trend in daily 90% dependable flow using the minimum ecological requirement for non-monsoon season as the lowest value of E-Flows for non-monsoon period. For monsoon season, the flows corresponding to D_3 is first deducted from the 90% dependable flow, and the higher value between the flow corresponding to D_2 and highest value of E-Flows during non-monsoon seasons, is specified as minimum monsoonal flow. The Environmental Flows for monsoon period are obtained by mimicking the trend in daily 90% dependable flow using the minimum monsoonal flow. Later, the deducted flow magnitudes are added to the mimicked hydrograph.

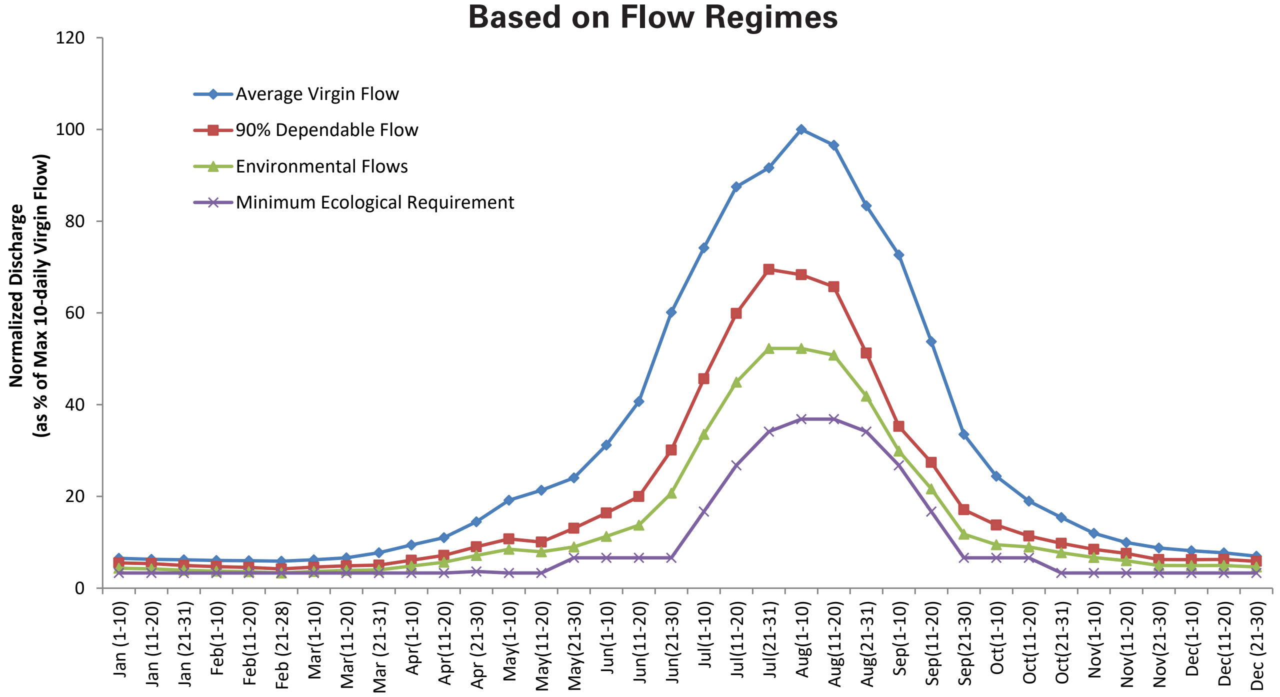
4.3 River Health Regime (RHR)

The procedure mentioned above delineates the entire river flow distribution into several flow regimes. The limits of these regimes are determined by (i) Average flow, (ii) 90% dependable flow, (iii) E-Flows, and (iv) Minimum Ecological Requirements.

The lower limit, Minimum Ecological Requirement, may be considered as absolutely essential for minimal river functioning (with bare survival of biota), while the higher limit, average flow, will allow normal healthy river functioning (allowing maintenance of healthy biodiversity and production of ecosystem goods and services by the river in sustainable manner). Thus, considering the intermediate flow regimes, 5 health regimes for river flow condition called River Health Regimes (RHR), viz. Pristine, Near Pristine, Slightly Impacted, Impacted, and Degraded are defined.

White water rapids in Bhagirathi river at Devprayag, Uttrakhand, India

FIGURE 2: Conceptual Frame Work for River Health Regime Based on Flow Regimes



FLOW REGIME	RIVER HEALTH
Matching with average virgin	Pristine
Between average and 90% dependable	Near Pristine
Between 90% dependable and E-Flows	Slightly Impacted
Between E-Flows and Minimum Ecological Requirement (MER)	Impacted
Inferior to MER	Degraded

Any river flow regime matching the average flow regime is considered to be in Pristine state/condition. River flow regime that is between 90% dependable flow and average indicates Near-Pristine state/condition. Flow regime between E-Flows and 90% dependable flows indicates the river to be in Slightly Impacted state/condition.

Flow regimes inferior to E-Flows but better than Minimum Ecological Requirements is considered to be in Impacted state/condition. However, flow regime inferior than the flow corresponding to Minimum Ecological Requirement would render the river in Degraded state/condition. This conceptual framework for RHR is illustrated through Figure 2.

It should be noted, however, that this distinction of River Health status pertains to hydrological quantities only, and not to river water quality, geomorphology or biology.

The popular Lakshman Jhula across
Ganga just above Rishikesh

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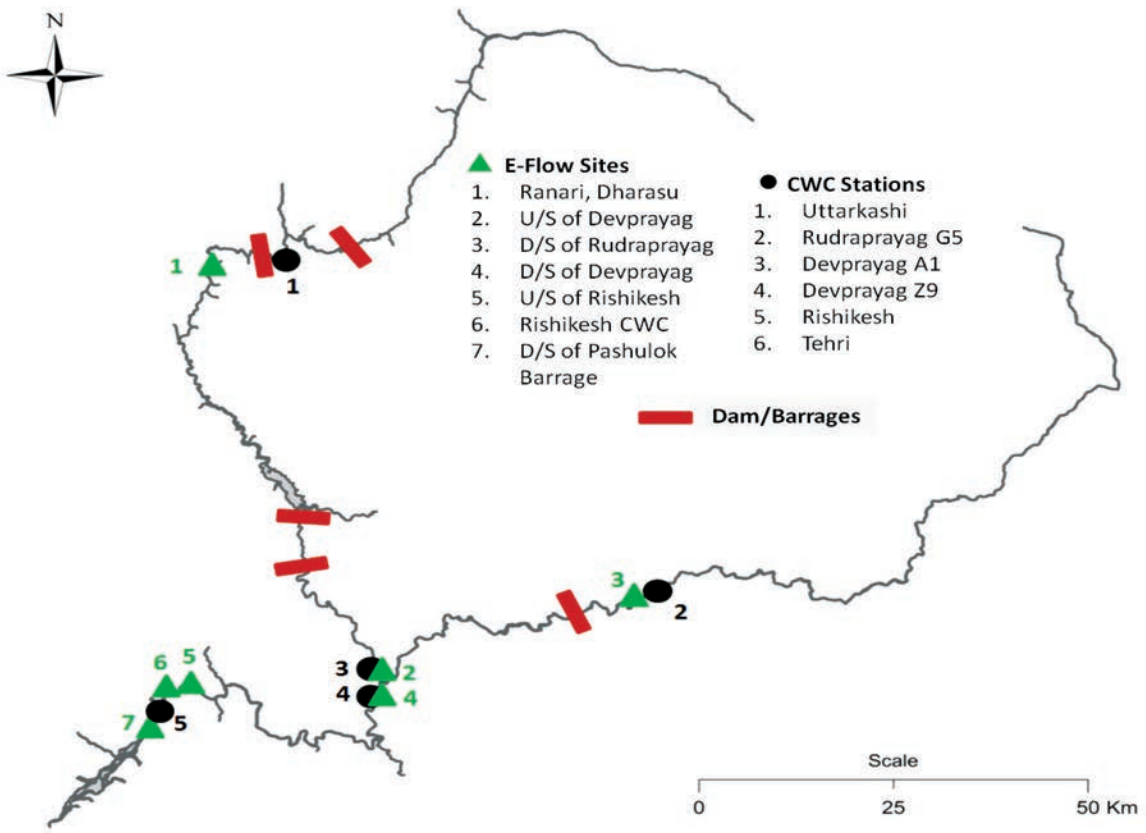
5. Illustration of E-Flows Assessment for a typical Site in Upper Ganga Segment

To illustrate the E-Flows Concept and Assessment Methodology, typical sites on river Alaknanda and Bhagirathi of the Upper Ganga Segment are considered. The geo-morphological and biological features of the respective sites were analysed and the sites were physically surveyed to map the river cross-sections. The Virgin River flows for sites on Bhagirathi river were considered for the period of data availability from CWC for the period 1972 to 1982 (prior to construction of Tehri Dam when the rivers could be considered 'virgin' or undisturbed), and for the site on Alaknanda for the period 1977 to 1987. The virgin flows at the E-Flows sites were then estimated from the virgin flows at the nearest measuring stations.

E-Flows at the sites selected consider the ecological and geo-morphological requirements, which in turn, ensure the critical ecosystem services of the river (including the cultural, spiritual and livelihood requirements that depend on these).

The sample results for E-Flows and Minimum Ecological Requirements for different sites are illustrated as follows, excluding quantitative flow data (which are classified government data).

FIGURE 3: Location Map of Flow Monitoring Stations and E-Flows Sites



The plight of trickling Bhagirathi due to water diversion at Maneri Bhali Dam

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5.1 Site : D/S Rudraprayag on Alaknanda River

(30°16’23”N, 78°57’41”E)

FIGURE 4: Schematic and Photographic Representation of the E-Flows Site at D/S Rudraprayag on Alaknanda River

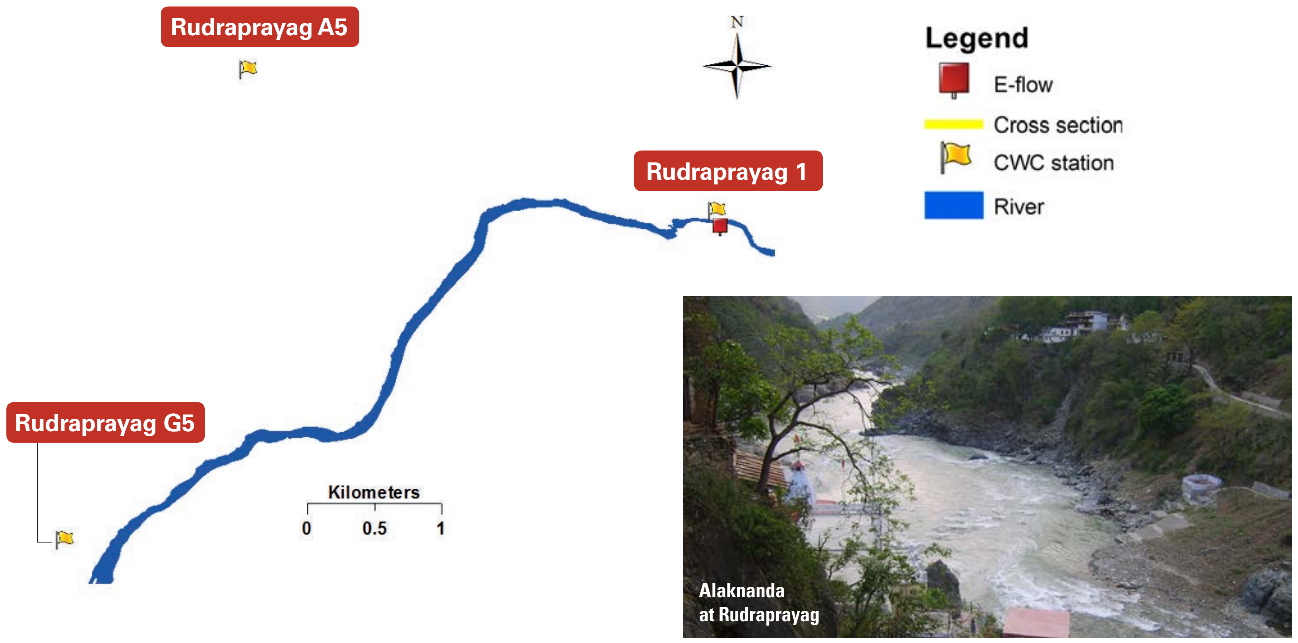
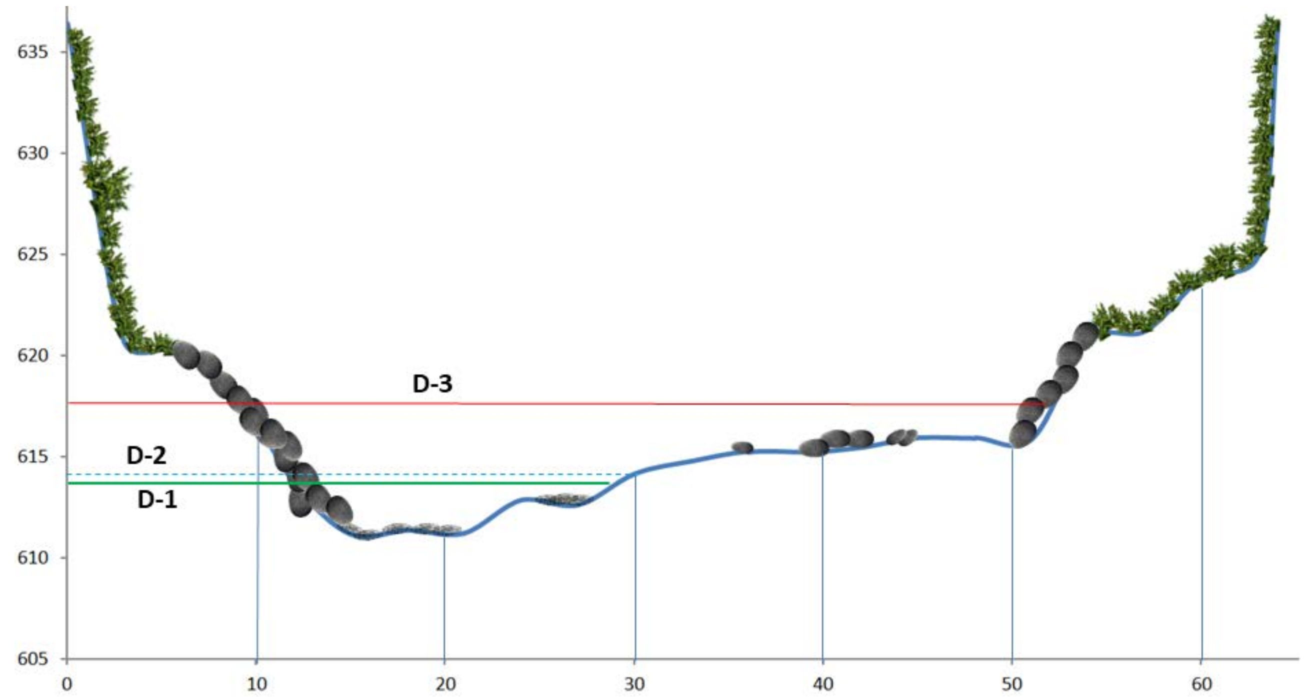


TABLE 1: Geomorphic Attributes

RIVER STYLE	Himalayan bedrock
CHANNEL CONFINEMENT	Confined
CHANNEL FEATURES	Very less mid channel bars, side bars and confluence bars
SINUOSITY	1.05-1.55
RIFFLE AND POOL	Present
BED MATERIAL	Boulders, cobbles, pebbles and sand are prominent bed material
GEOMORPHOLOGICALLY	Degradational regime

FIGURE 5: River Cross-section at D/S Rudraprayag on Alaknanda River



HFL (m)	Maximum Depth (m)	Bankfull Width (m)	Width/Depth ratio
625.6	1.8	18.6	10.33

TABLE 2: Salient Features of Biotic Components of the River Aquatic System at D/S Rudraprayag on Alaknanda River

ALGAL DIVERSITY	Vishnuprayag to Devprayag
ALGAL RATIO (D* G* BG*)	Total Taxa: 186; Diatoms: 164; Green algae: 15; Blue green: 7
SPECIFIC ZOOBENTHOS	100:9:4 (164, 15, 7)
CARPS/ ALL FISH TAXA	Plecoptera, Tricoptera, Ephemeroptera, Diptera, Coleoptera
CARPS/ CAT FISHES	0.60 (26/43)
RET FISH SPECIES	5.4 (43/8)
CHARACTERISTIC FISH SPECIES	10
HIGHER VERTEBRATES	Snow Trout (*Schizothorax richardsonii*)
HIGHER VERTEBRATES	No aquatic higher vertebrates

TABLE 3: Description of Key-stone Species, Corresponding D_1 and D_2 and Computed D_3 at D/S Rudraprayag on Alaknanda River

Keystone Species	Required Depths for E-flows		
	D_1	D_2	D_3
Snow Trout (*Schizothorax richardsonii*)	0.5 m	0.8 m	4.23 m
Golden Mahseer (*Tor putitora*)			

FIGURE 6A: Representation of Various Flow Regimes at D/S Rudraprayag on Alaknanda River over 12 Months

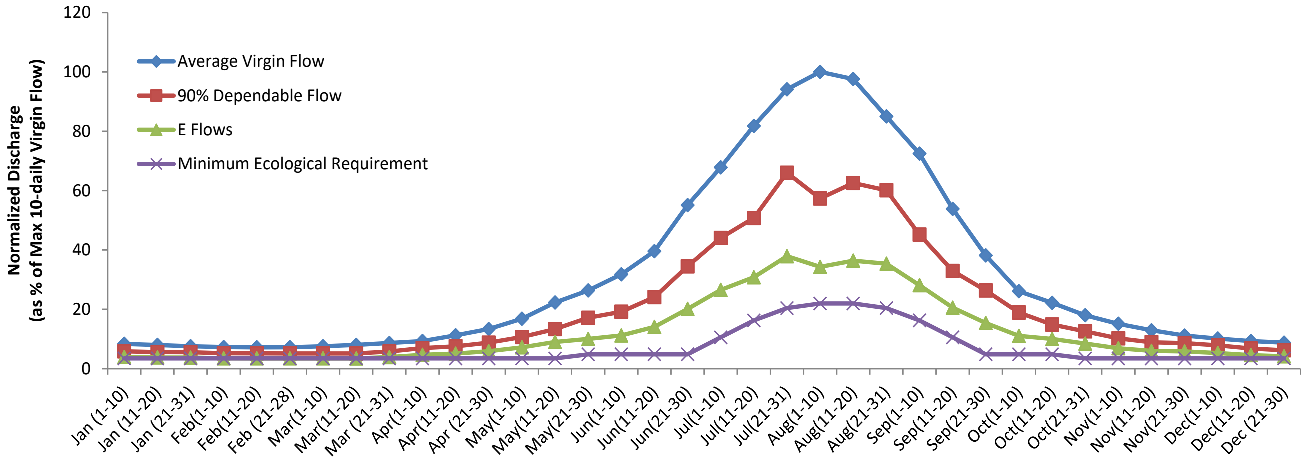


FIGURE 6B: Representation of Various Flow Regimes at D/S Rudraprayag on Alaknanda River during Non-Monsoon Period

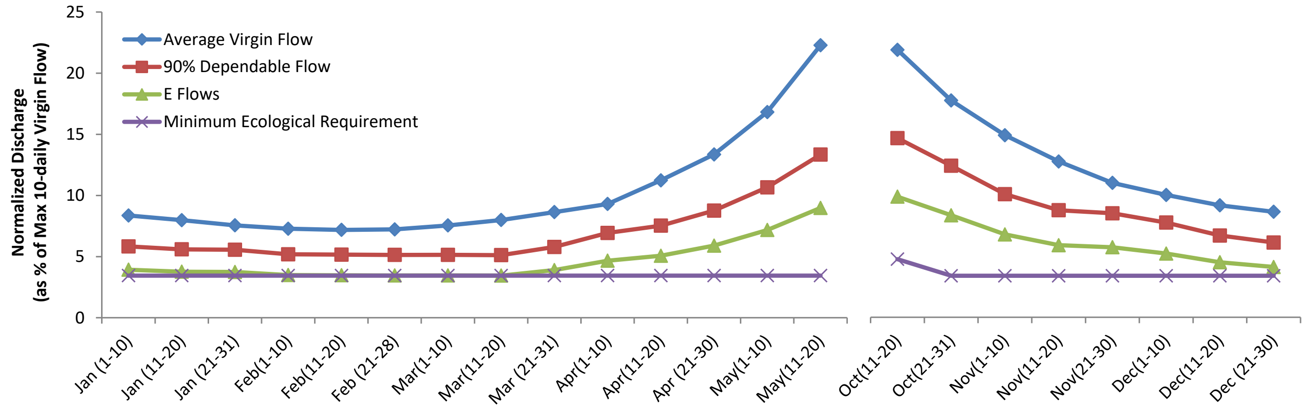


TABLE 4: Assessed E-Flows as Percentage of Virgin River Flows at D/S Rudraprayag on Alaknanda River

Basis	Minimum Ecological Requirement as % of Average Virgin Flow	E-Flows as % of Average Virgin Flow	E-Flows as % of 90% Dependable Flow
Wet Period	31.71	46.19	68.62
Dry Period	19.30	38.16	64.29
TOTAL	21.83	39.95	65.26

The sun, the mountains and the river — a perennial tango along the Ganga

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6. Observations on EFA at Seven Selected Sites

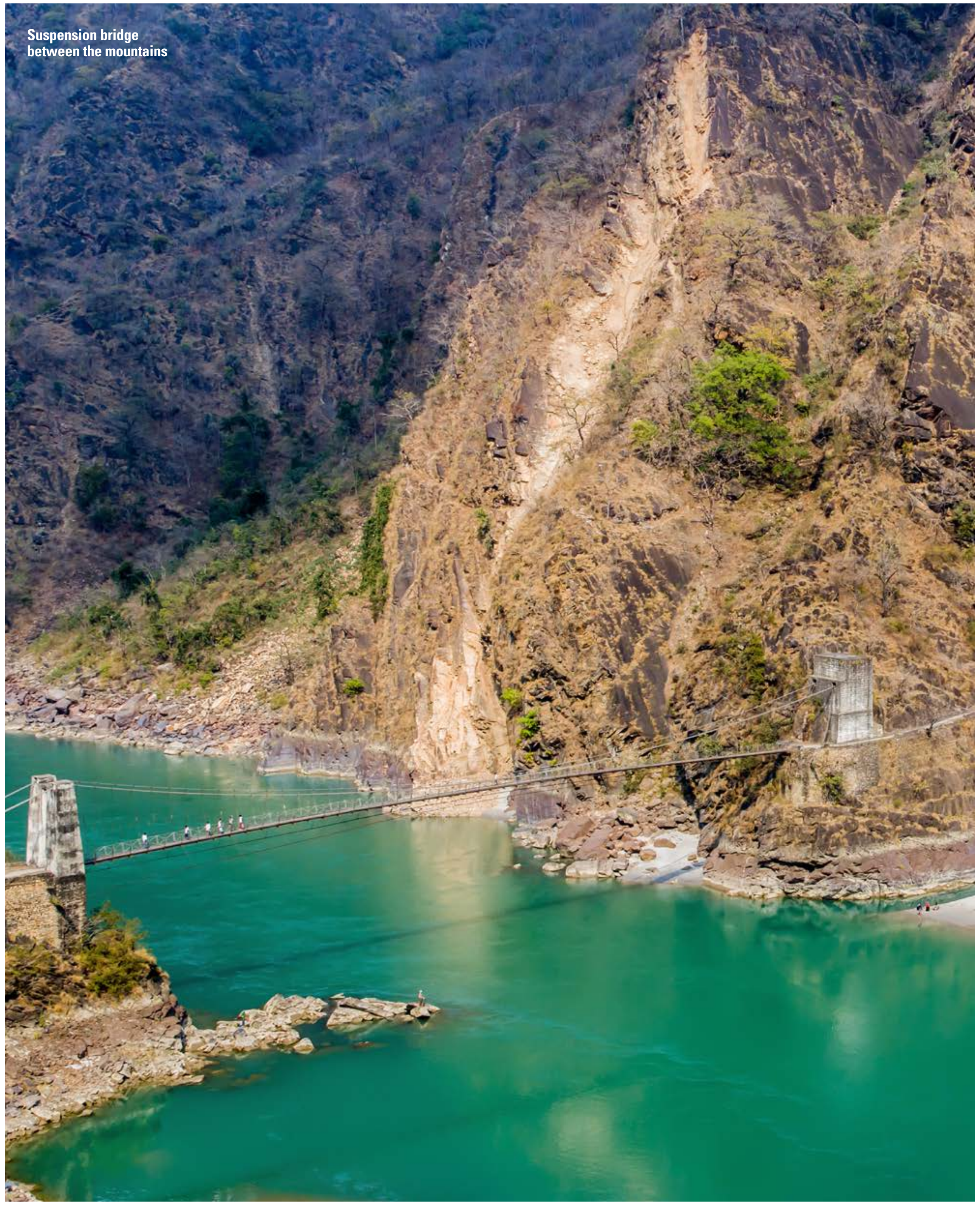
A summary of the Environmental Flows Assessment (EFA) exercise carried out for seven selected sites in the Upper Ganga Segment is presented in Table 5. The assessed E-Flows are in the range of 35 to 59%, 37 to 71% and 42 to 83% in the monsoon, non-monsoon and lean flow period respectively of the average virgin flows. Similarly, the assessed E-Flows are in the range of 61 to 71%, 67 to 76% and 71 to 85% in the monsoon, non-monsoon and lean flow period respectively of the 90% dependable virgin flows.

TABLE 5: Summary of EFA Results at Seven Selected Sites in Upper Ganga Segment

LOCATION	Monsoon		Non Monsoon		Lean Flow Period		Annual	
	A	B	A	B	A	B	A	B
Ranari, Dharasu on Bhagirathi River	46	61	53	67	62	79	47	62
U/S Dev Prayag on Bhagiathi River	35	67	38	69	43	77	35	67
D/S Rudra Prayag on Alaknanda River	40	64	46	69	48	71	42	65
D/S Dev Prayag on Ganga River	59	71	61	71	72	83	60	71
U/S Rishikesh on Ganga River	50	64	67	72	79	85	54	66
CWC Station Rishikesh on Ganga River	53	64	71	72	83	85	56	66
D/S Pashulok Barrage on Ganga River	58	64	37	76	42	85	55	66

Monsoon: June 1 – October 20;
Non-Monsoon: October 21 – May 31;
Lean Period: December 16 – March 15;
A: as % of Average Virgin Flow;
B: as % of 90% Dependable Flow

THE ASSESSED E-FLOWS ARE IN THE RANGE OF 35 TO 59%, 37 TO 71% AND 42 TO 83% IN THE MONSOON, NON-MONSOON AND LEAN FLOW PERIOD RESPECTIVELY OF THE AVERAGE VIRGIN FLOWS. SIMILARLY, THE ASSESSED E-FLOWS ARE IN THE RANGE OF 61 TO 71%, 67 TO 76% AND 71 TO 85% IN THE MONSOON, NON-MONSOON AND LEAN FLOW PERIOD RESPECTIVELY OF THE 90% DEPENDABLE VIRGIN FLOWS.


Suspension bridge between the mountains

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7. Concluding Remarks

1. E-Flows Assessment (EFA) is an important step in determining the River Health Regime (RHR).

2. E-Flows are location specific, and are essentially governed by ecological and geo-morphological requirements.

3. For EFA, information regarding (i) river hydrology, (ii) stage-discharge relationship, (iii) geo-morphological settings, (iv) bio-diversity of the stretch that represents and includes the river location under consideration is of critical significance.

4. E-Flows that maintain natural geo-morphology and biodiversity status can also be considered to fulfill and support the socio-cultural and local river-based livelihood aspirations.

5. EFA, thus is essentially a scientific process while the choice to maintain the river in a particular RHR is a social process that strives to strike a balance between societal aspirations and preservation of aquatic ecosystems.

6. Comparison of E-Flows with Virgin Flows (historical average and 90% dependable flows) and minimum ecological requirements (MER) can guide in determining RHR in terms of Pristine, Near-Pristine, Slightly Impacted, Impacted and Degraded regime.

7. Maintaining E-Flows to achieve a specific RHR may warrant (i) certain policy decisions to set boundary conditions for planned actions (e.g. irrigation and hydropower projects that are at planning stage), and/or (ii) reversal of trends in ongoing activities (e.g. hydropower projects and water diversions schemes that are operational). The time line, resource requirements and challenges faced are expected to be different and may have to be based on strategic planning (e.g. Ganga River Basin Management Plan).

8. In this report Concept of Environmental Flows (E-Flows), Methodology for Assessing E-Flows, Concept of River Health Regime (RHR) and Criteria for assessing Hydrologic RHR for any specific flow regime based on state-of-the-art for Indian Rivers has been presented.

9. Water quality considerations are considered external to EFA as water quality is significantly influenced by anthropogenic pollution sources. Controlling pollution sources by adopting reuse and recycle policy rather than following the principle of "dilution is the solution to pollution" is a better strategy in water stressed regions.

10. The E-Flows methodology has been illustrated for seven locations on river Ganga and some of her head-streams up to Rishikesh for which the relevant data/ information was available with IITC. Similar exercise may be carried out for all desired locations on the main stem of river Ganga as well as all her tributaries once the relevant data and information as stated at point 3 above are collated.

11. It is to be noted that EFA and RHR assessment are dynamic in nature and will get refined and improved as and when requisite information gets collated or updated.

Boating on the contented and placid Ganga in her middle reaches

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