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ENVIRONMENTAL FLOW ASSESSMENT FOR RIVER VALLEY PROJECTS

N.N. RAI
Director, Central Water Commission, New Delhi

AKSHAT JAIN
Dy Director, Central Water Commission, New Delhi

ABSTRACT

Water is an essential component of life. Water, energy and transport are the basic components for social prosperity and economic growth of any country. In a developing economy like India as the economic growth and social prosperity is advancing, the demand for water resources projects is also increasing. Consequently, rivers and their ecosystems are coming under immense pressure due to storage, diversion and abstraction of water for various consumptive and non-consumptive uses. So far, we have exploited river basins for various uses, mostly without considering the water requirements of the living systems themselves. Therefore, it is critical to balance the requirements of various human uses and ecological needs in a river system from a basin-wide perspective. In this regard river flows of a certain quantity and quality called as environmental flows (E-Flows) are needed required to maintain the river in desired environmental condition or predetermined state where there are competing water uses. The criteria for estimating environmental flows requirements should imitate the spatial and temporal flow patterns of river flow, which affect the structural and functional diversity of rivers, and which in turn influence the species diversity of the river. All components of the hydrological regime have certain ecological significance. High flows of different frequency are important for channel maintenance, bird breeding, wetland flooding and maintenance of riparian vegetation. Moderate flows are critical for cycling of organic matter from river banks and for fish migration, while low flows of different magnitudes are important for algae control, water quality maintenance and the use of the river by local people. Therefore the element of flow variability has to be maintained in a modified E-Flows regime. The present paper describes the importance of environmental flows, methodologies for environmental flow assessment and methodology adopted for the assessment of environmental flow for a reach of river Ganga between Haridwar to Unnao.

Keywords *- Flow Regime; Riverine Ecology; Hydraulic Variables, Habitat Simulation*

1.0 ENVIRONMENTAL FLOW

The International Union for Conservation of Nature (IUCN) (2003) defines “E-Flows as the water regime provided within a river, wetland or coastal zone to maintain ecosystems and their benefits where there are competing water uses and where flows are regulated”. The IUCN makes a clear conceptual distinction between the water needed to maintain the ecosystem in near pristine condition, and that which is eventually allocated to it, following a process of a holistic assessment for E-Flows.

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

Another recent definition specifies the objectives of E-Flows “to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems” (Arthington et al., 2018).

2.0 IMPORTANCE OF E-FLOWS

The National Water Policy (2012) recognized the ecological needs of riverine ecosystems. In the Preamble of the policy, it is stated that "water is essential for sustenance of eco-system, and therefore, minimum ecological needs should be given due consideration". Clause 3.3 specifies that "a portion of river flows should be kept aside to meet ecological needs ensuring that the low and high releases are proportional to the natural flow regime, including base flow contribution in the low flow season through regulated ground water uses".

E-Flows must ensure river health and should be capable of sustaining the full range of goods and services provided by riverine ecosystems. This aspect has been duly recognized in the National Water Policy (2012), the Ganga River Basin Management Plan (GRBMP, 2011) and the Ganga Notification of 2016 (MoWR, 2016). The River Ganga Authorities Order of 2016 underline the urgency of maintaining ecological flows in the River Ganga.

An environmental management plan is an integral part of any water resources development project in a country. In India, an Expert Appraisal Committee (EAC) for River Valley and Hydroelectric Projects, constituted by the Ministry of Environment, Forest and Climate Change (MoEF&CC), examines the project (planning) reports and recommends the required E-Flows in the affected river reach. Cumulative Impact Assessment studies are also suggested for some river basins.

The National Green Tribunal (NGT) order of August 2017 specified that for all rivers in the country a minimum 15 % to 20% of the average lean season flow of that river shall be maintained.The Ganga E-Flows Notification of 2018 (amended in Sept 2019) is so far the strongest E-Flows implementation action, demanding and specifying the continuous release and monitoring of E-Flows from the Upper Ganga until the middle/lower reaches at Unnao, Uttar Pradesh (NMCG, 2018). Central Water Commission (CWC) is responsible for the supervision and monitoring of E-Flows.

As such, the current policy and practices duly emphasize the assessment and provision of E-Flows in river reaches affected by storage, diversion or abstraction of river water. However, due to various reasons, it remains challenging to assess E-Flows requirements rationally, particularly in over exploited basins.

3.0 ENVIRONMENTAL FLOW ASSESSMENT METHODS

There are four types of environmental flow assessment methods: (1) hydrological, (2) hydraulic rating, (3) habitat simulation and (4) holistic methodologies

3.1 Hydrological Methods

These represent the simplest set of methods where, at a desktop level, historical hydrological data daily, 10-daily or monthly flow records are analysed to derive standard flow indices, which then become the recommended environmental flows. Environmental flow is usually given as a percentage of average annual flow or as a percentile from the flow duration curve, on an annual, seasonal or monthly basis. The most common hydrological methods are Tennant and Modified Tennant Method

3.1.1 *Tennant Method*

The Tennant Method (Tennant 1975, 1976a,b), also known as the Montana Method, is one of the oldest methods developed specifically for the needs of fish. It was based on Tennant's 17 years of experience on hundreds of streams, and testing in the field on 11 streams (58 cross sections, 38 different flows) in Nebraska, Wyoming, and Montana. Tennant used empirical hydraulic data from cross-channel transects combined with subjective assessments of habitat quality to define relationships between flow and aquatic habitat suitability. He considered an average depth of 0.3m and velocity 0.25 m/s to be the lower limit (for short-term survival) and an average depth of 0.45 to 0.6m and velocities of 0.45 to 0.6 m/s to be optimal for fish. These levels were obtained at 10% and 30% of the mean annual discharge respectively, in the streams studied by him. Instream flow regimes for fish, wildlife, recreation and related environmental resources, as described in Tennant (1976) are given in Table 1, where flows are expressed as percentages of mean annual discharge (MAF).

Mann (2006) observed that Tennant's original dataset represented low gradient streams (<1% slope), and hence was not applicable to high gradient streams even in the western USA (>1 % slope).

3.1.2 *Modified Tennant Method*

It was quickly recognized that the original Tennant Method may not apply to geographic locations outside the region for which it was originally devised. Various modifications have made the technique more applicable to other regions. Tessman (1980) modified the Tennant method and it resulted in an approach called as Modified Tennant Method or Tessman Method. Tessman (1980) followed it up by considering natural variations in flow on a monthly basis to determine the flow thresholds.

Table 1 : Instream flow regimes for fish, wildlife, recreation and related environmental resources, as described in Tennant (1976)

Description of Flow	**Flow to be released during**	
	April to September	**October to March**
Flushing flow (from 48 – 96 hours)	200% MAF (Mean Annual Flow)	Not Applicable
Optimum range of flow	60-100% MAF	60-100% MAF
Outstanding habitat	60% MAF	40% MAF
Excellent habitat	50% MAF	30% MAF
Good habitat	40% MAF	20% MAF
Fair or degrading habitat	30% MAF	10% MAF
Poor or minimum habitat	10% MAF	10% MAF
Severe degradation	<10% MAF	<10% MAF

Tessman adopted Tennant seasonal flow recommendation to calibrate the percentage of Mean Annual flow (MAF) to local hydrologic and biological conditions including monthly variability in terms of Minimum Monthly Flow (MMF).

Under these changes, the following rules were formulated.

If MMF < 40% of MAF, then monthly minimum equals the MMF

If MMF > 40% MAF, then monthly minimum equals 40% MAF

If 40% MMF > 40% MAF, then monthly minimum equals 40% MAF

where MAF is mean annual flow and MMF is mean monthly flow. Further, a 14-day period of 200% MAF is required during the month of highest flow for channel maintenance.

3.1.3 *Flow Duration Curve (FDC) and Environmental Management Class (EMC) Method*

The flow-duration curve (FDC) is a cumulative frequency curve representing the percent of time during which the average discharge (flow rate) equaled or exceeded a particular value at a given location (Fig. 1).

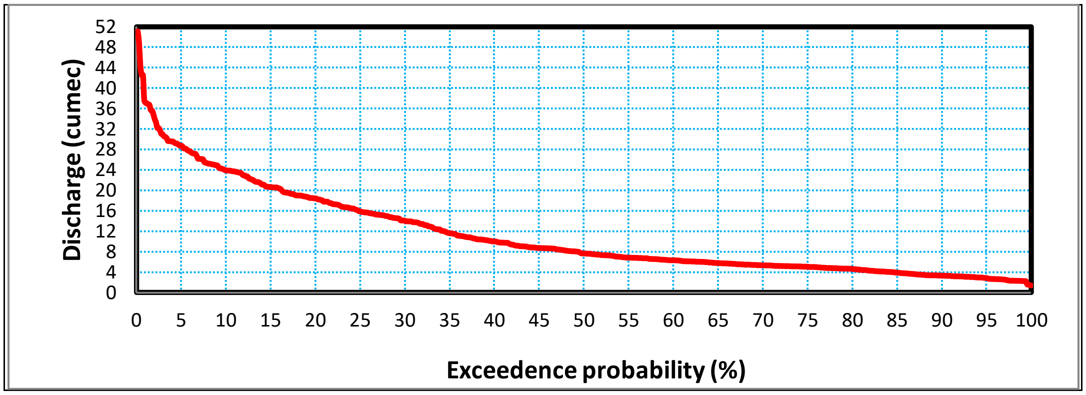

Fig. 1 : Flow duration curve

The FDC may be based on daily, weekly or monthly values of discharge. It is a measure of the range and variability of a stream's flow which is best projected when daily discharge data are used for its preparation. A large number of hydrological indices have been suggested on the basis of Flow Duration Curves by specifying the exceedance percentile or the period of a particular flow level observed over a number of years. Many of these indices were developed keeping in mind the low flow thresholds for allowing surface water abstraction for different uses, especially hydropower, and also for the assessment of effluent discharge limits in receiving streams (Smakhtin and Toulouse 1998). Low flow indices were interpreted later as environmental flows for protecting the fish or other biota.

In the UK, the Q95 (daily flows exceeding 95% of the time) has been proposed as a threshold at which abstraction is either not allowed or is restricted to a certain percentage depending on the season and river type.

In shifting FDC method, mostly, to maintain specific river classes, management and planning authority, decides the quantity of E-flow to be released to maintain a particular environmental management class (EMC) of the river. A river may be classified into six environmental management classes viz. Class A (Natural); Class B (Slightly modified); Class C (Moderately modified); Class D (Largely modified); Class E (Seriously modified) and Class F (Critically modified). The flow-duration curve for that specific month is represented by a table of flow values (percentiles) covering the entire range of probabilities of occurrence corresponding to 17 fixed percentage points: 0.01, 0.1, 1, 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 95, 99, 99.9, and 99.99%. The flow-duration curve developed using the historical data is termed as the reference class. For estimating the Environmental Flow (E-flow) requirement for different categories of EMC, the flow duration curve is shifted by one step, two steps, three steps, and four steps for EMC-A, EMC-B, EMC-C, and EMC-D, respectively.

3.2 Hydraulic Rating Methods

Hydraulic rating methodologies use changes in simple hydraulic variables, such as wetted perimeter or maximum depth, usually measured across single, flow-limited river cross-sections (commonly riffles), as a surrogate for habitat factors known or assumed to be limiting to target biota. Environmental flows are determined from a plot of the hydraulic variable(s) against discharge, commonly by identifying curve breakpoints (Fig. 2) where significant percentage reductions in habitat quality occur with decreases in discharge. It is assumed that ensuring some threshold value of the selected hydraulic parameter at a particular level of altered flow will maintain aquatic biota and thus, ecosystem integrity.

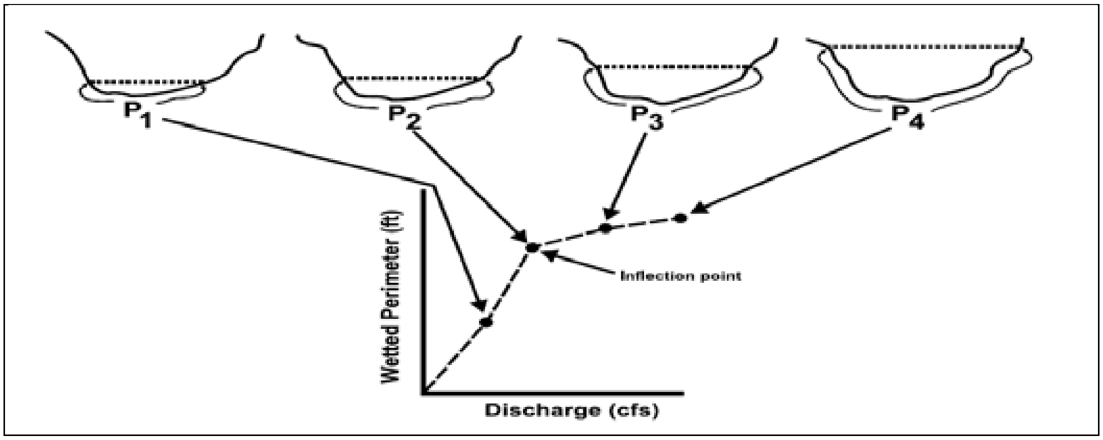

Fig. 2 : Hydraulic rating method for E-flow assessment

3.3 Habitat Simulation Methods

These methods are an extension of the hydraulic methods (Jowett 1989) as they also use the hydraulic conditions, which meet specific habitat requirements for biota, to determine flow requirements (Bovee et al. 1998). Whereas some features of the physical habitat (depth and velocity) are directly related to flow, other features e.g., substrate (river bed material) and cover are indirectly related. These methods use a variety of models to establish relationship between flow regimes and the amount and quality of physical habitat for various species, as well as with other environmental aspects of interest such as sediment transport, water quality and fish passage. These methods differ from the hydraulic methods in the emphasis on quantification of physical habitat using field data from multiple cross-sections to define the hydraulic aspects of species microhabitats along a stream.

3.4 Holistic Methodologies-Building Block Method/DRIFT

The Building Block Methodology (BBM) was developed in South Africa in the 1990s (King and Louw 1998, King et al. 2003), as part of a nationwide program to develop environmental flow recommendations for the country's major rivers. There was a mandate to include aspects of the flow regime that would manage the ecosystem as a whole, not simply one aspect like fish. The basic approach of BBM is to examine the hydrograph as a whole, and through available data and expert judgments determine an overall flow regime that will maintain the riverine ecosystem in some pre-determined desired state. This "desired state" may be different for different streams, such that some streams may be retained in a natural or near-natural state, whereas a considerably altered state may be acceptable for another river that supports a high degree of water use. In a structured, workshop setting, biologists, fluvial geomorphologists, hydraulic modellers, and hydrologists examine the hydrograph and identify the magnitudes, timing and duration of recommended stream flows. At first, the focus is on characteristic features of the natural flow regime of the river, such as degree of perenniality; magnitude of base flows in dry and wet seasons; magnitude, timing and duration of large floods in the wet season; and small pulses of flow that occur at other times. Attention is then given to which flow features are considered most important for maintaining or achieving the desired state of the river, and thus should not be eradicated during development of the river's water resources. Each flow component is a building block of the final environmental flow requirement (EFR), and each is included because it performs an ecological or geo-morphological function. The low-flow component is the first building block, with subsequent building blocks adding essential higher flows at specified times of year. BBM in many respects represents an incremental change to the existing toolbox of assessment methods. Many of the early methods, like some of the early hydrologic standards, were an attempt to formalize the initial building block of low flow protection (i.e., "minimum flows"). Subsequent EFA methods or revisions have recognized additional building blocks, and added methods for determining protective levels of other aspects of the hydrograph, such as geomorphic flows, passage flows, spawning flows, water quality, etc. One of the recognized shortcomings of BBM is that it is prescriptive: a single desired river condition is specified, and the flow regime to maintain it, is recommended (King and Brown 2006). Decision makers considering a possible development such as a dam often prefer to consider several options with different kinds of flow regimes, river conditions, and thus different impacts on people.

In response to this need, the BBM has been expanded in to a scenario-based assessment tool called Downstream Response to Imposed Flow Transformation, or DRIFT (King and Brown 2006). DRIFT allows an exploration of multiple scenarios, and considers socioeconomic effects as well as environmental effects. BBM and DRIFT are not standard-setting methods. However, the methods may have application where proponents wish to deviate from the output of a standard-setting technique, or if there is a need to engage in planning over a larger geographic scale. The BBM is also very useful as a framework for developing an explicit rationale for adherence to a "natural flow regime" approach.

4.0 ENVIRONMENTAL FLOW NORMS IN DIFFERENT COUNTRIES

Extensive work has been carried out in the area of E-flows assessment in many countries, viz., South Africa, Australia, United States and United Kingdom and more than 200 methodologies have been developed to assess E-Flows. Most of the methodologies are based on hydrological methods. A glimpse of the diversity of practices being followed in other countries is given below.

- The French Freshwater Fishing Law of 1984 requires that flows remaining in the river in bypassed sections of rivers must be a minimum of 1/40 of the mean flow for existing schemes and 1/10 of the mean flow for new schemes
- In United Kingdom (UK), Q95 (flow which is equaled or exceeded 95% of the time) should be maintained. Figure of Q95 was chosen purely on hydrological ground.
- USA (Montana Method): Percentages of mean flow are specified that provide different quality habitat for fish, e.g., 10% for poor quality(survival),30% for moderate habitat and 60% for excellent habitat.
- In Greece, at least 1/3 of the average summer flow of the river shall be reserved for environmental flows.
- In Spain, residual flows are to be kept at 10 percent of inter-annual average flow.
- In South Africa, a hydrological index [i.e. coefficient of variation of flows (CV) divided by the proportion of total flow that is base flow (BFI) or(CV/BFI)] is used to assess the E-flow needs.

There is no single best method, approach, or framework to determine the environmental flows. There are many factors such as hydro-meteorological, ecological characteristics of river, dependence of society on the river water as arrived at through the stakeholder consultations at the basin level etc, which are to be considered for adopting appropriate methodology and guidelines for deciding e-flows. Due to a variety of reasons, including the high hydrological variability and difficult tradeoffs between environment and other uses, the practices adopted in other countries for assessment of E-flow are unlikely to be directly applicable in India.

5.0 ENVIRONMENTAL FLOW NORMS IN INDIA

Till early 2000, concept of assessing the environment flow requirement was almost non-existent in the planning and design of hydropower projects and focus was on utilization of available potential. In the name of ecological flow, a provision of 5-10% of minimum flow in lean season was considered to be sufficient for the purpose. First initiative was taken by Government of Himachal Pradesh when they issued a circular during the year 2005 making 10% of minimum lean season flow as mandatory environment release; which in 2009 was increased to 15% of average lean season flow. During the period 2008-09, Expert Appraisal Committee (EAC) for River Valley and Hydropower Projects, has started emphasizing on the need of environment release downstream of the diversion structure. EAC recommended, 20% of average lean season discharge (4 leanest months) in 90% dependable year to be released as environment flow and since 2008-09, this has almost become the norm during the planning of hydropower projects. Norm became acceptable and fixed environment flow was considered to be released throughout the year irrespective of the inflows. During the next 2-3 years, concept was developed further requiring site specific studies and focus was also shifted to the varied environment flow release during the year. Lean season environmental flow requirement was kept as 20% of average flow of four leanest months in 90% dependable year; monsoon season (4 months) as 30% of inflows in 90% dependable year and other months i.e. pre-monsoon and post monsoon period as 20-30% of inflows in 90% dependable.

6.0 ENVIRONMENTAL FLOW ASSESSMENT FOR REACH OF RIVER GANGA BETWEEN HARIDWAR AND UNNAO

For environmental flow assessment, a combination of hydraulic rating methodologies and habitat simulations have been used. The primary reason for applying this method is its objectivity, availability of data including river cross-sections and better applicability to quantify the environmental flow in a scientific manner. In the reach of river Ganga between Haridwar and Unnao, discharge of river Ganga is being observed by CWC at Garhmukteshwar and Kachhlabridge G&D sites. Garhmukteshwar G&D site is located between Bijnor and Narora barrages, about 80 km downstream of Bijnor barrage. Kachhlabridge G&D site is located about 60 km downstream of Narora barrage. An index map of the study river reach on Google Earth showing the locations of barrages and G&D sites is presented in Fig.3.

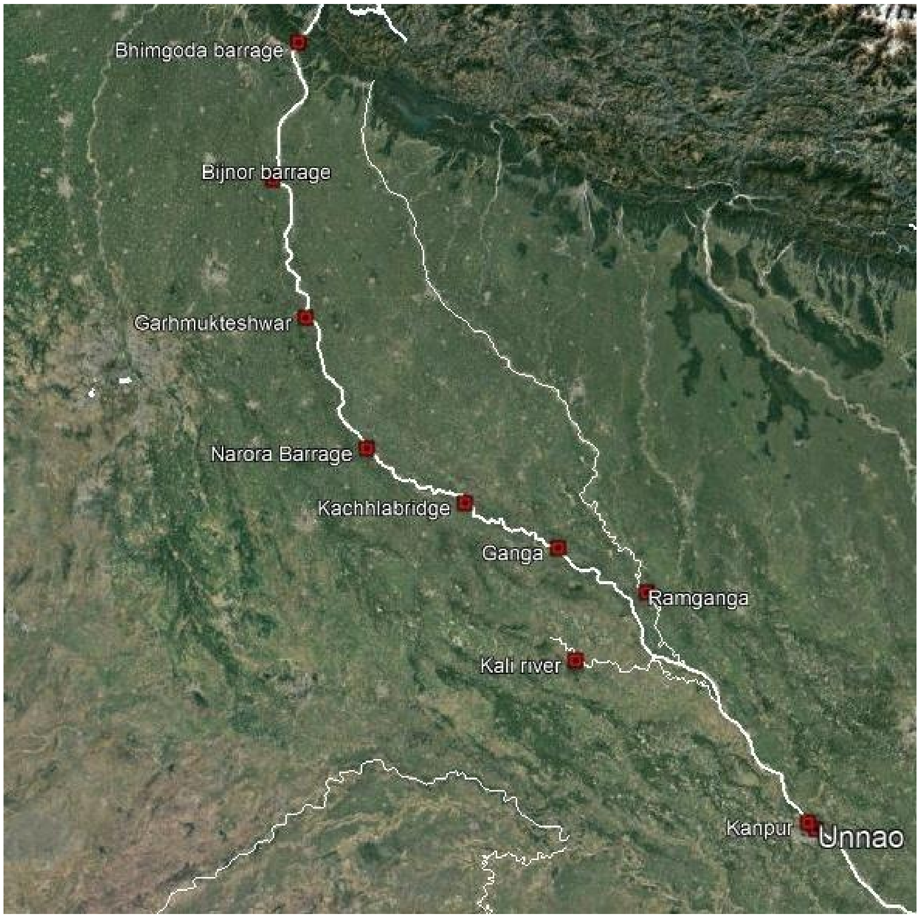

Fig. 3 : Reach of river Ganga between Haridwar and Unnao depicting locations of barrages and G&D sites

6.1 Data used for the Present Study

For environmental flow study, flow, river geometry and habitat parameters are the key data. Furthermore, in the present case water is also being diverted from a number of locations for consumptive uses from the reach. Hence, inflow, diversion and release data at various diversion sites along with their command area is required and the same has been collected from the Govt. of Uttar Pradesh. A list of data used for the study is given below:

- 10 daily discharge data of river Ganga at Garhmukteshwar and Kachhlabridge G&D sites
- Inflow, diversion and release data at Bhimgoda, Bijnor and Narora barrages
- Command area of Upper, Middle and Lower Ganga Canals
- 4 to 5 cross sections of river Ganga at Garhmukteshwar, Kachhlabridge and Kanpur to represent a river reach of about 1 km.

6.2 Flow patter analysis

In order to estimate the base flow contribution in the reach of river Ganga between Haridwar and Unnao, a flow pattern analysis of flow released from barrage and flow observed at CWC G&D sites has been carried out.

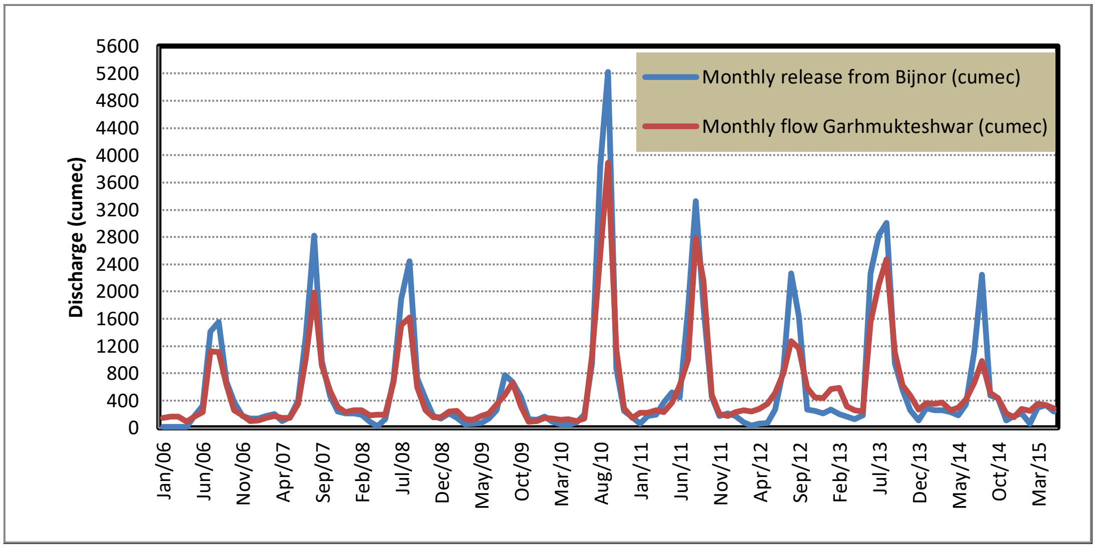

Fig. 4 : Release from Bijnor barrage and flow observed at Garhmukteshwar G&D site

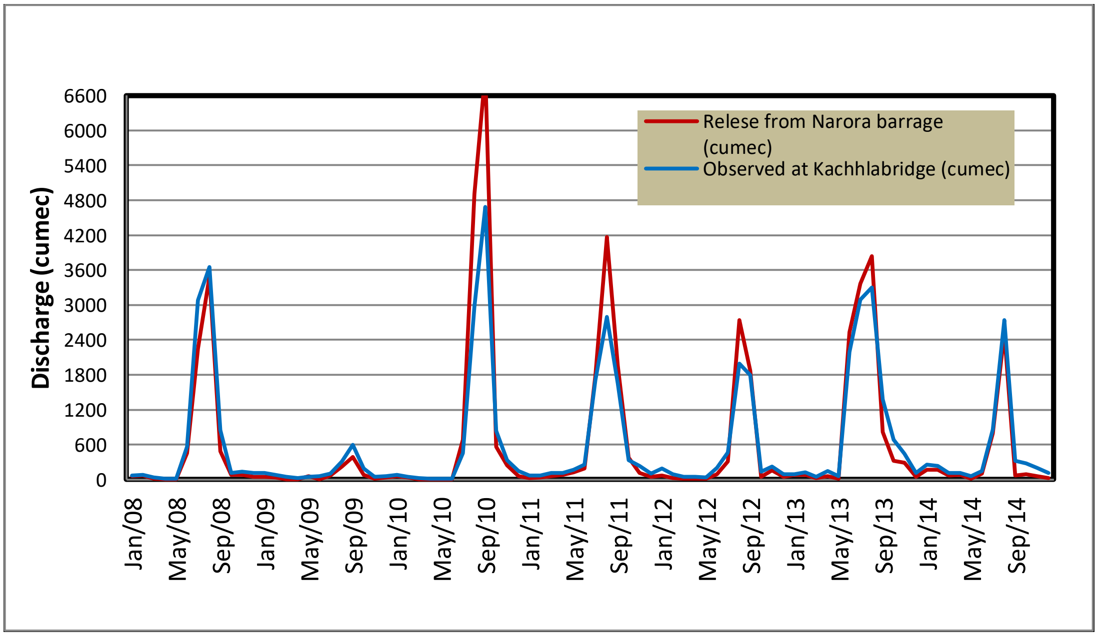

Fig. 5 : Release from Narora barrage and flow observed at Kachhlabridge G&D site

From the flow pattern analysis it was observed that in general the reach of river Ganga between Haridwar and Kanpur is of effluent nature, where ground water contribution to base flow during the lean months and return flow from the command are able to augment the lean season discharge in the river up to some extent.

6.3 Habitat parameters

Habitat parameter for the study river reach was supplied by CIFRI, major fish species contributing to the fishery below:

Species	Weight range	Depth (Lean period)	Velocity
Labeodyocheilus	30-800g	60-80 cm	0.8-1.5m/s
Labeodero	94-563g		
Cyprinuscarpio	120-563g		
Schizothoraxrichar-dsonii	80-500g		
Crossocheiluslatius			
Botialohachata	10-175g		
Bariliusbendelisis			
Tor putitora	30-800g		

To quantify the environmental flow requirements a depth of 0.90 m has been considered in monsoon months to mimic the natural flow conditions. Further, the flow parameters have been studied taking the representative river reach of 1 km at a few locations, where the undulations in river bed profile may not be captured. Hence, to account for undulation in bed and uncertainties in flow parameter, a further margin of 10 cm has been considered. Hence, E-Flows assessments have been made for a depth requirement of 0.70 m during the non-monsoon months. From the analysis of flow data, it has been found that considerable quantity of water is getting released from all the barrages during the monsoon months (June to September). However, to quantify the E-Flows requirements a depth of 0.90 m has been considered in monsoon months to mimic the natural flow conditions.

6.4 Assessment of hydraulic parameters for different flow conditions

Hydraulic parameters viz depth of flow, topflow width, flow velocity etc have been estimated using hydrodynamic simulation on HEC-RAS at three different locations where surveyed river cross sections were taken. HEC-RAS model set up at Kachhlabridge is presented in Fig.6 for the illustration. Similar model were set up at all other locations.

Fig. 6 : HEC-RAS Model Set up at Kachhlabridge

From the simulation results plot of discharge vs depth were prepared. Plot of Discharge vs depth at Kachhlabridge and Garhmukteshwar are shown in Fig.7 and 8 respectively.

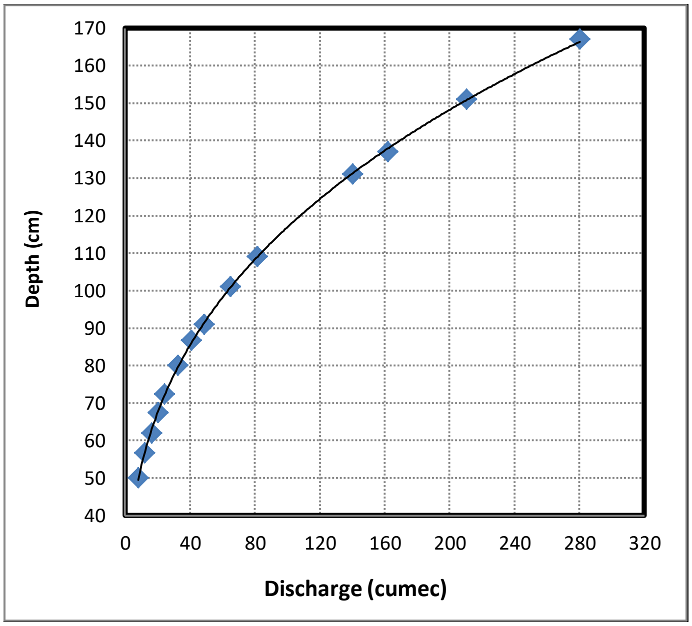

Fig. 7 : Plot of Discharge vs depth at Kachhlabridge

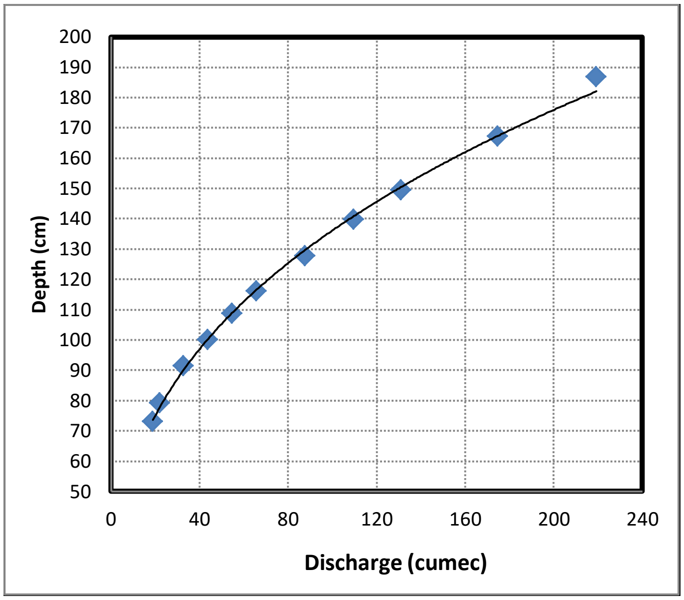

Fig. 8 : Plot of Discharge vs depth at Garhmukteshwar

6.5 Study outcome

From the study it was found that a minimum release of 36 cumec (1270 cusec) from Bhimgoda barrage and 24 cumec (850 cusec approx) from Bijnor barrage shall suffice the E-Flows during non-monsoon months (November to May). During the monsoon months the minimum release from Bhimgoda and Bijnor barrages should be ensured as 57 cumec (2000 cusec) and 48 cumec (1700 cusec approx) respectively. A minimum release of 24 cumec (850 cusec) during the non monsoon months (October to May) and 48 cumec (1700 cusec) during the monsoon months (June to September) should be ensured downstream of Kanpur barrage to meet the environmental flow requirements.

6.6 High flows to connect with flood plains

Environmental flows regime is not only low flows, it is also concerned with high flows which establish connectivity between the river and flood plains. It is seen that high flows at various places in the river are; 2600 cumec at Haridwar, 2800 cumec at Bijnor, 2800 cumec at Garhmukteshwar, 2800 cumec at Narora, and 2400 cumec at Kachlabridge. These flows stay for about

15 days or more. Analysis of data by using HEC-RAS shows that during these periods, the top width is about 400 m or more and the flow inundates flood plains. Thus, the connectivity between the river and flood plains is maintained satisfactorily.

7.0 CONCLUSION

Protecting and maintaining river flow regimes and hence the ecosystems they support by providing adequate environmental flows should be a critical aspect of planning of River Valley Projects. For assessing environmental flow requirements, different methodologies like hydraulic rating methodologies, habitat simulations or micro-habitat modeling methodologies along with desktop methods based on hydrological data like Environmental Management Class (EMC) etc. are available. The choice of methodology depends upon the objective, availability of data including surveyed river cross-sections and the timeframe available for the study. The hydraulic rating cum habitat simulation methodology can be considered one of scientific approach to quantify the E-Flows.

Further, in case of river stretches especially the higher elevation reaches where there are no fishes (fishless zone), it does not imply that E-Flows requirements in different seasons are not necessary. The river in these reaches performs certain essential ecological functions with high biological productivity. There is specialized flora that grows along the banks of rivers known as the river's riparian zone. These riparian zones are critical to the health of the rivers. Often, the greatest contributor of plant food for riverine fauna is the riparian zone filled with vegetation along the margins of the streams. These plants loke others, shed their leaves, which fall into the stream. This is allochthonous matter (from outside the stream), as opposed to autochthonous matter (from inside the stream, like algae and diatoms). These leaves being dead are unable to provide oxygen, but they are a source of food to the aquatic life in the stream. Not only the leaves, but also the bacteria or fungus covering the leaves are food for aquatic life. Riparian plants also carry bugs on them, which falls into the stream and are added food source to stream dwellers. In the absence of wetting of this riparian vegetation, the entire food chain gets disrupted, leading to disappearance of riparian vegetation as well as the possibility of growth and survival of even minimal populations of fish.

Disclaimer : The views expressed in the paper are purely personal and not necessarily the views of the organisation.

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BIOGRAPHICAL DETAILS OF AUTHORS

N. N. Rai is a graduate in Civil Engineering from KNIT, Sultanpur. He obtained his Masters in Hydrology from IIT, Roorkee. He is recipient of Merit Award of Central Water Commission and Vice Chancellor Gold Medal of Avadh University. He has over 26 years of experience with Central Water Commission and currently working as Director of Hydrology with focus of hydrological and hydrodynamic studies of River Valley Projects. He has carried out hydrologic and hydrodynamic analysis for more than 200 river valley projects for Water availability study, Design Flood estimation, dam break studies, Glacial lake outburst flood studies, back water studies, reservoir sedimentation profile studies, surge analysis, reservoir and channel routing studies. He is overall incharge of Design Flood review of projects under DRIP-II and more than 350 design flood review studies of River Valley Projects were completed by his team in last 3 years. He has been using appropriate techniques and models such as; HEC-HMS, HEC-GeoHMS, ARC-GIS, ILWIS, HEC-RAS, HEC-GeoRAS, HEC-RAS2D and MIKE11 software. He is one of the very few experts who have evolved the methodology for Glacial Lake Outburst Flood estimation and carried out number of studies including a very detailed analysis of Uttarakhand flood of June 2013, J&K flood of September 2014, Kerala Flood of 2018, Flood storage estimate of Ganga and Brahmaputra basins. He made significant contribution in Environmental flow estimation for proposed river valley projects in Siang, Subansiri, Himalayan Ganga sub basins and reach of river Ganga between Haridwar and Unnao using hydraulic rating cum habitat simulation techniques. He represented CWC as an expert member of Hydrology in EAC of MoEF&CC. Played key role in publication of PMP Atlas and several guidelines published under DRIP. He has delivered a number of lectures on hydrological, hydrodynamic and environmental flow modeling for CWC, IIT Rookee, NIH, NHPC, CBIP, NTPC and Water Resources Departments of State Governments. He has authored more than 33 technical papers in the field of hydrological and hydrodynamic studies, Environmental flow estimation in journals, National and International Conferences.