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ENVIRONMENTAL FLOWS ASSESSMENT: A REVIEW

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ABSTRACT

The present paper reviews the basic concept of environmental flows (EF) and its assessment. Review on initiation of EF concept and modifications in it with course of time are described comprehensively. The paper introduces the circumstances, which has prompted EF term to be evolved and then elaborates on changing ideas, concept, nomenclature and definition. The various methodologies available in literature for environmental flow assessment on the basis of classification developed since early times are also highlighted. The methodologies include prescriptive and interactive categories and further reclassification of these categories. At the ending excerpts, it incorporates the opportunities and threats for environmental flow assessment.

Keywords: *Environmental Flows Requirement, Environmental Flows Assessment, Riverine Ecosystem, Flow Duration Curve*

INTRODUCTION

The surge of population growth and stimulus industrial development in last 50 years instilled the unprecedented water demand in the developed and developing countries. The scientific effort to fulfil this vast water demand resulted in evolution of in-situ and ex-situ water harvesting structures and techniques. Although, the current water problem of this large population have been solved with water abstraction through dam and dug- out water storage structure, but the new and unidentified as well as difficult problem of water resource ecological deterioration has aroused. After the vigorous review and analysis of this problem, various hydrologists and water resource engineers came forward to recognize and understand this complex problem up to certain extent. In this initial situation, the main focus was on the release of minimum flow to ensure the protection of individual aquatic species like trout, etc. After the subsequent studies conducted for the better understanding of behaviour of different component of riverine ecosystem, in 1990s scientists and water resource engineers insisted own selves on this world dilemma and presented the concept of single minimum flow requirement before the world forum. This term, although, is referred as minimum amount of water reserved for sustenance of biological diversity and ecological atmosphere of riverine regimes, but various countries had defined it in different ways according to the physical and environmental as well as social and hydrological requirement of corresponding region. In Brisbane declaration (2007) in which 142 countries had participated, the term Environment Flow was defined in an appropriate manner, which was to be maintained by all member countries (Subramaniam, 2013). Accordingly the environmental flow is defined as the quality, quantity and timing of water flows required to sustain freshwater and estuarine ecosystem and human livelihood and wellbeing that depend on this ecosystem (World Bank, 2007)." Apart from this, several terms used in this manner in different countries are bypass flow, escapage, minimum flow, In-stream flow, environmental allocation, ecological reserve, natural flow, surplus flow, compensation flow, etc.

There are differential stances of various countries in amount of reservation of environmental flow. Nevertheless, in general sense 95% dependable flow of flow duration curve (FDC) is recognise as minimum environmental flow at global context. In India, the technical difficulties and data shortage kept reluctant the environmental scientist to do more effective in field, but in recent decade's hydrologist intelligentsia has been too active and proposed valuable and rational hydrological based methods suitable for Indian condition in various research studies. In addition ,supreme court guideline to all hydro water project inhibiting in India to release minimum 10 m^3/s of water as minimum flow for ecological sustainability as par maintain general water demand from water resource system in 2003, was forwarding endeavour in administrative correspondence also. In our contingent region; Nepal, the minimum EF is 10% of minimum flow of average annual flow (AAF) or monthly minimum flow (MMF) series, which appears robust technological advancement in hilly region in this regard.

The methods used for environmental flow assessment (EFA) are many in literature. Due to plethora of existing EFA approach, theses have been classified in different categories in course of time. So far 11 Indian Rivers has been categorized as "strongly affected by fragmentation and regulation (Nilsson et al., 2005)", which has resulted into severe degradation of the river ecology. Hence, it is necessary to modify the ecology for sustaining the biodiversity within the flow regime by maintaining and releasing the appropriate environmental flow. Therefore, the present study is proposed to gather details of various available environmental flow assessment (EFA) methods and to recommend valid method in Indian River basin.

PREVAILING METHODS OF ENVIRONMENTAL FLOWS ASSESSMENT (EFA)

Hydrological Approach

Although there is no direct relationship between hydrological and ecological characteristics of any river basin, yet somewhat indirect relationship exist in two. Therefore discharge time series or hydrological data series for at least 20

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years is used for calculation of EF. So, this method is called as hydrological approach.

Tenant Method (Montana Method)

This method is initially developed for protection of trout; a fish species, in mid-West USA in 1975. This method is in the form of look up table which provide "minimum flow" in the form of percentage of Mean Annual Flow (MAF) for set of 7 levels of eco-status of river (Tennant et al., 1976). Even though this method is best suited for developed countries like USA where the hydrological and ecological characteristics of river are well studied and well understood and region-specific, but in developing countries where adequate data is in scarcity, suitability of the method need to be ascertained. Tenant method is not reliable method for planning purpose. Tenant methods proposes the value of minimum environmental flow and optimum environmental flow as equal to the 10% and 60-100% of mean annual flow (MAF) respectively, whereas for outstanding, excellent and good habitat condition it recommend the percentage of environmental flow differs with seasons (Tennant et al., 1976). Also look-up table which initially developed for USA is not utilisable everywhere and need certain medication based on location parameters. In this process, long time is required, thus leading to time constraint in this method. Besides time constraint, Tenant method involves numbers of limitation like region specificity, approximate value, and implicit relationship between hydrological and ecological characteristics of river ecosystem, etc. The EF can be estimated using MMF (mean monthly flow) or MAF (mean annual flow), or mean 10-daily flow series. However, EF estimate based on 10-daily flow series is most suitable approach as it reflect most precise and adequate variability in EF (environmental flow) series vis-à-vis 10-daily flow series. The percentage of EFR reduces with degradation in habitat condition and flow regulation in riverine ecosystem. EF variability with respect to time decrease with degradation in habitat condition and flow regulation in riverine ecosystem. In this method, the microhabitat and microhabitat condition which implies ecological characteristics of riverine regime is presented by the environmental management class or category (EMC). The major limitation of this method in non-inclusion of intra-annual and inter-annual variation in flow series.

Modified Tennant method

This is modified version of Tennant method, where spatial restriction could be resolved up to extent after having requisite modification. Like the Tennant method, in Tressman method also, the value of EF is fixed percentage value of MMF and MAF. This method does not show even seasonal variability. The values of EF changes with changing the hydrological flow regimes. Accordingly, the EF is calculated throughout the year. In this method, if mean monthly flow (MMF) is less than 40% of mean annual flow (MAF), then EF is taken as equal to MMF, whereas for MMF equal to or greater than 40 % of MAF, EF is taken as 40% of MAF. It is modification of tenant method where there are spatial restriction on use of this method other than in area where it was originally evolved. In essence, this method can be used anywhere with requisite modification. It is based on the mean monthly flow (MMF), and also considers mean annual flow (MAF), thereby reflecting inter-annual and intra-annual variation in EF series simultaneously, which was main drawback of Tennant method. Therefore, this method provides more variable EF series than Tennant method. Besides this method removes the spatial restriction problems exhibiting in previous tenant method and provides more accurate and precise value of EFR.

Modified Tennant method for multi-habitat condition (MTMMHC)

In a recent study conducted by Li and Kiang (2014), it has been said that modified Tennant methods can be categorised in three categories on the basis of inclusion of inter-annual and intra-annual variability in flow series during estimation of EF. The proposed three modifications in Tenant method; Modified Tennant method for multi-habitat condition (MTMMHC)-I is estimation of EF based on average annual flow (AAF), which rarely exhibits extreme and intra-annual and inter-annual variability in environmental flow regimes, while MTMMHC-II is EFA based on average annual flow series and aimed at year-to-year and rich-to-poor flow variability . It takes into account the monthly and inter-annual flow variability. Yet, this method does not incorporate the intra-monthly or daily variability in EF regimes. MTMMHC-III is solution of challenges occurs in both method prescribed above. In additon, it takes in consideration the spatial and temporal variability as well as scalability of EF regimes obtained from this method. In others words, the EFR changes with respedt to changes in hydrological regimes in ecosystem. For purpose of including temporal variability in EF series, the flow seires is devided in wet years, drought year and normal years using 25% and 75% dependable flow. If MMF or tendaily flow series is less than 25% depnedable flow then , the year, which MMF or tendaily flow series seires is involved in, is categorised as wet year, while If MMF is less than 75% depnedable flow then , the year which MMF seires is involved in, is categorised as drought year and if If MMF or tendaily flow series is between 25% and 75% depnedable flow then , the year which MMF seires is involved in, is categorised as normal year.For purpose of presenting spatial varibaility in EF series, this method takes 50% dependable flow as optimal EF and 90% dependabel flow as minimum EF or low flows or minimum flows. The EF from minimum flow to optimal flow is assumed to be in arithmatic progeression. The classifying numbers between minimum EF and optimal EF is caulculated using following formula:

nij=ROUND{(5/9)*[($\boldsymbol{Q_{50}(ij)}$−$\boldsymbol{Q_{90}(ij)}$)/($\boldsymbol{0.1*Q_{50}(ij)}$)]-1}

n_j=MODE(n_{ij})-1

here , i= months (from jan to dec)

j= year (normal , wet or drought year)

The scalability for large rivers is involved in obtained EF series using the following formula instead of above used -

$$\frac{Q_{90}(ij) + (n-1)[Q_{50}(ij) - Q_{90}(ij)]}{9} = E_n(ij)$$

Here, n=1, 2, 3, 4,5 …….10

E_1, E_2, E_3, E_4, E_5 = lower bound EF

E_6,E_7,E_8,E_9,E_{10} = values of optimal EF

It is Latest method ever been used for EFA which take into account the spatial and temporal variability of flow regimes. In contrast to previous hydrological methods, it also considers the intra-annual and inter-annual variability in flow regimes of riverine ecosystem (Li and Kiang, 2014). Due to its generalized form, it can be used at any river ecosystem either having good or poor habitat condition. In other words, it makes decision on choosing EMC on basis of hydrological flow series. It takes less time as compared to other available technical methods. It is somewhat combination of hydrology and statistics i.e. stochastic hydrology, thereby no shortcut - model or software is available for EFA by this method, whereby makes it complicated and require more data interpretation and data handling capability.

Range of Variability Approach (RVA)

Originally, Richter et al. (2006) has developed this method after incorporating 32 hydrological parameters which jointly reflect different aspects of flow variability (magnitude, frequency, and timing of flow) estimated from natural daily flow time series at a site of interest. Later it has been recalibrated by the National Institute of Hydrology (NIH), Roorkee for Indian River basin (Jha et al., 2008). It is mandated that in modified (ecological acceptable) flow regime, all 32 parameters should be maintained within the limits of their flow variability. For each parameter, a threshold value of one standard deviation from the mean is recommended as default limit for setting EF target. For pilot EFA, monthly flow time series can be used instead of daily. Thereby, amount of these parameters and stepwise procedures for these parameters can be limited. This method would effectively lead in situation in data-deficit condition. This is why; this approach is more suitable in Indian context.

On basis of above study, RVA approach has further been applied at Brahmani and Baitrani river basin in order to check the region specificity of methodology (Jha et al., 2008). In this study 32 parameter of mean and SD of 1-day, 7-day and 30-day flow duration curve was determined and in addition ,Q95 for 1 year,2 year, 5 year, 10 year, 20 year, 50 year and 100 year are also calculated. Maxima and minima value of these derived parameters are plotted and according to difference between two, values of EF are calculated. Later, a study in Nepal has reduced number of parameters from 32 to 16, using 27 years return period and 1-day, 7-day, 30-day and 90-day flow duration curve.

HYDRAULIC APPROACH

The Hydraulic Rating Method (Tharme et al., 2000) is one of the method for environmental flow assessment, where hydraulic approach is considered. This method uses the relationship between wetted-perimeter and discharge, depth and velocity to set minimum discharges for fish production and rearing. The resulting recommended discharges are based on the inflection point on the wetted perimeter vs. discharge, which are assumed to represent the maximum habitat for minimum flow before the next inflection point. This has been observed that relationship between wetted perimeter and discharge used to recommend suitable habitat are based on general principal, but are not proven to be relevant to the fish of a particular river (Tharme et al., 2000)

ECOLOGICAL APPROACH

The ecological approach in environmental flow assessment is considered in the In-Stream Flow Incremental Methodology (IFIM) - Habitat Simulation Methodology (Oldest Method) (RE Tharme et al., 2003). IFIM is used to evaluate the effects of incremental changes in discharge on channel structure, water quality, temperature, and availability of suitable microhabitat for selected target aquatic species. Both microhabitat and macro habitat are assessed for specific species. Microhabitat is the small physical area in any place in a river that is directly relevant to the species being studied. The availability of suitable microhabitat over a range of flows is modelled using PHABSIM II (Physical Habitat Simulation Model-II). PHABSIM II predicts; how the water depth, water velocity, and riverbed features change with changing flow, and thus their changing suitability for the chosen species. The model was designed for fish habitat. The microhabitat suitability is not qualified unless macro habitat component i.e. water quality and temperature, have been proven to be suitable. That is why even the physical microhabitat requirements are met, yet some fish species will not breed if the correct water temperature and flow cues are absent. Eventually, the suitable habitat for particular species over a period of changing flow is modelled in the form of time series.

A partial study for assessment of microhabitat variability and macro-habitat variability has been carried out in Western Ghat region using PHABSIM modelling (Arunachalam, 2000).

COMBINATION OF HYDROLOGICAL AND ECOLOGICAL APPROACH

There are some of the methodologies for environmental flow assessment where both hydrological and ecological approach is followed.

Catchment Abstraction Management Strategies (CAMS)

This procedure is developed by UK environment Agency in 2001. This procedure is carried out in two stages. In first stage, the environment management class (EMC) is defined based on 4 parameter i.e. physiographic, fisheries, etc. Thereafter, in second stage, target FDC is achieved. Then based on EMC (known in first stage), the EF is determined using 95

Desktop Reserve Model (DRM) (Hughes and Hannart, 2003)

The most advanced of existing hydrology- based approach used to determine the ecological reserves in South Africa, is developed by Hughes & Munster (2000) and further modified by Hughes & Hannart (2003). In this approach, Ecological Reserves determination involves the determining of volumes and discharge of EF to sustain a river in predetermined condition. In this method, Environment Management Category or Class (EMC), or level of ecological protection (LEP), is defined from to Class A to Class D, based on how much present condition deviates from the natural condition. While Class A is for largely Natural River, then Class D for largely modified or regulated river. These EMCs are determined by using appropriate scoring system based on a number of indices related to river importance & sensitivity. The DRM originates from BBM. The DRM uses similar BBs and is rapid and low-confidence EFA approach. The DRM was based on extrapolation of higher confidence EWR determination (with special input from ecologist and geo-morphologist) using hydrological characteristics of the river flow regime. The DRM, therefore, explicitly introduces the principle of 'assurance of supply' into EFA. The estimated BBs are then combined into a time series of EF using a set of assurance rules and the natural flow time series. One additional advantage of the DRM is that it is originally based on monthly flow data which are more readily available or accessible in developing countries like India.

Major deadlock for direct DRM application in other countries is regional DRM parameters that are used originally in model for South Africa, is not readily available in developing countries including India. Therefore, DRM model can be used only with proper calibrations according to region.

A case study conducted in Great Ruaha River basin in Tanzania using DRM approach where flowing in dry season is ceased completely because of social conflict between upstream and downstream users , disrupting appropriate habitat condition and thus, causing change in their behaviour. The maintenance low flows has been found out 15.9% MAR and maintenance high flows 5.8% of MAR (Kashaigili et al. 2007).

Building Block Methodology (BBM) (King and Louw, 1998)

This approach considers both physical (hydrology, physical habitat and chemical water quality) and biological (vegetation, fish and macro invertebrate) parameters for water resource system. For each of the above discipline, all available data are synthetically generated and new data are collected from only necessary sites. Physical field measures includes surveying of cross-section at concerning sites along the river, then a relationship between flow ,and depth , velocity and area of inundation ,is developed. Whereas, Biological field measures include surveying from which correlation between aquatic species and flow in the river with time can be developed. The specialist then reach consensus on a modified flow regime that would achieve a desired condition. Building Blocks' (BBs) are environmental flows, which jointly comprise the ecologically acceptable, modified flow regime. These BBs are defined for every month of calendar year and are categorized between 'normal years' and 'drought years'. The BBs for normal years are known as 'maintenance requirement' and those for drought year are known as 'drought requirement'. Thus, the set of BBs include 'maintenance low flows', 'maintenance high flows', 'drought low flows' and 'drought high flows'. It can be used in both data-rich and data-poor condition.

HOLISTIC APPROACH

Expert Panel

The composition of the expert panel will depend on the specific environmental and social characteristics of the river of interest, but typically include a hydrologist, geo-morphologist, aquatic botanist, and fish biologist. Collective expertise of all is used in determination of EFR. (Arthington and Tharme, 2004).

Holistic Approach

This method is the integration of all existing procedures to secure better output that none could have produced individually. This approach were developed in the southern hemisphere, because the northern hemisphere methods are confined to only individual target species i.e. commercially valuable, so not effective to manage health of whole river ecosystem (Tharme, 2003).

Downstream Response to Imposed Flow Transformation (DRIFT) (Newest Method)

This method is developed during assessment of EF for the Lesotho Highlands Water Project in South Africa. For instance, PHABSIM II could be used by the fish biologists to model changes in fish habitat arising from medium-level floods that affect in-stream fish habitat. DRIFT also uses data on cultural and subsistence use of the river to predict the socioeconomic implications of river change (Arthington et al., 2003).

Similar study was done on Lower Zambezi River and Delta, Mozambique for environmental flow assessment using DRIFT method (Richerd and Brown, 2010). In this study, the hydrological characteristics of river basin has been divided into 3 categories; dry season low flows, The 'annual' flood, 1:5 year return 'extreme' flood. Thereafter, hydropower lost for respective flow generation i.e. flow change, is plotted with respect to the integrity score i.e. 0-5. After analysing this plot, the optimized flow regime has been came out in combination of; One of six levels of change in the dry season low flows (present day plus five changes), one of 19 levels of change in the annual flood (present day plus 18 changes), One of two levels of change in the 1:5 year flood (present day and one change), The remainder of the flow regime at present-day levels.

PROBLEMS OF ENVIRONMENTAL FLOWS ASSESSMENT UNDER THE INDIAN CONTEXT

- No generalized methods are available.
- Methods are data-intensive and time consuming.
- Infancy of data, expertise and technical knowledge in developing countries including India.
- Non-availability of hydrology-ecology empirical relationship.
- More scientific and logical approaches are unavailable.
- Inter-state water disputes.

SCOPE AND SUITABLE METHOD FOR EFA IN INDIAN RIVER SYSTEM

Keeping in view different problems already described above, data-intensive and complicated methods such as hydraulic and holistic methodologies would not be suitable in Indian context as data required for river habitat simulation or determination are mostly not available for most of the locations. Moreover, available models reported in literature for estimation of physical habitat have been developed in specific region using regional parameters which vary from region to region. Thus, suitability of these models need to be ascertained in Indian context before these could be used. Hydrologic methods such as Tennant method, Tressman method, FDC method are simpler and easily accessible methods and their utility in Indian River ecosystem needs meagre modification in original look-up table values. Above all, MTMMHC-III which also falls under hydrological method category, is seems to be promising and efficient method in riverine ecosystem. Other methods for environmental flow assessment like Range of Variability Approach, also need more time and expertise, as well as this is efficient method and gives most appropriate value of EF among all hydrological approaches.

CONCLUSION

The EF concept is in a state of infancy and different concepts and hypothesis are under developmental stage. It has not achieved significant growth in India due to lack of willingness, technical inefficiency, data shortage and political imbroglio. Yet, in recent times there has been considerable understating on basic nature and importance of it among the environmental scientist and hydrologist. The dilemma of situation is coordination between water resource engineer and environmental conservationist. These deadlocks will not be resolved unless hydrological and biological approaches are integrated. It is common belief that releasing more EF reserve may improve habitat condition in riverine ecosystem of inhabiting species however, growth and survival of human beings are also linked with availability of water. Therefore, there is a need to establish a balance between requirements for inhibiting species and human beings. Development and testing of simple and less data demanding methods should be undertaken for developing a broader and area specific understanding of EF requirements. Recently proposed modified tenant method for multi habitat condition (MTMMHC)-III is most appropriate and efficient method for EF release. Desktop reserves model (DRM) (Hughes and Hannart; 2003) is globally effective and most adequate method for quick and timely estimation method of EF, even in data scarce situation.

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