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Environmental Flows Assessment for the Ramganga River Basin

Technical Report

Under the project

India-EU Water Partnership Action, Phase 2

Support to Ganga Rejuvenation

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Report Disclaimer

This report has been developed under the India-EU Water Partnership Action (Phase 2) under the steering of National Mission for Clean Ganga and in collaboration with the Central Water Commission, Central Inland Fisheries Research Institute, Wildlife Institute of India, and other agencies. The aim of the study is to assess Environmental Flows for the Ramganga River and all its tributaries. In total, 6 representative sites have been selected under this study (Garampani on Kosi River, Kaladhungi on Boar River Upstream of a diversion and one site downstream of the diversion, Seohara and Bareilly on Ramganga River and Jalalabad on Baigul River). Based on the data availability, the E-Flows assessments of these six sites have been completed and results are presented in this report along with implementation strategy and way forward.

Parallel to the process of E-Flows assessment, stakeholder consultations and key stakeholders' meetings were conducted. The outcomes of the Ramganga E-Flows assessment were discussed with the Ramganga E-Flows stakeholders and together led to the identification of climate-sensitive measures through the consultation process to ensure E-Flows in the Ramganga Basin. The report on the consultation process is separately prepared and shared alongside this report.

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The pivotal role played by the multi-disciplinary team of experts attributes to the successful execution of the field survey missions. Commitment of nodal and involved officials from National Mission for Clean Ganga, Central Water Commission, Central Inland Fisheries Research Institute, Wildlife Institute of India and representatives of State Water Resources Departments of Uttar Pradesh and Uttarakhand, and Uttarakhand Forest Department with their inputs and support has greatly enriched the quality and depth of this assessment study. Special thanks to dedicated individuals from the INRM consultants and TerrAqua UAV Solutions- IIT Kanpur.

The assessment report is a testament to the collaborative efforts of all the involved organisations and their representatives and collective insights from all the involved Ramganga Basin stakeholders and senior officials of various organisation/ departments of national and state governments.

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Appendices are included as separate documents.

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Abbreviations

2D	Two Dimensional
ASL	Above Sea Level
CA	Channel area
CIFRI	Central Inland Fisheries Research Institute (ICAR)
CWC	Central Water Commission
E-Flows	Environmental Flows
EU WFD	Water Framework Directive of the European Union
FDC	Flow Duration Curve
GES	Good Ecological Status
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GoI	Government of India
GRBMP	Ganga River Basin Management Plan
HMUs	Hydromorphological Units
HUGs	Habitat Use Guilds
IEWP	India-EU Water Partnership
lskm	Litres per second per square kilometre
MacHTs	Macrohabitat types
MAF	Mean Annual Flow
MesoHABSIM	Mesohabitat Simulation Model
NMCG	National Mission for Clean Ganga
RBMP	River Basin Management Plan
SGR	Support to Ganga Rejuvenation
UCUT	Uniform Continuous Under Threshold
UK	Uttarakhand
UP	Uttar Pradesh
WII	Wildlife Institute of India
WWF	World Wildlife Found

Executive Summary

The National Mission for Clean Ganga (NMCG) and the Central Water Commission (CWC) of the Ministry of Jal Shakti, Government of India, are working in close cooperation with GIZ (German Development Cooperation) India, and other partners to further strengthen the current procedures for Environmental Flows (E-Flows) assessment and implementation in India. The India-EU Water Partnership (IEWP) E-Flows Initiative, launched during 2018, has been working towards this goal through the joint implementation with partners of several aligned, interrelated projects on River Basin Management and E-Flows. Under the second phase of the IEWP Action, guided by the NMCG and CWC, with the State water agencies and other partners, the Ramganga River Basin continued to be a focal basin for E-Flows.

This report presents the findings of assessment of E-Flows in the Ramganga River Basin along with the approach and stepwise procedures. The assessment utilizes an approach and stepwise procedures founded on the current approach of the GoI, as well as recommendations for the advancement of the approach to better incorporate ecological requirements as presented in the Guidance Document for Environmental Flows Assessment and Implementation in India (2020). A flow-habitat modelling method capable of regionalization across river types was applied, based on the comprehensive habitat simulation method, MesoHABSIM, and hydrodynamic and hydrological modelling. Consideration was given to India's national policy and governance context for E-Flows, as well as the progress in E-Flows concepts, practices and methodological approaches over the past two decades.

The assessment was conducted by an Assessment Task Group comprised of specialists from Indian institutions with local understanding of the Ramganga, as well as European specialists in E-Flows processes and the specific methods to be applied for the local E-Flows assessment. Basin stakeholders were consulted in a process run parallel to the E-Flows assessment, with the main consultations timed to coincide with the milestone stages of the E-Flows assessment, when stakeholder values and perspectives, shared experiences, critical review and feedback, and key decisions on next steps were particularly important. The overall process followed for implementation of the activities of E-Flows Assessment to feed into the stakeholders' consultation process is presented in Figure ES 1.

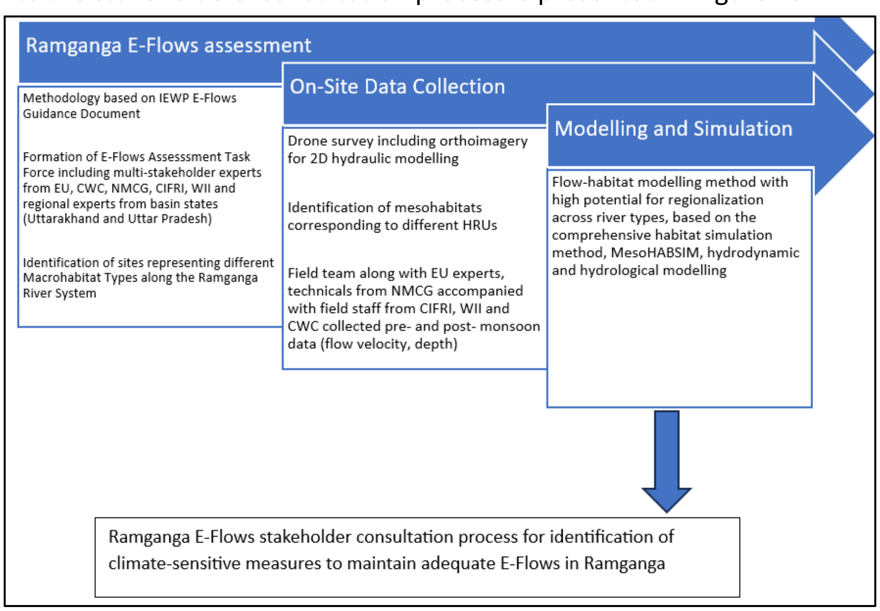


Figure ES1: overall process followed for implementation of the activities

In response to the basin stakeholders, the geographic scope of the assessment encompasses the entire Ramganga River Basin, including the mainstem Ramganga River and its tributaries (Figure ES2). This allows for assessment of the flow needs of the entire riverine ecosystem as a structurally and functionally interconnected drainage network. It includes various sub-basins, which are trans-boundary across the two basin states namely, Uttarakhand and Uttar Pradesh, and the corresponding basin, state and district administrative units. The Ramganga River Basin can be viewed as a microcosm of its parent basin, the Ganga River Basin. It has several comparable characteristics, including a biogeography reflective of the combined effects of mountains and plains, a large human population, issues of pollution and poor water quality in the middle parts of the basin, similar extents of development and use of water resources, significantly altered river flows regimes, and a high to exceptional biodiversity value and ecological significance.

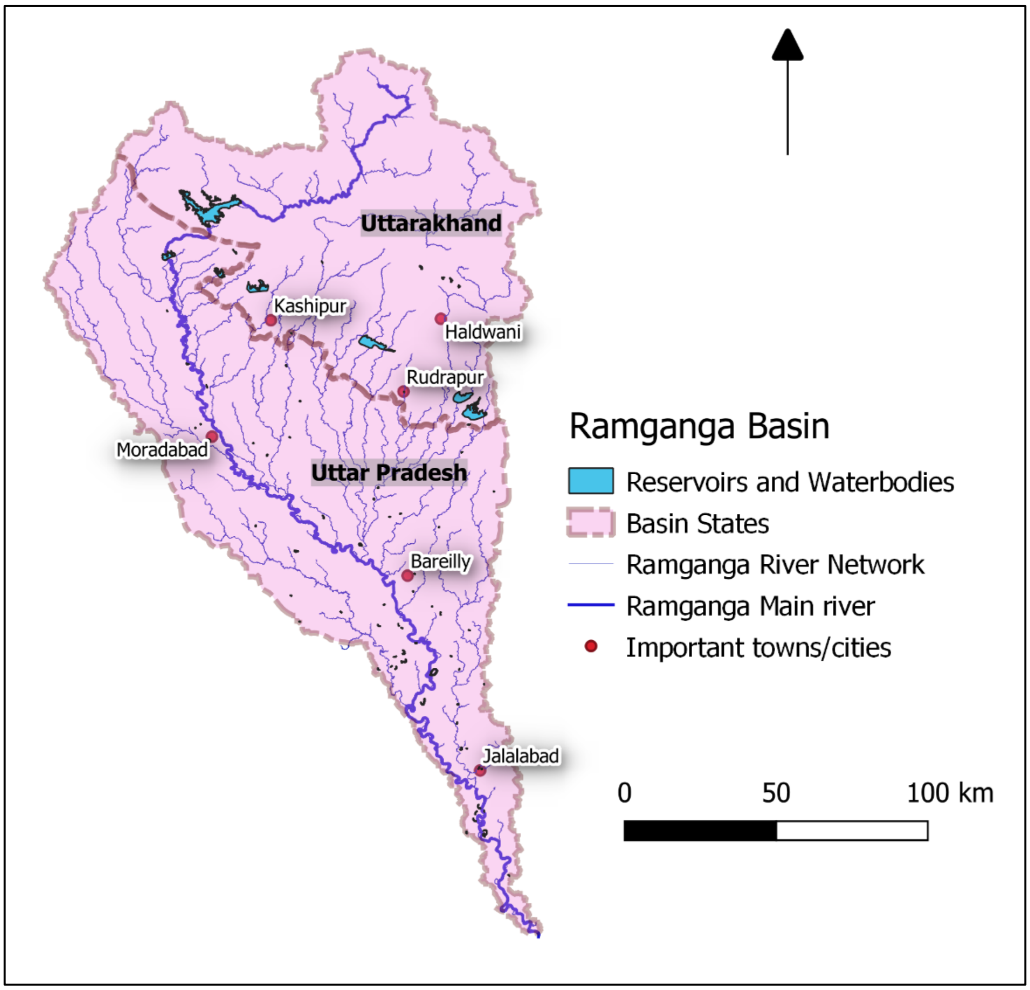


Figure ES2: Key Features of Ramganga River Basin.

Further, river reaches for detailed E-Flows assessment were selected to represent the range of fish community macrohabitat types (MacHTs) present in the Ramganga River Basin. Six river macrohabitat types with corresponding study reaches (called as sites) were identified based on similarities in their altitude, slope of river segment, stream order, catchment size, geology, and bioclimatic conditions. The types differentiated Himalayan Mountain and foothill transition zones, and the more human-impacted upper and lower Indo-Gangetic plains. Figure ES3 represents the distribution of the clusters in the basin, which can be described as follows:

- **MacHT 1** - **Himalayan Foothills Streams**, on igneous rock high elevation and slope, first and second order streams with catchment area smaller than 3 000km^2.
- **MacHT 2** - **Transition Streams** are located in Himalayan geology, at lower elevation and slope, their stream order is up to 3 and catchment areas up to 12 000km^2.
- **MacHT 3 – Upper Gangetic Plains Second and Third Order Streams,** low elevation (~100 m) and slope, with catchment areas less than 15000km^2.
- **MacHT 4** – **Upper Gangetic Plains First Order Streams** with small catchment areas
- **MacHT 5** - **Low Gradient Large Catchment Rivers** of 1st to 4th stream order with catchment areas between 15 000 and 22 000 km^2. This is the mainstem of the Ramganga River upstream of Bareilly.
- **MacHT 6** – **Lower Mainstem Ramganga** with an even lower elevation, stream order 5 and catchment area above 22 000 km^2.

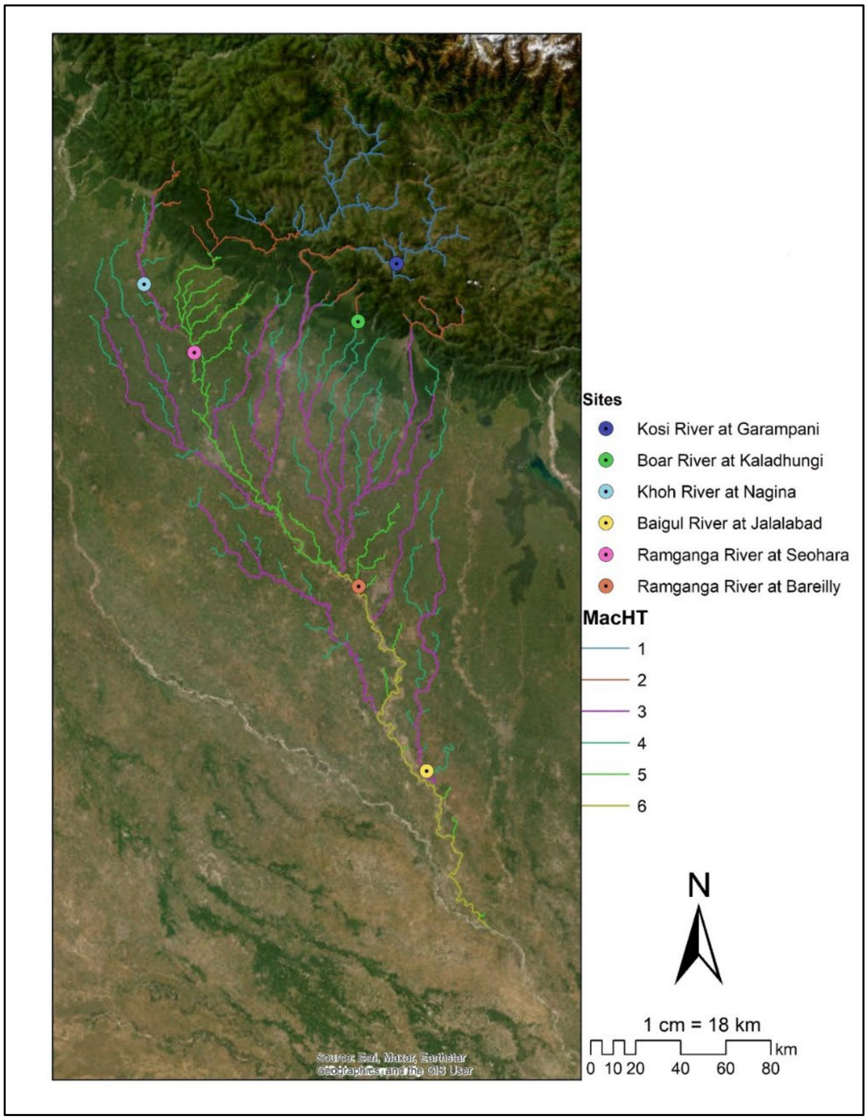


Figure ES3: Macrohabitat cluster distribution in the Ramganga Basin with the six E-Flows sites used in the assessment

The specific sites for detailed field surveys were selected with the premise to find the anthropogenically least modified portions of the river to collect the flow-hydraulic habitat and ecological information needed to establish E-Flows meso-habitat simulations (See Figure ES2 for 6 sites). As each of the sites also represents a MacHT type of the river within the basin, it is possible, in a precautionary way, to extrapolate the calculated E-Flows figures for any site to other reaches of the same type, wherever they are located in the basin.

At each study site, biological targets were set, consisting of the fish species groups for which E-Flows will be identified. Biologists on the Task Team identified the fish species that typically occur in the area and grouped them into assemblages (guilds) using similar habitats. Abundances of the expected assemblages were then ranked as a proxy for determination of dominance structure of assemblages in the fish community. The ranks are used to compute a fish community model.

Annual hydrographs were also constructed for each site, detailing changes in flow over the year for both naturalized (near-natural) and present-day conditions. The hydrographs illustrated flow variability between and within years, and were used to identify periods of high flows and low flows. A range of hydrologic indicators was then used to describe normal and extreme flow conditions. To allow transferring of corresponding flow values between distant locations, the flows were standardized to specific discharge per unit area of upstream basin (litres/second/km^2, i.e. lskm).

A range of field data were collected including the in the E-Flows study reaches to determine the spatial proportions of mesohabitat units. Mesohabitat units correspond with Hydromorphological Units (HMUs; i.e. pools, riffles, runs), which are river sections with similar morphologic, hydraulic, and cover attributes. During the on-site surveys, information on habitat features, habitat distributions, flow velocity, flow depth and substrate type etc was collected for further assessment. The data collection was done using a combination of remote sensing and on-site surveys. The procedure varied depending on the size of the river as for larger streams measurements were made using a boat and then verified using the orthoimages annotating HMUs while for smaller streams measurements were based on wading.

Fish habitat variables under different flow conditions in the study reaches were then simulated using two numerical models. Flow depth and velocity were modelled in two dimensions using the River 2D model (Ghanem et al 1995). River 2D creates a digital representation of the river that can be used to simulate hydraulic patterns. Grain (substrate) sizes of sediments in different HMUs of the study reaches were simulated using the SubDisMo model, which uses depth and velocity data derived from the River 2D model and annotations of HMUs according to MesoHabsim protocols. Both models were calibrated using measured variables from the Seohara and Bareilly sites on the mainstem Ramganga River, Jalalabad site on the Baigul River, Kaladhungi site on Boar River and Garampani site on the Kosi River. They were further used to simulate hydraulics and substrate distributions at three flow conditions that have not been measured.

Finally, Sim-Stream Software was applied to organize the collected habitat data and to calculate the suitable habitat area for each fish guild for different study reaches and at different flow levels. Results are presented as habitat suitability maps in which every mapped unit is colour coded as unsuitable, suitable or optimal habitat (Figure ES4).

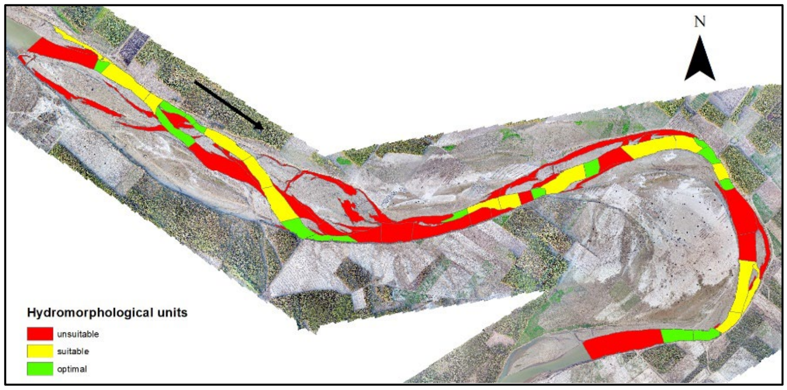


Figure ES4: Habitat suitability maps for Rheophilic water column sand-gravel habitat use guild in Seohara site of Ramganga River at flow of 3 m^3/s (defined in pilot project 2020)

The results of simulations of suitable habitat areas for different fish guilds at different flow levels were then plotted to produce habitat rating curves. This curve is applied to calculate habitat time series for past and future scenarios of flow. The habitat time series is based on the amount of flow in the river recorded on any given day. With help of the habitat rating curve, flows are evaluated for how much habitat they provide, and this value is plotted as a habitograph depicting fluctuation patterns of habitat occurring in the river over time. The frequency of habitat area occurrence over time is used as the basis for determining **habitat thresholds**, which specify a boundary condition necessary to support the native fish community structure.

To assess the temporal patterns, the habitat time series was analysed using Uniform Continuous Under Threshold (UCUT) analysis, a habitat duration analysis method which observes the frequency of continuous events with low habitat availability and identifies rare and common habitat conditions associated with subsistence and habitat base flow conditions. Four E-Flow thresholds were calculated for each study reach:

- **habitat base flow** offers stable and sufficient living conditions for the fish community**;**
- **trigger flow** alerts for management actions preventing subsistence conditions;
- **subsistence flow** provides survival conditions for the fish community;
- **absolute Minimum** is the lowest flow on record.

These thresholds are accompanied by continuous duration thresholds separating drought events of persistent and catastrophic duration. To offer E-Flow criteria for any other site falling in same MacHT, the specific E-Flow values are then divided by the mean annual flow for the site location. Obtained index p-values can be used to compute E-Flows for any other location using a formula based on p-value, catchment area and flow observations at that location.

The main characteristics of the study sites are presented in Table ES1. They cover all 6 macrohabitat types, range in stream order from 1 to 5, and represent different hydromorphological and substrate conditions.

Table ES1: Key characteristics of selected reference sites

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
Location	**Garampani**	**Kaladhungi**	**Kaladhungi**	**Nagina**	**Jalalabad**	**Seohara**	**Bareilly**
River	**Kosi**	**Boar**	**Boar2**	**Khoh**	**Baigul**	**Ramganga**	**Ramganga**
MacHT	1	2	4	3	3	5	6
Drainage area	1207	10	10.64	736	2169	5099	17560
Elevation (m ASL)	922	440	406	237	144	212	163
Stream Order	3	1	1	2	2	4	5
Gradient (m/km)	32	16	1	1.2	1.1	0.8	0.6
Length (m)	800	350	1120	2144	2132	2000	2555
Channel Width (m)	100	30	60	250	50	130	270
Hydromorphology	straight	straight	braided	braided	meander-ing	meandering	meander-ing
Dominant sub-strate	cobble	cobble	gravel	sand	sand	sand	sand
MAF (m3/s)	9	0.2	0.2	7.3	18.1	39.9	165

Based on the physical characteristics of the sites, their naturalized flow regime, and the flow-habitat relationships of their fish assemblages, the environmental flow criteria were derived for each site (Table ES2). Criteria are presented for three seasons (bioperiods) of the year: post-monsoon (IX-X), lean (XI-II) AND dry (III-V). As monsoon flows cannot be regulated or controlled, no criteria will be applied for monsoon season. For each criterion, flow is expressed in units of m^3s^{-1} (cumecs). Allowable and catastrophic durations of flow deficits in days at each level are also indicated. The latter is equivalent to events with 10 years occurrence interval.

Table ES3 presents the p-values for each E-Flow type (base, trigger, subsistence) and continuous duration thresholds. They can be used for defining E-Flow strategies for each MaCHT using the trigger E-Flow value as a threshold for introducing management criteria. There are two strategies that can be followed: static and dynamic E-Flows.

Table ES2: E-Flows calculated for the representative sites for three bioperiods

Site	Kosi River Garampani			Boar River Kaladhungi			Baigul River Jalalabad			Ramganga River Seohara			Ramganga River Bareilly		
Bioperiod	IX-X	XI-II	III-V	IX-X	XI-II	III-V	IX-X	XI-II	III-V	IX-X	XI-II	III-V	IX-X	XI-II	III-V
Base flow (m3s-1)	**2.28**	**1.68**	**1.17**	**0.26**	**0.26**	**0.08**	**7.05**	**4.34**	**4.34**	**5.92**	**5.51**	**5.10**	**640.44**	**236.03**	**130.39**
Allowable duration under (days)	16	18	12	*25*	*43*	*10*	*26*	*52*	*17*	*19*	*37*	*23*	26	59	59
Catastrophic duration (days)	31	66	33	*47*	*120*	*72*	*41*	*120*	*92*	*24*	*43*	*41*	45	120	92
Trigger flow (m3s-1)	**0.97**	**0.34**	**0.23**	**0.08**	**0.05**	**0.05**	**1.40**	**0.74**	**0.03**	**2.29**	**2.29**	**0.14**	**351.16**	**128.45**	**92.47**
Allowable duration under (days)	*12*	*6*	*9*	14	19	10	*11*	*49*	*12*	*6*	*18*	*5*	*10*	*35*	*37*
Catastrophic duration (days)	*13*	*40*	*12*	20	60	61	*34*	*120*	*92*	*11*	*27*	*8*	*10*	*59*	*52*
Subsistence flow (m3s-1)	***0.87***	***0.23***	***0.13***	***0.05***	***0.03***	***0.03***	***0.74***	***0.61***	***0.004***	***1.68***	***1.68***	***0.07***	***328.86***	***110.64***	***89.95***
Allowable duration under (days)	*5*	*6*	*8*	*5*	*8*	*10*	*6*	*48*	*11*	*5*	*11*	*3*	*8*	*17*	*24*
Catastrophic duration (days)	*10*	*24*	*9*	*18*	*37*	*33*	*34*	*119*	*92*	*10*	*27*	*4*	*8*	*47*	*34*
Abs. Minimum (m3s-1)	0.87	0.23	0.13	0.000	0.000	0.000	0.02	0.02	0.00	0.00	0.01	0.05	200.59	93.37	88.69

Table ES3: E-Flows criteria for investigated Machrohabitat types of Ramganga River Watershed

MacHT	1			3			4			5			6		
Bioperiod	IX-X	XI-II	III-V	IX-X	XI-II	III-V	IX-X	XI-II	III-V	IX-X	XI-II	III-V	IX-X	XI-II	III-V
Base flow p-value	**0.25**	**0.19**	**0.13**	**0.39**	**0.24**	**0.24**	**1.32**	**1.31**	**0.41**	**0.15**	**0.14**	**0.13**	**1.80**	**0.66**	**0.37**
Allowable duration under (days)	*4*	*3*	*2*	*26*	*52*	*17*	*25*	*43*	*10*	*19*	*37*	*23*	*26*	*59*	*59*
Catastrophic duration (days)	*16*	*18*	*12*	*41*	*120*	*92*	*47*	*120*	*72*	*24*	*43*	*41*	*45*	*120*	*92*
Trigger flow p-value	**0.107**	**0.038**	**0.025**	**0.077**	**0.041**	**0.002**	**0.405**	**0.225**	**0.225**	**0.011**	**0.011**	**0.001**	**0.989**	**0.362**	**0.260**
Allowable duration under (days)	*12*	*6*	*9*	*11*	*49*	*12*	*14*	*19*	*10*	*6*	*18*	*5*	*10*	*35*	*37*
Catastrophic duration (days)	*13*	*40*	*12*	*34*	*120*	*92*	*20*	*60*	*61*	*11*	*27*	*8*	*10*	*59*	*52*
Subsistence flow p-value	***0.097***	***0.025***	***0.015***	***0.019***	***0.015***	***0.000***	***0.225***	***0.130***	***0.130***	***0.008***	***0.008***	***0.0004***	***0.926***	***0.312***	***0.253***
Allowable duration under (days)	*5*	*6*	*8*	*6*	*48*	*11*	*5*	*8*	*10*	*5*	*11*	*3*	*8*	*47*	*24*
Catastrophic duration (days)	*10*	*24*	*9*	*34*	*119*	*92*	*18*	*37*	*33*	*10*	*27*	*4*	*8*	*47*	*34*
Abs. Minimum p-value	0.02	0.001	0.000	0.00	0.00	0.00	0.000	0.000	0.000	0.0000	0.0001	0.0013	0.57	0.250	0.263

The static strategy uses the trigger value as the E-Flow and prescribes it for the duration of a bioperiod. The dynamic strategy involves introducing management actions at the moment when the continuous duration thresholds of flows below trigger, or base flow are exceeded. These may consist of reducing water withdrawals or short (2 days) releases of water from reservoirs to reset the continuous duration count. Management actions in response to conditions of flow below base flow thresholds for more than the allowable duration are highly recommended to ensure suitable habitat for fish communities. While management action in response to conditions of flow below trigger flow thresholds for more than the allowable duration should be required to avoid significant harm to fish communities. Another rule frequently used is that exceedance of catastrophic duration is allowed every 10 years and that three consecutive exceedances of allowable durations in one bioperiod are equivalent to catastrophic duration.

1 Introduction

1.1 Background

The National Mission for Clean Ganga (NMCG) and the Central Water Commission (CWC) of the Ministry of Jal Shakti, Government of India, are working in close cooperation with GIZ (German Development Cooperation) India, and other partners to further strengthen the current procedures for Environmental Flows (E-Flows) assessment and implementation in India. The India-EU Water Partnership (IEWP) Action E-Flows Initiative, launched during 2018, has been working towards this goal through the joint implementation with partners of several aligned, interrelated projects on River Basin Management and E-Flows. Under the first phase of the IEWP Action and the Indo-German technical cooperation project, Support to Ganga Rejuvenation (SGR), GIZ organized an international knowledge exchange workshop on E-Flows assessment and implementation (2019) to inform stakeholders on the overall aims and targets for E Flows assessment in India and discuss the steps to accordingly implement E-Flows. Data collection and E-Flows assessment methods were evaluated for their performance in various hydro-climatic regions in India, and in line with global good practice, including that of the European Union Water Framework Directive (EU WFD). An E-Flows pilot study on various locations on the upper reaches of Ramganga River was part of this work (as documented in Nale et al. (2020a)). A Guidance Document for E-Flows Assessment and Implementation in India (Nale et al. 2020b) was produced, based on these various efforts and learnings, which provides much of the context for the prevailing E-Flows assessment approach and the need and ways to advance it further. It is intended to help stakeholders understand the science and administration of E-Flows along with their roles in achieving E-Flows objectives. The guidance also presents a Road Map for a gradual adaptation of the current E-Flows assessment method over the next few years to enable comprehensive strategic planning (Nale et al. 2020b). The Ramganga E-Flows assessment detailed in this report is a contribution to the activities in the Road Map.

For the current, second phase of the IEWP Action, guided by the NMCG and CWC, with the State water agencies and other partners, the Ramganga River Basin continued to be a focal basin for E-Flows. To steer and reinforce the technical E-Flows assessment, a series of stakeholder consultations, which comprised the social part of the process, are conducted under the complementary Support to Ganga Rejuvenation (SGR) II Project. The stakeholder consultation process aimed to take the results of the E-Flows assessments forward to steer the discussions with stakeholders relevant for Ramganga Basin to identify and agree on 3 key climate sensitive improvement measures towards ensuring adequate E-Flows. Together, the two project components support the integrated management of water resources, including the water needed by the environment, in the Ramganga River Basin.

1.2 The national policy and governance context for E-Flows

India has embraced the principles and practice of Integrated Water Resources management (IWRM), where water resources are being developed and managed to maximize the social and economic benefits, for multiple users of the resource in an equitable and efficient manner, while ensuring that the natural ecosystems are not degraded. The high dependency of Indian society on its rivers for water, food and energy, as well as many other ecosystem services and benefits, has made it critical to balance the needs of society and riverine ecosystems. Protection, and where required, restoration (rejuvenation) of the health of the country's rivers and associated waterbodies, including by ensuring that sufficient water is allocated for environmental sustainability, is advocated at the national political level (For more detail see E-Flows Guidance Document, Nale et al., 2020b).

1.3 Status of E-Flows assessment and implementation

E-Flows concepts, practices and methodological approaches have emerged over the past two decades in India, since the first national workshop introducing E-Flow concepts and practices took place in 2005 (Nale 2018). As a result, significant progress has also been made in developing the institutional and technical capacity to undertake E-Flows assessments and implement the results as part of river basin planning and management. The Ganga Basin has been, and continues to be, a focal basin for E-Flows efforts, with several studies initiated in 2012, drawing on the definition of E-Flows as presented in the Ganga River Basin Management Plan (GRBMP (IIT Consortium) (2011)): "E-Flows are a regime of flow in a river or stream that describes the temporal and spatial variation in quantity and quality of water required for freshwater as well as estuarine systems to perform their natural ecological functions (including sediment transport) and support the spiritual, cultural and livelihood activities that depend on these ecosystems". Further, E-Flows assessments in Ganga Basin continued as part of the planned rejuvenation of the wider Ganga system and in line with what became the overall vision for the Ganga of "Restoring the wholesomeness of the River Ganga" while also maintaining sustainable growth within the basin (cGanga and NMCG 2017). The vision focuses on four elements to ensure a healthy, clean ('nirmal') river with an uninterrupted flow ('aviral') which supports geological, ecological, and societal needs and will be resilient under future changes in water demands and climate.

The trialling and comparison of various approaches to assess E-Flows during this period led to the development of the Hydraulic Rating Cum Habitat Simulation Method presently used by the Central Water Commission (CWC) and other agencies to establish E-Flows recommendations for existing and proposed projects. Based on similar assessments, the Ganga E-Flows Notification of 2018 (amended September 2019) demands and specifies the continuous release and monitoring of E-Flows in the upper reaches of the Ganga. Considering the progress made for the main stem of Ganga, it is indeed imperative that other river basins in India and other sub-systems of Ganga receive similar focus for E-Flows assessments and implementation.

2 Ramganga Basin Characteristics

The Ramganga River Basin, India, can be viewed as a microcosm of its parent basin, the Ganga River Basin, and as such, a focal sub-system of the Ganga. It has several comparable characteristics, including a biogeography reflective of the combined effects of mountains and plains, a large human population, issues of pollution and poor water quality in the middle parts of the basin, similar extents of development and use of water resources, significantly altered river flows regimes, and a high to exceptionally biodiversity value and ecological significance.

The Ramganga River originates in the Doodhatoli Ranges of the lower Himalayas in the in Garhwal district of Uttarakhand State, at an elevation of about 3,100 m, and flows 596 km to merge with the Ganga River in Hardoi district of Uttar Pradesh State at an elevation of about 150 m. It drains a basin area of over 31,843 km^2 inhabited by some 24 million people.

The features of the Ramganga River vary distinctly from its source streams at the top of the basin to its lower floodplain outlet with the Ganga. Basin topography and elevation change sharply from the steep and mountainous areas typical of the upper basin sub-catchments, to the gently sloping and flat plains of the lower basin. Geologically, the upper basin consists mainly of pre-Cambrian, crystalline rocks, while the lower catchment comprises mostly deep, alluvial quaternary sedimentary deposits. Land use and land cover changes coincide with the changes in topography and associated patterns of human settlement. The hills are heavily forested and crop cultivation is of very low intensity, whereas the plains are without much forest cover and intensively cultivated, as reflected by an extensive network of irrigation diversions and canals.

Rainfall patterns also change sharply across the length of the basin, with the highest rainfall experienced in the sub-Himalayan region. The annual precipitation reduces, first abruptly and then gradually, from the mountainous areas in Uttarakhand to the plains in Uttar Pradesh. The natural discharge of the river is estimated to be about 17 billion m^3, which represents an estimated 3.1% percent of the average annual flow of the Ganga River. The runoff in the river is naturally heavily skewed, with most of it occurring during the high flow monsoon months of August, September and October; lean season river discharges are significantly lower. The Ramganga River carries naturally heavy sediment loads during the monsoon months, after which loads reduce markedly with reduction in precipitation and catchment runoff.

There are 8 major dams, 10 major barrages, 3 weirs and 1 powerhouse located in the basin. Kalagarh Dam is the largest dam and a vital source of water for the wide range of water users and economic activities within the basin. The current hydrology and connectivity of the river is strongly altered by the presence and operation of these reservoirs and diversion systems, the majority of which reduce streamflow to varying degrees in certain stretches of the main river and its tributaries. Conversely, river flow is augmented through irrigation return flows from the gravity systems in the lower stretches of the Ramganga mainstem, along with increased nutrient loads from agriculture. The basin both exports water for irrigation and imports it, through a complex system of inter-basin transfers. From Kalagarh dam, about 140 cumecs water is transferred through Ramganga Feeder Canal to Ganga River for off-taking from Narora barrage while water from Sharda canal system significantly supports irrigation in Ramganga Basin.

Water pollution from various sources, including agriculture and industry, is having a significant negative impact on the health of the basin. A reported 445,000 m^3 per day of wastewater, from 121 major industries and several cities, discharges into the Ramganga River, such that the lower 375 km of the river from Moradabad to its confluence with Ganga are critically polluted. Sand mining is markedly altering river morphology, as already evident in the middle and lower reaches of the mainstem and some major tributaries.

The Ramganga Basin is immensely important for biodiversity, both nationally and internationally. The basin division into two biogeographic zones, the Himalaya zone and the Gangetic Plain, is influential in this regard. Numerous species of flora and fauna (both freshwater and terrestrial) of high conservation value, including the iconic Royal Bengal Tiger, Asian Elephant, Gangetic Dolphin and Golden Mahseer occur in the basin, and it also supports important migratory birds. Around 22 % of the basin is designated as Forest Area, with a further approx. 2000 sq. km. constituting other different types of Protected Areas. Over half of that area (1200 sq. km) is within Uttarakhand, where Jim Corbett National Park is located.

Various inland waters and wetland systems make up a basin total of around 1200 sq. km, including the river network of the Ramganga, oxbow lakes, swamps and other wetlands, as well as manmade reservoirs. Where they are in near-natural condition particularly, these inland waters serve as exceptional habitats for a rich diversity of native wildlife. While many reaches of the Ramganga River system are measurably modified from natural by human uses and water resources development, several reaches and tributaries, including key refuges for the future under a changing climate, remain ecologically functional and healthy. Such reaches are critical for ecosystem services for local communities, particularly in terms of food fisheries and flood-driven subsistence agriculture, as well as for cultural purposes. Thus, it is important to assess and implement the E-Flows in the Ramganga Basin, on priority, for its protection and conservation as a source of life for the biodiversity of immense ecological significance while also supporting the ecosystem services and livelihoods for human populations dependent on it, within and beyond the basin.

A more detailed description of the characteristics of the Ramganga Basin may be found in Appendix 1.

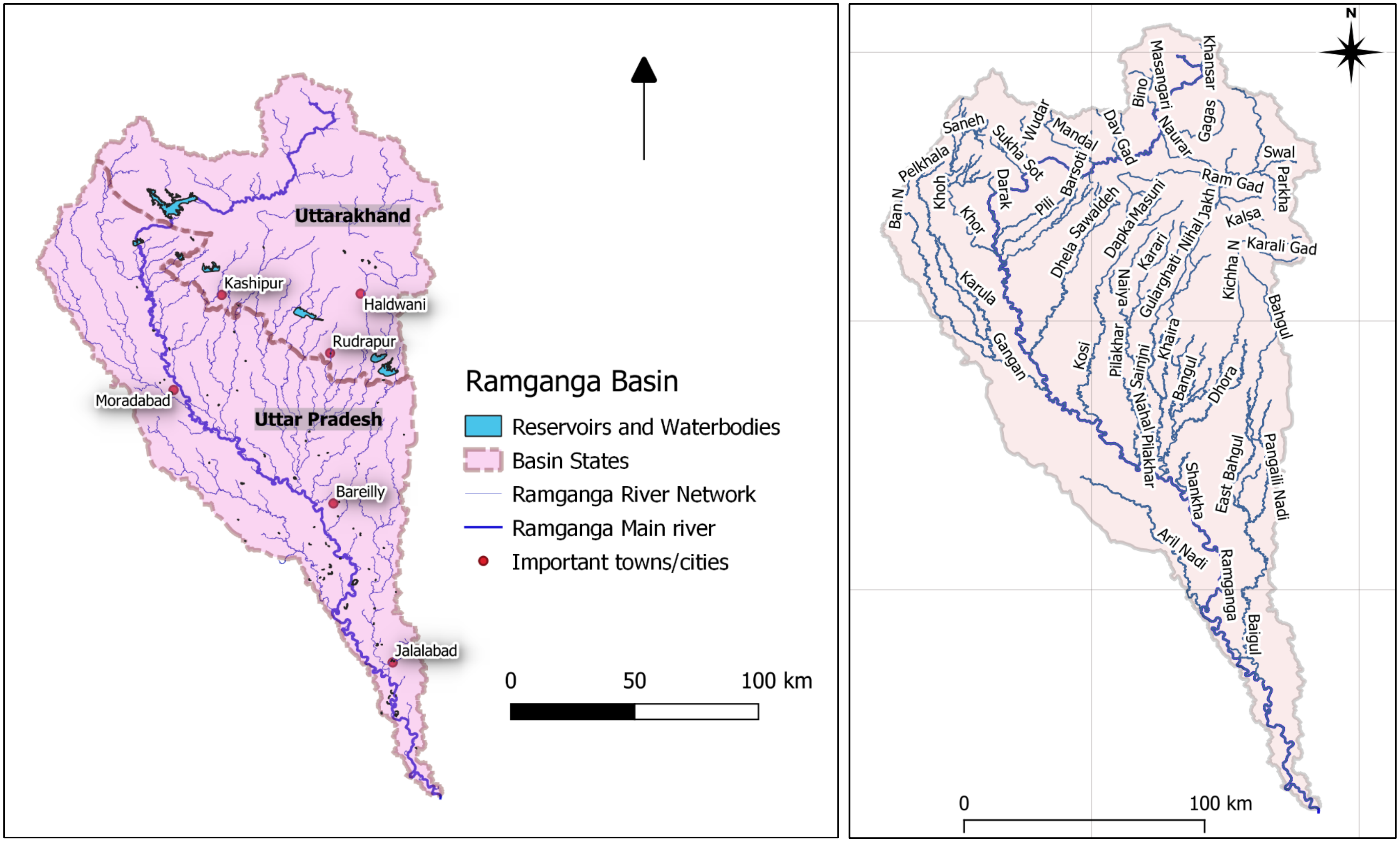


Figure 1: Key Characteristics and Drainage Netwrok of Ramganga River Basin

3 Overall approach for E-Flows Assessment

3.1 Overview of the approach and scope

The general approach for E-Flows Assessment applied to the Ramganga River Basin and the stepwise procedures to support it (see Section 5 below) are necessarily founded on the current approach of the Indian E-Flows assessments. It was intended to incorporate, to the extent feasible within the scope of the current project, the recommendations for the advancement of the approach for India in the direction of good practice as presented in the Guidance Document for Environmental Flows Assessment and Implementation in India (Nale et al. 2020b). These recommendations include aspects of the present E-Flows guidance based on the Water Framework Directive of the European Union (EU WFD) (European Commission 2015) and the practical application of that guidance (e.g., Acreman and Ferguson 2010).

The choice of method was made based on the outcomes of the piloting of different habitat-flow assessment methods for four sites on the Ramganga River, during the IEWP Action Phase 1 (Nale et al. 2020a). Flow-habitat modelling method with high potential for regionalization across river types was selected for the current assessment, based on the comprehensive habitat simulation method, MesoHABSIM (Parasiewicz 2001, 2007ab, 2008ab), hydrodynamic and hydrological modelling (Ghanem et al 1995, Almendinger et al 2014).

3.2 Strategy for consultations with basin stakeholders

An inclusive, tiered strategy for engagement with stakeholders at all relevant levels, from the national and state levels to the basin and local community scales, was run in parallel to this assessment (under SGR Phase 2). Consultations served as the core of the social process of the E-Flows Assessment, with which the technical procedures for determining the E-Flows (under IEWP Action II) were aligned. The main consultations were timed to coincide with the milestone stages of the E-Flows assessment, when stakeholder values and perspectives, shared experiences, critical review and feedback, and key decisions on next steps were particularly important. In addition to the main consultations, smaller, more targeted consultation sessions with key stakeholders were held to address specific issues. Additional details of the Stakeholder Consultation process are presented in a separate series of reports.

3.3 Assessment scope

In response to the key basin stakeholders, the geographic scope of the assessment encompasses the entire Ramganga River Basin, including the mainstem Ramganga River and its tributaries. This allows for assessment of the flow needs of the entire riverine ecosystem as a structurally and functionally interconnected drainage network. It includes Ramganga sub-basins, which are transboundary across the two states of UK and UP, and the corresponding state and district administrative units.

The technical scope of the assessment was adapted to the extent required based on the availability of data and resources in terms of time and financial support to conduct the necessary field surveys etc.

3.4 The expert group

Conducting a basin-scale assessment, as well as making it more inclusive, integrative, and interdisciplinary requires the participatory involvement of national, state and other basin stakeholders from the outset, as well as a team of technical multidisciplinary specialists. The Ramganga E-Flows Assessment Task Group was assembled with the joint role of undertaking the technical E-Flows assessments. It comprised specialists from Indian institutions with local understanding of the Ramganga, as well as European specialists in E-Flows processes and the specific methods to be applied for the local E-Flows assessment. The team collaborated in an interdisciplinary way throughout the process, to ensure all members became sufficiently familiar with other technical areas with which they needed to exchange knowledge during the field and desktop steps of the assessment. This collaboration necessitated some desktop (online) and hands-on learning-by-doing training activities, which were developed as part of a supporting training activity under the project (See Concept- Interactive Trainings on Environmental Flows Assessments under the IEWP Action Phase 2; Part 1, 2 and 3).

4 Main steps in the methodology for E-Flows assessment based on MesoHABSIM

4.1 Application of the MesoHABSIM E-Flows method

The core of the methodology applied for estimating E-Flows is the Mesohabitat Simulation Model (MesoHABSIM). Conceptually, the approach is well grounded in the current river ecosystem theory and practices that are particularly relevant for habitat simulation type E-Flows methods and their upscaling from site/reach scale to larger, regional scales, such as the basin and river network scale. In particular, it draws on a multi-scale, hierarchical framework for developing process-based understanding of catchment-to-reach hydromorphology for sustainable river management applications such as E-Flows (see Gurnell et al. 2016, for further details).

MesoHABSIM uses a computer model, Sim-Stream, that predicts the quantity of habitats available at different flow levels for aquatic communities in rivers and streams. Changes in the quantity of habitats available can then be evaluated for different water management (flow alteration) scenarios. The system is based on data resolution that reflects animal responses to changes in the environment and their effective extrapolation to a scale that allows planning and management. MesoHABSIM has been created and developed in last 20 years and has been applied in numerous environmental flow studies ranging from E-Flow determination for individual facilities to prescriptions for entire regions and countries (e.g., Parasiewicz et al 2008a, 2018, Pegg et al. 2014, Vezza et al 2012).

The methodology applying MesoHABSIM has already been adapted for the local context, based on the lessons learned during a test site application in the Ramganga River Basin in early 2020, during the IEWP Action Phase 1 Ramganga pilot study (Nale et al. 2020a). Standard methods for the collection of data necessary for the application of the MesoHABSIM model are detailed in a field data collection manual (Parasiewicz and Suska 2020). The steps of the method were adapted as needed during the course of its application in the Ramganga River Basin.

The procedure of computing MesoHABSIM model results consists of seven steps. Each step is described briefly below.

4.2 Selection of river reaches for meso-habitat simulation

River reaches for detailed meso-habitat simulation were chosen to represent the range of fish community macrohabitat types (MacHT) present in the Ramganga River Basin. The procedure begins with a desktop analysis, using basin characterization data presented in Appendix 1, to identify the most useful subset of variables for describing river features across the basin, including: altitude, slope of river segment, stream order, catchment size, geology, and bioclimatic conditions. These features have been shown to determine fish community structure through such habitat characteristics as flow velocity, river width and depth, and longitudinal profile. Further, land cover and water pollutants were not selected as habitat determining attributes, as these are the most sensitive to human induced alteration. River reaches were classified, using standard multivariate statistical techniques (e.g., K-means clustering, ANOSIM), into a meaningful and practical number of clusters of reaches of similar character, representing different fish community macrohabitat types.

For each macrohabitat type, in discussion with experts familiar with local conditions, individual reaches were identified for detailed field surveys to collect the flow-hydraulic habitat and ecological information needed to establish E-Flows meso-habitat simulations. As each of the sites represents a type of river within the basin, it is possible, in a precautionary way, to extrapolate the calculated E-Flows figures for any site to other reaches of the same type, wherever they are located in the basin.

These representative sites were selected, with the premise to find the least anthropogenically modified portions of the river. Available maps of irrigation/diversion canal networks, barrages, population density and land use were used to guide the selection process. An estimated 5-10 representative reaches were to be identified as potential E-Flows sites, for subsequent validation during the first of the three proposed field surveys. A field reconnaissance trip was conducted as part of the assessment. A rapid reconnaissance of the sites, including aerial imagery, was done during the May, 2022, field mission, leading to final selection of suitable sites and identification of their modification/alteration status (A/B/C/D).

4.3 Establishment of biological targets

The biological targets are the fish species groups for which E-Flows will be identified, using the Target Fish Community approach of Bain and Meixler (2009). Accordingly, it is necessary to determine what species, in what numbers, can be expected at the location during different times of the year. To establish such biological targets, seasons are defined (bioperiods), in which different fish communities and life stages occur in the river. Biologists on the team then identify the fish species that typically occur in the area and group them into assemblages (guilds) using similar habitats. Abundances of the expected assemblages are then ranked as a proxy for determination of dominance structure of assemblages in the fish community. The ranks are used to compute a fish community model (Bain and Meixler 2008) presenting the expected proportion of assemblages in the community (community structure). Each assemblage is assigned conditional habitat suitability criteria, which can be applied for all rivers in India.

4.4 Hydrological analyses

Hydrologic characteristics were identified for the preliminary E-Flows reaches. Annual hydrographs were constructed, for both naturalized (near-natural) and present-day conditions, through hydrological modelling process, to show changes in flow over the years at a specific location. The hydrographs illustrated flow variability between and within years and were used to identify periods of high flows and low flows. Annual Flow Duration Curves (FDCs) were developed for each site of interest in the basin, supplying additional data about the flow characteristics of each river reach, across all modelled (or recorded) discharges. Using the FDCs, specific flow percentiles (percentage of time a particular discharge is equalled or exceeded) were obtained. To allow transferring of corresponding flow values between distant locations, the flows were standardized to specific discharge per unit area of upstream basin (litres/second/km^2).

4.5 Morphological assessment

While, a comprehensive geomorphological analysis was beyond the project scope, geomorphology was in part assessed through the hydraulic habitat assessments at the sites.

4.6 Field data collection and survey methods

A range of field data were collected in the E-Flows study reaches to determine the spatial proportions of mesohabitat units following Parasiewicz and Suska (2020). Mesohabitat units correspond with Hydromorphological Units (HMUs; i.e. pools, riffles, runs), which are river sections with similar morphologic, hydraulic, and cover attributes. The data collection was done using a combination of remote sensing and on-site surveys. The procedure varies depending on the size of the river (Figure 2) but generally one site and one flow condition can be completely surveyed in one day. Data were also collected on fish ecology and water quality.

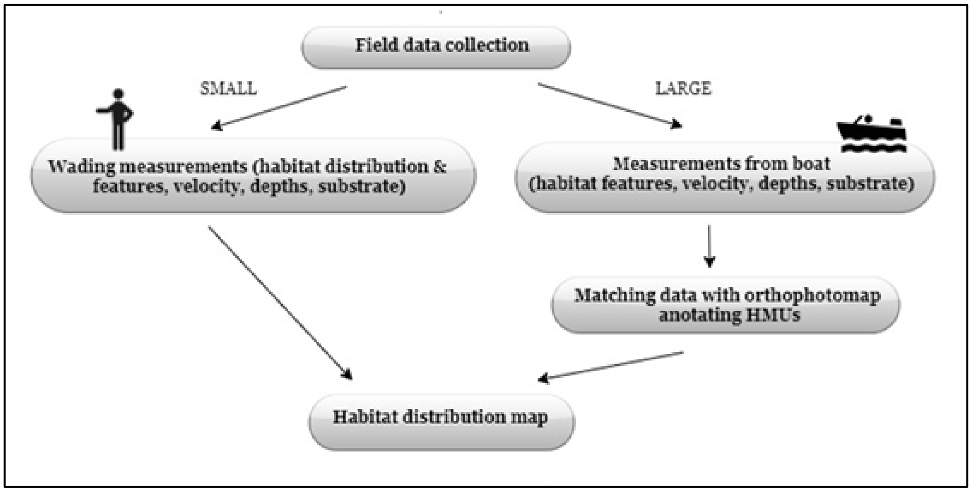


Figure 2: Habitat survey process for small and large rivers (modified from AMBER Field Manual).

While in the field, the team also assessed the present ecological condition of the study reaches. This is needed to assess the ecohydrological health in each river reach. It also helps identify if each of the individual reaches/sites for which E-Flows will be calculated is on a downward (negative, degrading condition), stable or positive (i.e. improving in condition) trajectory.

4.7 Hydrodynamic model development

Two numerical models were applied to the study reaches in order to simulate fish habitat variables under different flow conditions. Flow depth and velocity were modelled in two dimensions using River 2D model (Ghanem et al 1995). River 2D creates a digital representation of the river that can be used to simulate the movement of water through the river and predict how habitat factors change over time. Grain (substrate) sizes of sediments in different units of the study reaches were simulated using the SubDisMo model (Parasiewicz and Suska 2020), which uses depth and velocity data derived from the River 2D model and annotations of hydromorphological units according to MesoHabsim protocols. Both models were developed and calibrated using measured variables from the Seohara and Bareilly sites on the mainstem Ramganga River and the Jalalabad site on the Baigul River. They were further used to simulate hydraulics and substrate distributions at three flow conditions that have not been measured. It served as a foundation for desktop mapping of Hydromorphologic Units (see Appendix 3).

Since repeated mapping of remaining sites became impossible due to staffing and resource limitations, we used Digital Elevation Model generated from aerial imagery obtained with UAV on the upstream sites in Kosi River at Garampani and Boar River at Kaladhungi to serve as an input for River2D model. This is much less accurate option especially for the low flows, but since the water transparency (or lack of water at Kaladhungi) allowed for relatively good terrain model accuracy, we decided to try this option as the only alternative.

4.8 Flow-habitat modelling

The Sim-Stream Software by Rushing Rivers Institute (Parasiewicz et al 2006; www.mesoHABSIM.org) was applied to organize the collected habitat data and to calculate the suitable habitat area for each fish guild in different units of the study reaches and at different flow levels. Results on habitat suitability maps are presented in Appendix 4 in which every mapped unit is colour coded as unsuitable, suitable or optimal habitat (Figure 3).

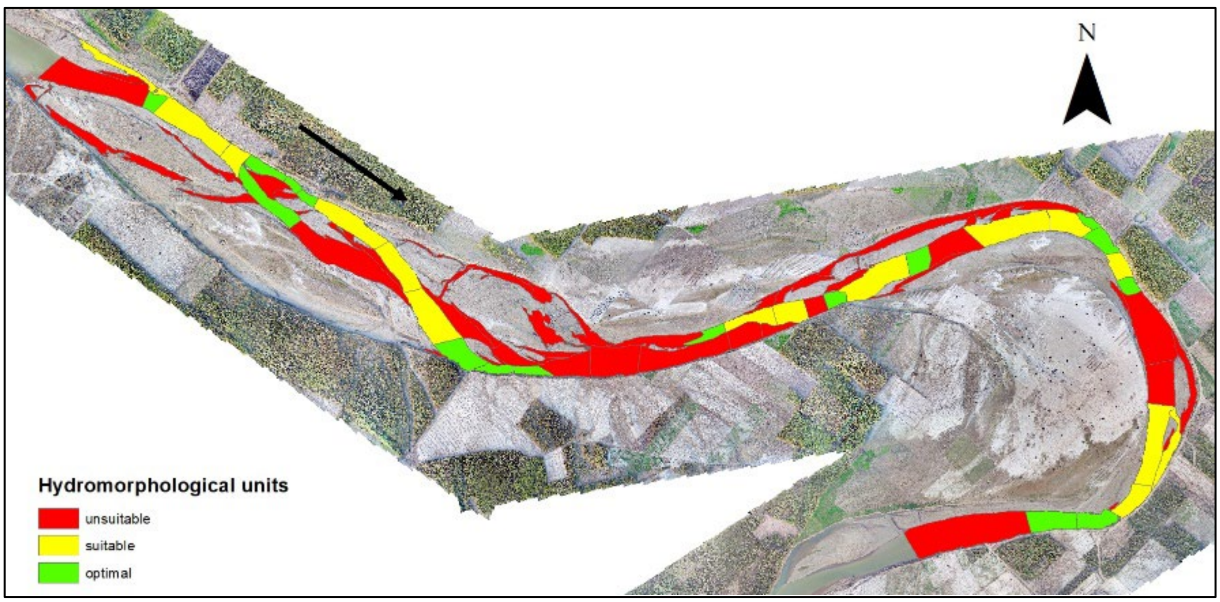


Figure 3: Habitat suitability maps for Rheophilic water column sand-gravel habitat use guild in Seohara site of Ramganga River at flow of 3 m^3/s (defined in pilot project 2020)

The results of simulations of suitable habitat areas for different fish guilds at different flow levels were then plotted to produce habitat rating curves (Appendix 5). The flow habitat rating curve for the fish **community** is developed by weighting the habitat area of each guild by its proportions. It is presented together with wetted area and **generic fish** habitat, which is the total habitat surface area used by the all the members of the fish community (Figure 4). This curve is applied to calculate habitat time series for past and future scenarios of flow.

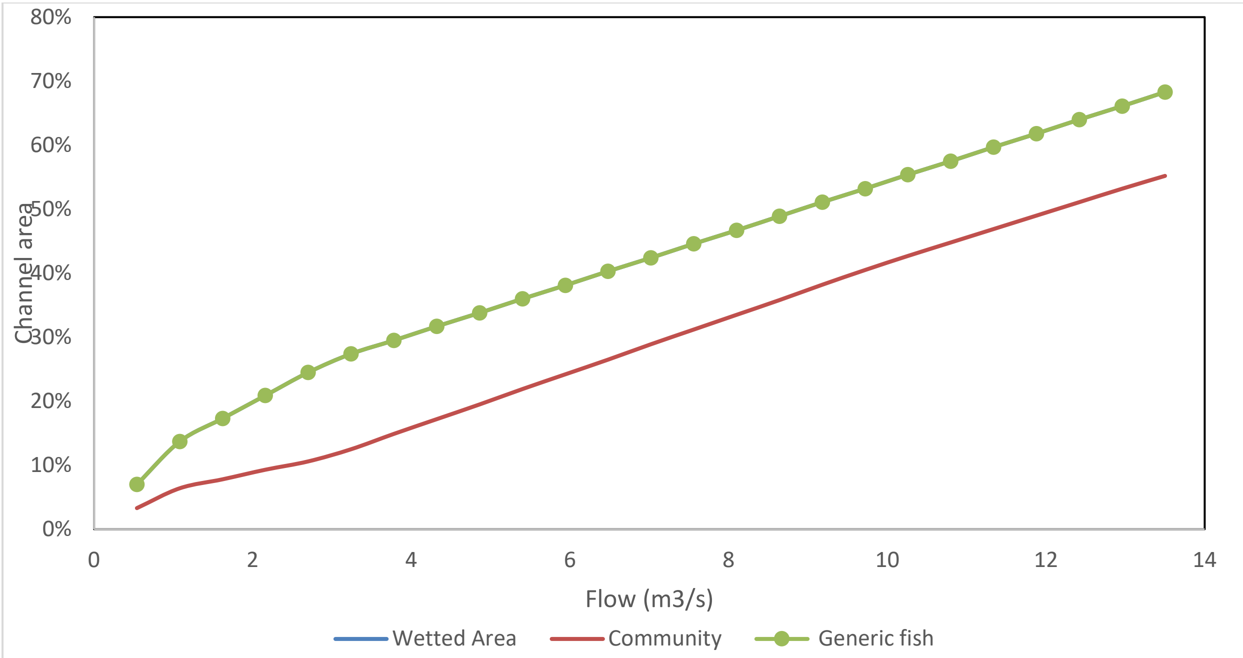


Figure 4: Habitat rating curves for fish community and Generic Fish Habitat at Seohara Site of Ramganga River

4.9 Establishment of E-Flow criteria

One of the most important underlying characteristics of any riverine environment is its continuous change over time due to the fluctuations of water flows. Since flow rates during different seasons create various habitat conditions, habitat availability is also in flux. Consequently, fauna is shaped by varying environments rather than by static conditions. To investigate the habitat availability and the flows that create them, the temporal patterns that occur in the time series were analysed.

The habitat time series is based on the amount of flow in the river recorded on any given day. With the help of the fish community rating curve, flows are evaluated for how much habitat they provide, and this value is plotted as a habitograph instead of flow value for every day in the record. The habitograph depicts fluctuation patterns of habitat occurring in the river over time. The adequacy of the available habitat for the survival of the fauna needs to be analysed with a reference habitograph of close to natural conditions. The assumption is that the native fish community is adapted to natural flow patterns. Following the theory of habitat templates, we also assume that this adaptation is oriented on the predictability of the events (Parasiewicz 2007ab, Poff and Ward 1990) and hence, conditions that occur rarely in nature create stress to aquatic fauna. For this reason, we observe frequency of habitat area occurrence as the basis for determining **habitat thresholds**, which specify a limit of conditions necessary to support the native fish community structure.

To assess the temporal patterns, the habitat time series was analysed using Uniform Continuous Under Threshold (UCUT) analysis, a habitat duration analysis method which observes the frequency of continuous events with low habitat availability and identifies rare and common habitat conditions associated with subsistence and habitat base flow conditions. Detail of this method is presented in Appendix 6:

Time Series Analysis. Four E-Flow thresholds were calculated for each study reach (see Ramganga pilot study report 2020 for biological justification):

- **habitat base flow** offers stable and sufficient living conditions for the fish community**;**
- **trigger flow** alerts for required management actions preventing subsistence conditions;
- **subsistence flow** provides short-term survival conditions for the fish community;
- **absolute Minimum** is the lowest flow on record and is used as a reference point and not a management objective.

In addition to E-Flow threshold values, the UCUT analysis specifies allowable and catastrophic durations of flow deficits at each level. The latter are equivalent to events with 10 years occurrence interval.

4.10 Extrapolating E-Flows to Macrohabitat types (MacHTs)

To offer E-Flows criteria for the MacHTs represented by the surveyed sites, the specific E-Flows values are divided by the Mean Annual Flow (MAF) for the site location. Such obtained index p-values can be used to compute E-Flows for any location within the basin for the investigated MacHTs using following formula (1):

$$\mathbf{Q_{ef,\,bk}} = \boldsymbol{p_b} \cdot \mathbf{Q_{MAF,k}} \quad \ldots\ldots(1)$$

Where: $Q_{ef,bk}$ = E-Flows for the bioperiod b at any given location k within the basin (m^3s^{-1})

p_b = tabulated value of habitat index obtained from the representative site study according to the bioperiod and MacHT. It is the E-Flow calculated for the representative site expressed as a proportion of Q_{MAF} at that site location,

$Q_{MAF,k}$ = mean annual flow at given location k (m^3s^{-1})

5 Process to identify macrohabitat types and Representative Sites

5.1 River macrohabitat types

Six river macrohabitat types (MacHT) were identified based on the final round of non-hierarchical clustering with the classification cut off of approximately 75% similarity. Detailed discussion on the process of identification of MacHTs is provided in Appendix 2. The types differentiated Himalayan Mountain and Foothill Transition zones, and the more human-impacted upper and lower Indo-Gangetic plains. The final six representative sites were the focus for all subsequent steps of the assessment.

Figure 5 represents the distribution of the clusters in the basin, which can be described as follows:

- **MacHT 1** - **Himalayan Foothills Streams**, on igneous rock high elevation and slope, first and second order streams with catchment area smaller than 3 000km^2.
- **MacHT 2** - **Transition Streams** are located in Himalayan geology, at lower elevation and slope, their stream order is up to 3 and catchment areas up to 12 000km^2.
- **MacHT 3 – Upper Gangetic Plains Second and Third Order Streams,** low elevation (~100 m) and slope, with catchment areas less than 15000km^2.
- **MacHT 4** – **Upper Gangetic Plains First Order Streams** with small catchment areas
- **MacHT 5** - **Low Gradient Large Catchment Rivers** of 1st to 4th stream order with catchment areas between 15 000 and 22 000 km^2. This is the mainstem of the Ramganga River upstream of Bareilly.
- **MacHT 6** – **Lower Mainstem Ramganga** with an even lower elevation, stream order 5 and catchment area above 22 000 km^2.

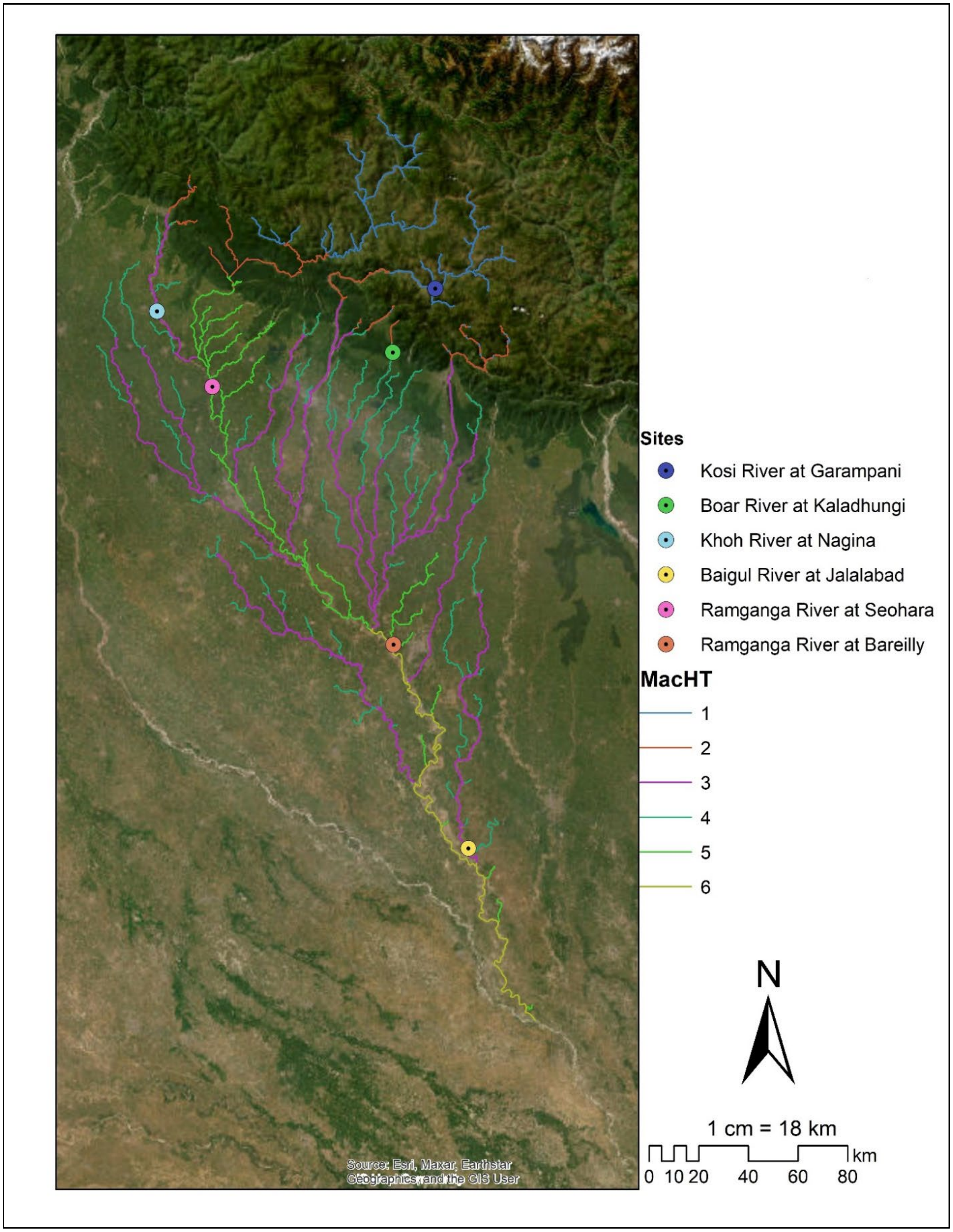


Figure 5: **Macrohabitat cluster distribution in Ramganga Basin with six representative E-Flows sites (MacHT)**

5.2 Description of the E-Flows sites

Table 1 presents the general features of the representative sites. They cover a wide range of circumstances occurring in Ramganga Basin. All the sites (with exception of site 2) are moderately impacted by human alteration.

Table 1: Key characteristics of selected reference sites

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
Location	**Garampani**	**Kaladhungi**	**Kaladhungi**	**Nagina**	**Jalalabad**	**Seohara**	**Bareilly**
River	**Kosi**	**Boar**	**Boar2**	**Khoh**	**Baigul**	**Ramganga**	**Ramganga**
MacHT	1	2	4	3	3	5	6
Drainage area	1207	10	10.64	736	2169	5099	17560
Elevation (m ASL)	922	440	406	237	144	212	163
Stream Order	3	1	1	2	2	4	5
Gradient (m/km)	32	16	1	1.2	1.1	0.8	0.6
Length (m)	800	350	1120	2144	2132	2000	2555
Channel Width (m)	100	30	60	250	50	130	270
Hydromorphology	straight	straight	braided	braided	meander-ing	meandering	meander-ing
Dominant sub-strate	cobble	cobble	gravel	sand	sand	sand	sand
MAF (m^3/s)	9	0.2	0.2	7.3	18.1	39.9	165

The HMU maps and corresponding summary of habitat hydraulics for the six sites are presented below.

5.2.1 Site 1: Kosi River at Garampani

This site is 800 m long and represents Macrohabitat type 1 (Himalayan Foothills Streams). A total of 19 units were distinguished and 131 hydraulic measurements were taken. The discharge measured at Suyalbari CWC site upstream of the representative site was 1.42m^3/s. As mentioned earlier, SWAT hydrological model was established and calibrated to develop near-natural and present-day scenarios of hydrological regime. Tabel 2 presents mean monthly flows obtained for Garampani site through the modelling process.

The Kosi River site at Garampani represents a high gradient stream with high velocities and coarse substrate (Figure 6). The variety of HMUs consists of cascades, rapids, riffles, runs, glides and two big pools (Figure 7). Substrate is dominated by boulders and gravel. There is a large extent of shallow margin habitat and some canopy shading.

Table 2: Mean monthly flows for the Site 1 simulated with SWAT model for 1975-2020 time series in Virgin and Present-Day scenarios.

Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Virgin flows (cms)	1.18	2.14	1.42	0.50	0.35	5.86	19.96	29.44	32.53	10.14	2.65	1.26
Mean Present flows (cms)	1.19	2.15	1.39	0.48	0.34	6.13	20.12	28.96	31.88	9.68	2.61	1.27

Figure 6: Kosi River site at Garampani

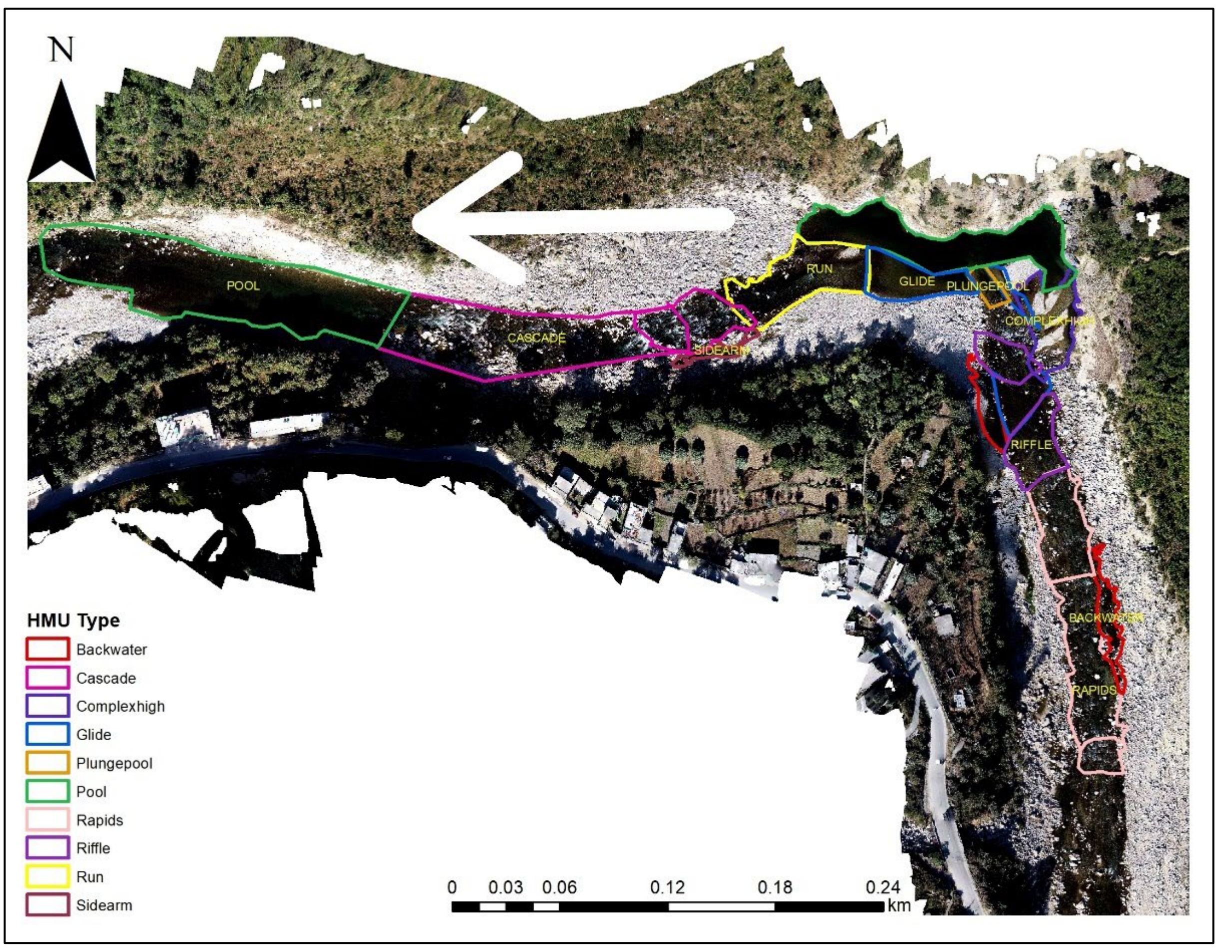


Figure 7: HMUs characteristic of the Kosi River at Site 1

Specific E-Flow objectives

The site is in a near-natural to minimally altered condition (A/B). The proposed objectives are to:

- Maintain a High Ecological Status (HES) in the reach and in all reaches of the same type showing similarly high to exceptional conservation value for biodiversity.
- Protect the natural pattern, timing and upper and lower range limits of low flows and high flows in all seasons and across years, with a particular focus on maintaining the pattern of near-natural low flows during the lean season and adequate flood flows (including for habitat complexity and channel maintenance).
- Maintain the present overall diversity of fish species and flow-habitat guilds/assemblages, the condition of the associated habitats, and key lifecycle requirements for all important bio periods.
- Ensure year-round connectivity with the network of mountain streams and rivers acting as key refuges from disturbance.
- Support any water needs of terrestrial wildlife.

In addition, the following objective(s) should be considered:

- Maintain excellent water quality, including the present water thermal regime, including for priority cool/cold water fish species.
- Mitigate the degree of alluvium mining (boulders and cobbles) and extent of channel hard engineering.
- Maintain flow levels to support local domestic water offtake(s).

5.2.2 Site 2: Boar River at Kaladhungi, Upstream of diversion

This site is 350 m long, located directly upstream of water diversion and represents Macrohabitat type 2 (Transition streams). A total of 14 HMUs were distinguished and depth, velocity and substrate were measured at 68 locations (Figure 8). Measured discharge was 1.7 m^3s^{-1}.

This site is of a mountainous stream character. Dominating HMUs are shallow riffle, run and glide, with stone and gravel substrate. Shores offer canopy cover shading and shallow margins (Figure 9).

Figure 8: Boar River upstream of diversion, at Site 2.

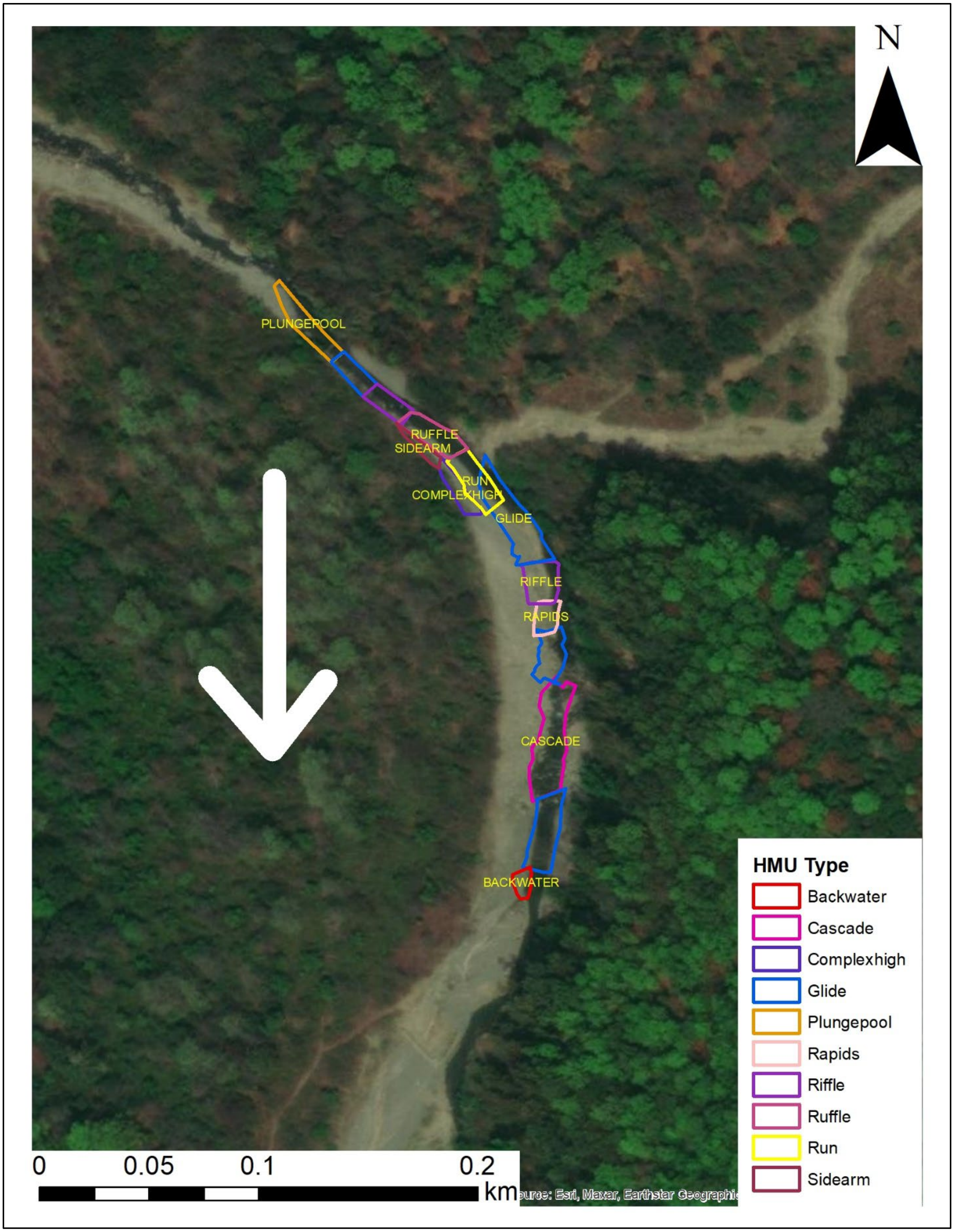


Figure 9: HMUs characteristic of the Boar River upstream of the flow diversion, at Kaladhungi-Site 2.

Table 3 presents mean monthly flow values for the Site 2

Table 3: Mean monthly flows for the Site 2 simulated with SWAT model for 1975-2020 time series in Virgin and Present Day scenarios

date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Virgin flows (cms)	0.022	0.024	0.014	0.006	0.009	0.168	0.798	0.714	0.481	0.071	0.013	0.013
Mean Present flows (cms)	0.025	0.026	0.015	0.006	0.010	0.209	0.826	0.717	0.471	0.059	0.011	0.014

Specific E-Flow objectives

The upper reach of this foothill transitional river type, above the existing irrigation diversion canal, is in a near-natural to minimally altered condition (A/B). Below the diversion, the reach is seasonally in a highly flow altered state (D) due to dewatering of the channel and stranding of the biota. The proposed objectives are to:

- Restore the natural pattern and timing of flows in all seasons, with a particular focus on reinstating flows during the lean season (months of dewatering), annually, and ensuring no periods of flow cessation or total instream habitat loss.
- Maintain a High Ecological Status (HES) in the remaining proportion of reaches of the same type in the basin that possess similarly high/exceptional conservation value for biodiversity, but which have negligible present-day diversion or abstraction of water.
- Maintain the present diversity of fish species and flow-habitat guilds/assemblages and the diversity of other high conservation value biota, and the condition of their associated habitats and lifecycle requirements, for all important bioperiods.
- Ensure year-round longitudinal, functional connectivity with the upstream mountain streams and lower plains rivers.
- Support the drinking water needs and riparian vegetation needs of priority terrestrial wildlife.

In addition, the following objective(s) should be considered:

- Maintain very good water quality, including the present water thermal, sediment and nutrient regimes.
- Maintain the very good condition of the riparian vegetation zone.

5.2.3 Site 3: Boar River at Kaladhungi, Downstream of diversion

This site is 1120 m long and represents Macrohabitat type 4 (Upper Gangetic Plains First Order Streams). The site was almost dry during the survey (Figure 10). Nevertheless, an attempt of mapping HMUs following aerial imageries and water traces in the field was undertaken. At low flows it is expected to consist of runs, riffles and pool (Figure 11). Thirty HMUs were distinguished. No hydraulic measurements could be taken. Specific E-Flow objectives have been considered the same as site 2.

Table 4 presents mean monthly flow values for the Site 3

Table 4: Mean monthly flows for the Site 3 simulated with SWAT model for 1975-2020 time series in Virgin and Present Day scenarios

date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Virgin flows (cms)	0.022	0.024	0.014	0.006	0.009	0.168	0.798	0.714	0.481	0.071	0.013	0.013
Mean Present flows (cms)	0.025	0.026	0.015	0.006	0.010	0.209	0.826	0.717	0.471	0.059	0.011	0.014

Figure 10: Boar River downstream of diversion, at Kaladhungi-Site 3

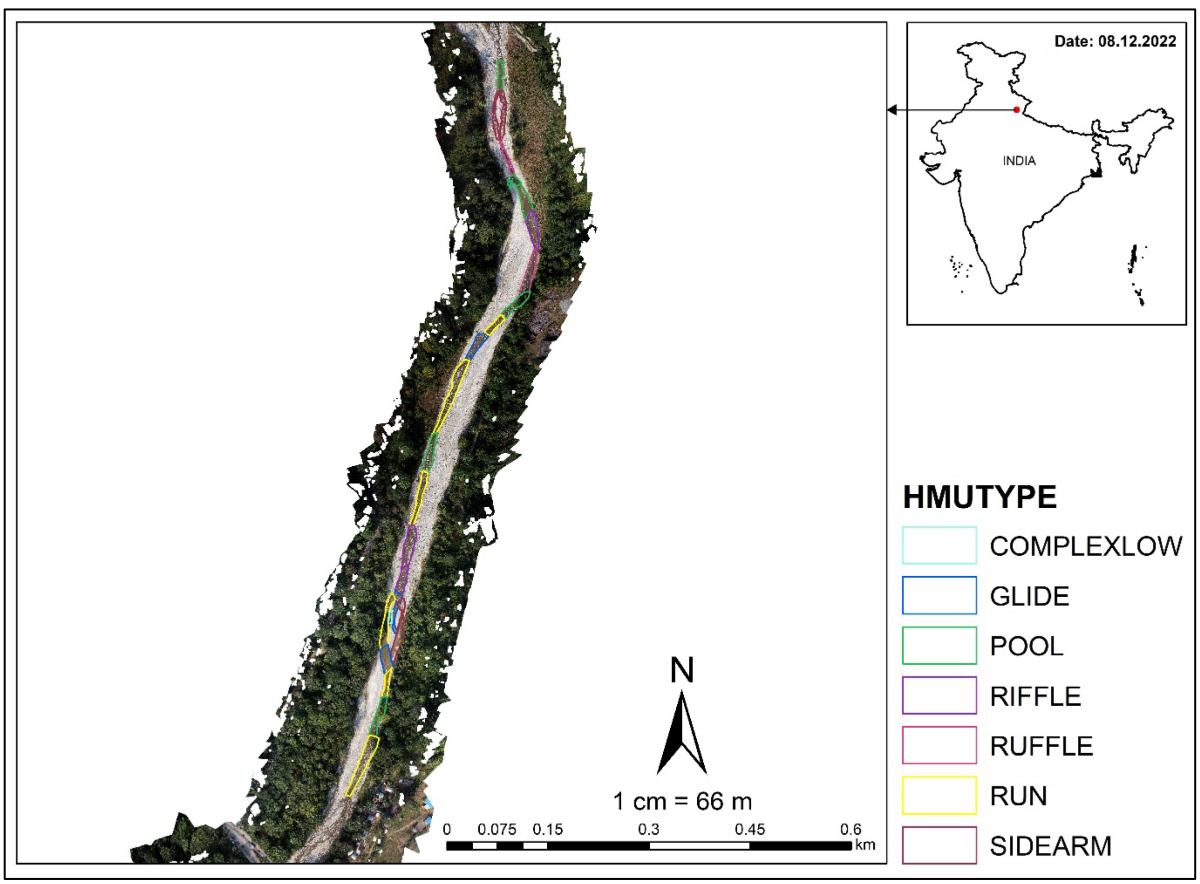


Figure 11: HMUs characteristic of the Boar River downstream of the flow diversion, at Site 3

5.2.4 Site 4: Khoh River at Nagina

This site is 2144 m long and has been assigned to MacroHabitat type 3 (**Upper Gangetic Plains Second and Third Order Streams**). A total of 40 HMUs were distinguished and 95 locations were sampled for hydraulics (Figure 12). This site has a braided character and is dominated by sandy substrate. Intensive farming and sand mining operations occur along the shores. The HMU structure is dominated by complex units with high and low numbers of channels. Runs, sidearms, glides, lobes and pools are also common (Figure 13).

Figure 12: Khoh River at Nagina

Table 5 presents mean monthly flow values for the Site 4

Table 5: Mean monthly flows for the Site 4 simulated with SWAT model for 1975-2020 time series in Virgin and Present Day scenarios

Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Virgin flows (cms)	0.856	1.278	0.746	0.264	0.159	2.465	26.084	35.517	20.004	2.062	0.819	0.656
Mean Present flows (cms)	0.859	1.301	0.778	0.251	0.151	2.553	23.991	35.051	18.847	1.922	0.762	0.611

Specific E-Flow objectives

The site is in a moderately altered condition (C). The proposed objectives are to:

- Maintain Good Ecological Status (GES) at the site and in similar reaches elsewhere in the basin.
- Protect the natural pattern, timing and upper and lower range limits of low flows and high flows in all seasons, with a particular focus on maintaining lean season flows.
- Maintain the present diversity of fish species and flow-habitat guilds/assemblages, the condition of the associated habitats, and key lifecycle requirements for all important bioperiods.

In addition, the following objective(s) should be considered:

- Recover the channel and bed morphology of the site, which have been significantly detrimentally altered by intensive sand mining.
- Maintain the flow levels needed for subsistence crop cultivation within the river channel, and on the banks and adjoining floodplain.

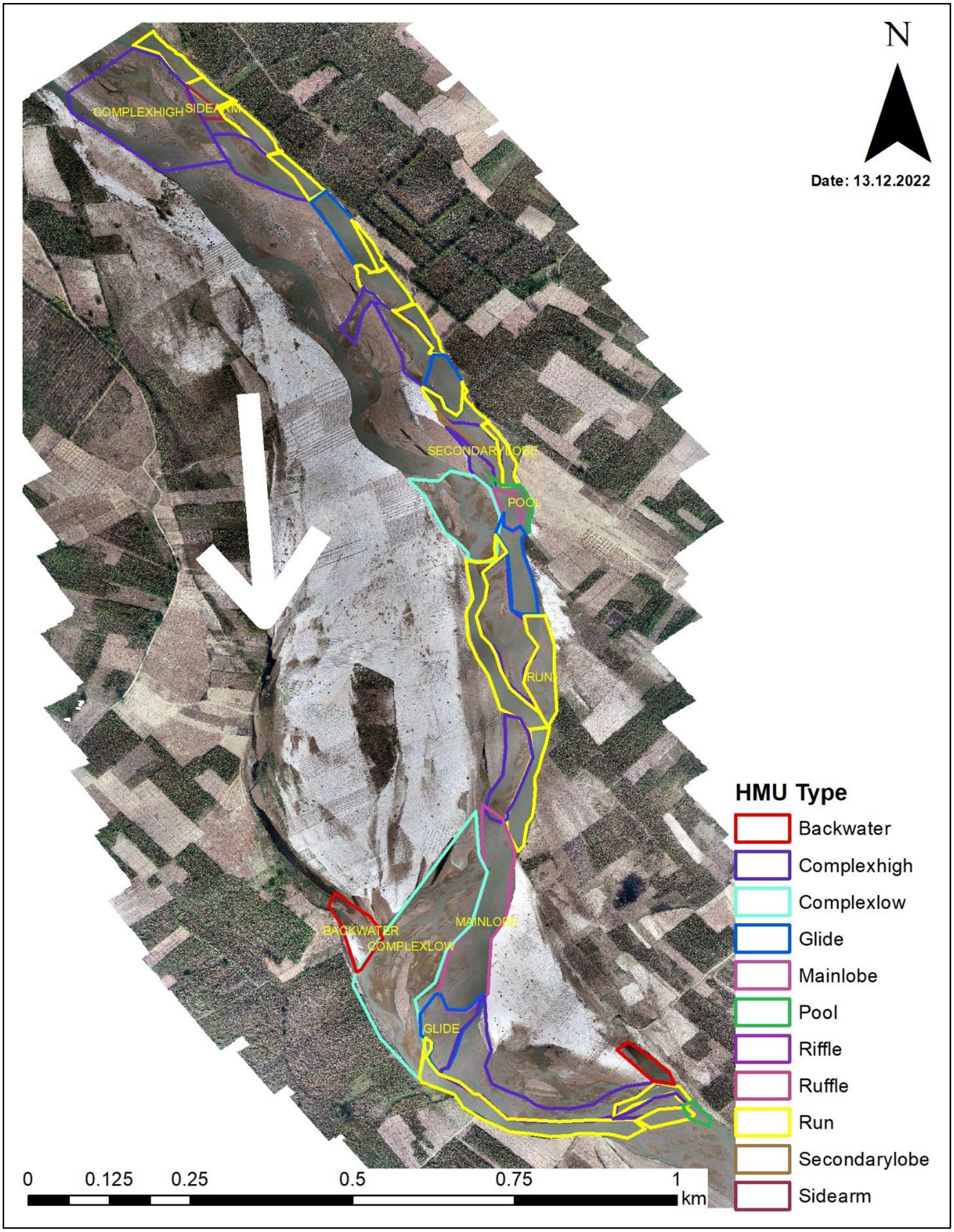


Figure 13: HMUs characteristic of the Khoh River Site 4

5.2.5 Site 5: Baigul River at Jalalabad

This site is 2132 m long and represents Macrohabitat 3 (Upper Gangetic Plains Second and Third Order Streams) (Figure 14). The survey flow was 8 m^3s^{-1}.

Figure 14: Baigul River at Jalalabad

This site is a single threaded low gradient channel, which begins with shallower straight section followed by a deeper bend, where depths reached 3 m (Figure 15). This site was measured with ADCP allowing to model and present spatially specific distribution of hydraulic patterns. Velocities were moderate with some higher velocity areas after the bend (Figure 16). The substrate is mostly psammal (sand) and pelal (mud). The upper section is rich in submerged vegetation. At 8 m^3s^{-1}, the hydromorphic units are dominated by glides and pools, with some backwaters and pools (Figure 17). The shores are covered in farm fields reaching almost to the river channel.

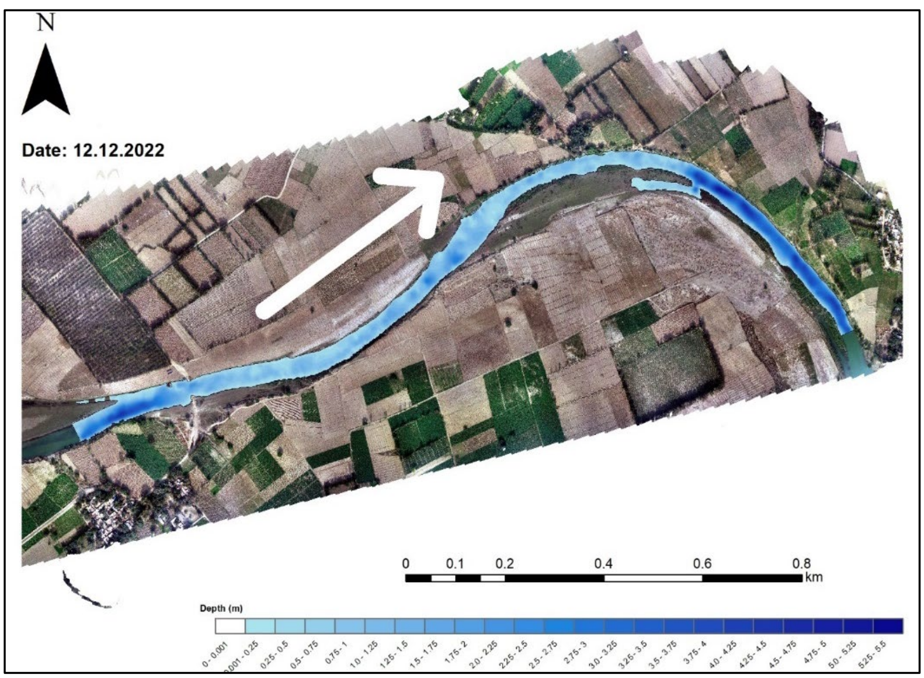


Figure 15: Bathymetry of the Baigul River reach at Site 5.

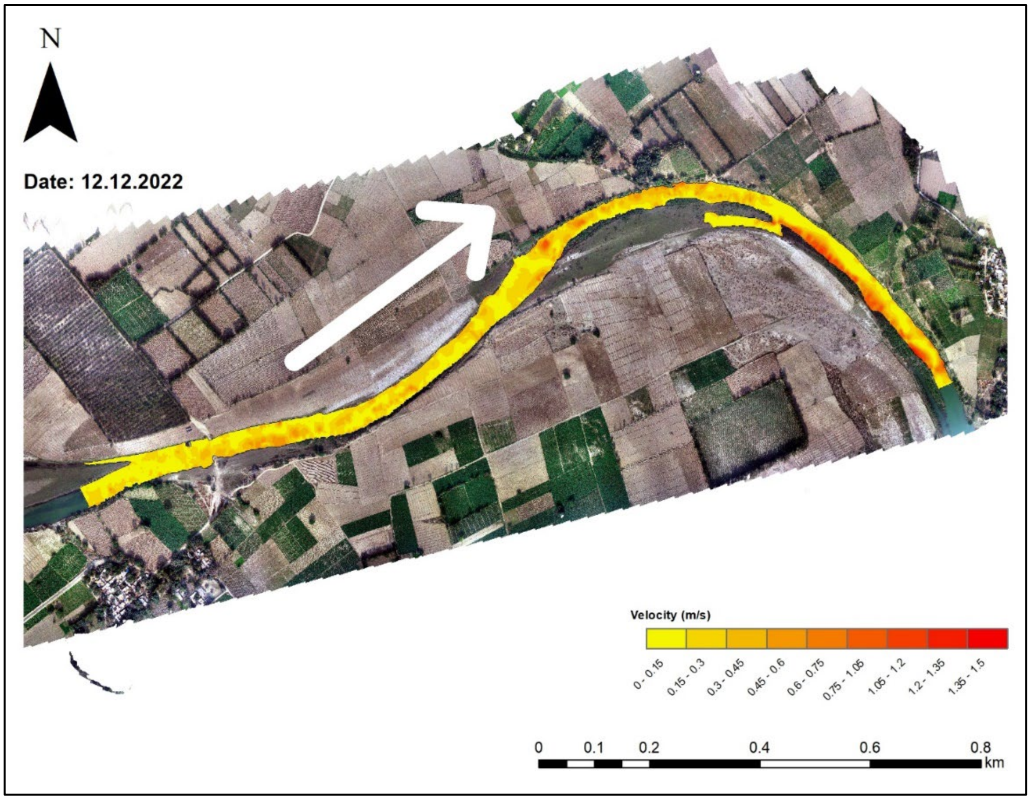


Figure 16: Velocity distribution of the Baigul River reach at Site 5.

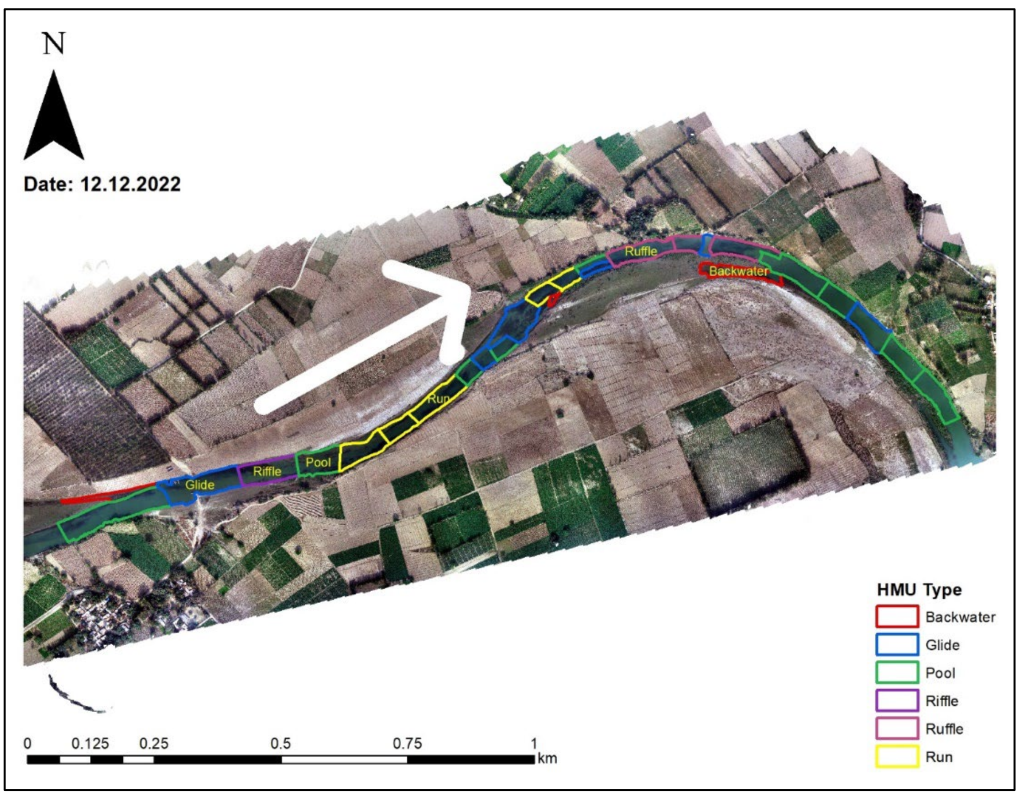


Figure 17: HMU map of the Baigul River at Site 5.

Table 6 presents the modelled mean monthly flows at the Jalalabad site

Table 6: Mean monthly flows for the Site 5 simulated with SWAT model for 1975-2020 time series in Virgin and Present Day scenarios.

date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Virgi	0.69	0.75	0.37	0.20	0.21	9.62	61.17	69.51	58.21	12.20	1.85	0.96
Mean Pres	0.51	0.40	0.14	0.14	0.23	8.58	51.46	58.21	53.69	12.47	1.74	0.78

Specific E-Flow objectives

The site is in a moderately modified condition (C). The objectives are to:

- Recover and maintain Good Ecological Status (GES) by maintaining the pattern and timing of floods, high flows and low flows within and between years.
- Maintain the expected diversity of native fish species and flow-habitat guilds/assemblages, including key fish species, the condition of the associated habitats, and key lifecycle requirements for all important bioperiods.
- Maintain the flows needed to support native macrophyte species populations.
- Maintain adequate flows to support waterbird habitats and life cycles.

In addition, the following objective(s) should be considered:

- Maintain the flow levels needed, at the appropriate times of the year, to support livelihoods, including subsistence crop cultivation on the adjoining floodplains and river banks, as well as ferry navigation.
- Maintain or improve water quality and address local pollution problems.
- Maintain and improve channel morphology and sediment transport (reduce incision risk).
- Manage non-native species.

5.2.6 Site 6: Ramganga River at Seohara

This site is 2000 m long and represents Macrohabitat 5 (Low gradient large catchment streams) (Figure 18). The river flow during survey was 14.34 m^3s^{-1}.

Figure 18: Ramganga River at Seohara

It is a low gradient site and includes a large U-shaped bend and straight channel with many sand bars and backwaters. The river is wide and shallow with depths exceeding 1 m downstream of the bend (Figure 19). In contrast the velocities are rather diverse, reaching in places 1 ms^{-1} (Figure 20) The sub-strate is mostly sandy clay. Shallow margins offer good nursery habitat. Some undercut banks can be observed downstream of the bend, which is dominated by a main lobe. Glide and run are dominating HMUs. The shores are covered in agricultural fields reaching almost to the river channel (Figure 21).

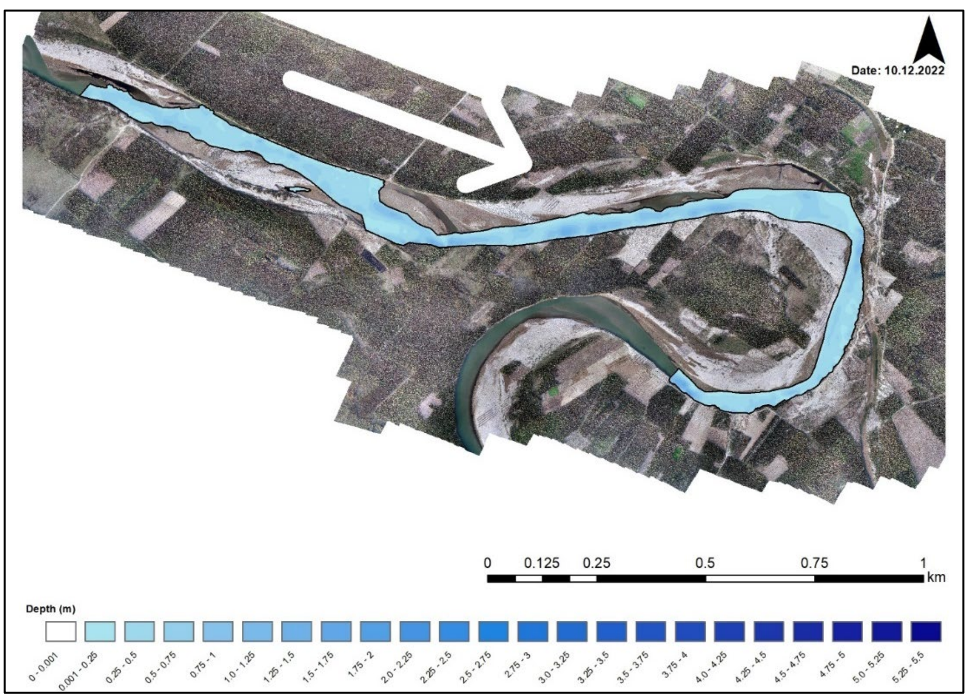


Figure 19: Bathymetry of the Ramganga River reach at Site 6.

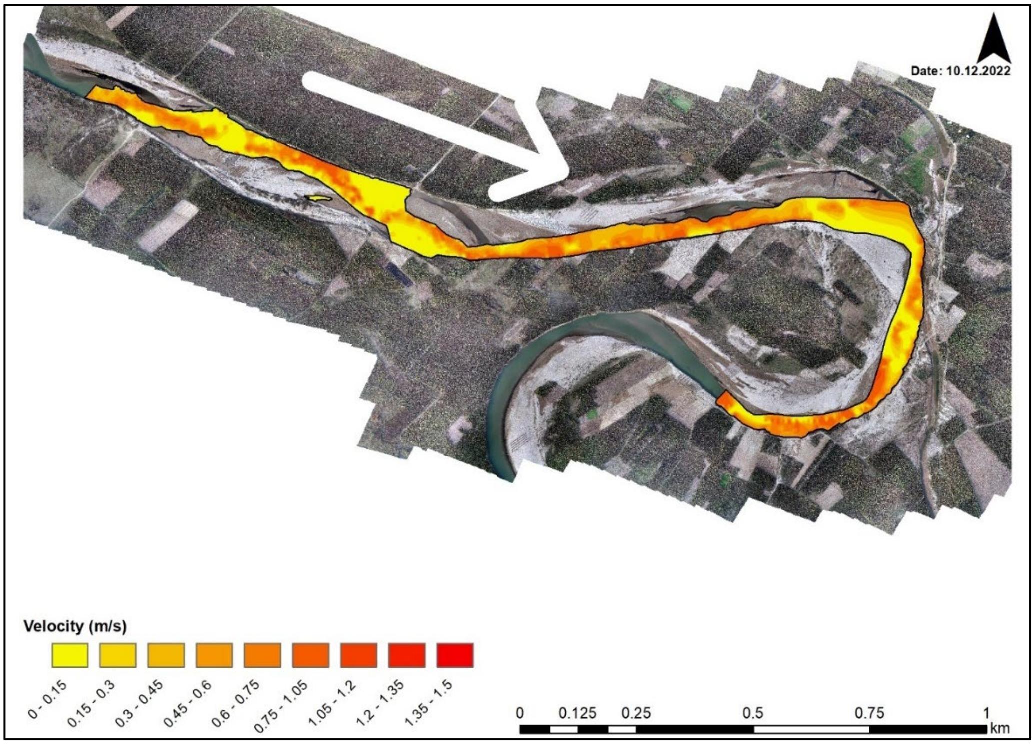


Figure 20: Velocity distribution of the Ramganga River reach at Site 6.

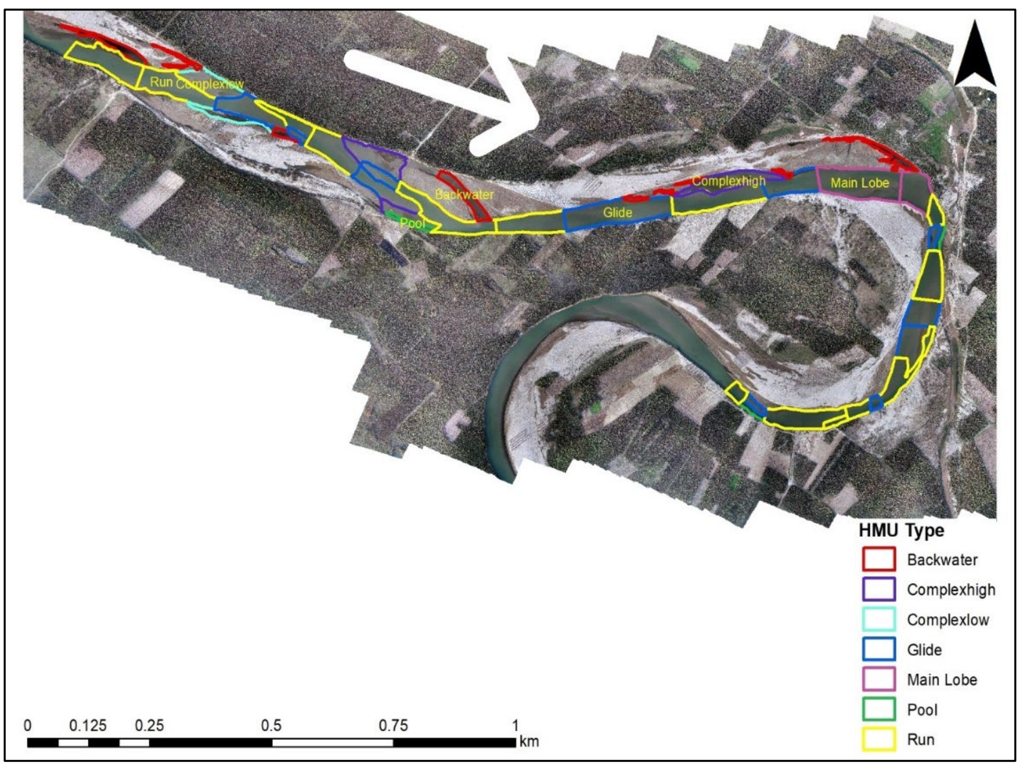


Figure 21: HMUs characteristic of the Ramganga River reach at Site 6.

Table 7: Mean monthly flows for the Site 6 simulated with SWAT model for 1975-2020 time series in Virgin and Present Day scenarios.

date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Virgin flows (cms)2	13.17	11.27	5.39	1.75	0.63	11.08	98.37	156.27	114.03	29.28	19.03	15.75
Mean Present flows (cms)	3.13	3.48	1.73	0.41	0.23	6.00	57.02	87.55	51.72	7.57	3.33	2.84

Specific E-Flow objectives

The site is in a moderately to highly modified condition (C-D). The presence of the upstream barrage is a significant source of alteration of river hydrological regime, morphology and sediment transport, and system connectivity. The proposed flow-related objectives are to:

- Recover and maintain GES by maintaining the pattern and timing of floods, high flows and low flows within and between years.
- Support the expected diversity of native fish species and flow-habitat guilds/assemblages, including any key fish species, the condition of the associated habitats, and key lifecycle requirements for all important bioperiods.

In addition, the following objective(s) should be considered:

- Maintain or improve water quality.
- Maintain and improve reach morphology and sediment transport (reduce incision risk, probably due to upstream barrage).

5.2.7 Site 7: Ramganga River at Bareilly

This site is 2555 m long and represents Macrohabitat 6 (Lower Mainstem Ramganga). The river flow during the survey was 57.2 m^3s^{-1} (Figure 22).

Figure 22: Ramganga River at Bareily

This is the largest of mapped sites and covers a large bend section. It is relatively deep with areas deeper than 2 m, with shallow margins along the convex shore of the right bank (Figure 23). The flow velocities frequently exceed 1 ms^{-1}, with a large proportion of slow sections in the shallows (Figure 24). Substrate is mostly sand and clay. No submerged vegetation was observed. The right shore and downstream section are characterized by numerous sand ripples creating lobes. Some undercut banks along the concave left shore in the downstream part of the site offer attractive cover for fish. HMUs consist of runs, glides and lobes (Figure 25).

Table 8: Mean monthly flows for the Site 7 simulated with SWAT model for 1975-2020 time series in Virgin and Present Day scenarios.

date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Virgin flows (cms)	22.93	25.13	11.71	3.09	1.57	79.59	502.80	674.47	496.07	96.36	29.09	23.70
Mean Present flows (cms)	47.01	66.44	55.31	53.42	6.93	220.66	660.81	783.42	617.38	71.98	13.79	58.54

Specific E-Flow objectives

The site is in a moderately modified condition (C). The proposed flow-related objectives are to:

- Recover and maintain GES by maintaining the pattern and timing of floods, high flows and low flows within and between years.
- Support the expected diversity of native fish species and flow-habitat guilds/assemblages, including key species for the local fishery, the condition of the associated habitats, and key lifecycle requirements for all important bioperiods.
- Maintain adequate flows to support waterbird habitats and life cycles.

In addition, the following objective(s) should be considered:

- Maintain the flow levels needed, at the appropriate times of year, to support subsistence crop cultivation in the riparian floodplain areas, on the banks and on in-channel sand bars.
- Improve water quality.
- Restore a more natural, dynamic channel morphology and maintain key habitats (e.g. instream river dune features)
- Manage non-native fish species.

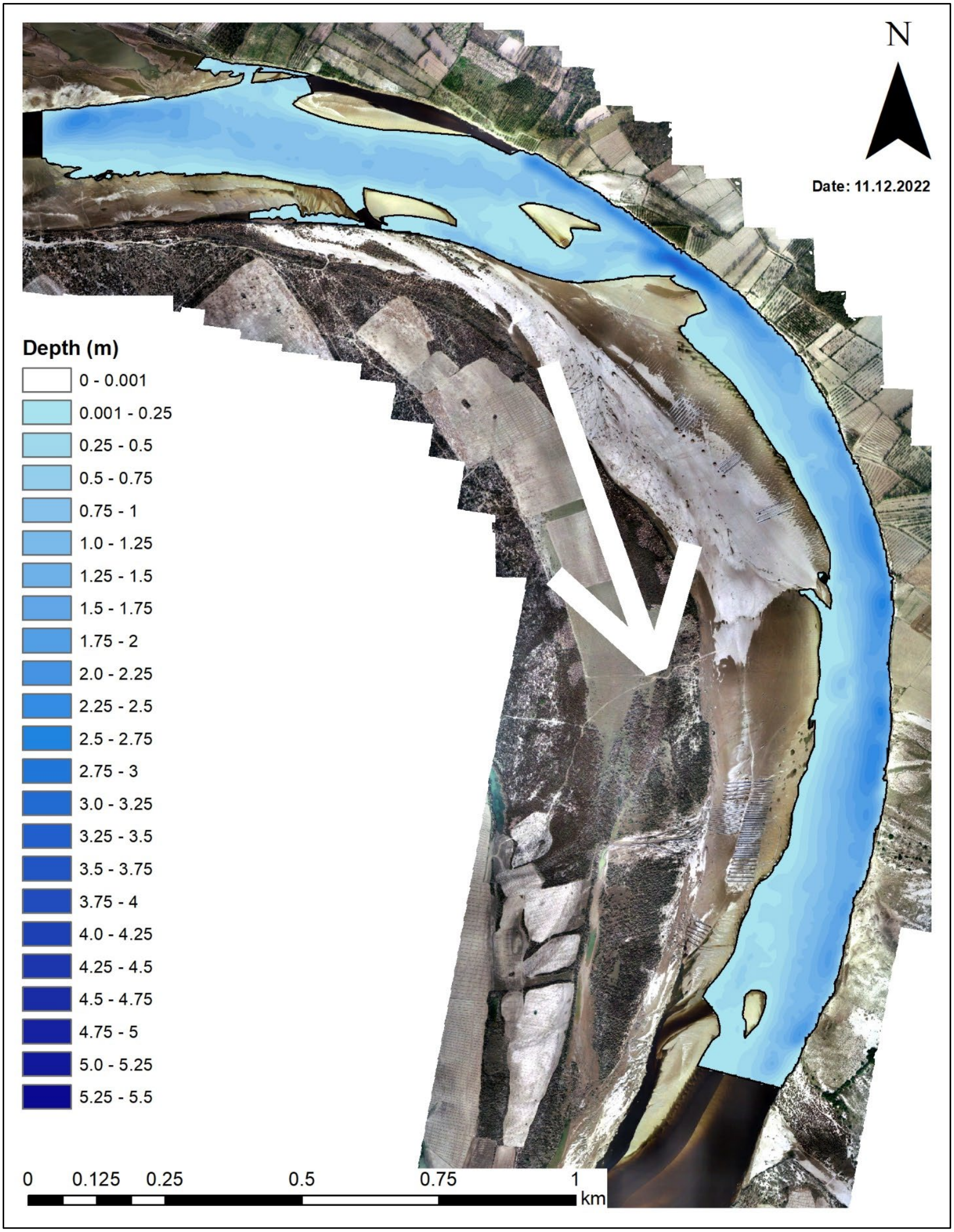


Figure 23: Depth distribution of the Ramganga River reach at Site 7

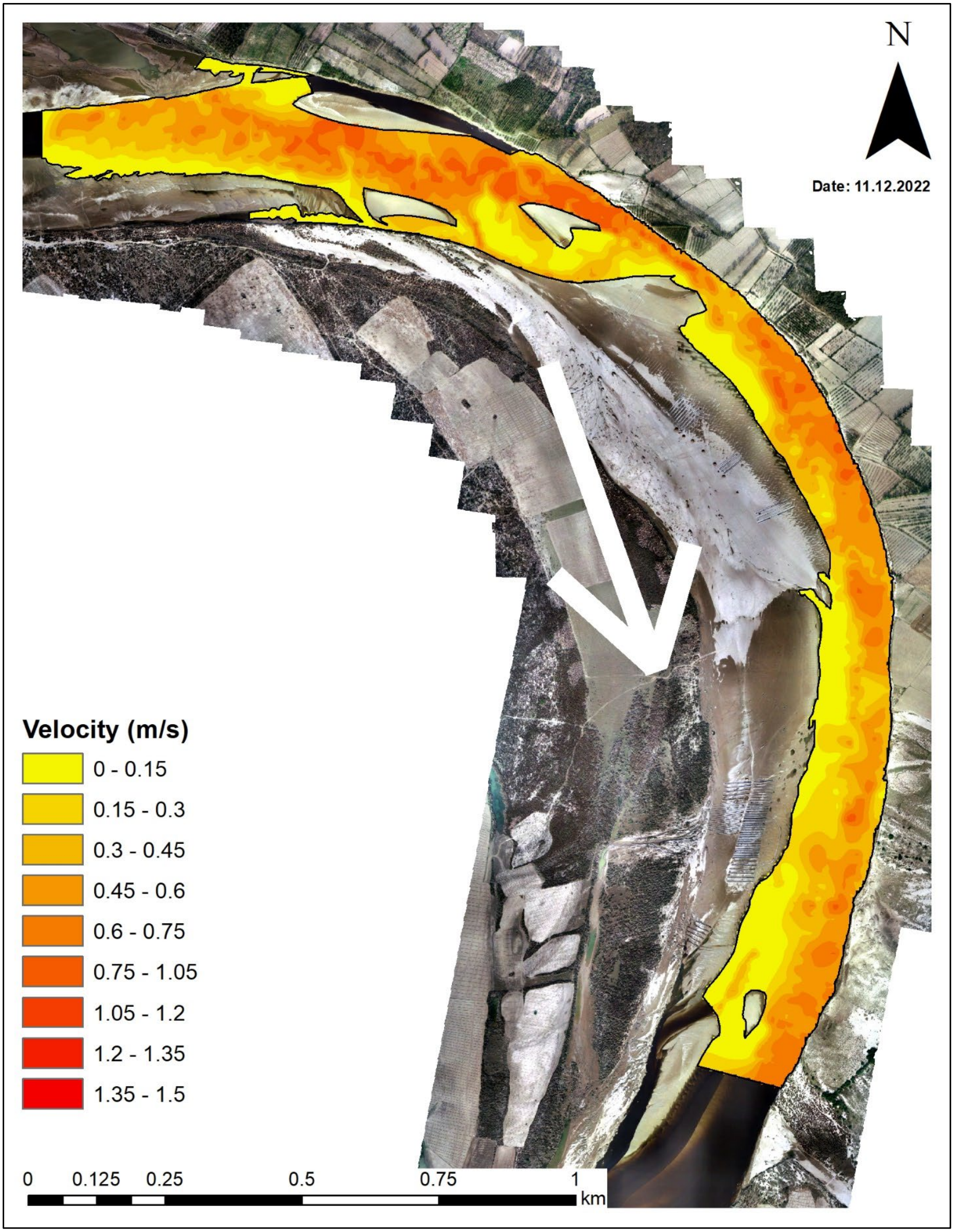


Figure 24: Velocity distribution of the Ramganga River reach at Site 7

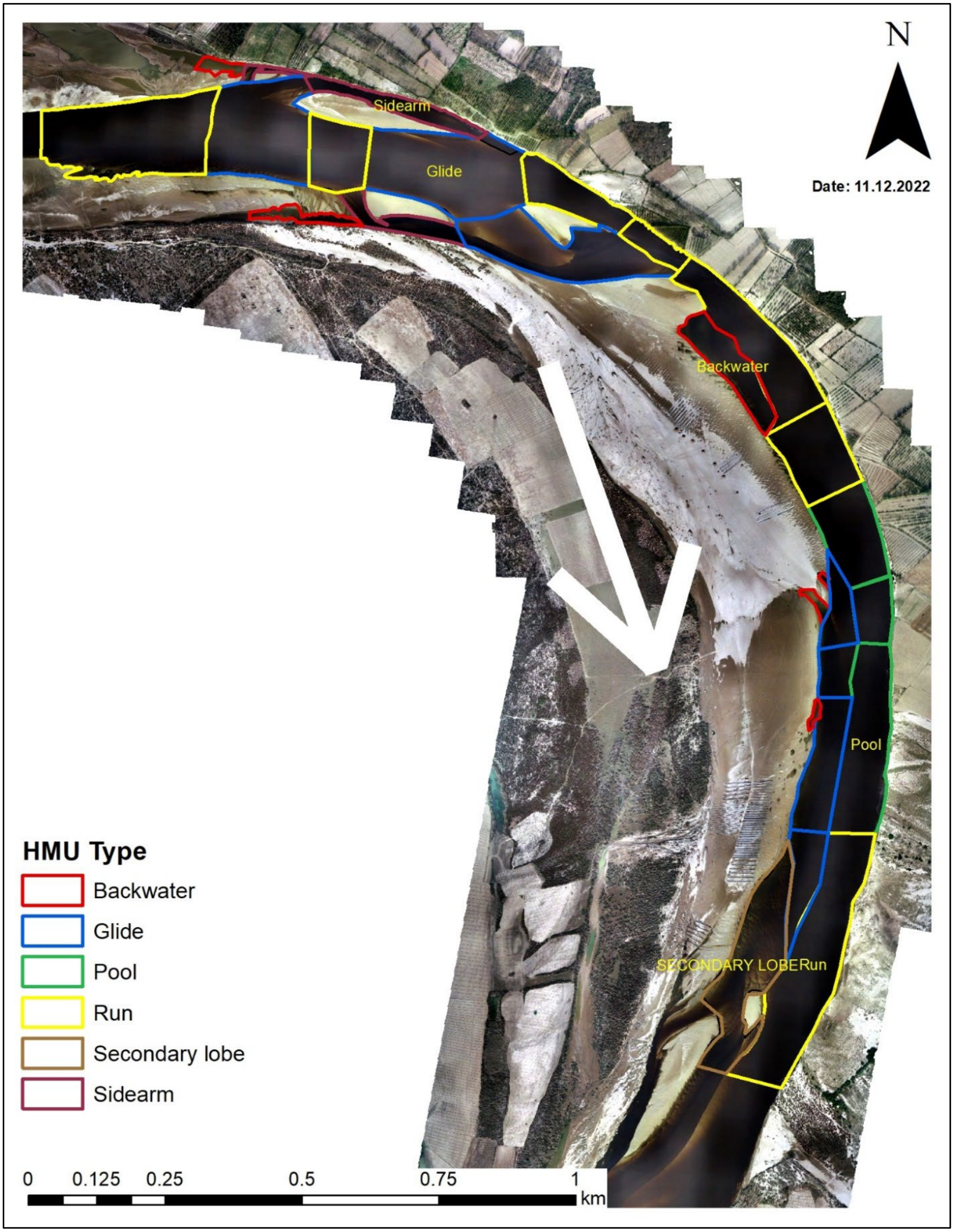


Figure 25: HMUs characteristic of the Ramganga River reach at Site 7

6 Ecological features and conditions of the E-Flow sites

6.1 Fish assemblage guilds and habitats preference

Indian fish biologists in the E-Flows Assessment Task Group suggested following Habitat Use Guilds (HUGs), modified from Europe, for Ramganga River Basin.

1) *Highly rheophilic, intolerant species* Pollution-tolerant, rheophilic, and/or lithophilic species are included in this guild. This guild necessitates a high-water velocity, a gravel bottom substrate, and interstitial space, as well as a low water trophy and temperature and high oxygen concentrations. Shelter and longitudinal connection are required for the species listed.

2) *Rheophilic benthic species, preferring sandy-gravel bottom substrate* All lithophilic and omnivorous species, independent of other assignments, are excluded from the guild, which consists only of rheophilic species foraging at the river's bottom. The preferences of this guild for habitat features are identical to those of the preceding guild. Furthermore, these species necessitate greater depth, the presence of rheophilic macrophytes and mosses, and habitat stability.

3) *Rheophilic water column species, preferring sandy-gravel bottom substrate.* The guild is made up of species that live in the open water column of fast-moving rivers with a sandy-gravel bottom. This guild has comparable preferences to the ones listed above, and it benefits from a bit more depth and a slower velocity. This guild has permissive water quality requirements, although these species need gravel regions and interstitial gaps for spawning, as well as cover and habitat stability.

4) *Limnophilic benthic species of moderate tolerance.* Except for those that are rheophilic, litophilic, phytophilic, or omnivorous, this guild consists of fish that like to live in slow moving, motionless, or stagnant water. This guild is found in lentic habitats with slow moving water, deep depths, and soft sediment on the bottom. It requires nothing in the way of water quality and habitat preservation.

5) *Limnophilic water column species of moderate tolerance.* Species that are not intolerant, not benthic, not rheophilic, and not phytophilic are included in this guild. Soft bottom sediments, macrophytes, and floodplain water bodies are all linked with this category. It is unaffected by habitat fragmentation and vulnerability.

6) *Intolerant, water column.* Pollution-intolerant species and non-benthic species make up this guild. This guild requires good water quality, a cool environment, cover, and long-term connectedness. It also requires moderate water velocity and coarse sediment, and it is sensitive to sand and mud variations in composition.

7) *Intolerant, rheophilic benthic species, preferring detritus or pelal bottom substrate.* Lamprey species have unique biology and habitat needs; hence this guild is made up of them. Detritivore's larvae live in shallow places. Some are also long-distance migrants with a parasitic adult phase in the water. Adults differ greatly in feeding strategy, as parasitic forms (typically marine) or do not feed (resorbed alimentary track) as a short life stage, feeding habitats in rivers are particular for detritivorous larval stadiums. This guild prefers shallow margins or backwaters with more lentic conditions, as well as moderate to high water velocity It re-

quires a muddy or detritus-based substrate, as well as high water quality and oxygen. This species is sensitive to habitat changes, particularly changes in water depth and substrate composition, and is reliant on natural hydromorphologic conditions. Habitat fragmentation is also a concern for it.

8) *Limnophilic lithophilic species of moderate tolerance.* lithophilic organisms that are neither very tolerant nor intolerant make up this guild. They're neither benthic, rheophilic, or phytophilic, either. This guild is linked to coarse bottom substrate, low water velocity, and greater depth. It necessitates some form of shelter, particularly woody detritus. River fragmentation and habitat instability are also major concerns for this guild.

9) *Limnophilic phytophilic species of moderate tolerance.* Phytophilic species that aren't tolerant, rheophilic, or lithophilic are included in this guild. This guild favours lentic settings with aquatic vegetation, slow water velocity, deep water, and soft bottom sediment. It can withstand higher water temperatures, decreased oxygen levels, and increased water trophy. Although the guild is less sensitive to disruptions in longitudinal river continuity, it is heavily reliant on floodplain waterbodies, therefore lateral connectivity is critical.

10) *Benthic species of moderate tolerance.* The guild is made up of non-tolerant benthic organisms. Medium water velocity and depth, as well as bottom habitats, are related with this guild. It favours coarse substrate and is quite vulnerable to predators. It has minimal water quality and habitat continuity needs, although it does require stable habitat conditions.

11) *Generalists – tolerant species.* There are only a few species in this guild that are widely distributed and have a high tolerance for habitat alteration. This guild has no evident preferences for habitat conditions. It can live in lentic and moderately lotic environments, but prefers deeper water and the presence of aquatic vegetation. Changes in substrate composition towards soft bottom sediments have little effect. This guild can withstand high water trophy, hot temperatures, and low oxygen levels. It is unaffected by breaks in longitudinal and lateral river continuity, as well as unstable habitat conditions.

Box.1: Description of HUG according to riverine macrohabitat typology

According to the opinion of biologists in the E-Flow Assessment Task Group, a ranking system of the HUGs abundance has been developed for each MacHT (Table 9).

Table 9: Abundance Ranking of HUGs based on the selected representative sites.

River	Kosi	Boar	Boar2	Koh 4	Baig 3	Ramg 3ga	Ramganga2
Site location	Garampani	Khaladhun	Khaladhun	Nagina	Jallalabad	Seohara	Braeily
Guild Rearing and Growth							
Highly rheophilic, intolerant species	1	11	11	3	11	0	11
Rheophilic benthic species, preferring sandy-gravel bottom substrate	2	1	1	10	7	9	8
Rheophilic water column species, preferring sandy-gravel bottom substrate	3	2	2	11	8	10	7
Limnophilic benthic species of moderate tolerance	7	5	5	7	2	4	2
Limnophilic water column species of moderate tolerance	8	6	6	2	4	2	4
Intolerant, water column species	5	9	9	5	9	7	9
Intolerant, rheophilic benthic species, preferring detritus or pelal bottom substrate	4	10	10	6	10	5	10
Limnophilic lithophilic species of moderate tolerance	6	4	4	1	6	8	6
Limnophilic phytophilic species of moderate tolerance	10	3	3	8	5	6	5
Benthic species of moderate tolerance	9	7	7	9	3	3	3
Generalists - tolerant species	11	8	8	4	1	1	1

Fish observations and expert assessment of the share of HUGs in the fish community are used for calculating the expected habitat proportions (Bain and Meixler 2008). The expected proportions of the guilds in the community are presented in Figure 26). The fish community of MacHT 1 (Kosi River) is dominated by rheophilic fish guilds (> 70%). Highly rheophilic intolerant species make up the largest proportion (>30%), followed by rheophilic benthic and water column species. In MacHT 2 and 3, rheophilic species still dominate, but highly reophylic intolerant species are replaced by rheophilic benthic and water column species. Since the two sites in Kaladhungi are very close to each other they were predicted to have identical communities despite morphological differences. Therefore, the species ranking for MacHT 2 and 4 needs to be verified. Among other guilds, limnophilic, phythophylic and lithophilic dominate. In MacHT 3 (Khoh River), the latter two guilds dominate, followed by limnophilic water column moderately tolerant species. This is the first MacHT without a large proportion of rheophilic species. The community composition is different from the one of MacHT 4, which is much closer to the lower portions of the basin. Fish community structures of MacHT 3 (Baigul River), 5 and 6 are very similar, greatly dominated by generalist species (>30%), with larger proportions of limnophilic benthic and water column species.

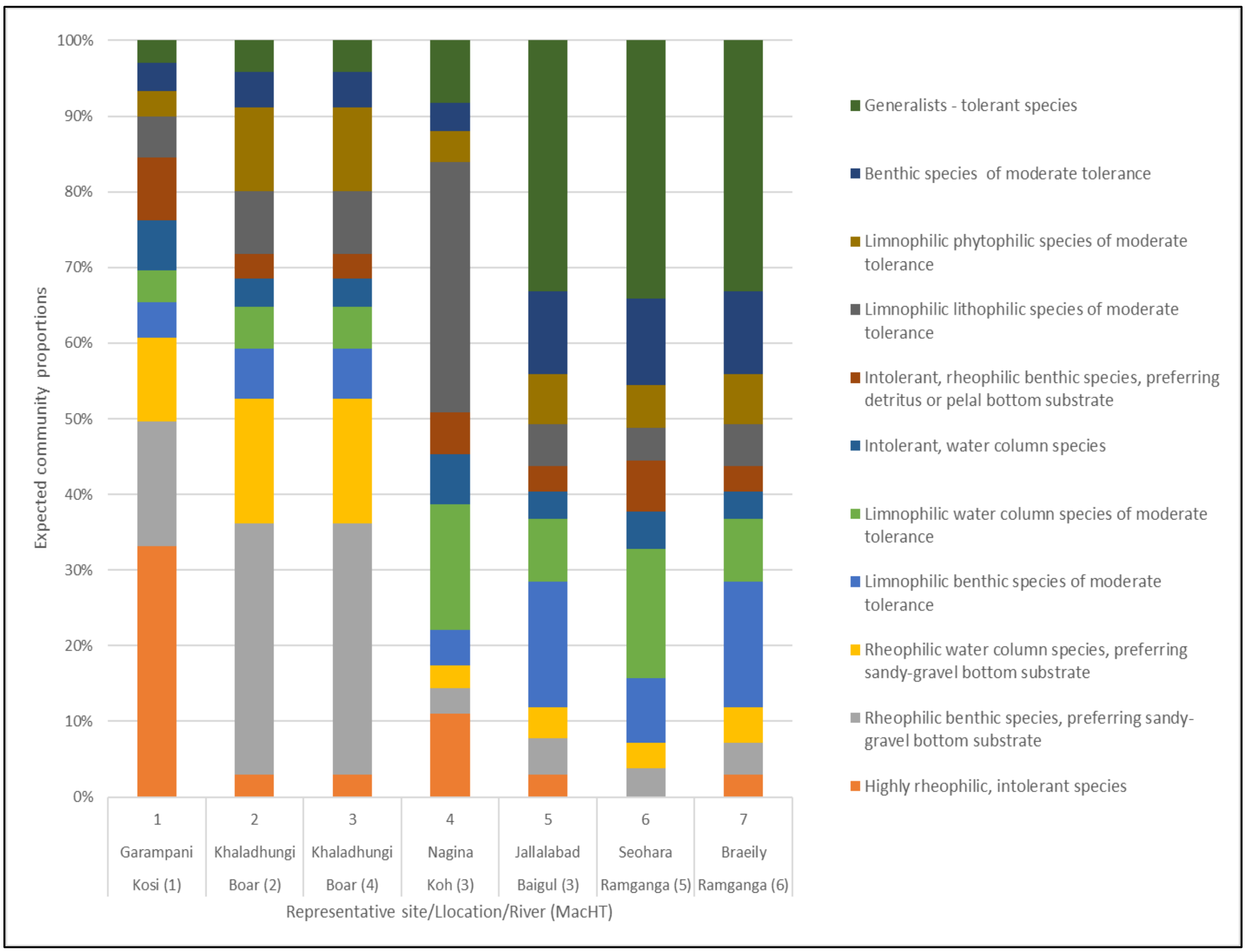


Figure 26: Fish community structures calculated for each of the MacHTs represented by selected sites

The equivalent habitat structure is necessary to support expected fish community structure. It can therefore be an indicator for E-Flow determination. Members of the E-Flows Assessment Task Group decided that securing habitat for rearing and growth life stages should also assure habitat for other life stages. As monsoon flows cannot be regulated or controlled, no criteria will be applied for monsoon season.

The fish community structures presented in Figure 26 were thus used as a biological target for 3 identified flow bioperiods:

1. **post-monsoon (September-October)** - higher flows, fish spawning, rearing and growing process.
2. **lean (November – February) -** moderate low flows, adult and young fish rearing and growth season.
3. **dry (March –May) –** lowest flows, fish spawning, rearing and growing process.

6.2 Fish preference guilds and habitat tolerances

For every HUG, habitat use criteria during the fish rearing and growth stages were developed. To determine habitat suitability for fish communities, suitability criteria are established (Table 10) on the basis of literature information. Using Conditional Suitability Criteria Approach of MesoHABSIM, the preferable ranges of depth, velocity, type of substrate, cover and hydromorphologic units are specified.

Table 10: Conditional Habitat Use Criteria of HUGs occurring in Ramganga River. Bold numbers indicate required habitat features.

No	Fish Guilds	Depth [m]	Velocity [m s^{-1}]	Choriotop	HMU Type	Covers
1	Highly rheophilic, intolerant species	0.25-1.5	0,3-1,2 (max. 2,0)	solid rock/ gigalithal megalithal >40 cm, **makrolithal 20-40 cm, mesolithal6-20 cm,** microlithal 2-6 cm	riffle, ruffle, cascade, rapid, fast run, plumge-pool, pool, backwater	**boulders,** undercut banks woody debris
2	Rheophilic benthic species, preferring sandy-gravel bottom substrate	0,3-2,0	0,15-0,9	megalithal >40 cm, makrolithal 20-40 cm, mesolithal 6-20 cm, **microlithal 2-6 cm psammal**	riffle, ruffle, cascade, rapid, fast run, run, glide, plunge-pool, pool,	boulders, undercut banks woody debris
3	Rheophilic water column species, preferring sandy-gravel bottom substrate	0,5-4,0	0,15-0,7	mesolithal 6-20 cm, microlithal 2-6 cm psammal, akal, debris, xylal	run, fast run, pool, plunge-pool, backwater riffle	boulders, undercut banks woody debris, canopy shading

No	Fish Guilds	Depth [m]	Velocity [m s^{-1}]	Choriotop	HMU Type	Covers
4	Limnophilic benthic species of moderate tolerance	0,25-2,5	0,0-0,2	microlithal 2-6 cm psammal, pelal, akal, debris, xylal	run, pool, glide, sidearm, backwater, rapid, fast run,	undercut banks woody debris, submerged vegetation, canopy shading
5	Limnophilic water column species of moderate tolerance	0,5-4,0	0,0-0,5	microlithal 2-6 cm psammal, pelal, akal, debris, xylal	run, pool, backwater, cascade, rapid, fast run,	woody debris, undercut banks, canopy shading
6	Intolerant, rheophilic benthic species, preferring detritus or pelal bottom substrate	0,20- 0,50	0,15-0,5	**detritus, pelal, sapropel**	**backwater, glide, pool, run**	**shallow margins**, woody debries
7	Intolerant, water column species	0,5-4,0	0,15-0,5	microlithal 2-6 cm psammal, akal, debris, xylal	run, pool, backwater, cascade, rapid, fast run,	undercut banks woody debris, canopy shading
9	Limnophilic phytophilic species of moderate tolerance	0,3-2,0	0,0-0,5	psammal, phytal, pelal, akal, debris, xylal	backwater, glide, pool, run, side-arm, cascade, rapid, fast run,	**submerged vegetation,** woody debris, undercut banks, canopy shading
10	Benthic species of moderate tolerance	0,25-2,5	0,0-0,90	mesolithal 6-20 cm, microlithal 2-6 cm psammal, akal, debris, xylal	riffle, ruffle, run, glide, pool, backwater, side-arm	shallow margins, submerged vegetation, undercut banks, woody debris
11	Generalists - tolerant species	0,25-4,0	0,0-0,5	**mesolithal 6-20 cm, microlithal 2-6 cm psammal,** akal, debris, pelal, sapropel, xylal	run, pool, glide, sidearm, backwater	submerged vegetation, woody debris, undercut banks, canopy shading

7 Flow-habitat relationship results based on MesoHABSIM

7.1 Flow-habitat relationship results

The flow-habitat relationship in the form of rating curves has been established. The guild and community rating curves are presented in Appendix 5 Rating Curves. To demonstrate the process the Seohara Site rating curves are presented and described below.

Site 6: Ramganga River at Seohara

The HMU and substrate distribution maps at three simulated flows: 1.5 m^3s^{-1} (0.3 lskm), 4.5 m^3s^{-1} (0.88 lskm) and 11 m^3s^{-1} (2.2 lskm) m^3s^{-1} are presented in Appendix 3. Habitat suitability maps for all flows and 11 guilds are presented in Appendix 4. Figure 27 demonstrates habitat rating curves for HUGs, where habitat suitable for limnophilic, lithophilic, phytophytophilic and generalist species is most dominant. It increases steeply to almost 30% of channel area (CA) at flows lower than 0.4 lskm, then more gradually towards 0.9 lskm and slightly more steeply to 55 % CA at flows above 3 lskm. Habitat for rheophilic benthic detritus or pelal species also rises steeply at lowest flows, but then remains rather stagnant as flows increase. An almost steady increase pattern is followed by water column species reaching eventually the same 55% CA. Habitat for highly rheophilic and rheophilic benthic sand-gravel species increases almost linearly towards 45% CA and 38% CA, respectively.

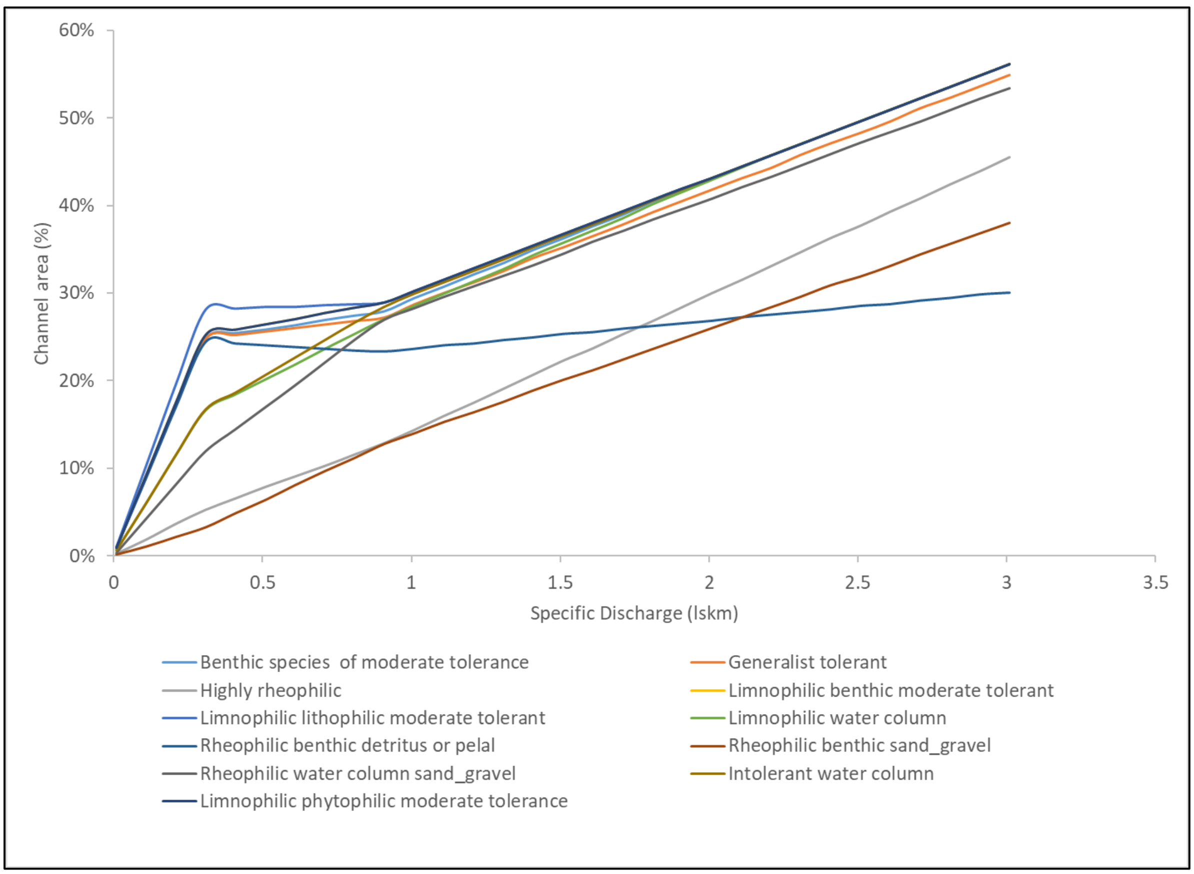


Figure 27: Habitat flow rating curves for the HUGs occurring in Ramganga River at site 6

Figure 28 indicates that the entire wetted area is suitable habitat for recorded fish species (generic fish) and this habitat well resembles expected fish community structure. Namely, the rating curve for community habitat is closely following the pattern of generic fish curve and the distance between the curves is not larger than 5% CA. This confirms the choice of the Seohara site as representative of a river reach not heavily impaired by human alterations.

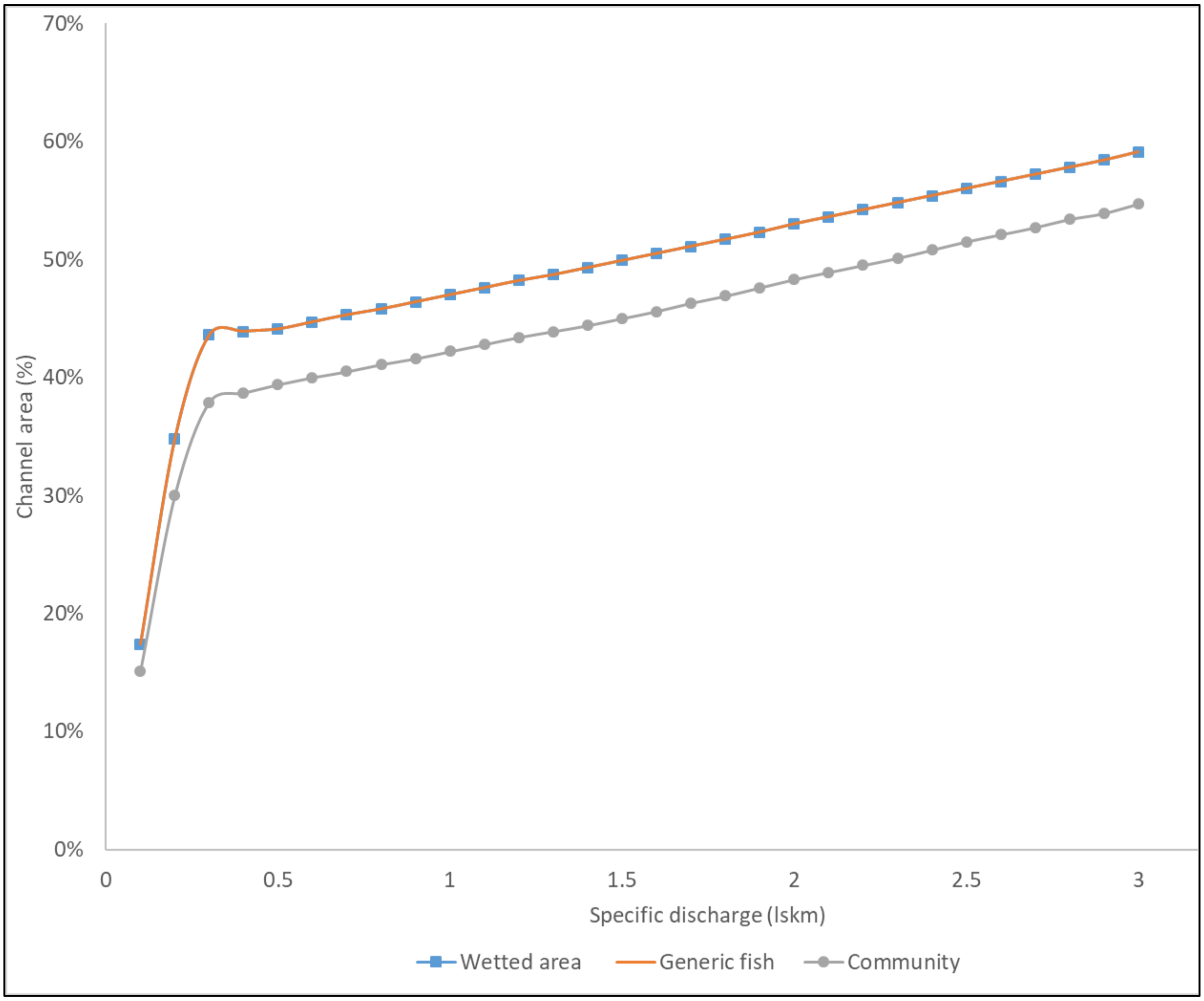


Figure 28: Rating curves for wetted, habitat area of generic fish and community habitat at site 6: Seohara

7.2 Habitat Time series and duration analyses

A SWAT hydrological model has been set up, calibrated and validated at identified CWC HO sites in the basin for the period of 1975-2020. Naturalised flows have been established by removing the effects of water abstractions and intense irrigation (dams/barrages, water intensive crops removed). These results have been used in the development of habitat time series for each site.

UCUT curves calculated for the community suitability curve are demonstrated in Appendix 6. To present the process of selection of habitat thresholds, the bioperiod-specific UCUT curves for Ramganga River at Seohara site are presented and described below (Figures 29-31).

UCUT curves for MacHT 5: Ramganga River at Seohara

In the post monsoon season, 22% CA (red curve) was chosen as rare and 23% (orange curve) as critical habitat threshold. The common habitat threshold is equivalent to 30% CA (green curve). The critical points on the rare, critical and common threshold curves indicate 5, 6 and 19 allowable duration days respectively as indicated by the blue line connecting the UCUTs (Figure 29). Catastrophic durations, i.e. with recurrence intervals of 10 years obtained from underlying data, are 10 days for rare, 11 days for critical, and 24 days for common threshold.

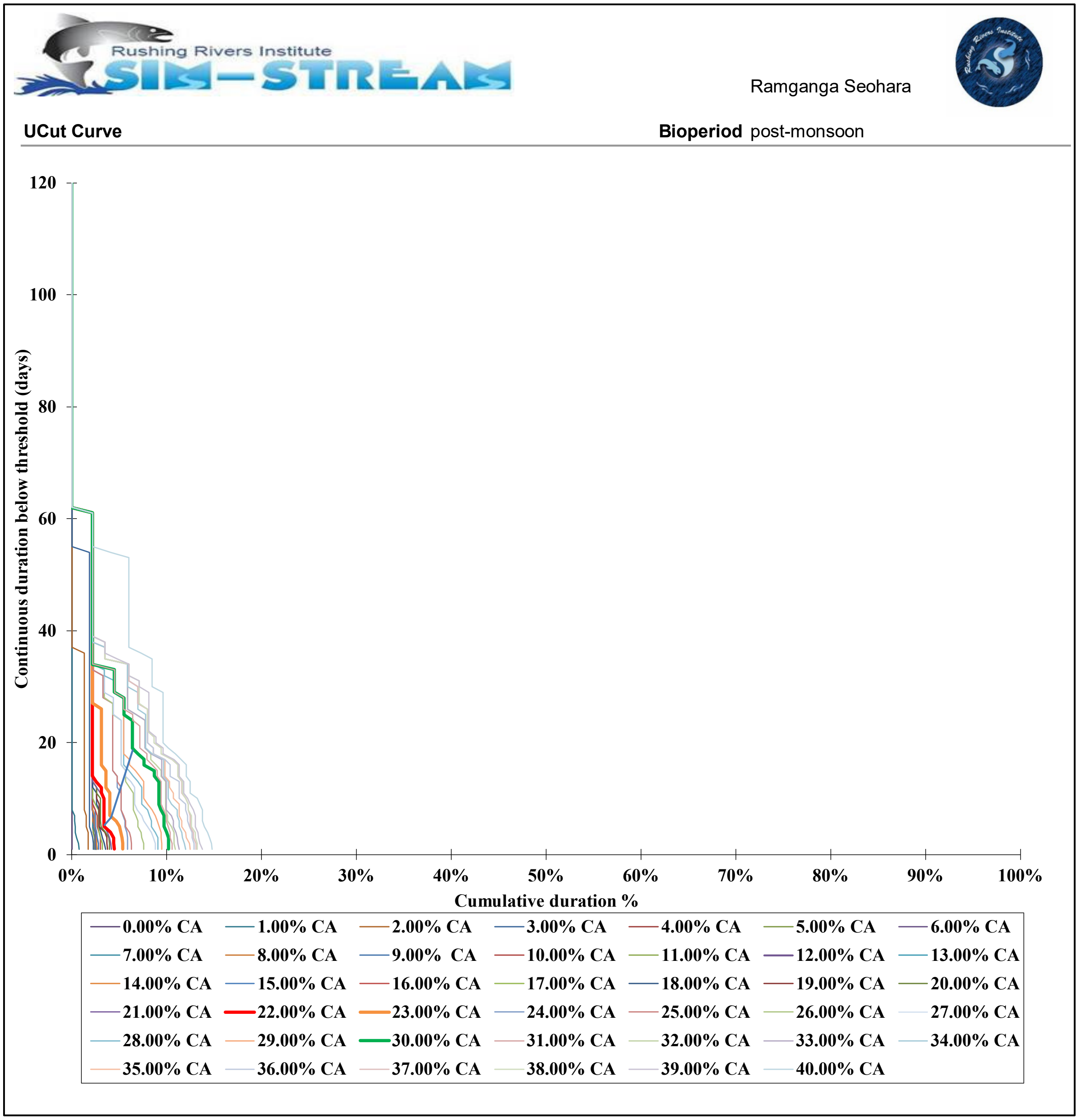


Figure 29: **UCUT curves showing frequency of continuous under habitat threshold events for fish community during post–monsoon bioperiod in Ramganga River in Seohara.**

Red, yellow and green lines indicate threshold to subsistence, critical and base habitat respectively. The blue line connects the critical points indicating allowable durations.

In the lean season 22% CA (red curve) was chosen as rare and 23% (orange curve) as critical habitat thresholds. The common habitat threshold is equivalent to 29% CA (green curve). The critical points on the rare, critical and common threshold curves indicate 11, 18 and 37 allowable duration days respectively (Figure 30). Catastrophic durations with recurrence intervals of 10 years are 27 days for rare and critical thresholds, and 43 days for common threshold.

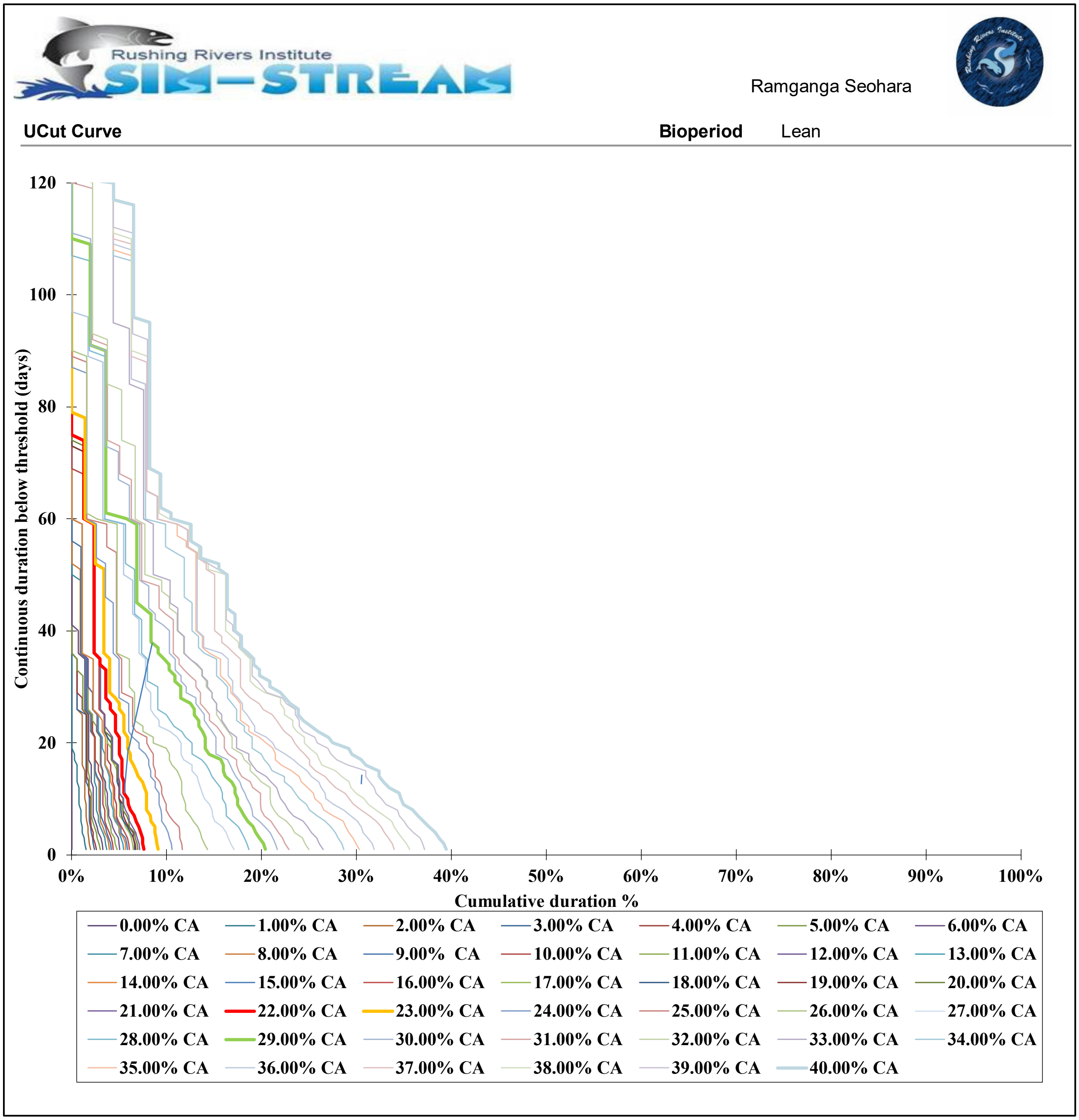


Figure 30: UCUT curves showing frequency of continuous under habitat threshold events for fish community during lean bioperiod in Ramganga River in Seohara.

Red, yellow and green line indicates threshold to subsistence, critical and base habitat respectively. The blue line connects the critical points indicating allowable duration.

In the dry season 1% CA (red curve) was chosen as rare and 2% (orange curve) as critical habitat thresholds. The common habitat threshold is equivalent to 28% CA (green curve). The critical points on the rare, critical and common threshold curves indicate 3, 5 and 23 allowable duration days respectively (Figure 31). Catastrophic durations with recurrence intervals of 10 years are respectively 4, 8 and 42 days.

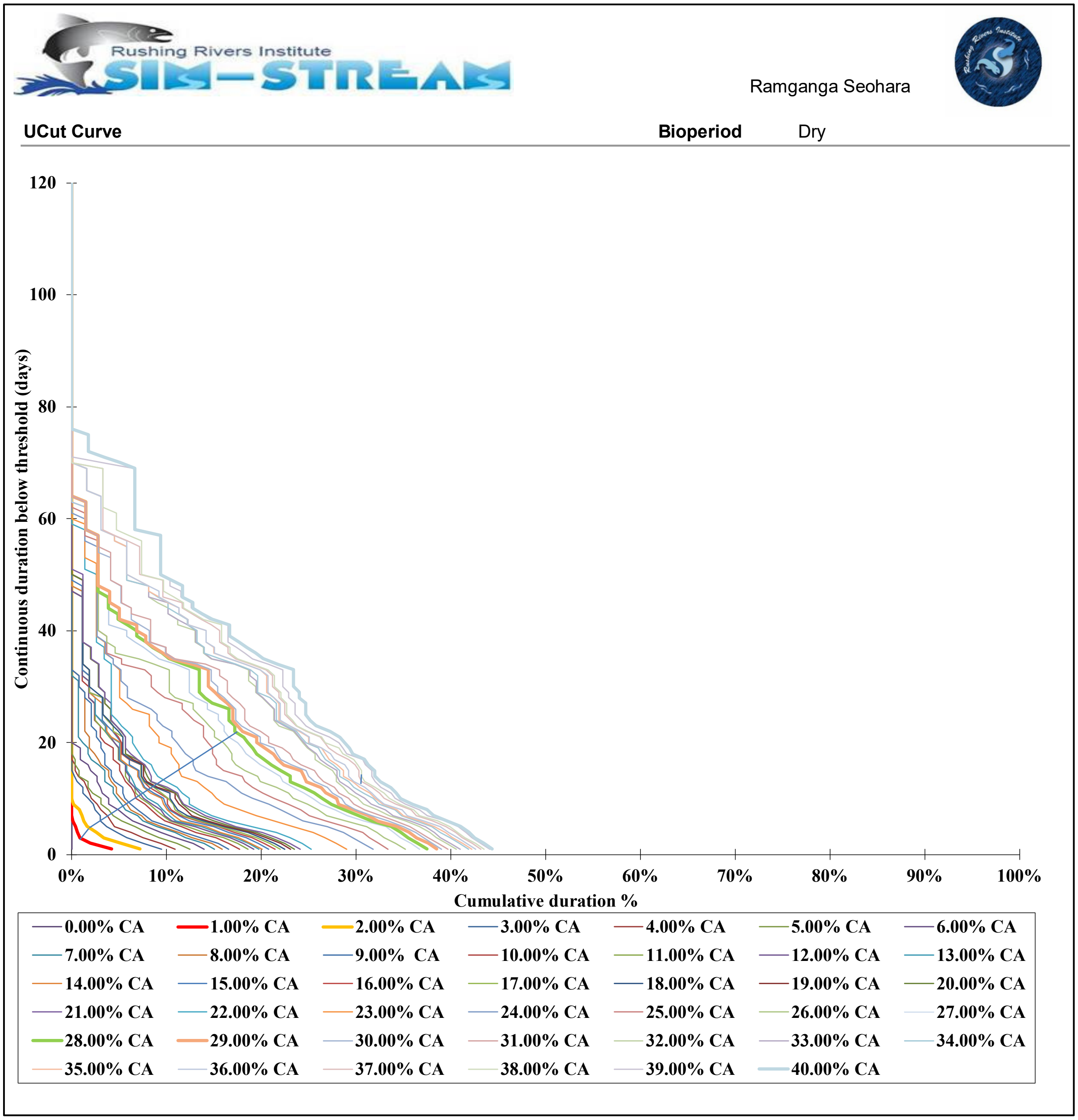


Figure 31: UCUT curves showing frequency of continuous under habitat threshold events for fish community during dry bioperiod in Ramganga River in Seohara.

Red, yellow and green line indicates threshold to subsistence, critical and base habitat respectively. The blue line connects the critical points indicating allowable duration.

7.3 E-Flows criteria for the representative sites: Results and Discussion

Tables 11-15 below present the environmental flow criteria derived from UCUT curves for the representative sites.

Identified Bioperiods are:

- Post monsoon (IX-X) -Sept-Oct
- Lean (XI-II) Nov-Feb
- Dry (III-V) March-May

7.3.1 Site 1: Kosi River at Garampani

Table 11 presents the summary of all thresholds and E-Flows corresponding to habitat thresholds. In the post-monsoon season, subsistence flow is equivalent to **0.72 lskm** (0.87 m^3s^{-1} for Garampani site), trigger flow is **0.80 lskm** (0.966 m^3s^{-1} for Garampani site) and habitat base flow is **1.89 lskm** (2.281 m^3s^{-1} for Garampani site). In the winter Rearing and Growth bioperiod, subsistence flow is equivalent to **0.19 lskm** (0.230 m^3s^{-1} for Garampani site), trigger flow is **0.28 lskm** (0.338 m^3s^{-1} for Garampani site) and habitat base flow is **1.39 lskm** (1.687 m^3s^{-1} for Garampani site). In the Dry bioperiod, subsistence flow is equivalent to **0.11 lskm** (0.230 m^3s^{-1} for Garampani site), trigger flow is **0.19 lskm** (0.229 m^3s^{-1} for Jalalabad site) and habitat base flow is **0.97 lskm** (1.171 m^3s^{-1} for Garampani site).

Table 11: E-Flows criteria for Kosi River at Garampani site

River/Site/watershed area (km2)	Kosi	Garampani	1207
Bioperiod	IX-X	XI-II	III-V
Habitat base E-Flow (lskm)	**1.89**	**1.39**	**0.97**
Habitat base E-Flow (m3/s)	**2.281**	**1.678**	**1.171**
Allowable duration under (days)	*16*	*18*	*12*
Catastrophic duration (days)	*31*	*66*	*33*
Trigger E-Flow (lskm)	**0.80**	**0.28**	**0.19**
Trigger E-Flow (m3/s)	**0.966**	**0.338**	**0.229**
Allowable duration under (days)	*12*	*6*	*9*
Catastrophic duration (days)	*13*	*40*	*12*
Subsistence E-Flow (lskm)	**0.720**	**0.190**	**0.110**
Subsistence E-Flow (m3/s)	**0.87**	**0.23**	**0.13**
Allowable duration under (days)	*5*	*6*	*8*
Catastrophic duration (days)	*10*	*24*	*9*
Abs. Minimum (lskm)	0.18	0.01	0.00
Abs. Minimum (m3/s)	0.22	0.01	0.00

Similarly, results for the remaining sites are presented in below tables.

7.3.2 Site 3: Boar River at Kaladhungi

Table 12: E-Flows criteria for Boar River at Kaladhungi site

River/Site/watershed area (km2)	Boar	Kladhungi	100
Bioperiod	IX-X	XI-II	III-V
Habitat base E-Flow (lskm)	**2.63**	**2.62**	**0.81**
Habitat base E-Flow (m3/s	**0.263**	**0.262**	**0.081**
Allowable duration under (days)	*25*	*43*	*10*
Catastrophic duration (days)	*47*	*120*	*72*
Trigger E-Flow (lskm)	**0.81**	**0.45**	**0.45**
Trigger E-Flow (m3/s)	**0.081**	**0.045**	**0.045**
Allowable duration under (days)	*14*	*19*	*10*
Catastrophic duration (days)	*20*	*60*	*61*
Subsistence E-Flow (lskm)	**0.450**	**0.260**	**0.260**
Subsistence E-Flow (m3/s)	**0.045**	**0.026**	**0.026**
Allowable duration under (days)	*5*	*8*	*10*
Catastrophic duration (days)	*18*	*37*	*33*
Abs. Minimum (lskm)	0.00	0.00	0.00
Abs. Minimum (m3/s)	0.00	0.00	0.00

7.3.3 Site 5: Baigul River at Jalalabad

Table 13: E-Flows criteria for Baigul River at Jalalabad site

River/Site/watershed area (km^2)	Baigul	Jalalabad	2169
Bioperiod	IX- X	XI-II	III-V
Habitat base E-Flow (lskm)	**3.25**	**2**	**2**
Habitat base E-Flow (m3s-1)	**7.0**	**4.3**	**4.3**
Allowable duration under (days)	*26*	52	17
Catastrophic duration (days)	*41*	120	92
Trigger E-Flow (lskm)	**0.65**	***0.34***	**0.016**
Trigger E-Flow (m3s-1)	**1.40**	***0.74***	**0.03**
Allowable duration under (days)	*11*	*49*	12
Catastrophic duration (days)	*34*	*120*	92
Subsistence E-Flow (lskm)	**0.34**	**0.28**	**0.002**
Subsistence E-Flow (m3s-1)	**0.74**	**0.61**	**0.004**
Allowable duration under (days)	**6**	**48**	**11**
Catastrophic duration (days)	**34**	**119**	**92**
Abs. Minimum (lskm)	0.01	0.01	0.00
Abs. Minimum (m^3s^{-1})	0.02	0.02	0.00

7.3.4 Site 6: Ramganga River at Seohara

Table 14: E-Flows criteria for Ramganga River at Seohara site

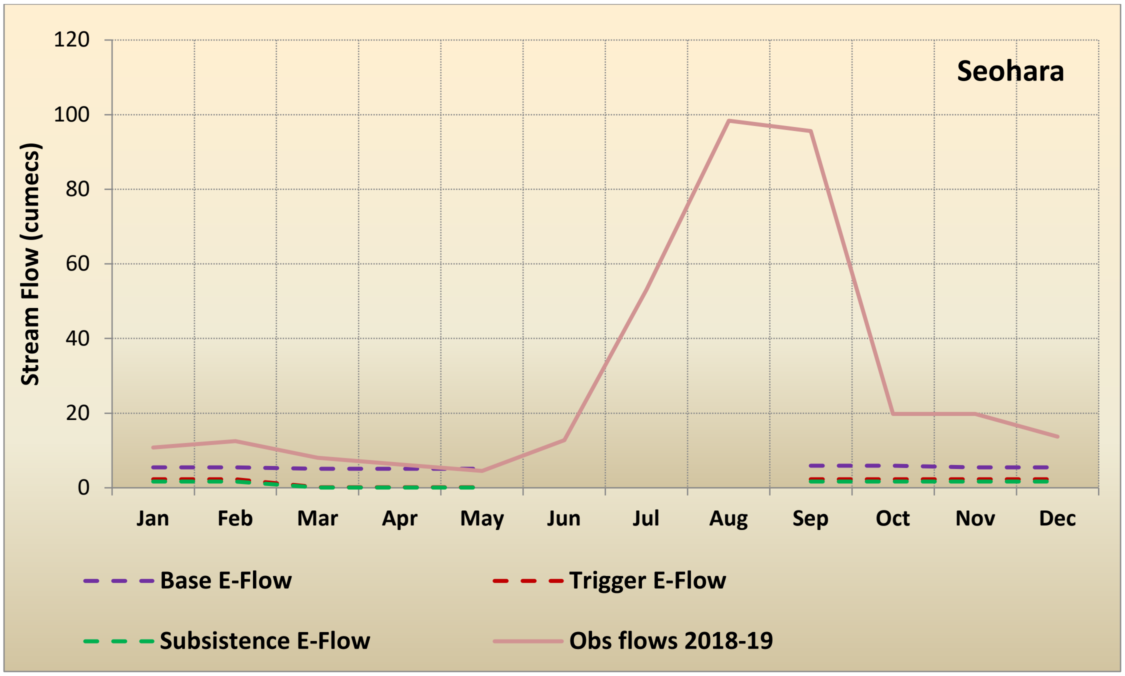
River/Site/watershed area (km2)	Ramganga	Seohara	5099
Bioperiod	IX-X	XI-II	III-V
Habitat base E-Flow (lskm)	**1.16**	**1.08**	**1.00**
Habitat base E-Flow (m3/s	**5.92**	**5.51**	**5.10**
Allowable duration under (days)	*19*	*37*	*23*
Catastrophic duration (days)	*24*	*43*	*41*
Trigger E-Flow (lskm)	**0.45**	**0.45**	**0.03**
Trigger E-Flow (m3/s)	**2.29**	**2.29**	**0.14**
Allowable duration under (days)	*6*	*18*	*5*
Catastrophic duration (days)	*11*	*27*	*8*
Subsistence E-Flow (lskm)	**0.33**	**0.33**	**0.01**
Subsistence E-Flow (m3/s)	**1.68**	**1.68**	**0.07**
Allowable duration under (days)	*5*	*11*	*3*
Catastrophic duration (days)	*10*	*27*	*4*
Abs. Minimum (lskm)	0.01	0.00	0.01
Abs. Minimum (m3/s)	0.00	0.01	0.05

For this site, observed flows at a nearby CWC site Seohara (about 10 km upstream) and a downstream distant site Moradabad (about 60 km downstream) were available and the same have been used for reference discussion (Table 15 &16).

Table 15. Observed flows at Seohara CWC site

Seohara Site-Observed flows 2018-2019	Flows (m^3/s)		
	Mean Flows	Median Flows	Minimum daily Flows
January	10.81	11.44	4.49
February	12.51	12.335	2.72
March	8.06	7.075	3.92
April	6.24	5.325	2.72
May	4.52	4.215	1.62
June	12.73	10.025	1.23
July	53.17	46.38	10.44
August	98.38	84.85	21.98
September	95.64	78.23	41.07
October	19.77	18.12	5.72
November	19.78	14.745	4.95
December	13.69	12.56	2.24

Comparison of the E-Flows scenarios with observed minimum and mean monthly flows of the year 2018-2019 is presented in the graph below.



Mean monthly flows and minimum daily flows at Moradabad during 1998-2018 are as presented in Table 16.

Table 16. Observed flows at Moradabad CWC site

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Mean Monthly (m3/s)	17.1	18.6	13.8	9.8	7.9	29.6	105.5	192.9	172.6	50	26.6	19.5
Minimum daily flow (m3/s)	2.72	4.69	4.47	1.12	0.51	0.22	1.22	4.82	11.3	6.78	5.75	3.51

Based on the observed mean monthly flows at Seohara, while all months seem to be meeting E-Flows requirements (except May) in 2018-2019, minimum daily values need attention. This finding is also true with the downstream site -Moradabad.

7.3.5 Site 7: Ramganga River at Bareilly

E-flows criteria developed for Bareilly Site are presented in Table 17.

Similar to Seohara site, comparisons have been made with the observed flows at Bareilly site (Table 18). While mean monthly flows suggest that E-Flows are being met, minimum daily flow values need careful attention to not exceed the allowable duration. For example, mean monthly observed flow value for May is more than base E-Flow. However, the daily flow that is equaled or exceeded 90% of the time in May is only 8.24 m^3/s.

Table 17: E-Flows criteria for Ramganga River at Bareilly site. Synopsis of E-Flows

River/Site/watershed area (km2)	Ram-ganga	Bareilly	17560
Bioperiod	IX-X	XI-II	III-V
Habitat base E-Flow (lskm)	**35.60**	**12.16**	**7.25**
Habitat base E-Flow (m3/s	**640.44**	**218.76**	**130.39**
Allowable duration under (days)	*26*	*55*	*59*
Catastrophic duration (days)	*45*	*59*	*92*
Trigger E-Flow (lskm)	**19.52**	**7.14**	**5.14**
Trigger E-Flow (m3/s)	**342.77**	**125.38**	**90.26**
Allowable duration under (days)	*10*	*35*	*37*
Catastrophic duration (days)	*10*	*59*	*52*
Subsistence E-Flow (lskm)	**18.28**	**6.15**	**5.00**
Subsistence E-Flow (m3/s)	**321.00**	**107.99**	**87.80**
Allowable duration under (days)	*8*	*17*	*24*
Catastrophic duration (days)	*8*	*47*	*34*
Abs. Minimum (lskm)	11.15	5.19	4.93
Abs. Minimum (m3/s)	195.79	91.14	86.57

Table 18. Observed Flows at Bareilly Site

Bareilly observed flows 1998-2018 (m^3/s)	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Mean Monthly	69.1	70.68	59.20	38.38	24.59	84.80	309.42	707.35	686.7	283.16	118.57	75.88
Minimum daily	18.8	16.93	16.58	10.68	5.3	3.58	3.75	12.17	62.87	40.73	29.03	27.4

Comparison of the E-Flows scenarios with observed mean monthly flows between 1998-2018 is presented in the graph below (Fig 32).

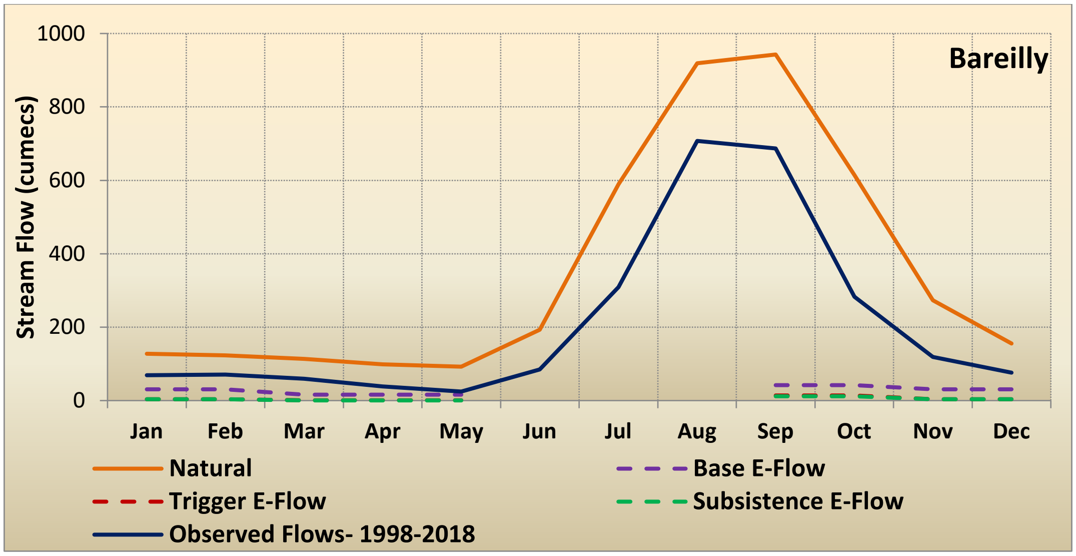


Figure 32. Comparison of E-flows scenarios with observed flows at Bareilly

7.4 Summary of results

Table 19 presents the E-Flows criteria calculated for each of the representative sites in absolute values. Across the sites, there is a clear pattern of trigger and subsistence flow reduction from post monsoon to dry bioperiod. The allowable and catastrophic durations are the longest during the lean season, except for very few exceptions.

Table 20 presents the p-values for each E-Flow type (base, trigger, subsistence) and continuous duration thresholds. They can be used for defining E-Flows strategies for each MaCHT using the trigger E-Flow value as a threshold for introducing management criteria.

Table 19: E-Flows calculated for the five representative sites for three bioperiods

Site	Kosi River Garampani			Boar River Kaladhungi			Baigul River Jalalabad			Ramganga River Seohara			Ramganga River Bareilly		
Bioperiod	IX-X	XI-II	III-V	IX-X	XI-II	III-V	IX-X	XI-II	III-V	IX-X	XI-II	III-V	IX-X	XI-II	III-V
Base flow (m3s-1)	**2.28**	**1.68**	**1.17**	**0.26**	**0.26**	**0.08**	**7.05**	**4.34**	**4.34**	**5.92**	**5.51**	**5.10**	**640.44**	**236.03**	**130.39**
Allowable duration under (days)	16	18	12	*25*	*43*	*10*	*26*	*52*	*17*	*19*	*37*	*23*	26	59	59
Catastrophic duration (days)	31	66	33	*47*	*120*	*72*	*41*	*120*	*92*	*24*	*43*	*41*	45	120	92
Trigger flow (m3s-1)	**0.97**	**0.34**	**0.23**	**0.08**	**0.05**	**0.05**	**1.40**	**0.74**	**0.03**	**2.29**	**2.29**	**0.14**	**351.16**	**128.45**	**92.47**
Allowable duration under (days)	*12*	*6*	*9*	14	19	10	*11*	*49*	*12*	*6*	*18*	*5*	*10*	*35*	*37*
Catastrophic duration (days)	*13*	*40*	*12*	20	60	61	*34*	*120*	*92*	*11*	*27*	*8*	*10*	*59*	*52*
Subsistence flow (m3s-1)	***0.87***	***0.23***	***0.13***	***0.05***	***0.03***	***0.03***	***0.74***	***0.61***	***0.004***	***1.68***	***1.68***	***0.07***	***328.86***	***110.64***	***89.95***
Allowable duration under (days)	*5*	*6*	*8*	*5*	*8*	*10*	*6*	*48*	*11*	*5*	*11*	*3*	*8*	*17*	*24*
Catastrophic duration (days)	*10*	*24*	*9*	*18*	*37*	*33*	*34*	*119*	*92*	*10*	*27*	*4*	*8*	*47*	*34*
Abs. Minimum (m3s-1)	0.87	0.23	0.13	0.000	0.000	0.000	0.02	0.02	0.00	0.00	0.01	0.05	200.59	93.37	88.69

Table 20: E-Flows criteria for investigated Machrohabitat types of Ramganga River Basin

MacHT	1			3			4			5			6		
Bioperiod	IX-X	XI-II	III-V	IX-X	XI-II	III-V	IX-X	XI-II	III-V	IX-X	XI-II	III-V	IX-X	XI-II	III-V
Base flow p-value	**0.25**	**0.19**	**0.13**	**0.39**	**0.24**	**0.24**	**1.32**	**1.31**	**0.41**	**0.15**	**0.14**	**0.13**	**1.80**	**0.66**	**0.37**
Allowable duration under (days)	*4*	*3*	*2*	*26*	*52*	*17*	*25*	*43*	*10*	*19*	*37*	*23*	*26*	*59*	*59*
Catastrophic duration (days)	*16*	*18*	*12*	*41*	*120*	*92*	*47*	*120*	*72*	*24*	*43*	*41*	*45*	*120*	*92*
Trigger flow p-value	**0.107**	**0.038**	**0.025**	**0.077**	**0.041**	**0.002**	**0.405**	**0.225**	**0.225**	**0.011**	**0.011**	**0.001**	**0.989**	**0.362**	**0.260**
Allowable duration under (days)	*12*	*6*	*9*	*11*	*49*	*12*	*14*	*19*	*10*	*6*	*18*	*5*	*10*	*35*	*37*
Catastrophic duration (days)	*13*	*40*	*12*	*34*	*120*	*92*	*20*	*60*	*61*	*11*	*27*	*8*	*10*	*59*	*52*
Subsistence flow p-value	***0.097***	***0.025***	***0.015***	***0.019***	***0.015***	***0.000***	***0.225***	***0.130***	***0.130***	***0.008***	***0.008***	***0.0004***	***0.926***	***0.312***	***0.253***
Allowable duration under (days)	*5*	*6*	*8*	*6*	*48*	*11*	*5*	*8*	*10*	*5*	*11*	*3*	*8*	*47*	*24*
Catastrophic duration (days)	*10*	*24*	*9*	*34*	*119*	*92*	*18*	*37*	*33*	*10*	*27*	*4*	*8*	*47*	*34*
Abs. Minimum p-value	0.02	0.001	0.000	0.00	0.00	0.00	0.000	0.000	0.000	0.0000	0.0001	0.0013	0.57	0.250	0.263

7.5 Strategies for E-Flows implementation: static or dynamic E-Flows

7.5.1 Static versus Dynamic E-Flows

There are two strategies that can be followed for implementation of E-Flows:

- A static E-Flow threshold is a value equivalent to habitat base flows or trigger flows varying only between the bioperiods. If flows are lower than trigger flow then measures limiting water withdrawals or releasing more water from reservoirs should be implemented.
- The dynamic E-Flow strategy allows for flows to be lower than the habitat base flow or trigger threshold for the duration typical for natural conditions. When the allowable duration below the threshold is exceeded, management action is necessary. This may also consist of short-term water releases to break continuous duration of flows under the threshold.

The static strategy uses the trigger value as the E-Flow and prescribes it for the duration of a bioperiod. The dynamic strategy includes introducing appropriate management actions at the moment when the continuous duration thresholds of flows below subsistence, trigger or base flow are exceeded. These may consist of reducing water withdrawals or short (2 days) releases of water from reservoirs to the level of the threshold and reset the continuous duration count. Management actions in response to conditions of flow below base flow thresholds for more than the allowable duration are highly recommended to ensure suitable habitat for fish communities. While management action in response to conditions of flow below trigger flow thresholds for more than the allowable duration should be required to avoid significant harm to fish communities. Another rule frequently used is that exceedance of catastrophic duration is allowed every 10 years and that three consecutive exceedances of allowable durations in one bioperiod are equivalent to catastrophic duration.

Figure 32 demonstrates the simulation of dynamic E-Flows based on the median daily flows measured over the period of last 20 years at Bareilly location. Median represents the most commonly occurring situation. For comparison the median of daily simulated flows for virgin conditions is plotted. The spikes in E-Flows present the interventions needed to maintain the fish population.

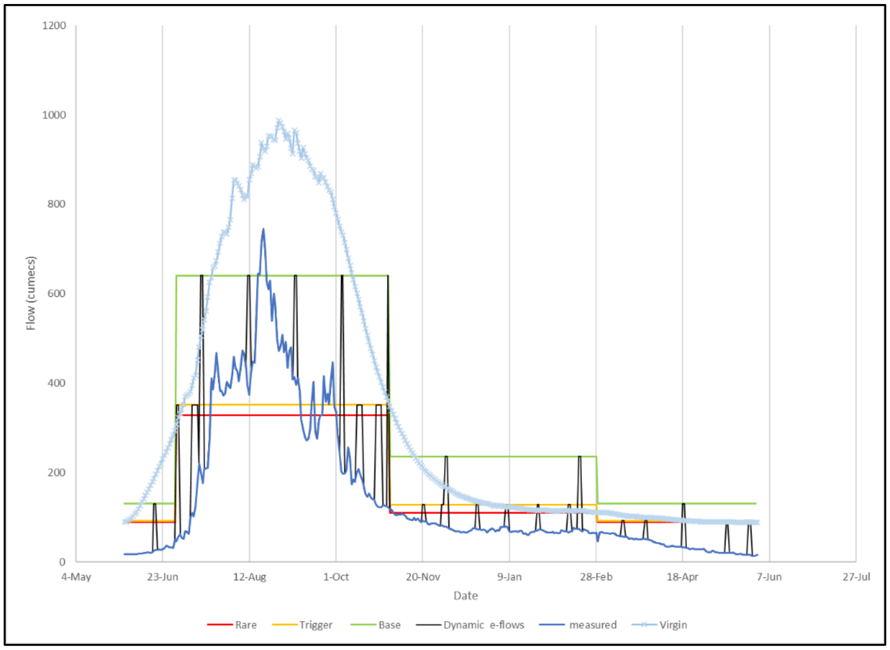


Figure 33: Dynamic E-Flows compared with medians of measured and virgin daily flows over the period of 20 years record, at Bareilly site

As presented in Figure 32 there is a large deficit of flows at Bareilly in Ramganga River if compared to virgin flows. This would therefore require a large number of interventions (20 interventions in the most typical year).

To investigate how often the two strategies would cause the need for intervention, we calculated the intervention days for dynamic and static E-Flows strategy using entire simulated flow record for present conditions at Bareilly site. For static E-Flows we assumed a very simple strategy, where only flows lower than trigger flows are taken into account.

Table 21: The proportion of time when the E-Flows criteria are not met under present flow conditions

Bioperiod	Dynamic	Static	Intervention Frequency Dynamic/Static
Entire non monsoon period	8%	77%	69%
post monsoon	11%	50%	39%
lean	6%	98%	92%
Dry	6%	82%	76%

Table 18 demonstrates the proportions of time when E-Flows thresholds are not met and intervention is needed. For dynamic and static E-Flows, the criteria were not met for a total of 8% and 77% of the entire period of record, respectively. The intervention frequency for dynamic E-Flows is 69% lower than the frequency for static E-Flows. Such situations mostly occur during the lean and dry bioperiods, both in excess of 80 % of the time for static E-Flows. Yet, for the lean period, the dynamic E-Flows offer 92%

savings. Therefore, implementation of a dynamic E-Flows strategy could be very beneficial in this season. For the dry bioperiod, the difference between the strategies is 76%.

This simulation offers a platform for further considerations regarding E-Flows implementation strategies and measures to be applied.

7.5.2 Transferability of the assessment results

The results of this assessment will enable relevant authorities to calculate E-Flows requirements for any river location (cross-section) in the Ramganga River Basin using the equation (1) presented in section 4.10. {$Q_{ef,bk} = p_b \cdot Q_{MAF,k}$}

The necessary steps are to:

1. Identify within which of the six macrohabitat (MacHT) types the target river location falls using Figure 5.
2. Calculate the catchment area (km^2) upstream of the location. This requires a digital elevation model of the basin which can be analysed in a geographic information system using the catchment area or flow accumulation algorithms or tools.
3. Calculate the naturalized mean annual discharge at the location. Given the limited discharge data for natural flows, this value will need to be simulated using a rainfall-runoff model. In this assessment the freely available SWAT model (https://swat.tamu.edu/) was used to calculate naturalized flows.
4. Select the representative p-values for the MacHT, flow threshold and bioperiod using Table 20
5. Insert the values into the equation and calculate Qef,bk, the E-Flow for the respective bioperiod in m^3s^{-1} and the three flow thresholds: habitat baseflows, trigger flows and subsistence flows.
6. Repeat the calculation for other bioperiods.

The result will be a table of the flow thresholds and allowable durations for the location, equivalent to Table 19.

8 Conclusion, recommendations, and next steps

The proposed E-Flows criteria serve as a basis for developing an implementation strategy that will be protective to aquatic fauna, particularly fish species, and effective management of available water resources of the Ramganga Basin. It is concluded that these criteria, if implemented with the use of most efficient dynamic approach, have the ability to improve the environmental health status of the Ramganga River, with the focus on aquatic biodiversity, creating least possible impacts on present human water use scenarios. Following recommendations can results in significant improvements in E-Flows Assessment and their subsequent implementations in India.

8.1 Increase available data and resolve caveats

One of the key obstacles in precise determination of E-Flows is the quality and availability of basic environmental data. During this project, it was recognized that there is need for improvement of such data. Similarly, the modelled time series for naturalized flows appears to be very low, and in some cases the predicted flows did not match the field observations. A more spatially systematic, quantitatively standardized way to collect fish biological data would provide for a more precise estimate of expected fish communities and therefore the environmental targets. In the study aimed at developing fish community macrohabitat types (FCMacHT) for Europe, data from more than 1000 systematic electrofishing surveys were used to cluster fish community structure (Parasiewicz et al. 2023). A similar effort would be necessary to create fish community templates for the whole of India. Therefore, focused effort to gather and verify additional input data is recommended.

During our modelling effort, we also documented limitations of modelling river hydraulics with hydrodynamic models for very low flows in highly turbulent environments. Despite substantial effort, the technical task group was unable to calibrate the River2D model to provide proper accuracy of velocity estimates. As a result, the velocities at 1.4 m^3s^{-1} of flow are obviously lower than expected. It caused underestimation of habitat for rheophilic species introducing uncertainties in the result.

The E-Flows calculated for the representative sites vary from each other quite remarkably despite some similarities of the fish community structures between the sites regardless of the units and standardisation applied. This may be a consequence of hydrological and biological data inaccuracies. The simulated flow time series are difficult to calibrate for very low flows. This is particularly visible in predicted high number of days with zero naturalized flows, especially for Baigul River at Jalalabad site. The reconnaissance survey of May 2022 corresponded to a time when the flows were very low, but the river was far from dry. This indicates the need for multiple on-site observations to better adjust the models in these flow ranges. A second source of inaccuracies may be the use of the same biological criteria for all 3 bioperiods, which reduces the model sensitivity to habitat needs. Further, the deviation for standard MesoHABSIM protocols requiring multiple aerial surveys and poor hydraulic data quality may have introduced additional errors. It is therefore recommended that in such circumstances the repeated MesoHABSIM surveys will be performed instead of hydrodynamic modelling.

8.2 Transfer to other basins

The model developed here allows us to calculate E-Flows at any location in the Ramganga Basin. It can be also transferred beyond the Ramganga, providing that similar macrohabitat types can be identified (referring to Appendix 2). For these purposes, the environmental attributes associated with each

MacHT can be used as the estimators. Figure 30 represents classification and regression tree calculated for the basin with Kappa coefficient of 0.989. It can be used to classify any river section with available data into one of the 6 clusters. Then for each clusters the p-value can be applied as explained above.

8.3 Build research and assessment capacity

Build a multidisciplinary research team or teams e.g. national or major basin task groups for E-Flows. Even if habitat simulation methods are the preferred method to assess E-Flows, it is essential to have a dedicated core team with expertise in hydrology, morphology and hydraulics, UAV and aerial imagery surveys and analysis, riparian vegetation and water biochemistry. Currently, the fish ecology and fisheries expertise are strongly developed but additional capacity and funding support are needed to cover additional disciplinary roles on a project or ongoing basis.

A basin situation assessment is a fundamental early step. This step can be dovetailed with the stakeholder transect walk step of the RBMP in future and should be undertaken early in the site selection process. Basin secondary data collation and analysis is a basic area of research that is invaluable in the E-Flows site selection process. Out of date secondary data help provide historical context and support status and trends analysis. However, they constrain the extent to which a desktop site selection exercise can mirror the on-ground reality. This is particularly significant in the case of river reaches that are undergoing rapid transformation under growing anthropogenic pressure – which is the case for many of the tributaries and most of the Ramganga main river.

A field reconnaissance trip to ground truth the outcomes of desktop site selection is an essential step. For E-Flows the focus is on pressures and stressors that affect freshwater ecosystem integrity and biodiversity. However, it is possible to undertake a freshwater ecological assessment as part of a wider basin situation assessment of status and trends.

The present ecological status of the river reach (site) and the relative proportions of rivers of the same type in different degrees of alteration from natural need to be ascertained. A baseline assessment of river ecological health, followed by monitoring of river condition after E-Flows are implemented, is needed. There is no established single, consistent procedure for the assignment of river reaches to different classes of ecological health, ecological integrity or future management objectives for India's rivers. Presently, there is also no procedure, approach or road map to address this. Standard indices have been developed for this purpose internationally and have good potential for application in the Ramganga Basin and beyond.

Naturalised reference and baseline ecological conditions are important to understand and need to be clarified and supported by research up front. E-Flows objectives are set according to stakeholder requirements for the river reach(es) concerned, and not in isolation of the desired future conditions for the river. They should nest within a wider agreed vision for the future sustainability of the river basins (typically, this vision forms a key early step in the development of the RBMP).

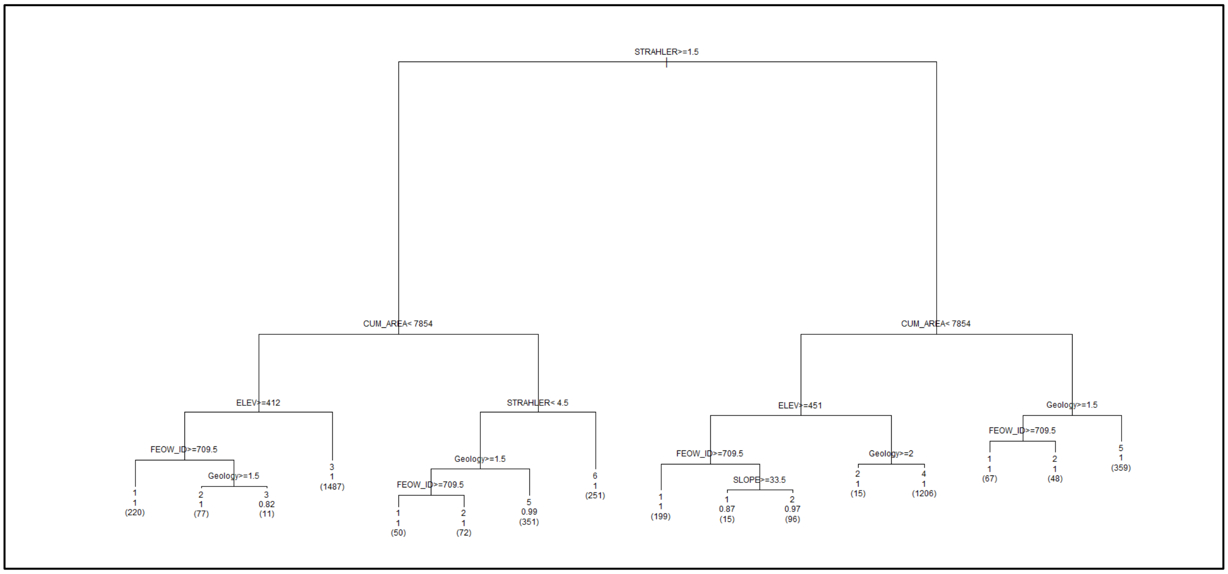


Figure 34: Classification and decission tree for defining MacHT classes. Geology 1 stands for GEO8AG_ID: 2110 and 2 for 2090

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