Report Code: 073_GBP_IIT_EFL_ANL_01_Ver 1_Dec 2014

River Connectivity, Flow Regimes and Assessment of Environmental Flows at Some Select Sites in Upper Ganga Segment

GRBMP: Ganga River Basin 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 Management Plan (GRBMP).

A Consortium of 7 Indian Institute of Technology (IIT) has been given the responsibility of preparing Ganga River Basin Management Plan (GRBMP) 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.

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 Management Plan (GRBMP). The overall Frame Work for documentation of GRB EMP and Indexing of Reports is presented on the inside cover page.

There are two aspects to the development of GRBMP. Dedicated people spent hours discussing concerns, issues and potential solutions to problems. This dedication leads to the preparation of reports that hope to articulate the outcome of the dialog in a way that is useful. Many people contributed to the preparation of this report directly or indirectly. This report is therefore truly a collective effort that reflects the cooperation of many, particularly those who are members of the IIT Team. Lists of persons who are members of the concerned thematic groups and those who have taken lead in preparing this report are given on the reverse side.

Dr Vinod Tare
Professor and Coordinator
Development of GRBMP
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. Vinod Tare, IIT Kanpur
2. Gautam Roy, IIT Kanpur
3. Shyam Prasad, IIT Kanpur
4. Nitin Kaushal, WWF-India
5. Ankit Modi, IIT Kanpur

Contents

1. Introduction

To achieve the objective of "Rejuvenation and Development of Ganga", assessment of Environmental Flows (E-Flows) is considered as one of the most important aspects.

Flow is one of the main drivers of biodiversity 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. E-Flows consider the equitable distribution of water between needs of aquatic ecosystems and the services availed from such 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 of people. 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-TR22, 2011].

The objective of E-Flows is to recognize the physical limit beyond which a water resource suffers irreversible damage to its ecosystem functions, and systematically balance the multiple water needs of society in a transparent and informed manner. E-Flows are 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-TR22, 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 (Mo E, F & 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 flow rates 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.

2. Concept of Aviral Dhara

Among many aspects, the vision for Ganga River includes the concept of Aviral Dhara. This can be defined as "the flow of water, sediments and other natural constituents of River Ganga are continuous and adequate over the entire length of the river throughout the year". As it can be seen from the above definition, a minimum quantity of flow is required in the river for it to support its natural processes. However, the increase in anthropogenic activities in the watershed of a river has the potential to alter the flows in the river leading to interference with the natural processes of a river.

In the river systems, several processes lead to differentially structured river sections, varying in geomorphology, hydrology, bio- & geo- chemistry, 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 characters of rivers become very clear in the case of construction of the dams and embankments (dikes), because these disrupt the longitudinal and lateral continuum, resulting in shifts in abiotic and biotic parameters and processes (Velde, 2014).

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 deviating the flows in the river from their natural conditions spatially and temporally. Further, maintaining river connectivity that allows for the energy, nutrients, sediment and organisms exchange between different parts of the river pathways is imperative before establishing the environmental flows for a stretch of a river.

2.1 River Connectivity

Connectivity is defined as the maintenance of lateral, longitudinal, and vertical pathways for biological, hydrological, and physical processes (Annear, 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 and change in response. Along its length, the rivers change from small, rocky-based, shaded streams in the upland mountainous region to wider rivers in the valleys to broad, muddy rivers in the lowland floodplain. While most movement is downstream, many fish 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 back to the river, replenishing in-stream energy sources and ensuring recruitment in fish populations and insect communities.

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.

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 rises and falls according to seasonal patterns, depending on rain and snowmelt.

2.2 Flow regime

Flow regime influences the water quality, energy cycles, biotic interactions, and habitat of rivers (Naiman, 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, 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 majority 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.

2.3 Geomorphological processes

Geomorphological processes contribute to the changes that will occur to a stream channel in response to alterations in watershed conditions; and, in turn, how these changes will impact human infrastructure and fish habitat. Stream morphology is dynamic and constantly changing 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 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 aggradations leads to embedded riffle substrate and the loss of riffle habitat.

2.4 Social Aspects of River Ganga

The river Ganga has significant economic, environmental and cultural value in India. The river Ganga also serves as 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, perennial source of fresh water, inseparable part of Indian culture, fisheries and 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 its important tributaries in search for salvation.

Despite its importance, extreme pollution pressures pose a great threat to the biodiversity and environmental sustainability of the Ganga, with detrimental effects on both the quantity and quality of its flows. Also, 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 seasons. 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 dry, 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.

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 in order to protect these systems. The various components under flow regimes have been explained in this section.

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 and consequent exploitation of the natural resources.

Factors that have contributed significantly toward these modifications include construction for hydroelectric power generation and tributary dams, 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 decades. 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, 2005).

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 floodplains, 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 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.

3.3 90% Dependable Flows

Dependable flows can be described as the nature of flow in a river based on which activities such as water supply, irrigation, power generation etc. can be 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. 90% dependable flow means that, the observed flow obtained by analyzing historical data, would be available in the river at least 90% of the time.

3.4. Environmental Flows

An environmental flow is the water regime that needs 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 start with 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 the setting of an Environmental Flows.

To set an Environmental Flows, one needs to identify clear objectives as well as water abstraction and 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.

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 during monsoon season.
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 to obtain E-Flows hydrograph for dry and wet seasons subject to the condition that minimum flow in wet season is to be 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.
9. Assessing the River Health for different Flow Regimes.

*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.

4.1 Minimum Ecological Requirement

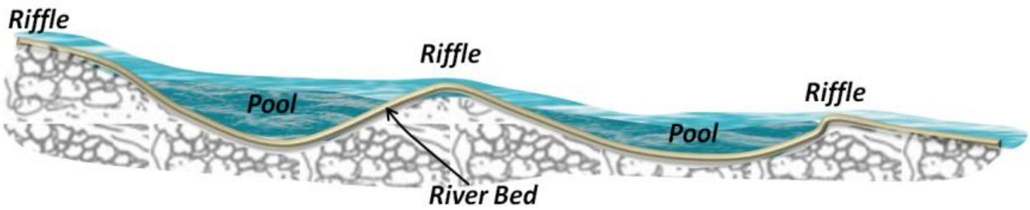
The objective of the E-Flows is the restoration of the river health. However, the river health itself depends on a wide range of variables. Identifying and addressing them individually is a complex and non-linear problem.

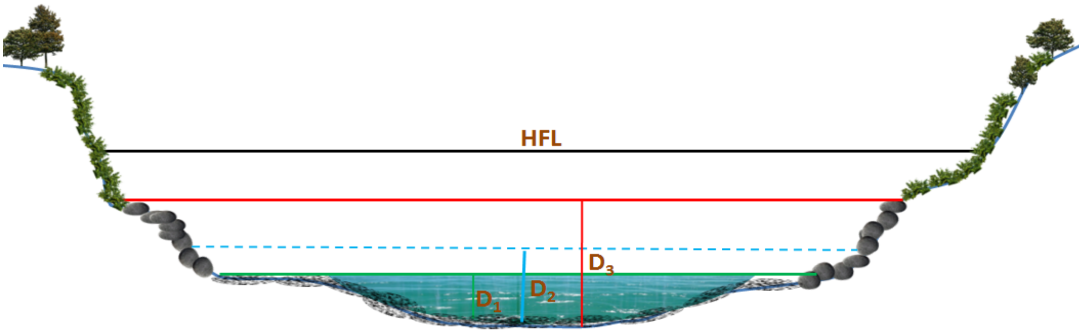
For upper Ganga Rivers, keystone fish species, such as Mahseer and Snow trout, are in danger due to fragmentation and loss of connectivity of the river due to the construction of numerous dams, barrages, and reservoirs. Also these fish species govern the minimum depth of flow required for sustenance 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.

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.

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.

Figure 1: E-Flows Assessment – Conceptual Diagram

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 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).

4.2 E-Flows Hydrograph

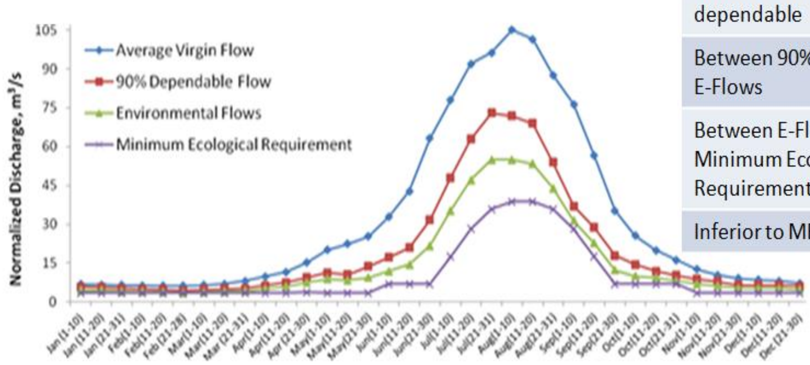
Environmental Flows are computed based on minimum ecological requirements and is done separately for monsoon (wet) and non-monsoon (dry) periods. Daily Average Flows and 90% Dependable Flows are first computed from historical flow data. The Environmental Flows are obtained by mimicking the trend in daily 90% dependable flow using the minimum ecological requirement for non-monsoon season as the minimum E-Flows for non-monsoon period. For monsoon season, the flows corresponding to D_3 is first deducted from the 90% dependable flow, and a higher value between the flow corresponding to D_2 and maximum 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 the (i) Average flow, (ii) 90% dependable flow, (iii) E-Flows, and (iv) Minimum Ecological Requirements.

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

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.



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

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

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.

5. Illustration of E-Flows Assessment for Some Select Sites in Upper Ganga Segment

To illustrate the E-Flows Concept and Assessment Methodology, some of the selected sites on Alaknanda and Bhagirathi rivers 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 minimum ecosystem goods and 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).

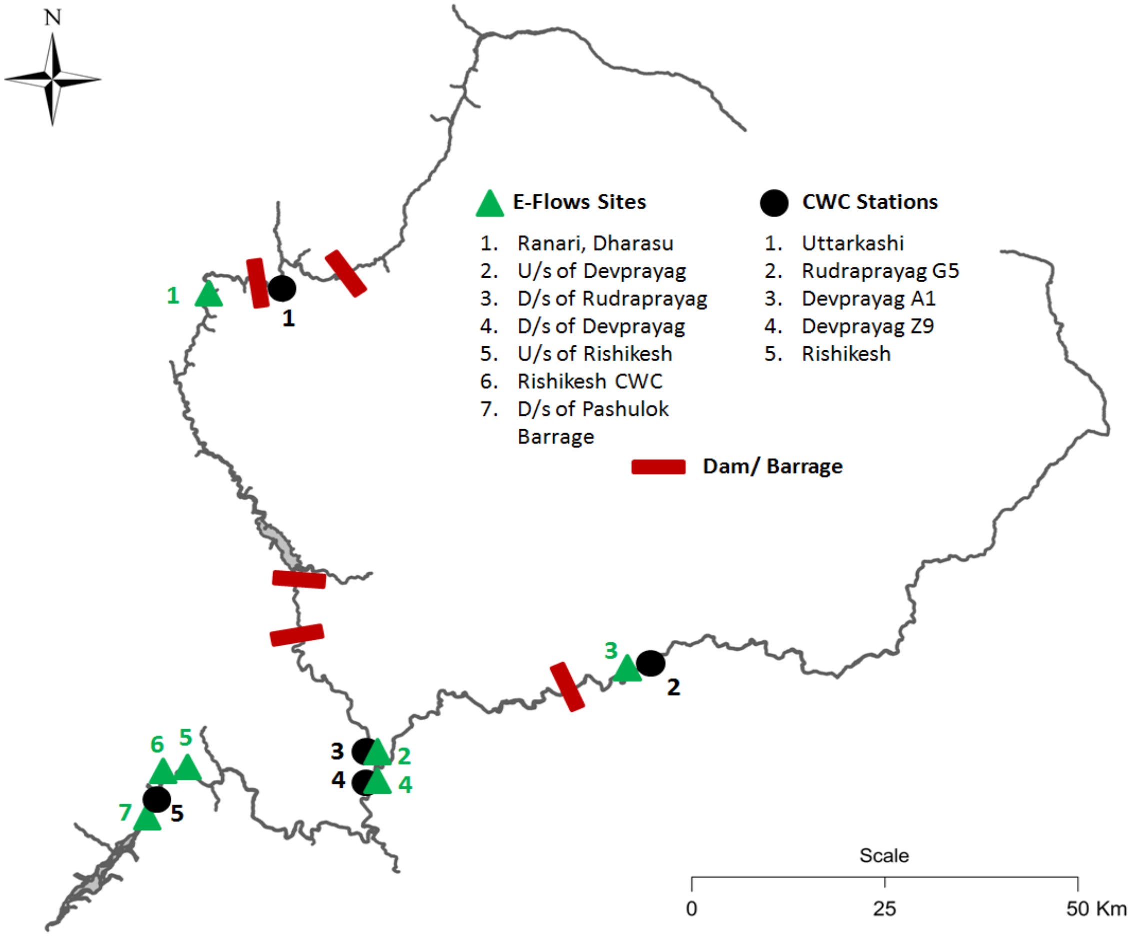


Figure 3: Location Map of Flow Monitoring Stations and E-Flows Sites

5.1 Site 1: Ranari, Dharasu on river Bhagirathi (30°43'02"N, 78°21'17"E)

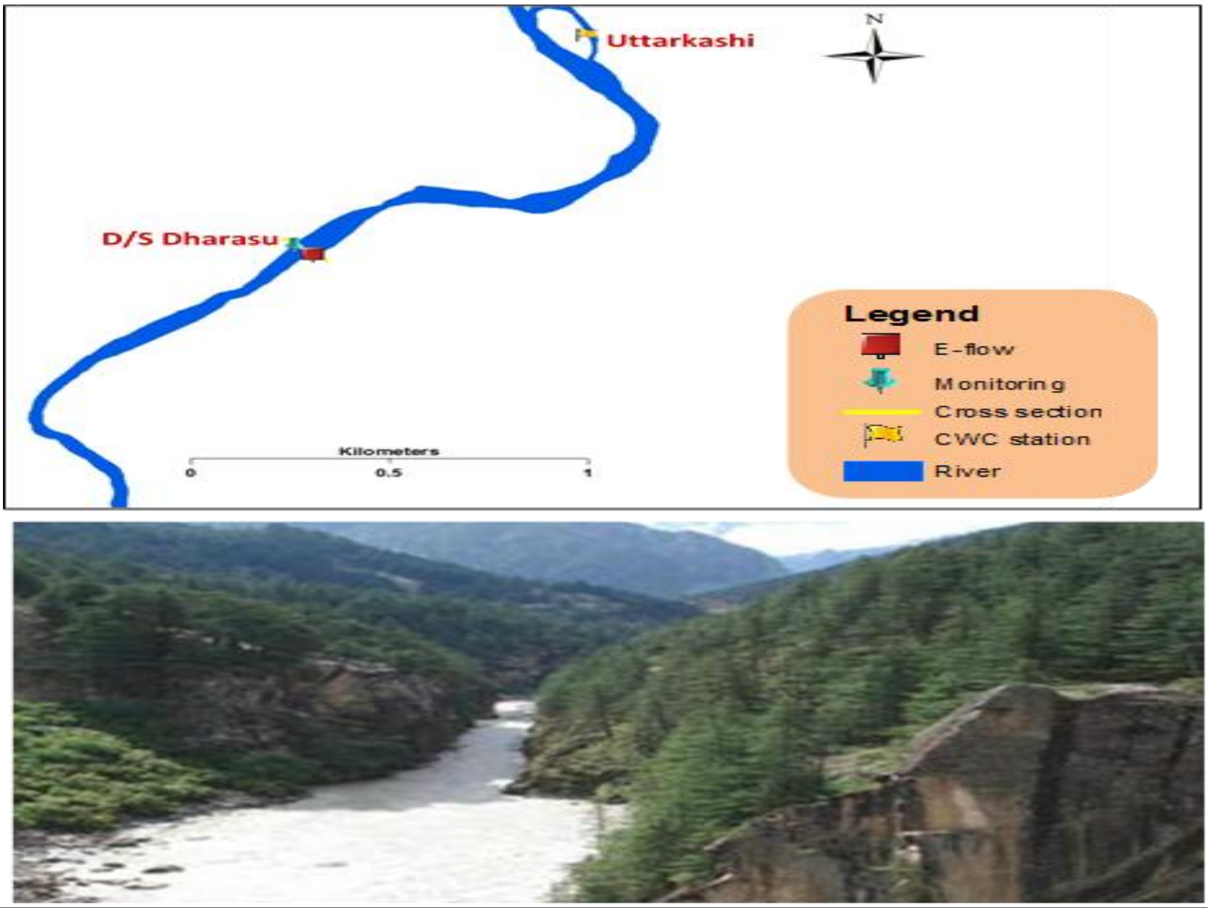
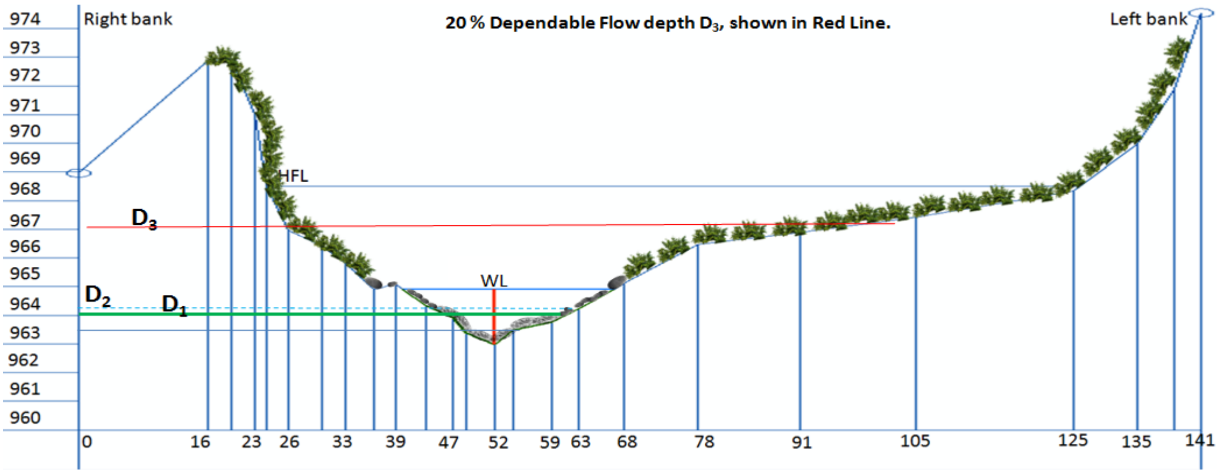


Figure 4: Schematic and Photographic Representation of the E-Flows Site at Ranari, Dharasu on Bhagirathi

Table 1: Geomorphic Attributes

River style: Himalayan steep valley
Channel confinement: Confined
Channel features: Very less mid channel bars, side bars and confluence bars
Sinuosity: 1.03-2.42
No floodplain
Slope: (2.10^0) Moderate to steep slope
Symmetricity: Symmetrical channel
Bed material: Boulders, cobbles, pebbles and coarse sand in channel belt
Geomorphologically: Degradational regime



HFL (m)	Maximum Depth(m)	Bankfull Width(m)	Width/Depth ratio	Velocity (m/s)	Discharge (m^3/s)
968.4	1.9	26.5	13.9	NA	NA

Figure 5: River Cross-section at Ranari, Dharasu

Table 2: Salient Features of Biotic Components of the River Aquatic System at Ranari, Dharasu

River Stretch	UG2 (Gangnani to Devprayag)
Algal diversity	Total Taxa: 151; Diatoms: 123; Green algae: 21; Blue green: 06
Algal ratio (D* G* BG*)	100:17:5 (123, 21, 6)
Specific Zoobenthos	Plecoptera, Tricoptera, Ephemeroptera, Diptera, Coleoptera
Carps/All Fish taxa	0.65 (23/35)
Carps/Cat fishes	3.83 (23/6)
RET Fish species	14
Characteristic fish species	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 Ranari, Dharasu

Keystone Species	Required Depths for E-flows		
	D_1	D_2	D_3
SnowTrout *(Schizothorax richardsonii)* **Golden Mahseer** *(Tor putitora)*	0.5 m	0.8 m	3.41 m

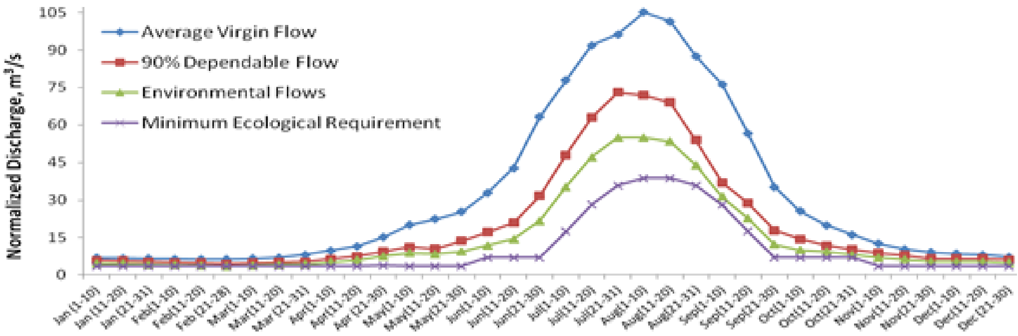


Figure 6a: Representation of Various Flow Regimes in Bhagirathi River at Ranari, Dharasu over 12 Months

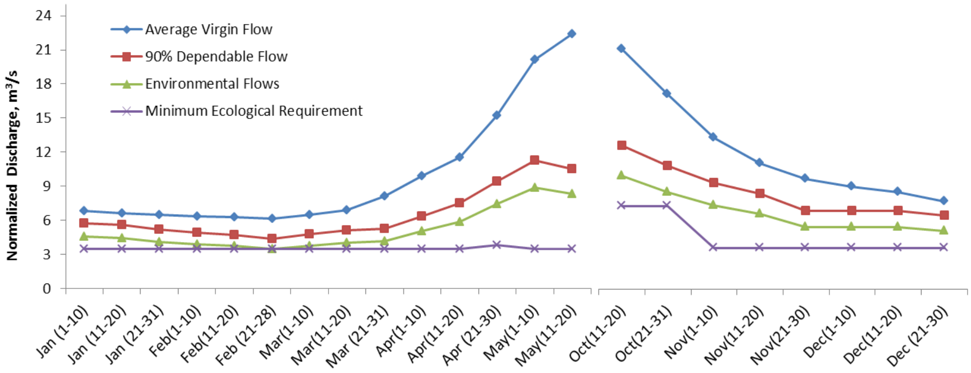


Figure 6b: Representation of Various Flow Regimes in Bhagirathi River at Ranari, Dharasu during Non-Monsoon Period

Table 4: Assessed E-Flows as Percentage of Virgin River Flows in Bhagirathi River at Ranari, Dharasu

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	32.59	46.13	61.04
Dry Period	32.96	53.12	67.23
Total	32.67	47.54	62.29

As seen from the above results, the minimum ecological flows required to maintain river integrity are about one-third of the average virgin flows of the river in both dry and wet seasons, while the E-Flows required are about half the average virgin flows. However, this fraction varies over the year and is relatively higher during dry season, river flows being minimum in winter.

5.2 Site 2: U/S Devprayag on Bhagirathi River (30°09'06"N, 78°35'56"E)

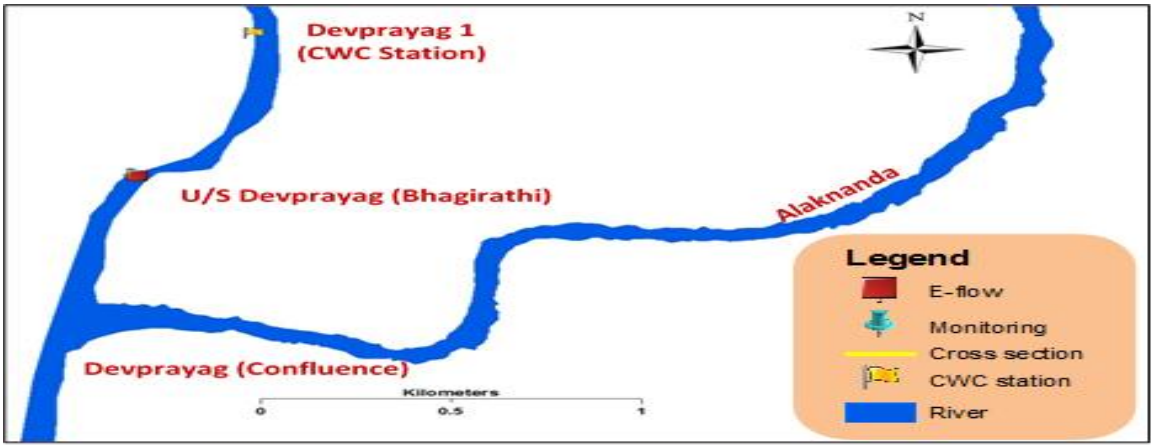
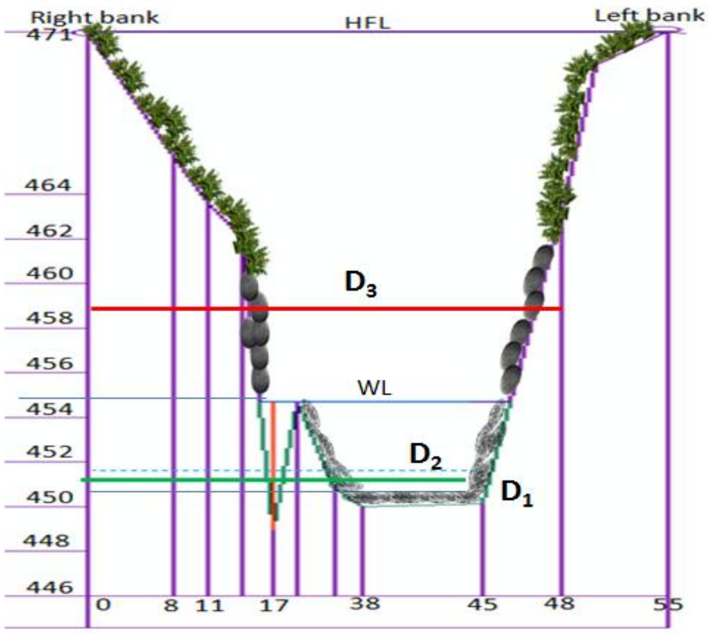


Figure 7: Schematic and Photographic Representation of the E-Flows Site at U/S Devprayag on Bhagirathi River

Table 5: 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
No floodplain
Riffle and Pool: Present
Bed material: Boulders, cobbles, pebbles and sand are prominent bed material
Geomorphologically: Degradational regime



HFL (m)	Maximum Depth(m)	Bankfull Width(m)	Width/Depth ratio	Velocity (m/s)	Discharge (m^3/s)
471	5.7	24.2	4.2	NA	NA

Figure 8: River Cross-section at U/S Devprayag on Bhagirathi River

Table 6: Salient Features of Biotic Components of the River Aquatic System at U/S Devprayag on Bhagirathi River

River Stretch	UG2 (Gangnani to Devprayag)
Algal diversity	Total Taxa: 151; Diatoms: 123; Green algae: 21; Blue green: 06
Algal ratio (D* G* BG*)	100:17:5; (123, 21, 6)
Specific Zoobenthos	Plecoptera, Tricoptera, Ephemeroptera, Diptera, Coleoptera
Carps/All Fish taxa	0.65 (23/35)
Carps/Cat fishes	3.83 (23/6)
RET Fish species	14
Characteristic fish species	Snow Trout *(Schizothorax richardsonii)*
Higher vertebrates	No aquatic higher vertebrates

Table 7: Description of Key-stone Species, Corresponding D_1 and D_2, and computed D_3 at U/S Devprayag on Bhagirathi River

Keystone Species	**Required Depths for E-flows**		
	D_1	**D_2**	**D_3**
Snow Trout *(Schizothorax richardsonii)* **Golden Mahseer** *(Tor putitora)*	0.5 m	0.8 m	8.48 m

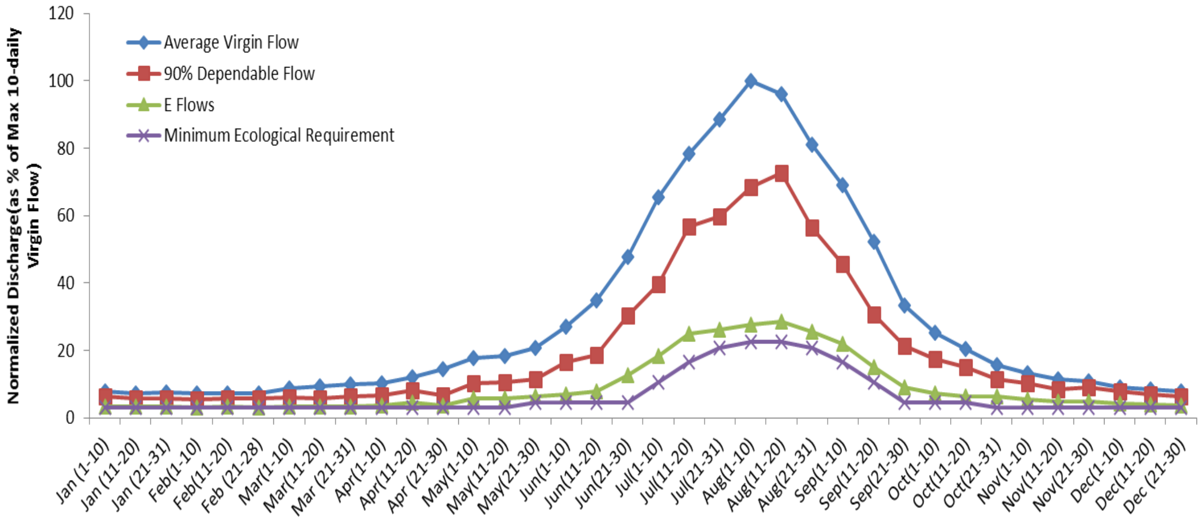


Figure 9a: Representation of Various Flow Regimes at U/S Devprayag on Bhagirathi River over 12 Months

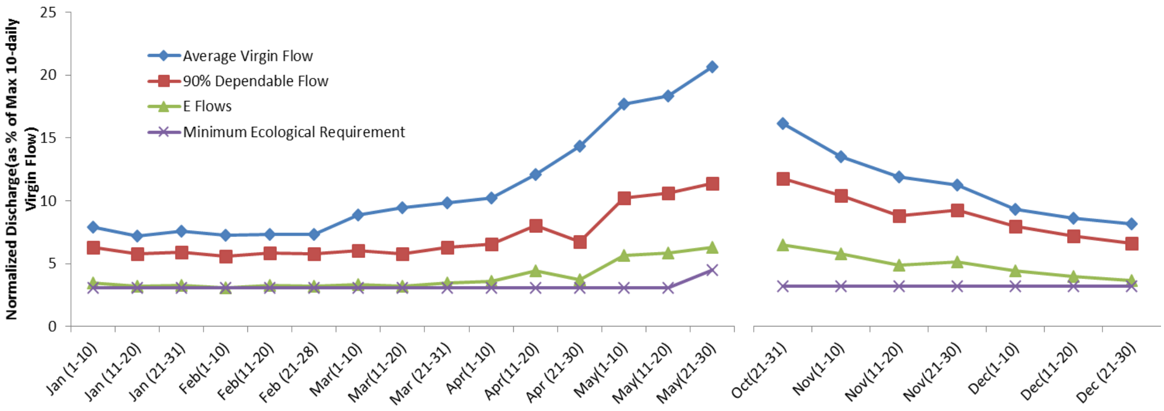


Figure 9b: Representation of Various Flow Regimes at U/S Devprayag on Bhagirathi River during Non-Mansoon Period

Table 8: Assessed E-Flows as Percentage of Virgin River Flows at U/S Devprayag on Bhagirathi 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	29.00	37.98	68.77
Dry Period	20.48	29.04	67.02
Total	22.27	31.09	67.42

5.3 Site 3: D/S Rudraprayag on Alaknanda River (30°16'23"N, 78°57'41"E)

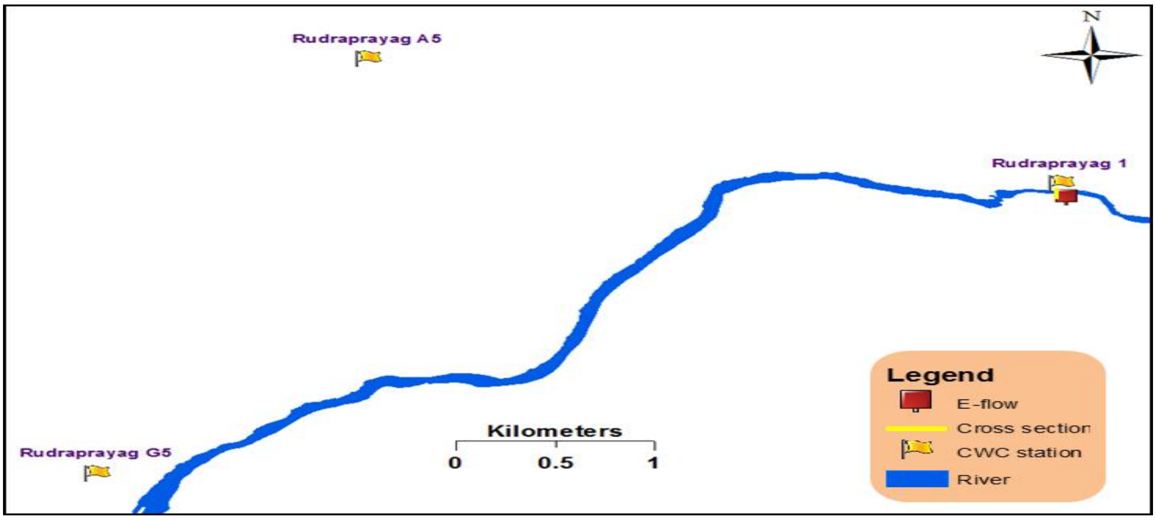
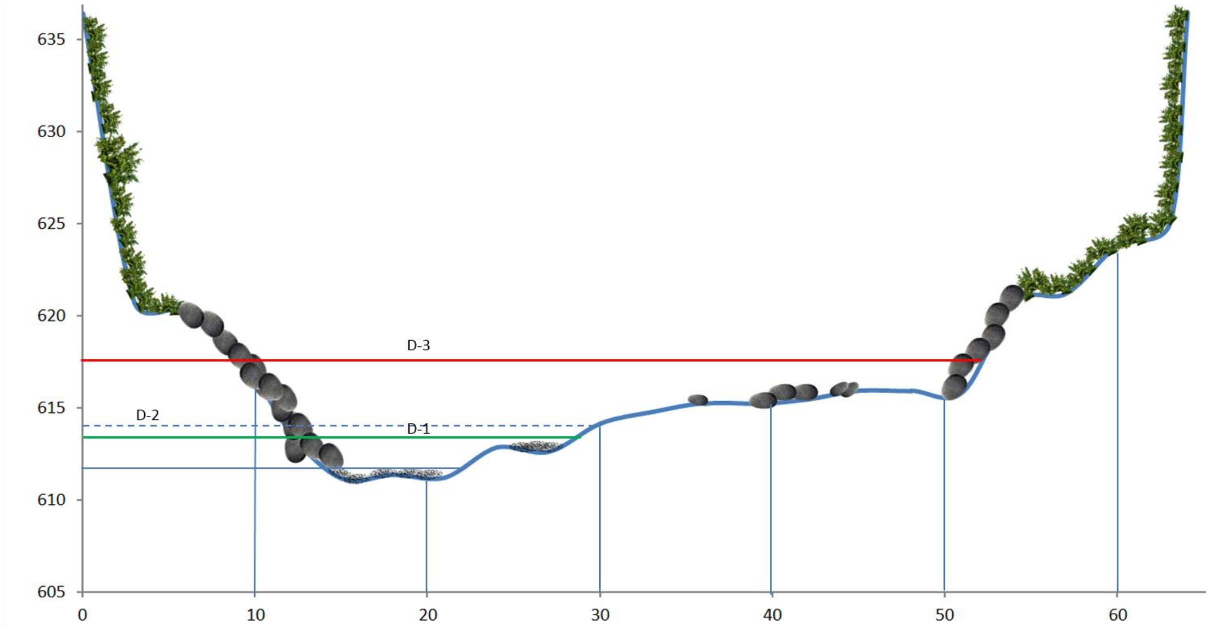


Figure 10: Schematic and Photographic Representation of the E-Flows Site atD/S Rudraprayag on Alaknanda River

Table 9: 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
No floodplain
Riffle and Pool: Present
Bed material: Boulders, cobbles, pebbles and sand are prominent bed material
Geomorphologically: Degradational regime



HFL (m)	Maximum Depth(m)	Bankfull Width(m)	Width/Depth ratio	Velocity (m/s)	Discharge (m^3/s)
471	5.7	24.2	4.2	NA	NA

Figure 11: River Cross-section at D/S Rudraprayag on Alaknanda River

Table10: Salient Features of Biotic Components of the River Aquatic System at D/S Rudraprayag on Alaknanda River

River Stretch	Vishnuprayag to Devprayag
Algal diversity	Total Taxa: 186; Diatoms: 164; Green algae: 15; Blue green: 7
Algal ratio (D* G* BG*)	100:9:4(164, 15, 7)
Specific Zoobenthos	Plecoptera, Tricoptera, Ephemeroptera, Diptera, Coleoptera
Carps/ All Fish taxa	0.60 (26/43)
Carps/ Cat fishes	5.4 (43/8)
RET Fish species	10
Characteristic fish species	Snow Trout (*Schizothorax richardsonii*)
Higher vertebrates	No aquatic higher vertebrates

Table 11: 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
SnowTrout *(Schizothorax richardsonii)*	0.5 m	0.8 m	4.23 m
Golden Mahseer *(Tor putitora)*			

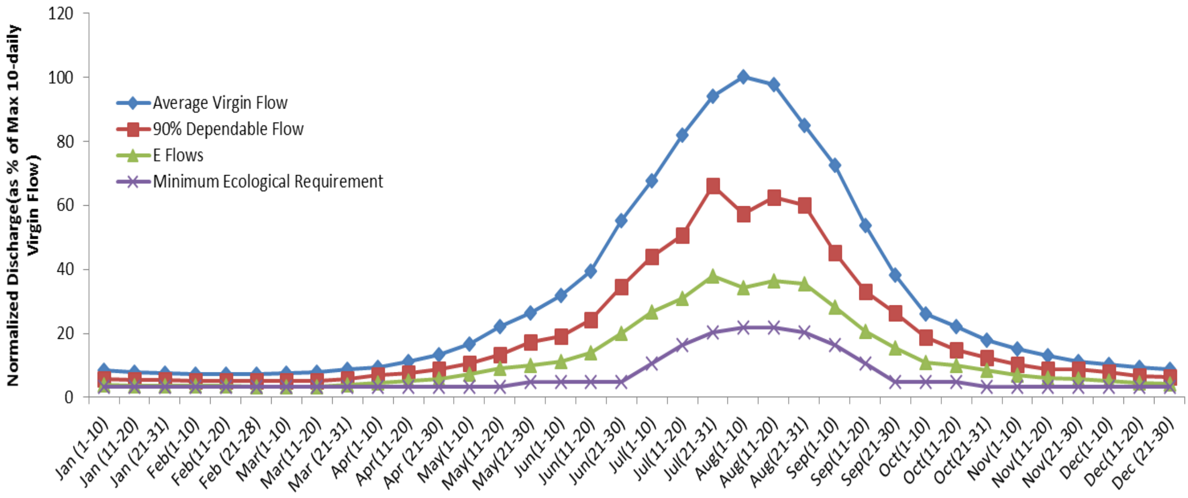


Figure 12a: **Representation of Various Flow Regimes at D/S Rudraprayag on Alaknanda River over 12 Months**

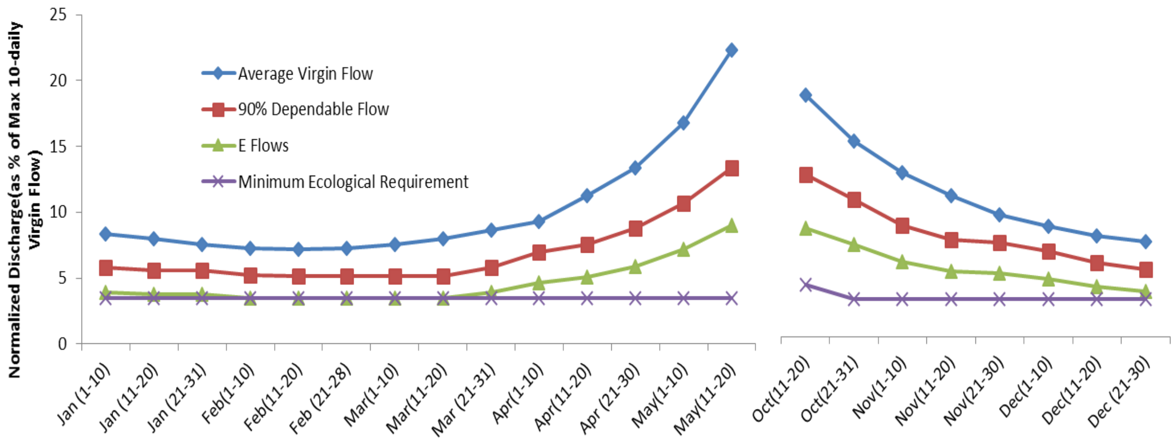


Figure 12b: **Representation of Various Flow Regimes at D/S Rudraprayag on Alaknanda River during Non-Mansoon Period**

Table 12: **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

5.4 Site 4: D/S Devprayag on Ganga River (30°08'27"N, 78°35'47"E):

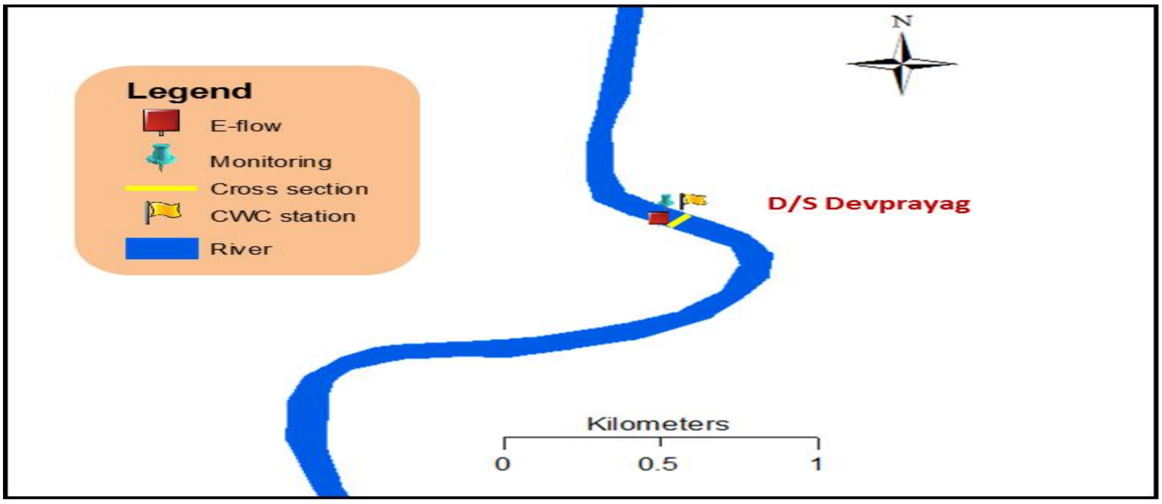


Figure 13: Schematic and Photographic Representation of the E-Flows Site at D/S Devprayag on Ganga River

Table 13: Geomorphic attributes

River style: Himalayan steep valley
Channel confinement: Confined
Channel features: Very less mid channel bars, side bars and confluence bars
Sinuosity: 1.03-2.42
No floodplain
Slope: (1.83^0) Moderate to steep slope
Channel incision: Incised
Symmetricity: Symmetrical channel
Bed material: Boulders, cobbles, pebbles ,sand
Geomorphologically: Degradational regime

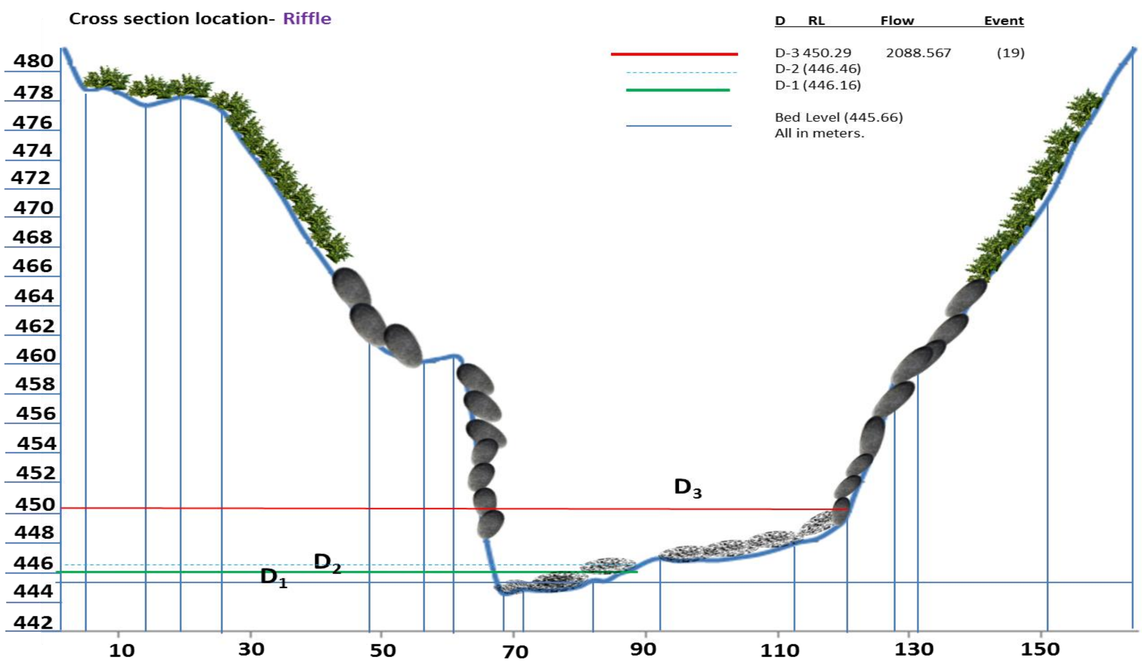


Figure 14: River Cross-section at D/S Devprayag on Ganga River

Table 14: Salient Features of Biotic Components of the River Aquatic System at U/S Devprayag on Ganga River

River Stretch	UG3 (Devprayag to Haridwar)
Algal diversity	Total Taxa: 123; Diatoms: 95; Green algae: 13; Blue green: 12
Algal ratio (D* G* BG*)	100:14:13 (95, 13, 12)
Specific Zoobenthos	Tricoptera, Ephemeroptera, Diptera, Odonata
Carps/ All Fish taxa	0.59(25/42)
Carps/ Cat fishes	3.57(25/7)
RET Fish species	8
Characteristic fish species	Snow Trout (*Schizothorax richardsonii*) Golden Mahseer(*Tor putitora*)
Higher vertebrates	No aquatic higher vertebrates

Table 15: Description of Key-stone Species, Corresponding D_1 and D_2, and Computed D_3 at D/S Devprayag on Ganga River

Keystone Species	**Required Depths for E-flows**		
	D_1	**D_2**	**D_3**
SnowTrout *(Schizothorax richardsonii)*	0.5 m	0.8 m	4.63 m
Golden Mahseer *(Tor putitora)*			

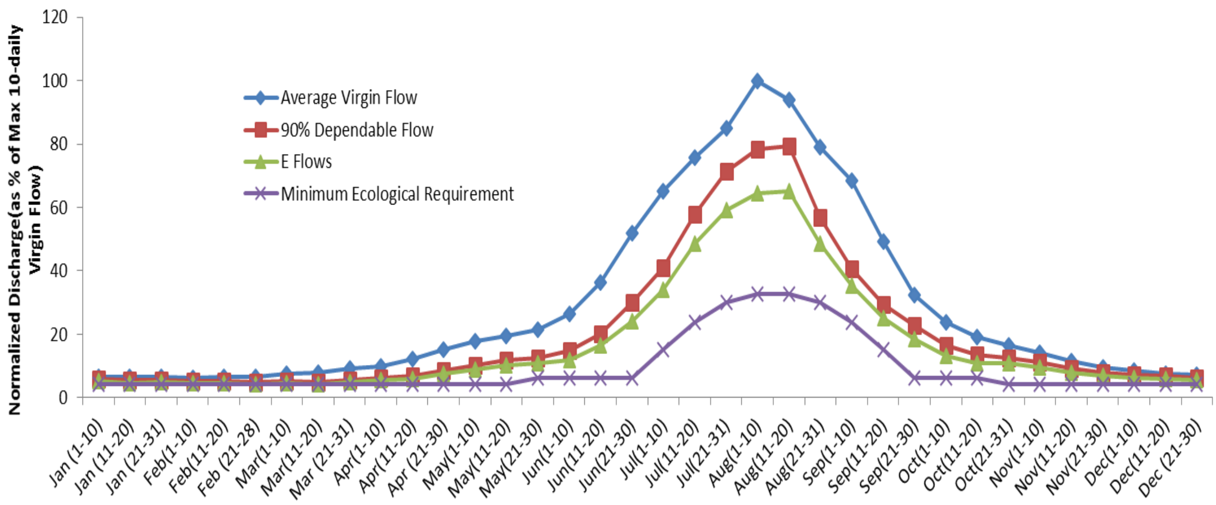


Figure 15a: Representation of Various Flow Regimes at D/S Devprayag on Ganga River over 12 Months

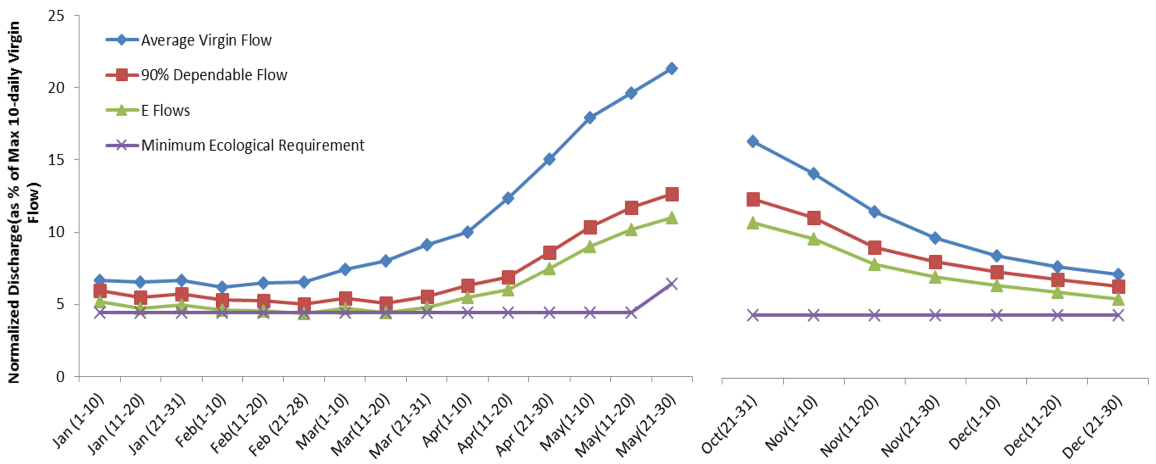


Figure 15b: Representation of Various Flow Regimes at D/S Devprayag on Ganga River during Non-Monsoon Period

Table 16: Assessed E-Flows as Percentage of Virgin River Flows at D/S Devprayag on Ganga 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	43.21	61.47	70.83
Dry Period	29.98	59.00	71.05
Total	32.69	59.55	71.00

5.5 Site 5: U/S Rishikesh on River Ganga (30°43'02"N, 78°21'17"E)

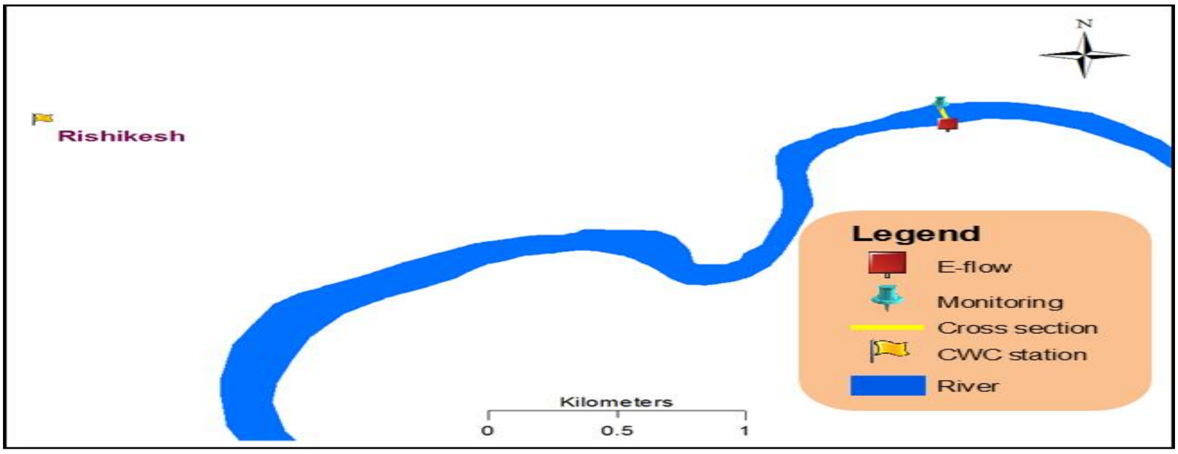
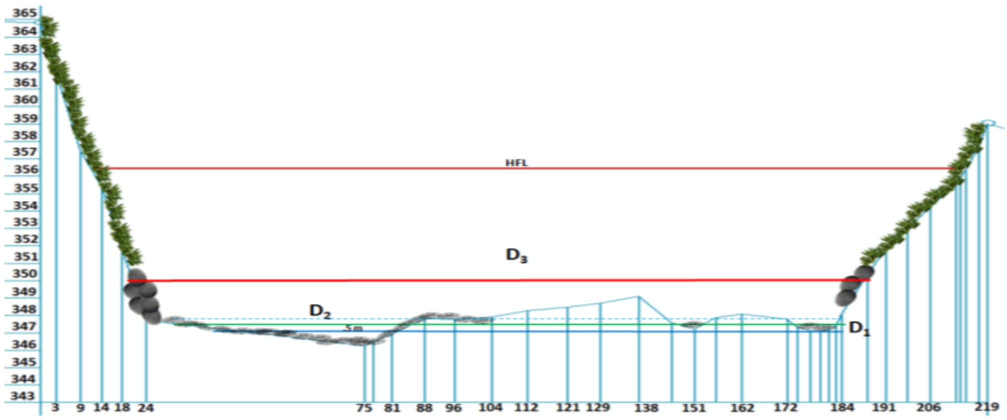


Figure 16: Schematic and Photographic Representation of the E-Flows Site at U/S Rishikesh on River Ganga

Table 17: Geomorphic Attributes

River style: Transition of Himalayan Bedrock and alluvial setting
Channel confinement: Partly confined
Channel features: Alluvial islands, mid channel bars and side bars
Sinuosity: 1.18.40
Active floodplain: Valley width-1:5
Slope: 0.518^{0}
Bed material: Conglomerate, cobbles, pebbles and sand are present
Geomorphologically: Agradational regime



HFL (m)	Maximum Depth(m)	Bankfull Width(m)	Width/Depth ratio	Velocity (m/s)	Discharge (m^3/s)
356.5	1.8	161.5	89.7	NA	NA

Figure 17: River Cross-section at U/S Rishikesh on River Ganga

Table 18: Salient Features of Biotic Components of the River Aquatic System at U/S Rishikesh on River Ganga

River Stretch	UG3 (Devprayag to Haridwar)
Algal diversity	Total Taxa: 123; Diatoms: 95; Green algae: 13; Blue green: 12
Algal ratio (D* G* BG*)	100:14:13 (95, 13, 12)
Specific Zoobenthos	Tricoptera, Ephemeroptera, Diptera, Odonata
Carps/ All Fish taxa	0.59 (25/42)
Carps/ Cat fishes	3.57(25/7)
RET Fish species	8
Characteristic fish species	Golden Mahseer (*Tor putitora*)
Higher vertebrates	No aquatic higher vertebrates

Table 19: Description of key-stone species, corresponding D_1 and D_2, and Computed D_3 at U/S Rishikesh on River Ganga

Keystone Species	**Required Depths for E-flows**		
	D_1	**D_2**	**D_3**
Golden Mahseer *(Tor putitora)*	0.5 m	0.8 m	2.91 m

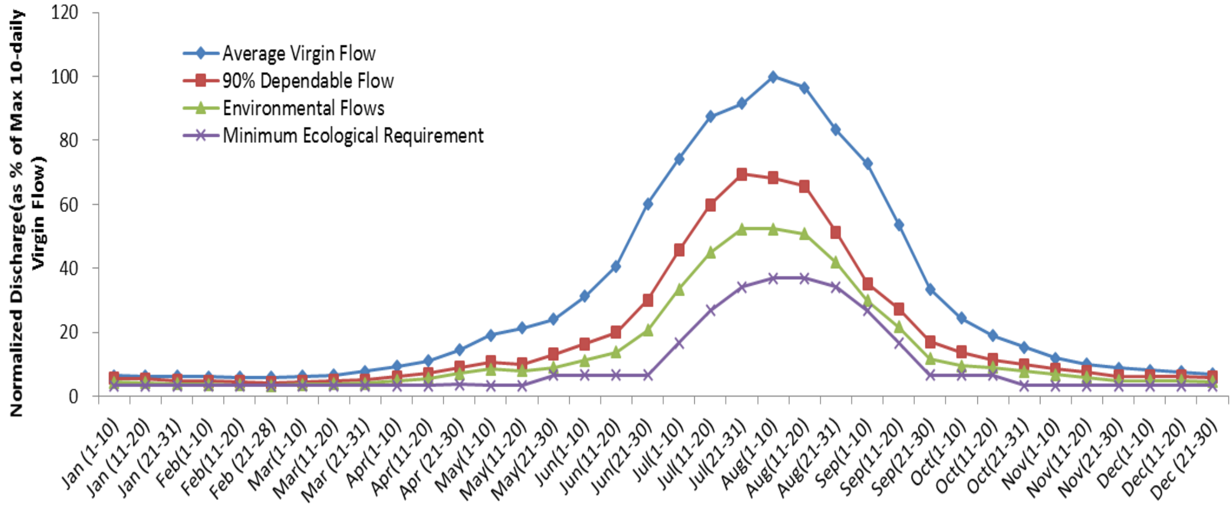


Figure 18a: Representation of Various Flow Regimes at U/S Rishikesh on River Ganga over 12 Months

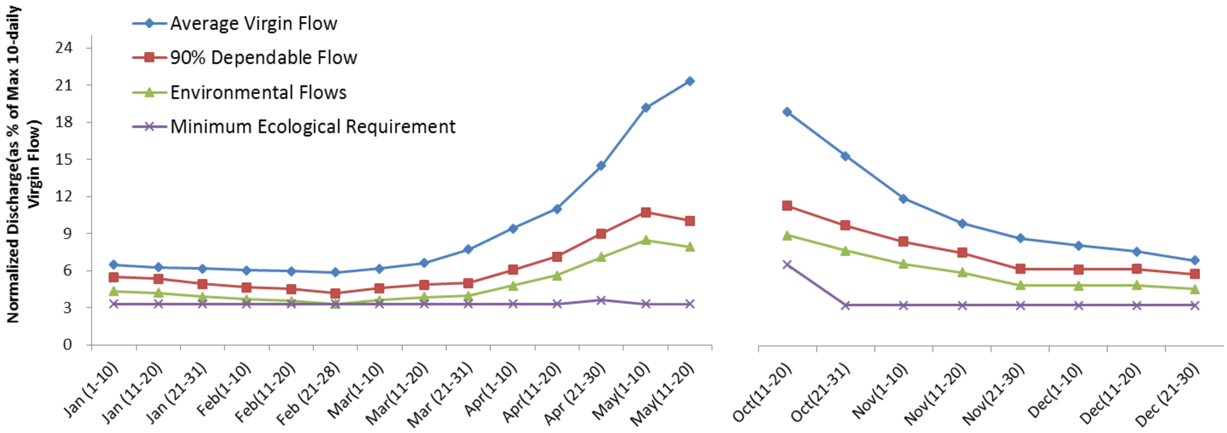


Figure 18b: Representation of Various Flow Regimes at U/S Rishikesh on River Ganga during Non-Monsoon Period

Table 20: Assessed E-Flows as Percentage of Virgin River Flows at U/S Rishikesh

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	53.00	67.29	72.42
Dry Period	30.23	50.23	64.16
Total	33.71	53.64	65.81

5.6 Site 6: Rishikesh CWC Monitoring Site on River Ganga (30°08'02”N, 78°20'11"E):

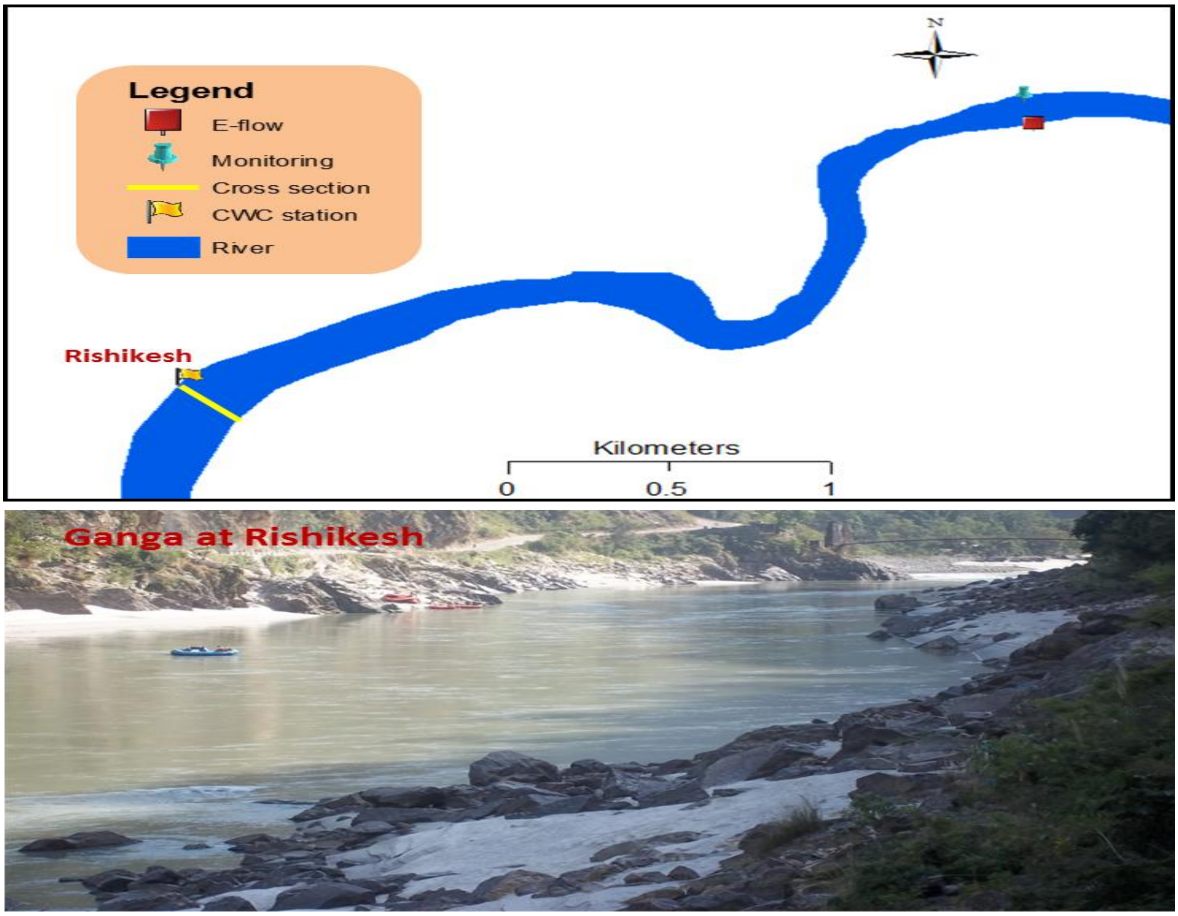
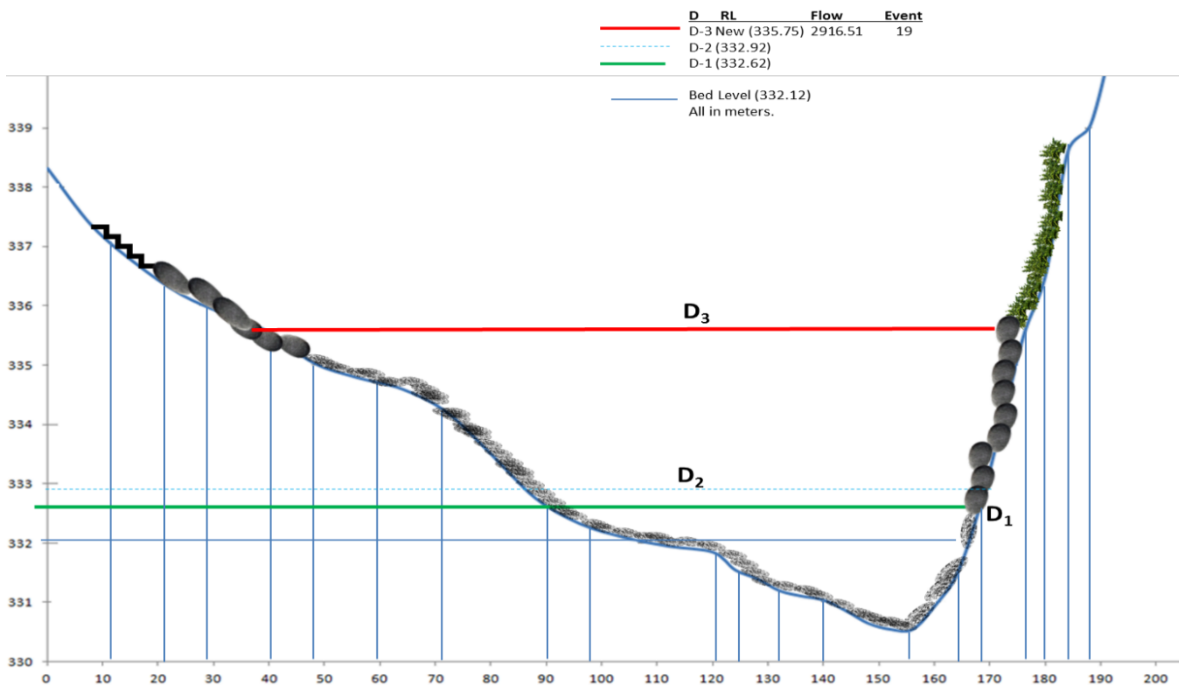


Figure 19: Schematic and Photographic Representation of the E-Flows Site at Rishikesh CWC Monitoring Site on River Ganga

Table 21: Geomorphic attributes

River style: Transition of Himalayan Bedrock and alluvial setting
Channel confinement: Partly confined
Channel features: Alluvial islands, mid
Sinuosity: 1.18.40
Active floodplain: Valley width-1:5
Slope: 0.518^0
Bed material: Conglomerate, cobbles, pebbles and sand are present
Geomorphologically: Agradational regime



HFL (m)	Maximum Depth(m)	Bankfull Width(m)	Width/Depth ratio	Velocity (m/s)	Discharge (m^3/s)
356.5	1.8	161.5	89.7	NA	NA

Figure 20: River Cross-section at Rishikesh CWC Monitoring Site on River Ganga

Table 22: Salient Features of Biotic Components of the River Aquatic System at Rishikesh CWC Monitoring Site on River Ganga

River Stretch	UG3 (Devprayag to Haridwar)
Algal diversity	Total Taxa: 123; Diatoms: 95; Green algae: 13; Blue green: 12
Algal ratio (D* G* BG*)	100:14:13 (95, 13, 12)
Specific Zoobenthos	Tricoptera, Ephemeroptera, Diptera, Odonata
Carps/All Fish taxa	0.59 (25/42)
Carps/Cat fishes	3.57 (25/7)
RET Fish species	8
Characteristic fish species	Golden Mahseer (*Tor putitora*)
Higher vertebrates	No aquatic higher vertebrates

Table 23: Description of key-stone species, corresponding D_1 and D_2, and computedD_3 at Rishikesh CWC Monitoring Site on River Ganga

Keystone Species	**Required Depths for E-flows**		
	D_1	**D_2**	**D_3**
Golden Mahseer *(Tor putitora)*	0.5 m	0.8 m	3.63 m

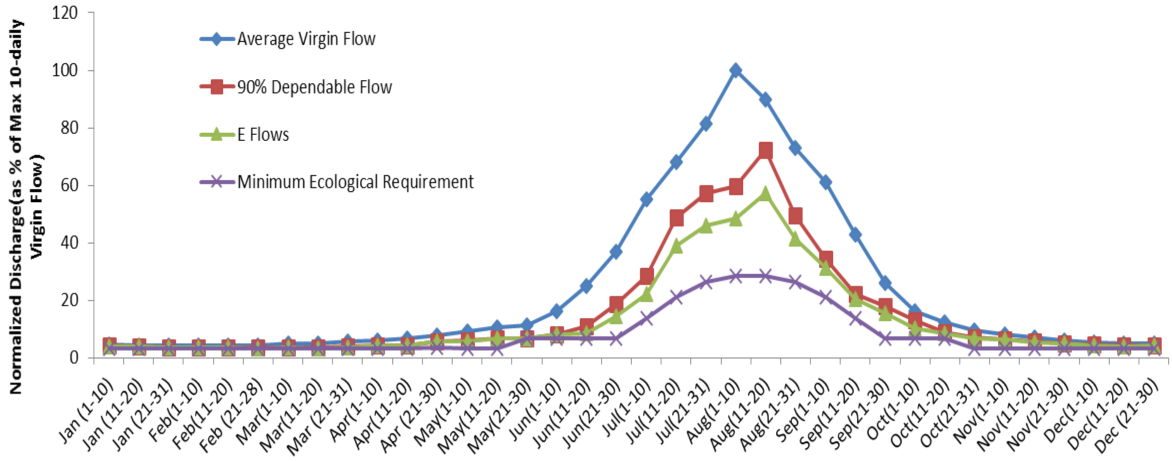


Figure 21a: Representation of Various Flow Regimes at Rishikesh CWC Monitoring Site on River Ganga over 12 Months

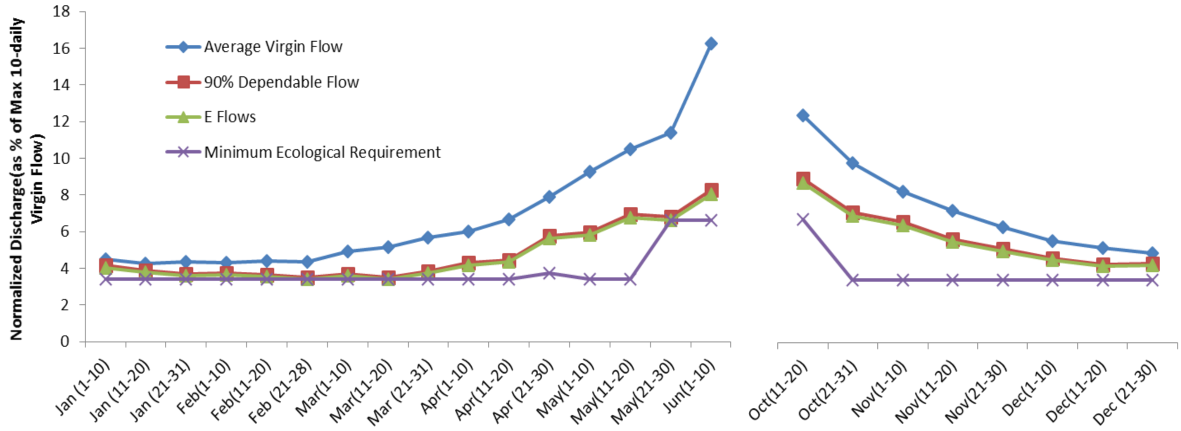


Figure 21b: Representation of Various Flow Regimes at Rishikesh CWC Monitoring Site on River Ganga during Non-Monsoon Period

Table 24: Assessed E-Flows as Percentage of Virgin River Flows at Rishikesh CWC Monitoring Site on River Ganga

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	55.83	70.55	72.42
Dry Period	31.72	52.55	64.16
Total	35.40	56.15	65.81

5.7 Site 7: D/S Pashulok Barrage, Rishikesh on River Ganga (30°08'02”N, 8°20'11"E)

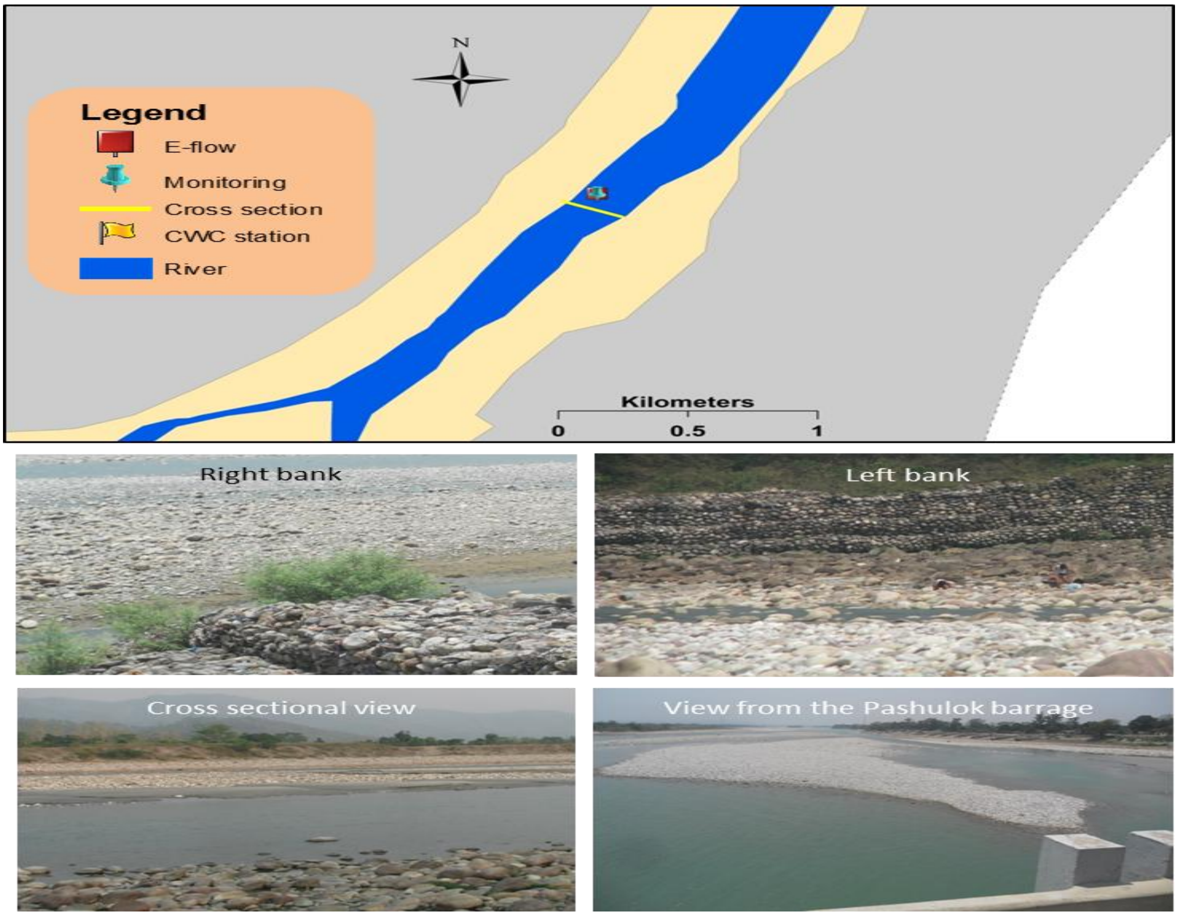
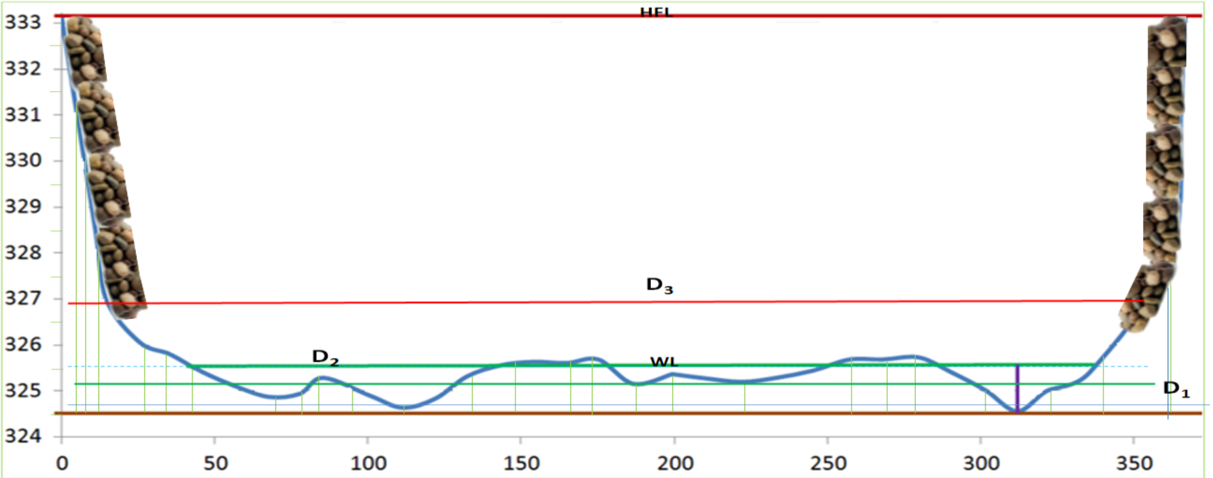


Figure 22: Schematic and Photographic Representation of the E-Flows Site at D/S Pashulok Barrage, Rishikesh on River Ganga

Table 25: Geomorphic attributes

River style: Himalayan Bedrock
Channel confinement: Confined
Channel features: Very less mid channel bars, side bars and confluence bars
Sinuosity: 1.18-1.40
Braid channel ratio: 1.21-2.78
Active floodplain: Valley margin width- 1:1.5
Slope: 0.518^0
Symmetricity: Asymmetrical channel
Bed material: Boulders, cobbles, pebbles and coarse sand in channel belt
Geomorphologically: Agradational regime



HFL (m)	Maximum Depth(m)	Bankfull Width (m)	Width/Depth ratio	Velocity (m/s)	Discharge (m^3/s)
333.141	1.04	294.25	282.9	NA	NA

Figure 23: River Cross-section at D/S Pashulok Barrage, Rishikesh on River Ganga

Table 26: Salient Features of Biotic Components of the River Aquatic System at D/S Pashulok Barrage, Rishikesh on River Ganga

River Stretch	UG3 (Devprayag to Haridwar)
Algal diversity	Total Taxa: 123; Diatoms: 95; Green algae: 13; Blue green: 12
Algal ratio (D* G* BG*)	100:14:13(95, 13, 12)
Specific Zoobenthos	Tricoptera, Ephemeroptera, Diptera, Odonata
Carps/All Fish taxa	0.59(25/42)
Carps/Cat fishes	3.57(25/7)
RET Fish species	8
Characteristic fish species	Golden Mahseer (*Tor putitora*)
Higher vertebrates	No aquatic higher vertebrates

Table 27: Description of key-stone species, corresponding D_1 and D_2, and Computed D_3 at D/S Pashulok Barrage, Rishikesh on River Ganga

Keystone Species	Required Depths for E-flows		
	D_1	D_2	D_3
Golden Mahseer *(Tor putitora)*	0.5 m	0.8 m	2.04 m

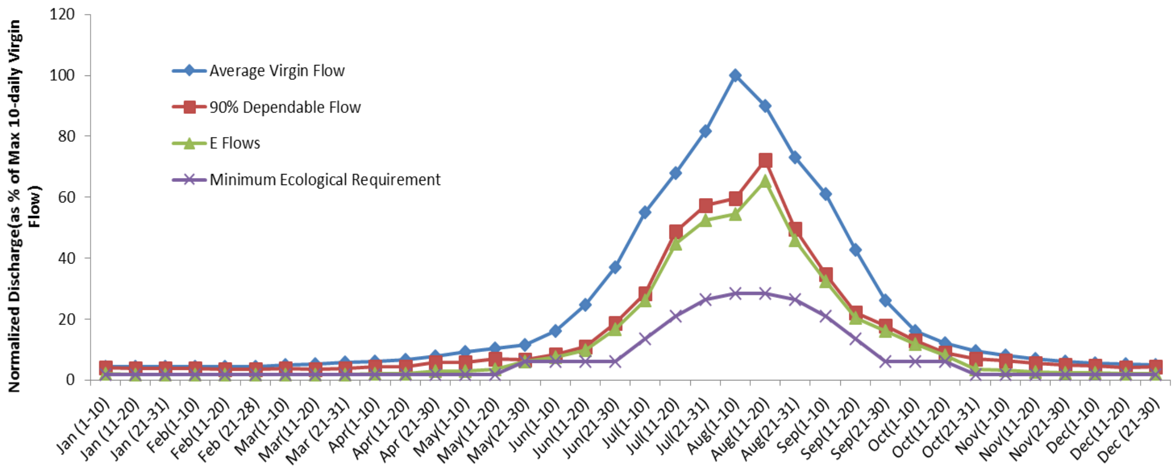


Figure 24a: Representation of Various Flow Regimes at D/S Pashulok Barrage, Rishikesh on River Ganga over 12 Months

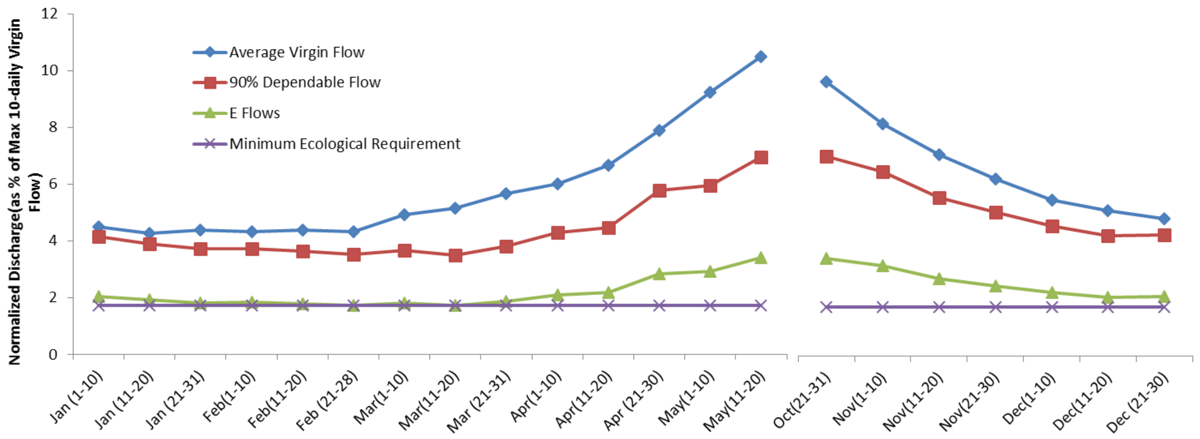


Figure 24b: Representation of Various Flow Regimes at D/S Pashulok Barrage, Rishikesh on River Ganga during Non-Maonsoon Period

Table 28: Assessed E-Flows as Percentage of Virgin River Flows at D/S Pashulok Barrage, Rishikesh on River Ganga

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	27.99	37.43	76.26
Dry Period	30.99	58.42	63.92
Total	30.53	55.22	65.80

6 Observations on EFA at Seven Select Sites

A summary of the Environmental Flow Assessment (EFA) exercise carried out for seven select sites in the Upper Ganga Segment is presented in Table 29. 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 29: Summary of EFA Results at Seven Select 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

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.
7. Achieving 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 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.

8 References

1. Brisbane Declaration (2007) Recommendations of the 10th International Riversymposium and International Environmental Flows Conference, held in Brisbane, Australia, on 3-6 September 2007; www.riversymposium.com/2006/index.php?element =2007 Brisbanbane Declaration 241007; accessed on June 10, 2011.
2. Expert Body Report [2014]: *"Assessment of Environmental Degradation and Impact of Hydroelectric projects during the June 2013 Disaster in Uttarakhand"* Submitted to the Ministry of Environment and Forests, Government of India
3. IITC [2011]:"*Environmental Flows State-of-the-Art with special reference to Rivers in the Ganga River Basin*", IIT-GRBMP Thematic Report – Report Code: 022_GBP_IIT_EFL_SOA_01_Ver 1_Dec 2011.
4. IITC [2014]:*"Assessment of E-Flows at Some Select Sits in Upper Ganga Segment"*, IIT-GRBMP Thematic Report – Report Code: 073_GBP_IIT_EFL_ANL_01_Ver 1_Dec 2014.
5. IITC [2015]:"*Ganga River Basin Management Plan – 2015: Mission 1: Aviral Dhara*", Consortium of 7 IITs (IITC).
6. IMG [2013]: *"Report of the Inter-Ministerial Group on Issues Relating to River Ganga"*, submitted to Government of India, New Delhi.
7. Nature Conservancy [2006]: "*Environmental Flow: Water for people, water for Nature*", TNC MRCSO1730, Boulder, CO: Nature Conservancy
8. Paine R T [1995]:"A Conversation on Refining the Concept of Keystone Species". *Conserv Biol*, 9 (4):962-964.
9. WII [2012]: "Assessment of Cumulative Impacts of Hydroelectric Projects on Aquatic and Terrestrial Biodiversity in Alaknanda and Bhagirathi Basins, Uttarakhand", Wildlife Institute of India, Dehradoon, Uttarakhand, India.
10. WWF-India [2011]: *"Assessment of Environmental Flows for Upper Ganga Basin".*
11. Van der Velde, G., R. S. E. W. Leuven & I. Nagelkerken, 2004. Types of river ecosystems. In: Fresh surface water. Water Sciences, Engineering and Technology Resources. Encyclopedia of life support systems (EOLSS). UNESCO, EOLSS Publishers, Oxford: 1–29 (http://www.eolss.net/).

12. Naiman, R. J., Bunn, S. E., Nilsson, C., Petts, G. E., Pinay, G., and Thompson, L. C. 2002. Legitimizing fluvial ecosystems as users of water: an overview. Environmental Management 30(4):455-467.
13. Mathews, R., and Richter, B. 2007. Application of the Indicators of Hydrologic Alteration software in environmental flow-setting. Journal of the American Water Resources Association (JAWRA) 43(6): 1400-1413.
14. http://www.wrc.org.za/Knowledge%20Hub%20Documents/Research%20Reports/TT%20354-CONSERVATION.pdf
15. http://web.cecs.pdx.edu/~jaylab/public/naik%26jay_jwrpmsubmitted.pdf
16. http://water.usgs.gov/edu/streamflow3.html
17. http://www.nccma.vic.gov.au/library/scripts/objectifyMedia.aspx?file=KMSMedia/pdf/66/63.pdf&fileName=NCCMA-43878%20-%20Understanding%20River%20Health%20-%20fact%20sheet.pdf
18. https://cmsdata.iucn.org/downloads/flow___the_essentials_of_environmental_flow___dyson_et_al.pdf