MoWR, RD & GR:
Report of the Three Member Committee
on

Assessment of Environmental Flows [E-Flows]

March 2015

Government of India
New Delhi

Contents

1. Preamble

Ministry of Water Resources, River Development and Ganga Rejuvenation (MoWR, RD & GR), Government of India constituted a three member committee consisting of Dr Vinod Tare, Professor, IIT Kanpur, Dr Shashi Shekhar, Special Secretary, Ministry of Environment, Forests & Climate Change (MoE, F & CC) and Dr Amarjeet Singh, Additional Secretary, MoWR, RD & GR on Assessment of Environmental Flows (E-Flows). The committee met four times and interacted with experts on E-Flows in Central Water Commission (CWC), New Delhi, National Institute of Hydrology (NIH), Roorkee, International Water Management Institute (IWMI), Srilanka, and World Bank, New Delhi. The committee had the privilege of the views and information collated through extensive consultation process by the Inter Ministerial Group (IMG) chaired by Mr B K Chaturvedi, Member, Planning Commission and the Expert Body appointed by the Ministry of Environment and Forests (MoEF). The committee also had the privilege of the reports prepared by the Consortium of 7 IITs (IITC) engaged in preparing the Ganga River Basin Management Plan (GRBMP) for National Ganga River Basin Authority (NGRBA). IITC's work on E-Flows is developed from an earlier exercise by WWF-India in partnership with several institutes including IIT Kanpur (WWF-India, 2011).

In the following sections the committee presents a brief review of the concept of Environmental Flows (E Flows), outline of the recommended methodology for assessment of E-Flows, significance of flow regime vis-a-vis river health, and illustration of the concept for a few select sites in the Upper Segment of the Ganga River Basin.

2. Concept of E-Flows

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 committee recommends adoption of this description of the E-Flows.

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.

3. 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.

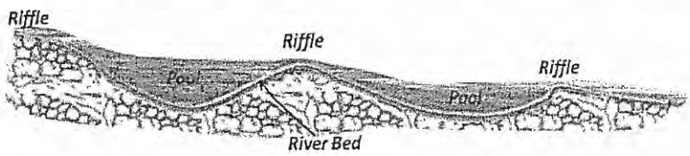
3.1. Minimum Ecological Requirement

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.

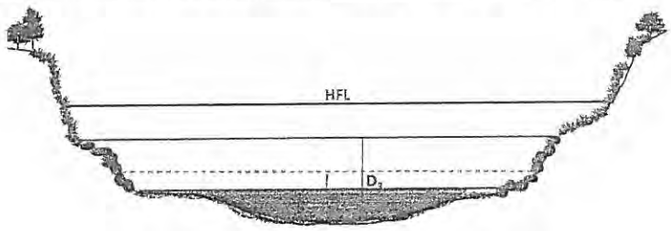
For upper Ganga Rivers, fish species, such as mahseer, snow trout, are in danger due to fragmentation and loss of connectivity of the river due to the construction of numerous dams, barrages, and reservoirs. Also these fish species govern the minimum depth of flow required for sustenance of the aquatic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

3.2. E-Flows Hydrograph

Environmental flow is 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 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.

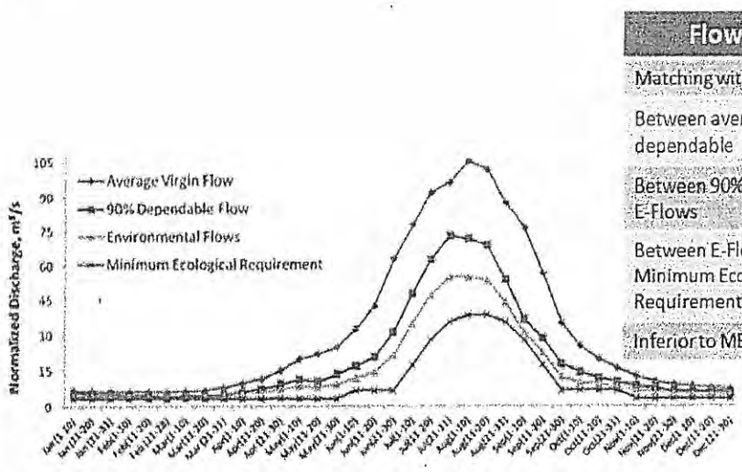
3.3. River Health Regime (RHR)

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.

4. 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 information presented in this section is taken from IITC Report [IITC, 2014]. 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).

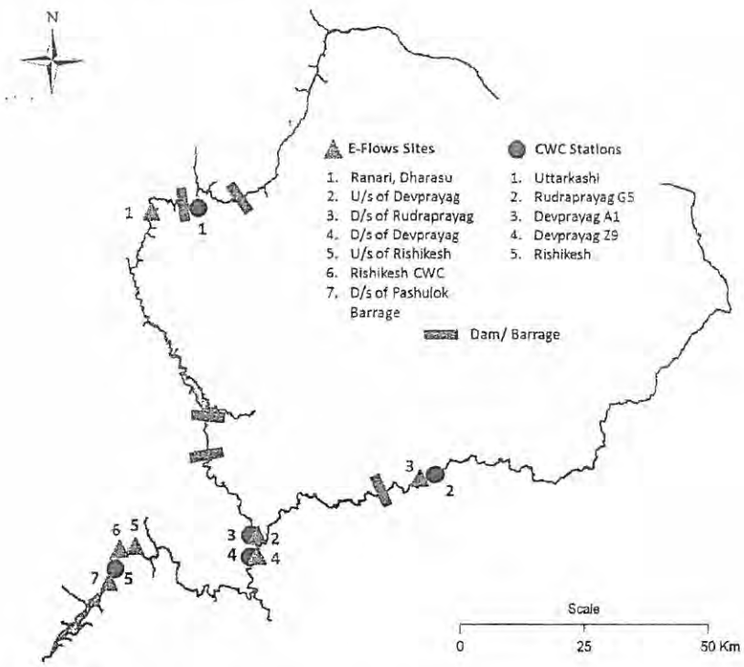


Figure 3: Location Map of Flow Monitoring Stations and E-Flows Sites

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

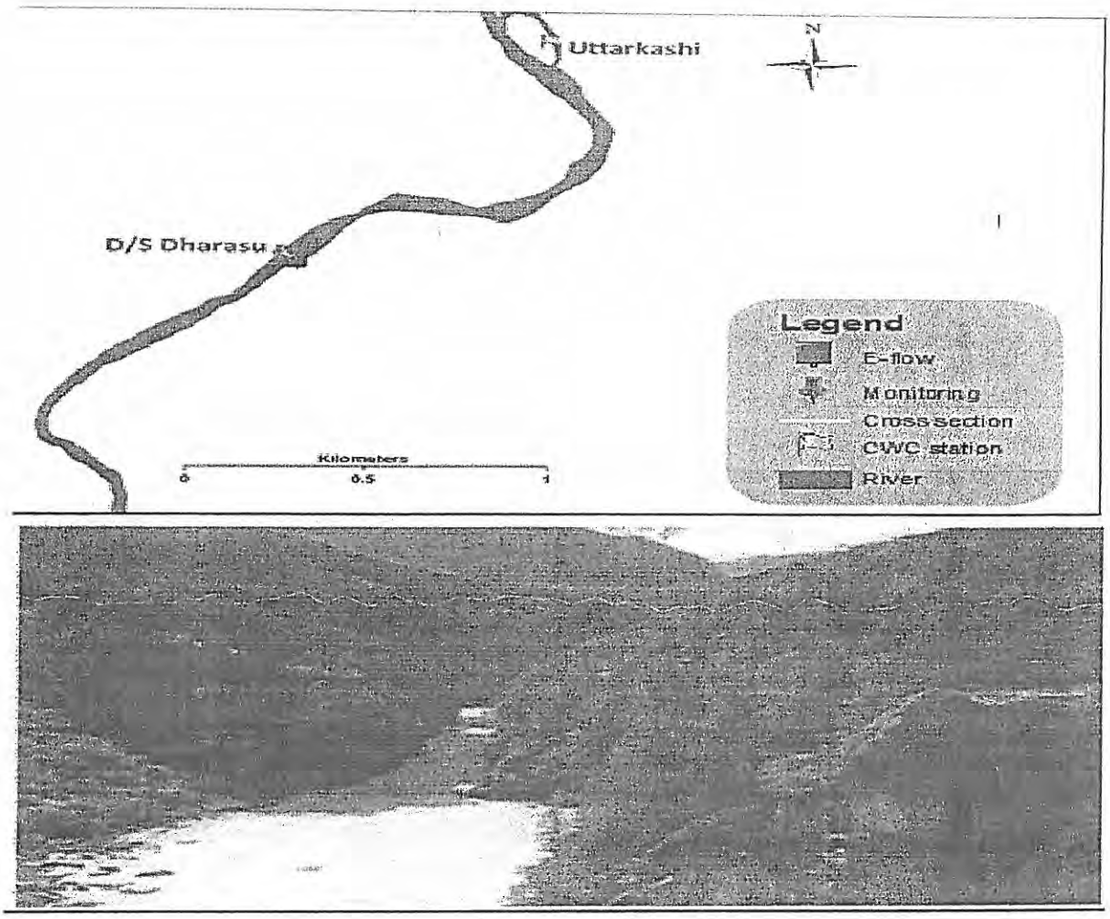
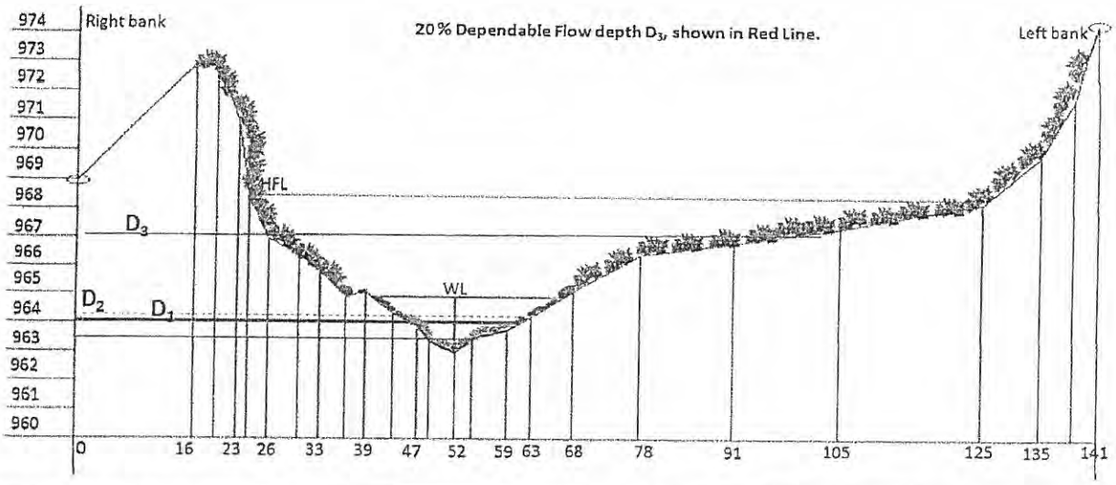


Figure 4: Schematic and Photographic Representation of the E-Flows Site at Ranari, Dharasu on Bhagirathi

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
Snow Trout *(Schizothorax richardsonii)*	0.5 m	0.8 m	3.41 m
Golden Mahseer *(Tor putitora)*			

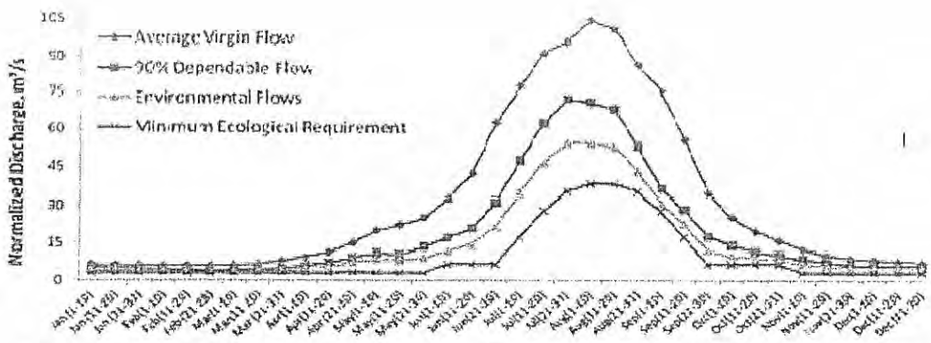


Figure 6a: Representation of Various Flow Regimes in Bhagirathi River at Ranari, Dharasu over 12 Months

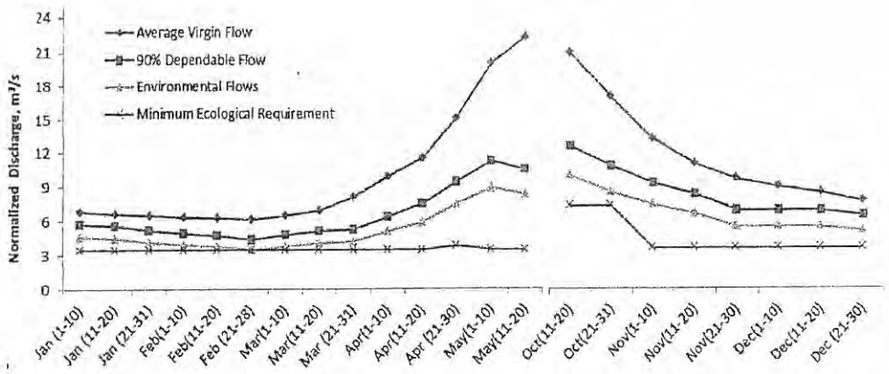


Figure 6b: Representation of Various Flow Regimes in Bhagirathi River at Ranari, Dharasu during Non-Monsoon Period

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.

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

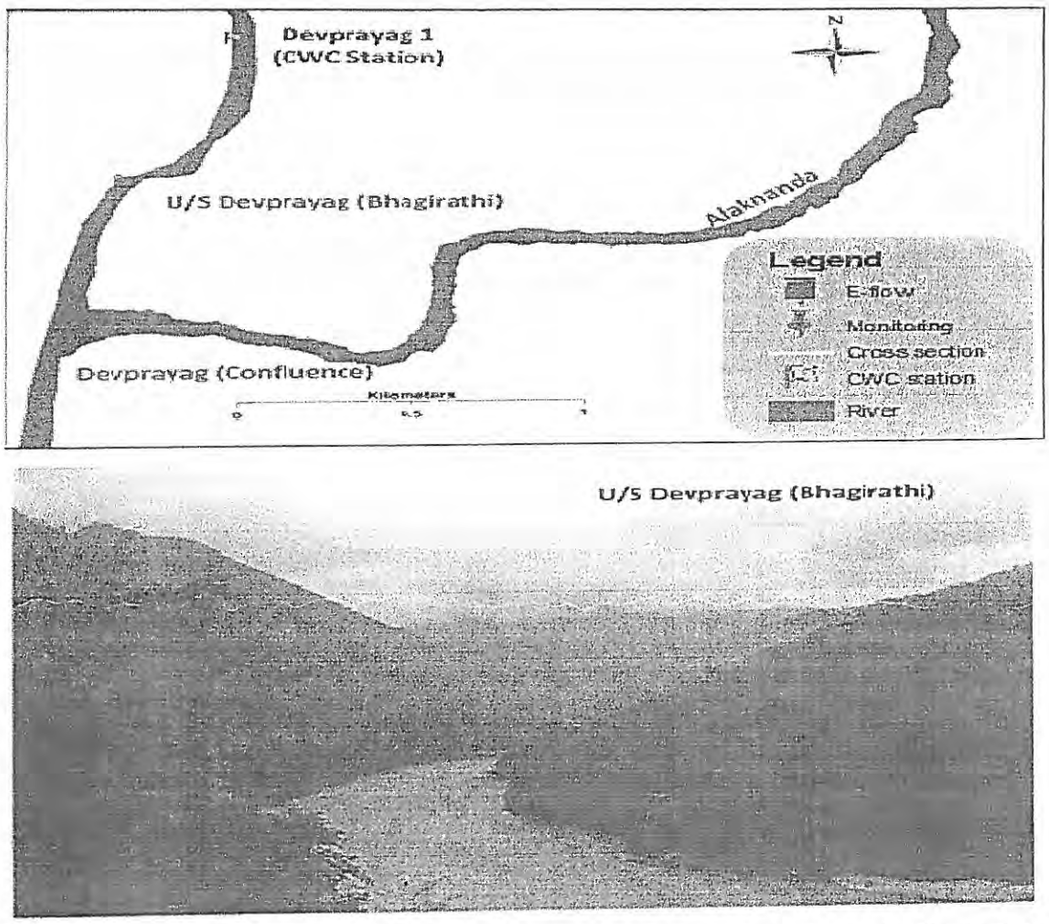
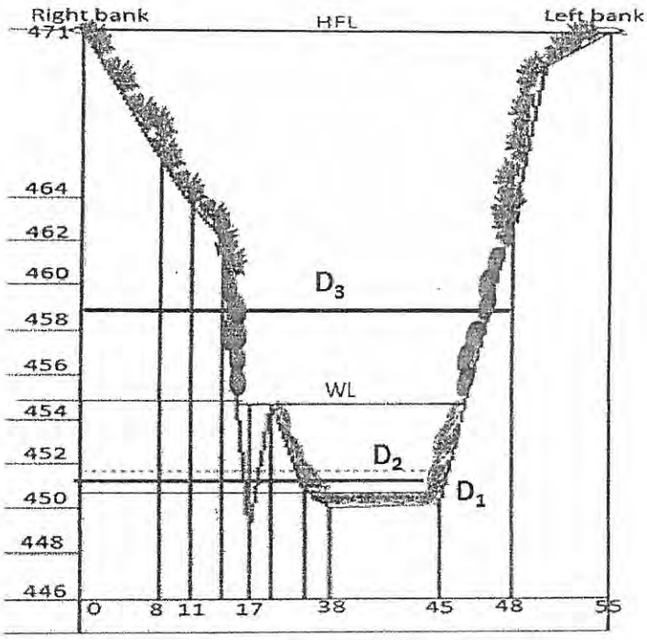


Figure 7: Schematic and Photographic Representation of the E-Flows Site at U/S Devprayag on Bhagirathi River

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
SnowTrout *(Schizothorax richardsonii)*	0.5 m	0.8 m	8.48 m
Golden Mahseer *(Tor putitora)*			

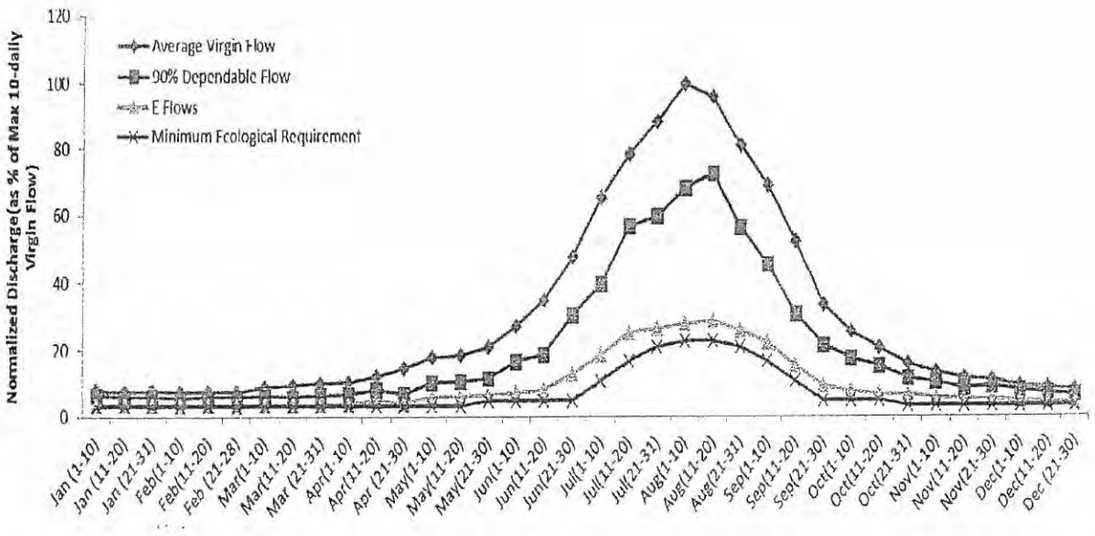


Figure 9a: Representation of Various Flow Regimes at U/S Devprayag on Bhagirathi River over 12 Months

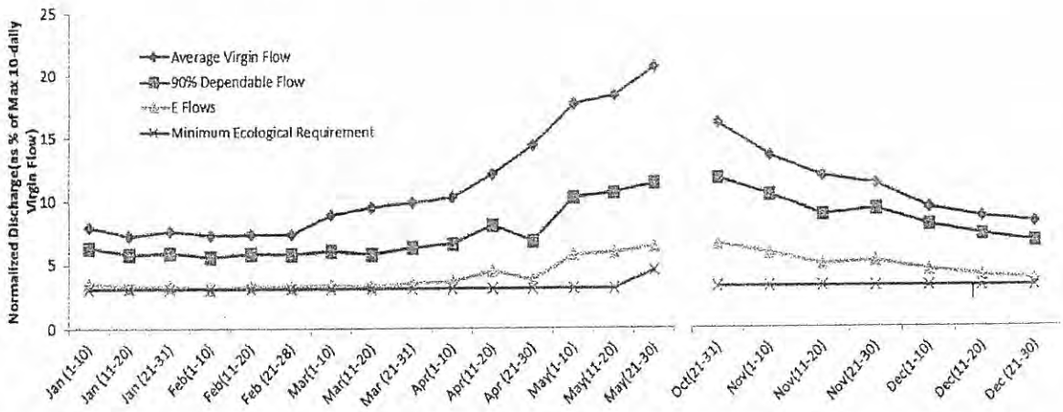


Figure 9b: Representation of Various Flow Regimes at U/S Devprayag on Bhagirathi River during Non-Mansoon Period

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

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

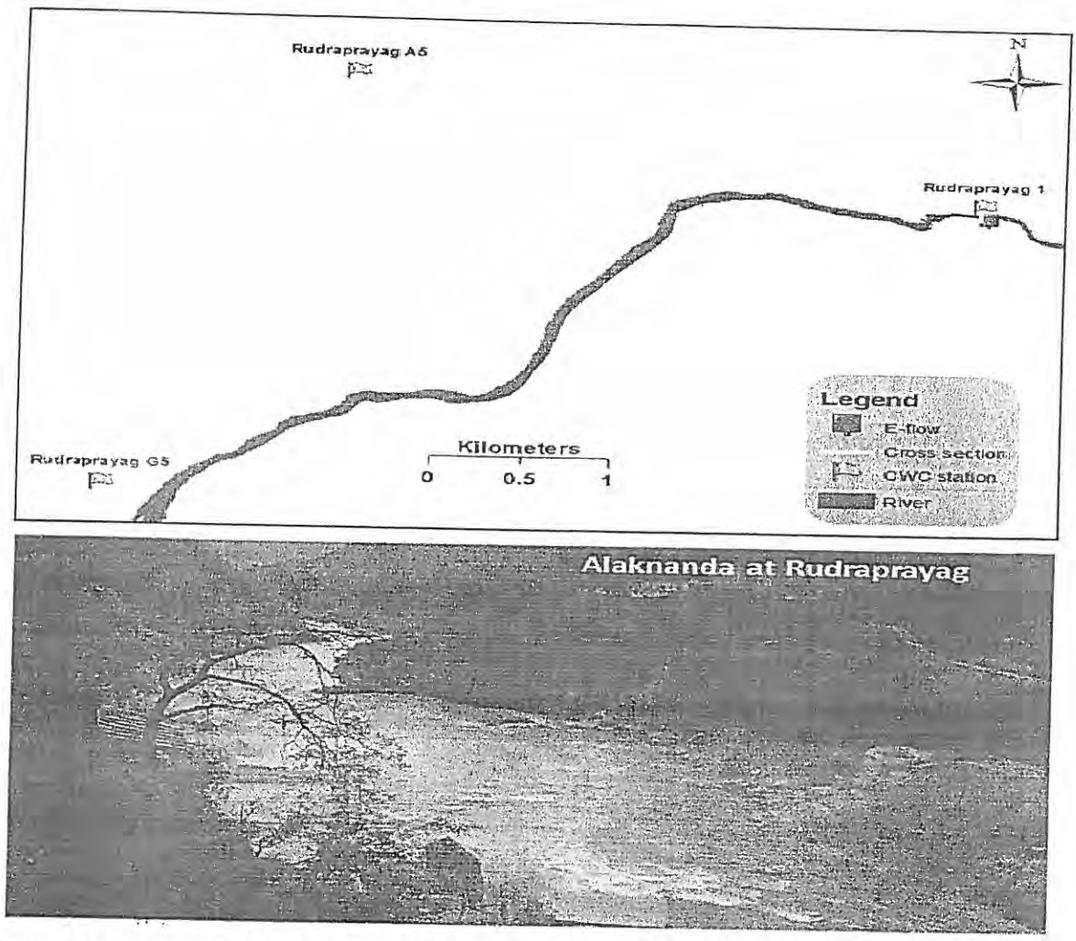
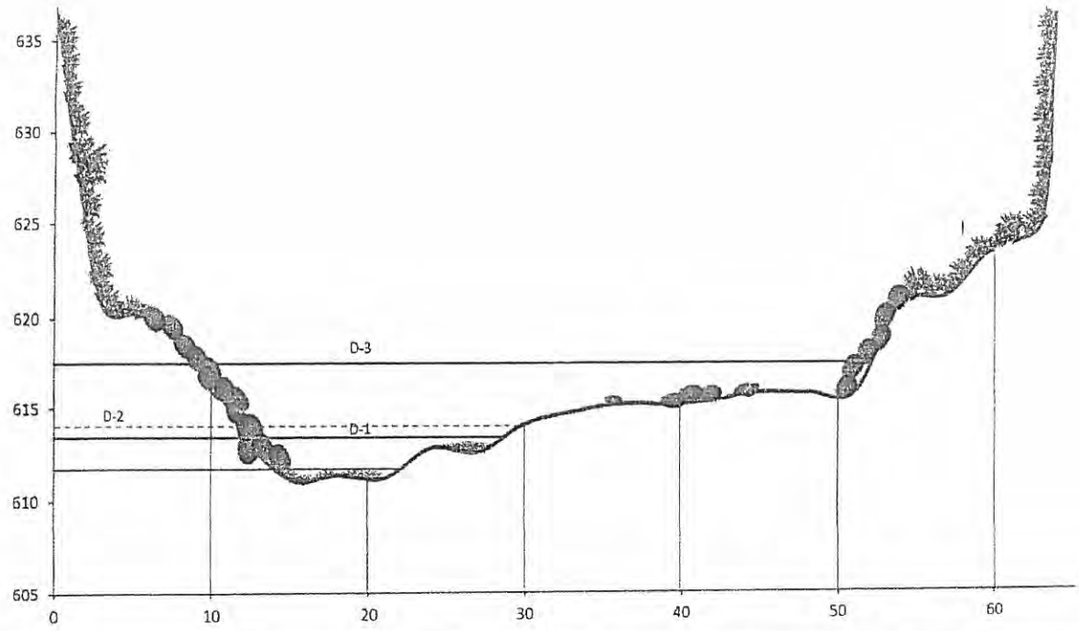


Figure 10: Schematic and Photographic Representation of the E-Flows Site at D/S Rudraprayag on Alaknanda River

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

Table 10: 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)*			

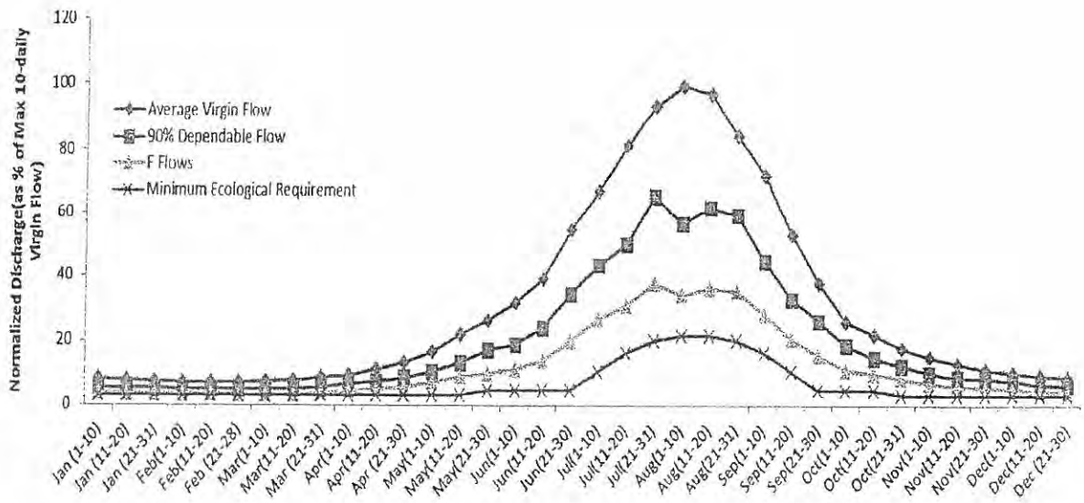


Figure 12a: Representation of Various Flow Regimes at D/S Rudraprayag on Alaknanda River over 12 Months

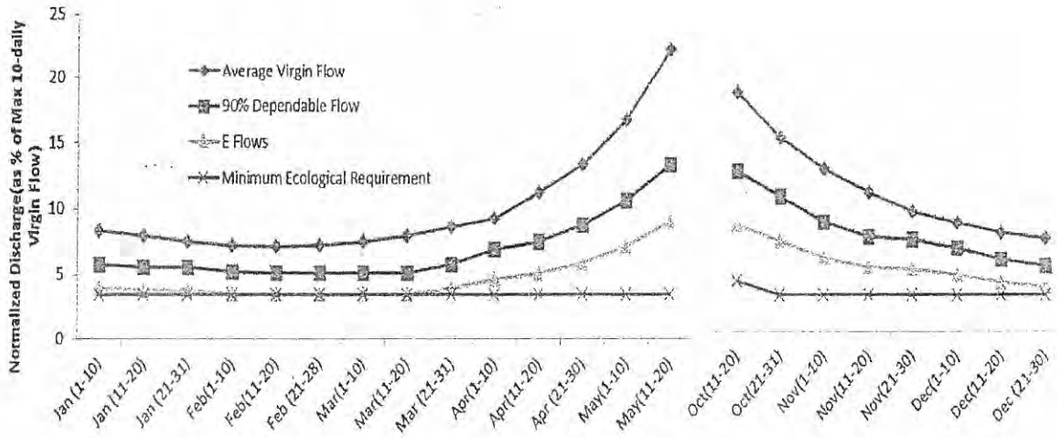


Figure 12b: Representation of Various Flow Regimes at D/S Rudraprayag on Alaknanda River during Non-Mansoon Period

Table 12: ssessed 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

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

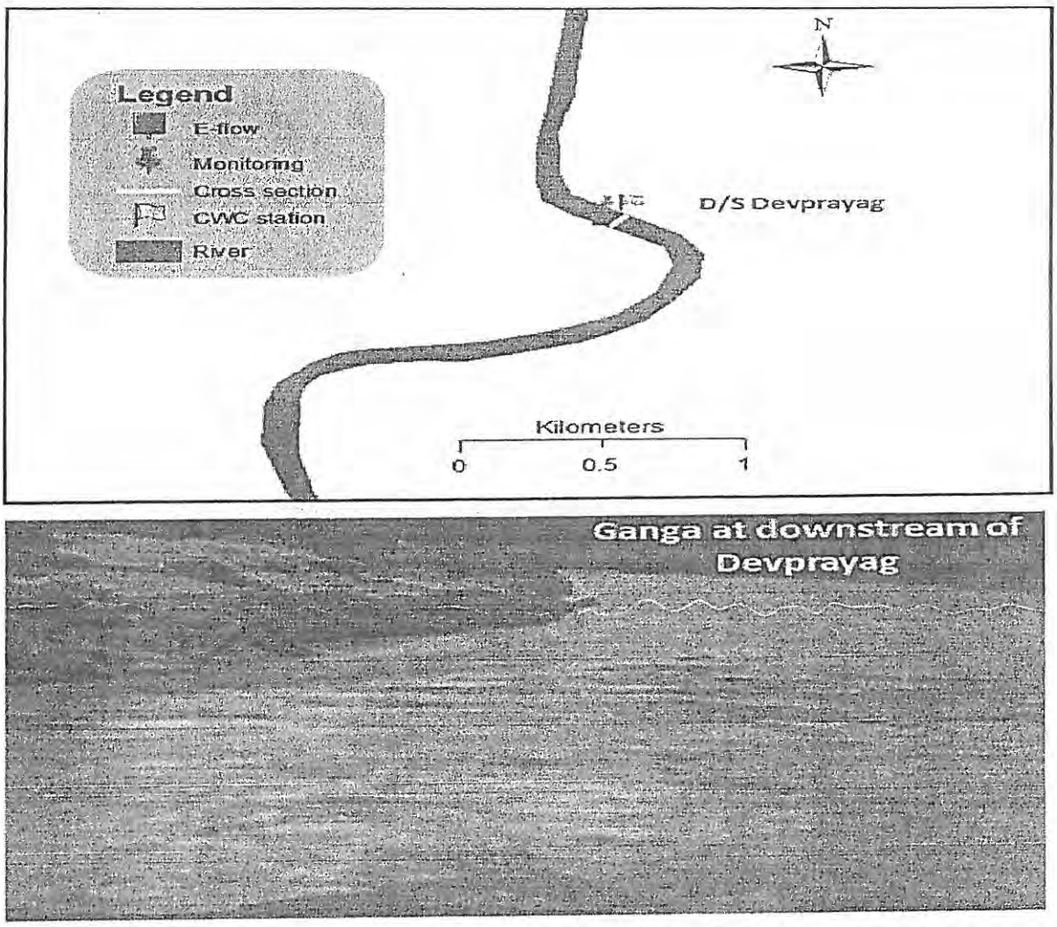


Figure 13: Schematic and Photographic Representation of the E-Flows Site at D/S Devprayag on Ganga River

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

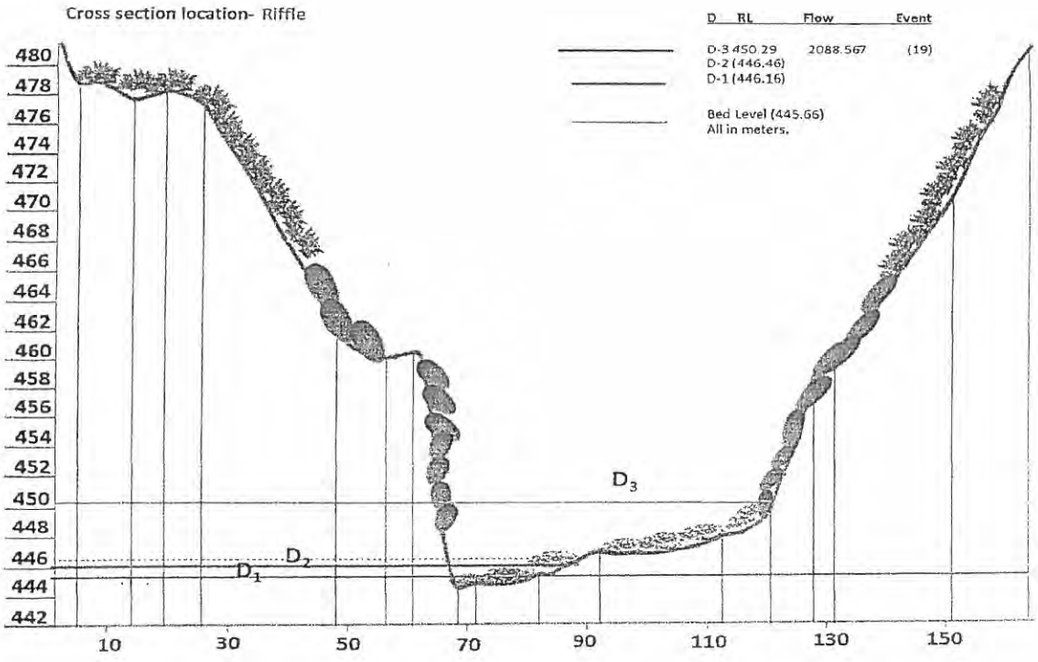


Figure 14: River Cross-section at D/S Devprayag on Ganga River

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)* **Golden Mahseer** *(Tor putitora)*	0.5 m	0.8 m	4.63 m

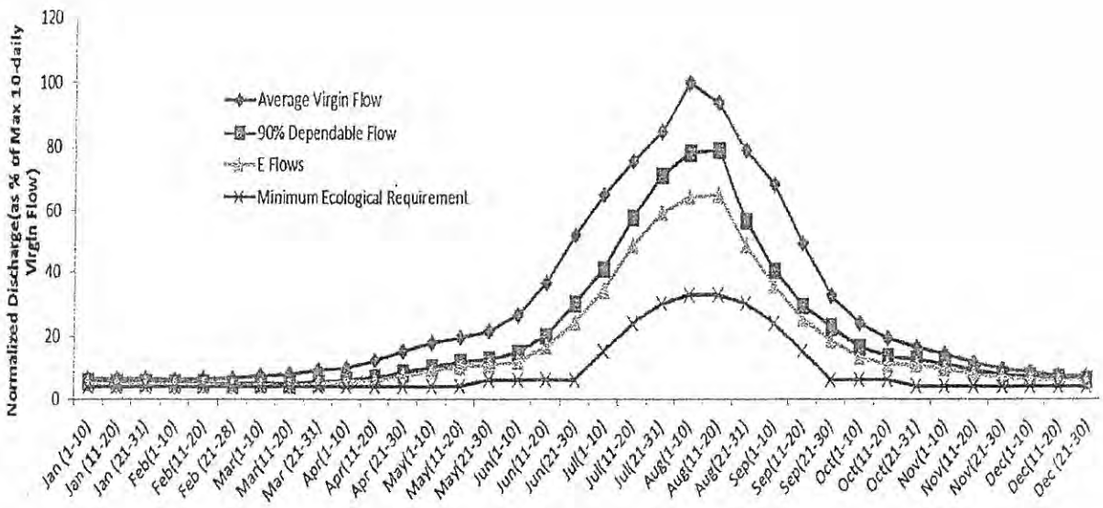


Figure 15a: Representation of Various Flow Regimes at D/S Devprayag on Ganga River over 12 Months

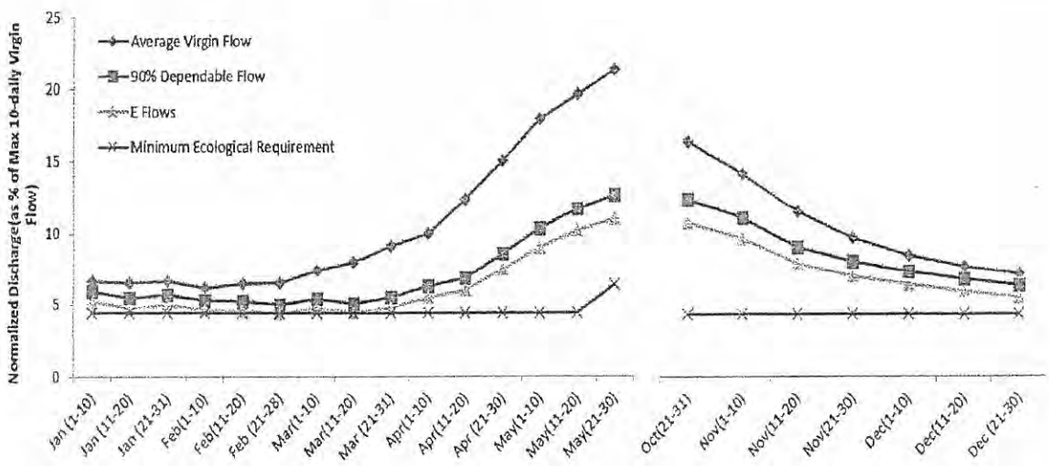


Figure 15b: Representation of Various Flow Regimes at D/S Devprayag on Ganga River during Non-Monsoon Period

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

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

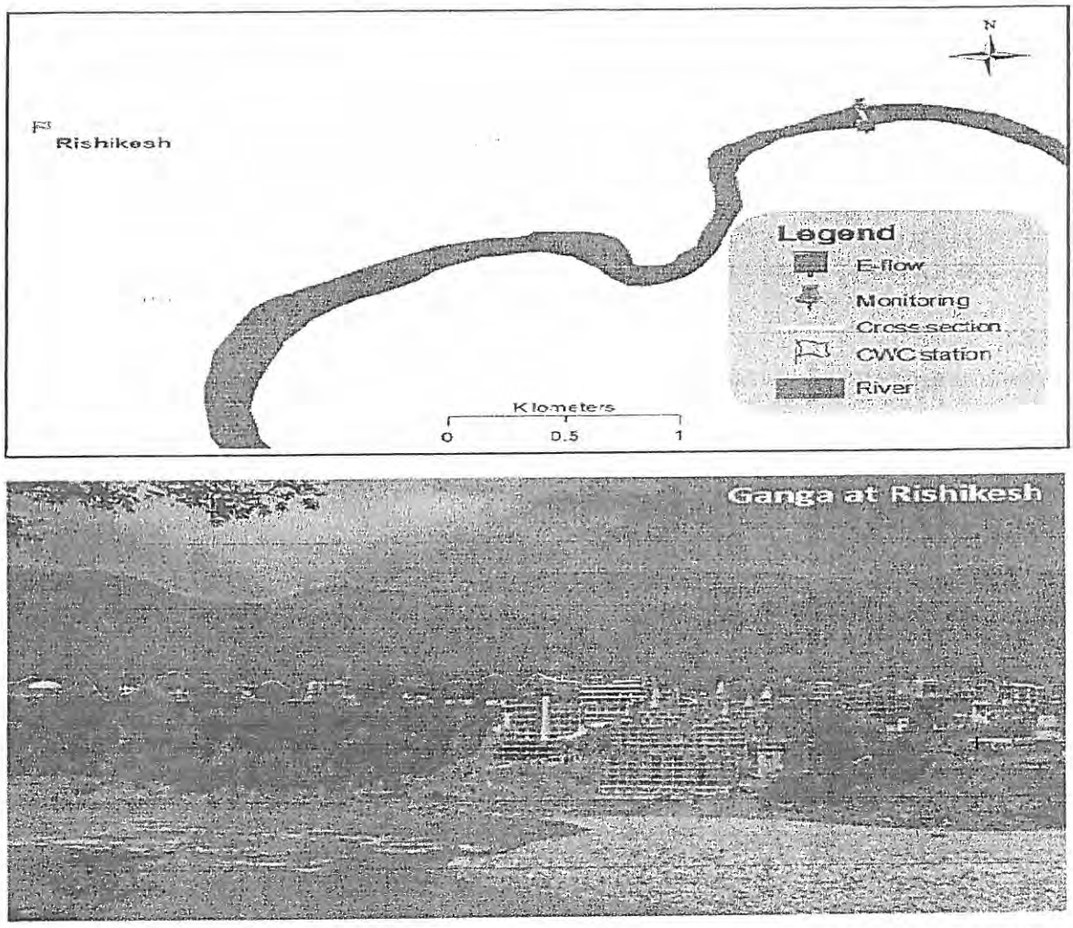
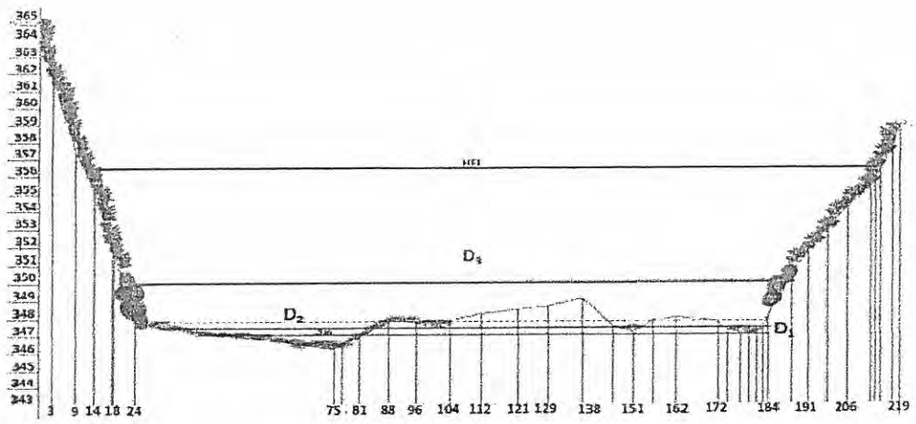


Figure 16: Schematic and Photographic Representation of the E-Flows Site at U/S Rishikesh on River Ganga

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

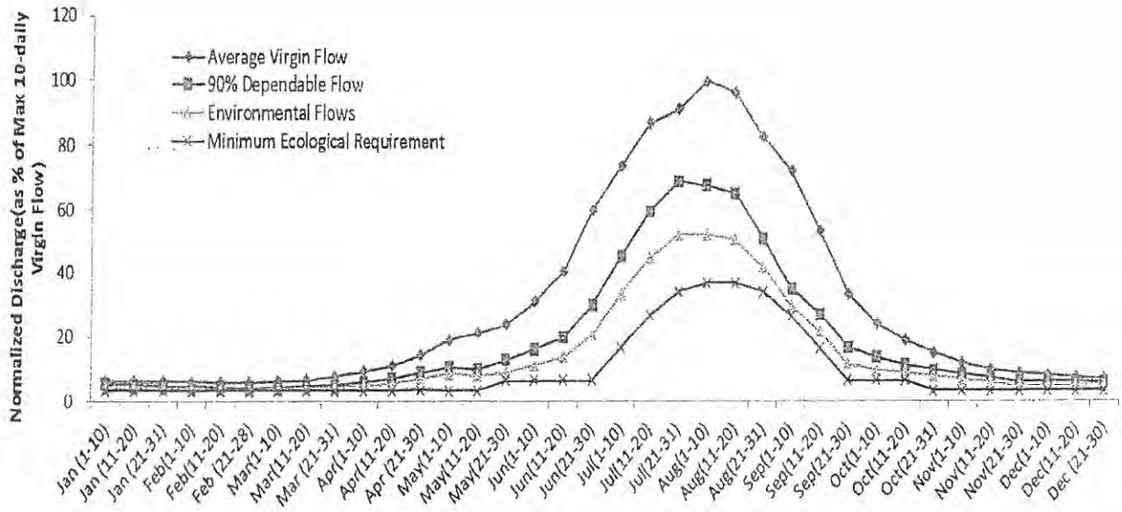


Figure 18a: Representation of Various Flow Regimes at U/S Rishikesh on River Ganga over 12 Months

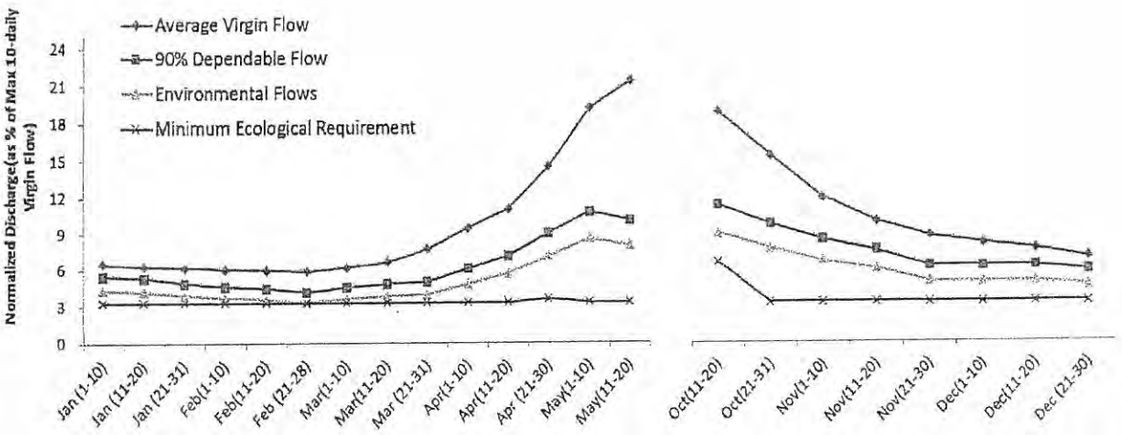


Figure 18b: Representation of Various Flow Regimes at U/S Rishikesh on River Ganga during Non-Monsoon Period

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

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

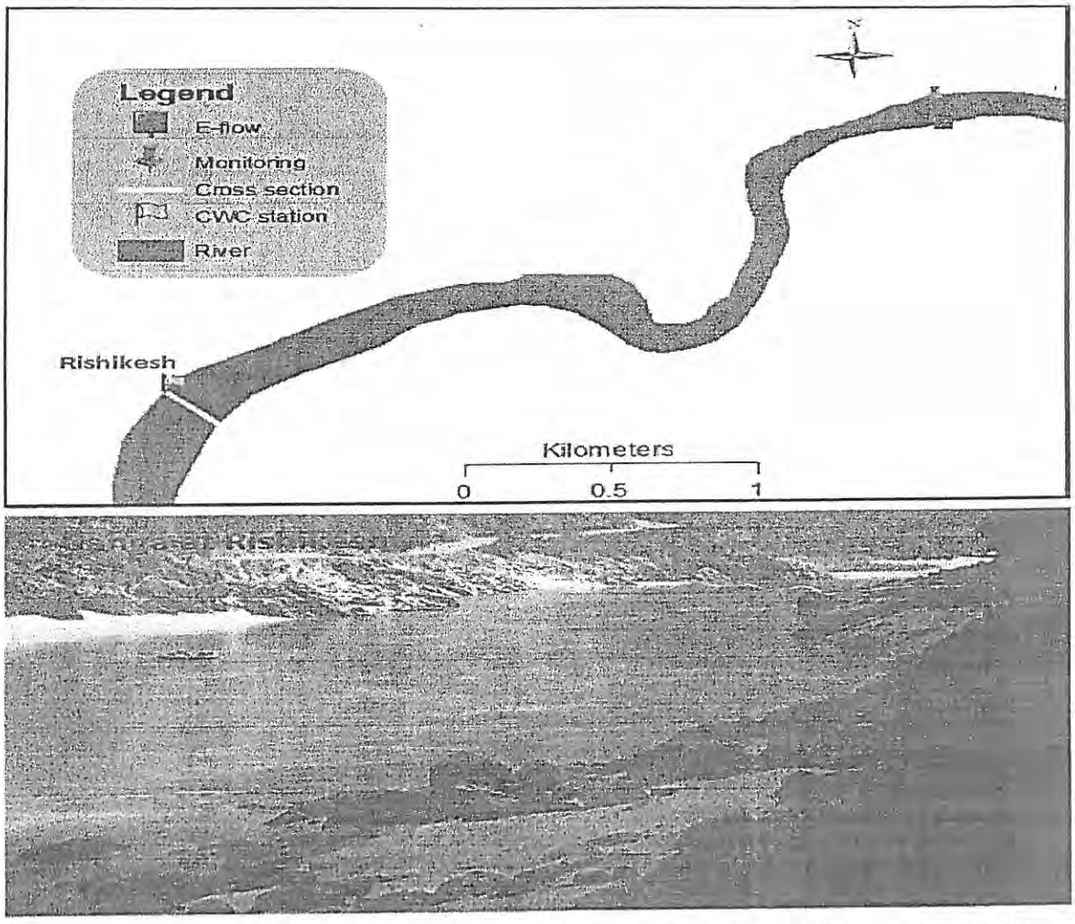
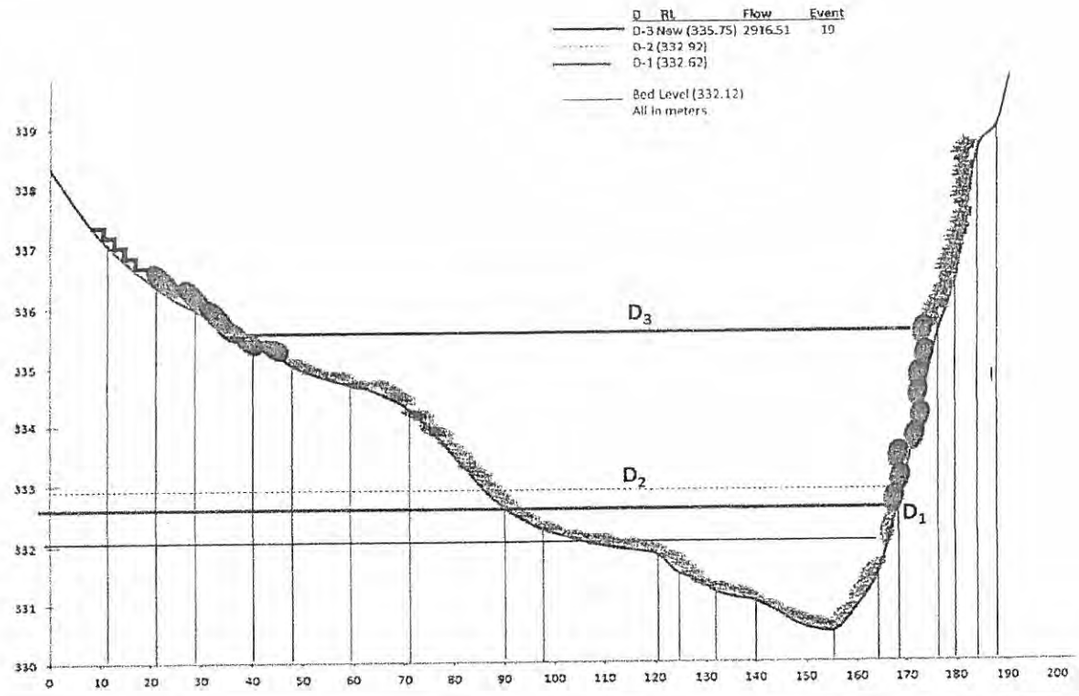


Figure 19: Schematic and Photographic Representation of the E-Flows Site at Rishikesh CWC Monitoring Site on River Ganga

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 computed D_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

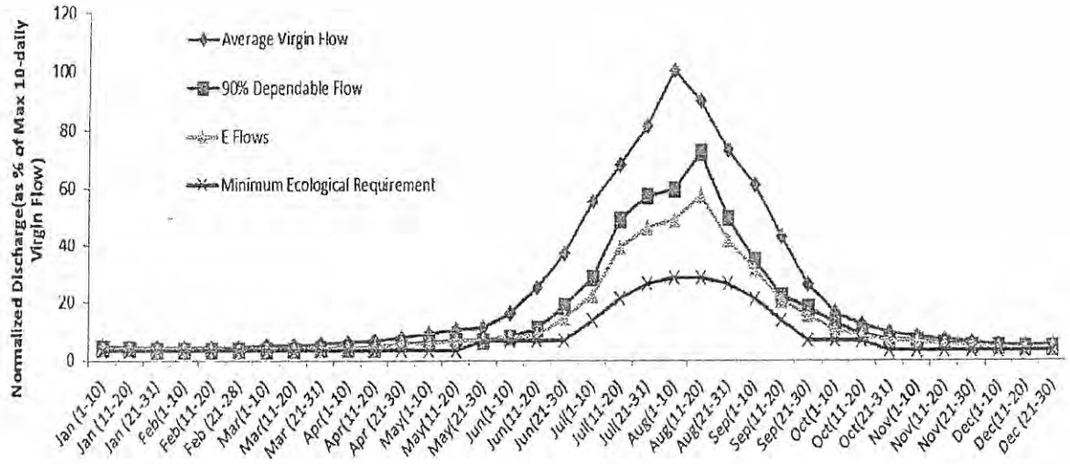


Figure 21a: Representation of Various Flow Regimes at Rishikesh CWC Monitoring Site on River Ganga over 12 Months

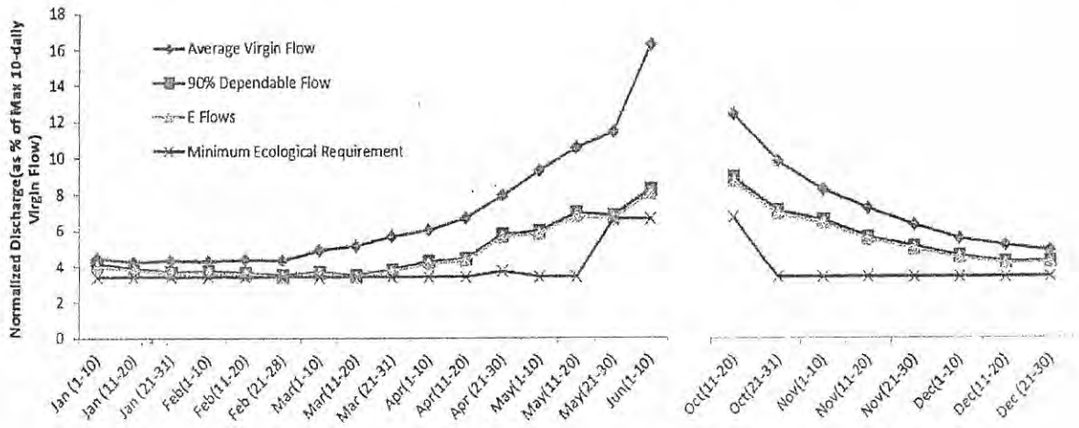


Figure 21b: Representation of Various Flow Regimes at Rishikesh CWC Monitoring Site on River Ganga during Non-Monsoon Period

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

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

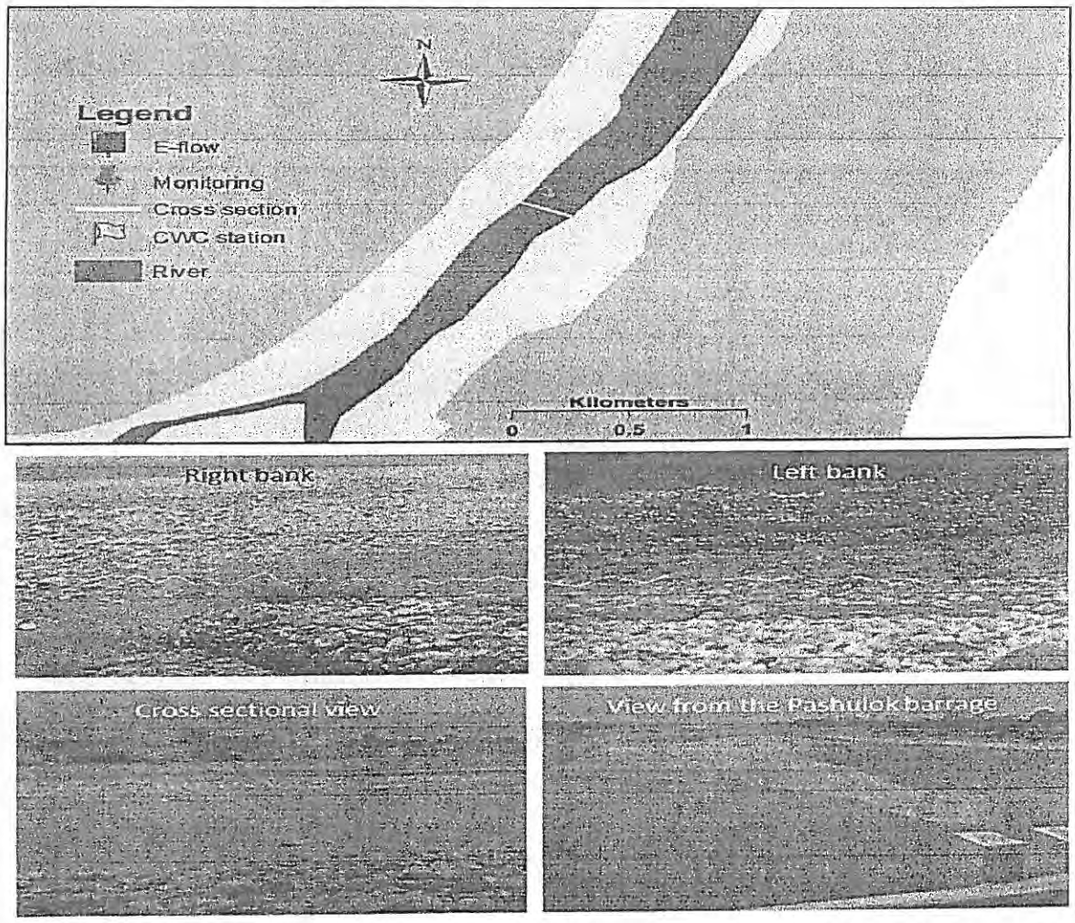
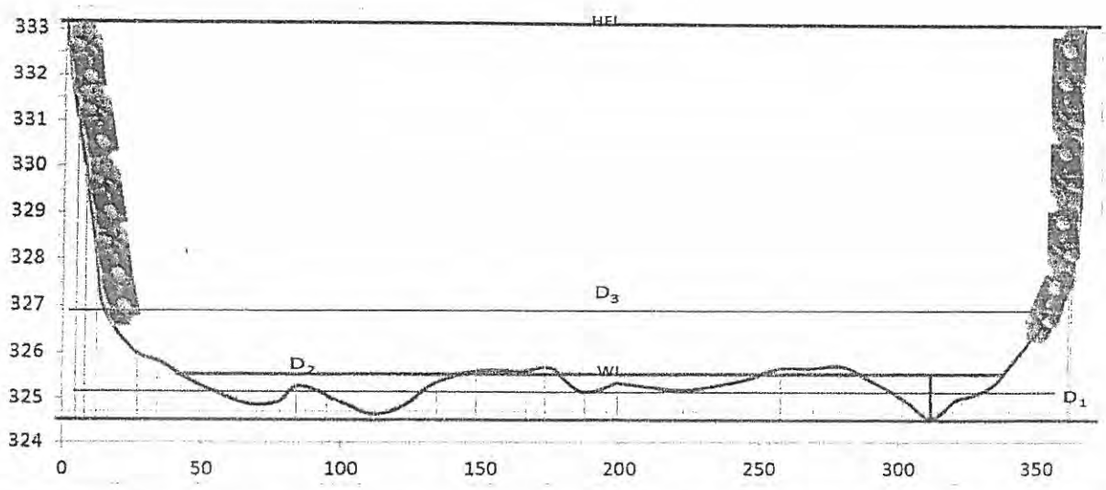


Figure 22: Schematic and Photographic Representation of the E-Flows Site at D/S Pashulok Barrage, Rishikesh on River Ganga

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

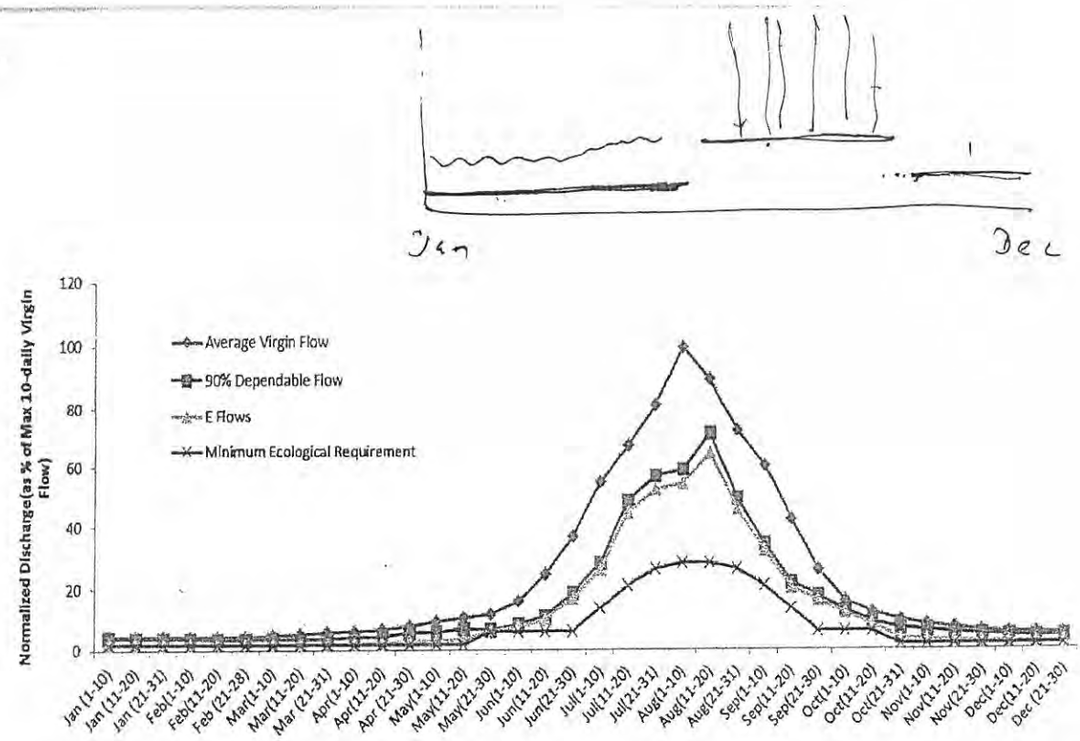


Figure 24a: Representation of Various Flow Regimes at D/S Pashulok Barrage, Rishikesh on River Ganga over 12 Months

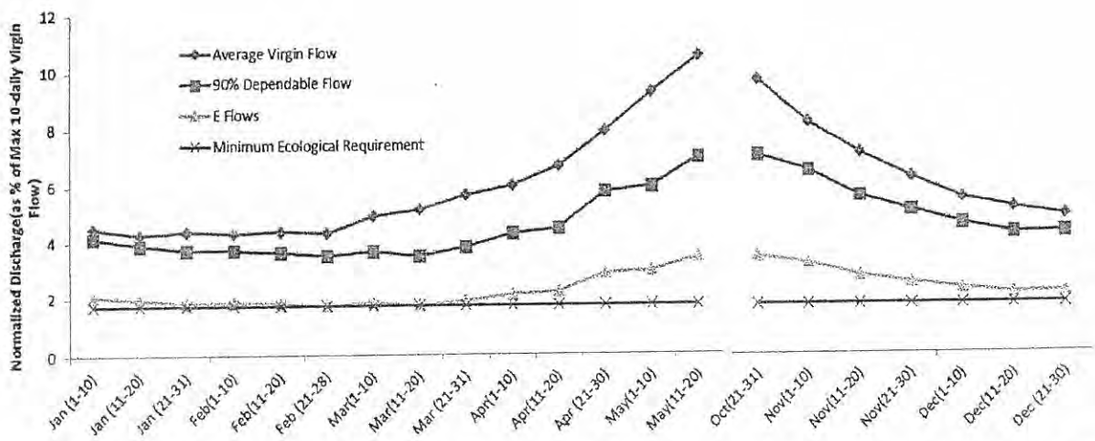


Figure 24b: Representation of Various Flow Regimes at D/S Pashulok Barrage, Rishikesh on River Ganga during Non-Maonsoon Period

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

5. 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).

6. References

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