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Maintaining the Environmental Flow Requirement's of a River to sustain It's Ecological Balance: A Challenge

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Water has been over-exploited by the human society, which has not only drained the vital river resources but has also exhausted of the ancient aquifers that are hard to replenish. The flows of the world's rivers are increasingly being modified through impoundments such as dams and weirs, abstractions for agriculture and urban water supply, drainage return flows, maintenance of flows for navigation, and structures for flood control. These interventions have caused significant alteration of flow regimes mainly by reducing the total flow and affecting the regime and seasonality of flows. It is estimated that more than 60 % of the world's rivers are fragmented by hydrological alterations.

Environmental flows describe the quantity, quality and timing of water flows required to sustain riverine ecosystems and the human livelihoods that is dependent on these ecosystems.

It is a great challenge for water manager's to account for natural differences in flow regime among rivers, understanding the importance of environment flow for the protection of freshwater biodiversity, estuarine ecosystems and maintenance of services that rivers provide. In the absence of detailed information of environmental flow requirements for rivers, it is proposed that a generic approach to be ascertained that incorporates key aspects of natural flow regime for the rivers, which can be validated with empirical biological data and other information. It is assumed that such approach can narrow up the gap between simple hydrological "guidelines" and more comprehensive "environmental flow requirements".

Keywords: Environmental flow, Riverine ecosystem, Estuarine ecosystem.

1. INTRODUCTION

Most of the rivers are excessively exploited to fulfill ever increasing demand from power, agricultural, industrial and municipal sectors. Damming of rivers or tributaries is the root cause of river obstructions causing severe modifications and perturbations to the river flow, velocity, depth, substratum, pools, ecology and fish habitats.

Each river system has an individual flow regime with particular characteristics such as seasonal pattern of flows, timing, frequency, predictability and duration of extreme events (e.g. floods and droughts), rates of change and other aspects of flow variability. Each of these hydrological characteristics has individual as well as interactive regulatory influences on the biophysical structure and functioning of the river and floodplain

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ecosystems. Deviations from natural flow regime result in drastic change in the riverine ecosystems and estuarine structures in the downstream.

Disruption of the natural flow regime can alter the entire river ecosystems and socio-economic activities that depend on them. The assessment of water requirements of freshwater-dependent ecosystems represents a major challenge due to the complexity of physical processes and interactions between the components of the ecosystems.

There is now a general acceptance for best interest of the society's rivers should be considered as legitimate "users" of fresh water [1,2]. However, the affirmation that rivers need adequate water of good quality to sustain ecological processes and associated services is not new. Methods developed to ascertain the minimum "in-stream flows" to sustain fish appeared in the United States in the late 1940s. With rise in concern about the impact of dams and flow regulation on river biota, more than 200 methods were developed for “minimum flow” or the "environmental flows" which can be grouped into four categories: hydrological rules, hydraulic rating methods habitat simulation methods, and holistic methodologies [3,4]. There is now general consensus amongst the water manager’s that to protect freshwater biodiversity and maintain the essential ecosystem provided by rivers, we need to introduce the components of natural flow regime along with the magnitude, frequency, timing, duration, rate of change and predictability of flow events (e.g. floods and droughts), and the sequencing of such conditions.

The natural flow concept has been accepted with an expectation that ecologists can easily provide specific environmental flow guidelines for maintaining the riverine ecosystems but translating general hydrologic-ecological principles and knowledge into specific guidelines for particular river basins and reaches still remains a challenge [5].

The question which haunts us all is: "To what extent the flow regime of river can be changed before the degradation of ecosystem begins”. In an effort to provide immediate answer for the minimum flows for river ecosystem, some scientists are returning to simple hydrological methods that associate the degrees of flow modification with likely ecological outcomes. Recent proposals are based on percentages of natural mean or median annual flow percentages of total annual flow allocated to wet and dry seasons and environmental flow prescriptions for rivers of the world based on a percentage of total annual base flow plus a high flow component derived as a percentage of mean annual runoff [6]. These simplistic approaches have no documented empirical basis and the temptation to adopt them represents a risk to the future of biodiversity of the world's riverine ecosystems. Similarly, implementing the suggested flow targets to achieve "fair" ecological condition at 20-30% MAR (mean annual runoff) for arid-zone regions with highly variable flow regimes and up to 50% MAR for rivers in equatorial regions and some lake-regulated rivers [6] would almost certainly cause profound ecological degradation, based on current scientific knowledge [7,8,9,10,11]. Indeed, such static rules defy fundamental understanding of the critical roles of flow variability in sustaining riverine ecosystems. Furthermore, in arid-zone streams and rivers have a very high interannual variation in MAR (mean annual runoff), such levels of abstraction would lead to complete de-watering in years of low runoff and severe ecological impacts [12,13]. With growing recognition of the value of river ecosystem goods and services and escalating global impacts of human development and climate change on aquatic systems [2,14,15,16]. Now it is a critically important time for scientists, managers and governments to agree on an approach for setting environmental flows guidelines and to identify methods that pose an acceptable level of risk of degradation. Here an approach is proposed for identification of “environmental flow guidelines” that bridges the gap between simple hydrological "rules" and more comprehensive, river-specific, environmental flow requirements.

2. EVOLUTION OF ENVIRONMENTAL FLOW “GUIDELINES”

Generally we neglect the simple “guidelines” which can effectively manage the riverine ecosystems; we know it is a challenge to formulate minimum flow norms for the rivers in the absence of site-specific ecological data. A "short term" path for developing scientifically approved “minimum environmental flow norms” needs to incorporate an essential understanding of natural flow patterns and a process for co-relating the flows with aquatic data and other available riverine information.

“Environmental flow guidelines” can be developed in two different conditions, each having a different criterion to a certain extent for application [17]. In case of particular river systems, the management process can be used to set flow benchmarks/threshold levels based on natural flow regime. This method is most suitable for particular rivers having great importance (e.g. restoration works) or for large river systems. This kind of system is applied or is proposed for several rivers in the United States [2,5,18] and aims to achieve important ecological benefits. The second and more widely accepted method relates with most of the world's rivers and streams, for which biotic, riverine, aquatic and hydrologic data neither exist nor is available easily. There is a necessity to develop a authenticated approaches to support flow management for these mentioned conditions [6,15,19]; however, this cannot be attained in a desired time frame if complete site-specific data is required for every river. Therefore, it is proposed that, rather than trying to maintain the "uniqueness" of every individual river's natural flow regime; we classify the rivers based on key attributes of flow regime and then develop a relationship between difference in each flow attribute and measures of ecological condition for each class of river. Accordingly, further dividing rivers into ecologically segments, this allows the identification of specific management units, i.e. distinct river classes for which there is a specific natural range of both hydrological and biotic variation.

It is recommended that hydrological classification based on statistically meaningful numbers of gauged rivers, combined with validation of ecological condition values for each class of river, is particularly suited for developing a scientifically defensible environmental flow guideline at which substantial variation in climatic and ecological conditions is tolerable. Within a region, the ecological characteristics of rivers in each hydrological class are expected to be relatively similar compared to ecological characteristics between the classes; therefore, these classes represent distinct "management units". Four basic steps to this proposed approach are as follows [20]

2.1. Step 1: Categorization of Reference Rivers

Many ecologically based river flow classifications have evolved throughout the world including that in the United States [21,22,23], Australia [24] and New Zealand [25]. All the classifications are result of study of the natural flow regime [26].

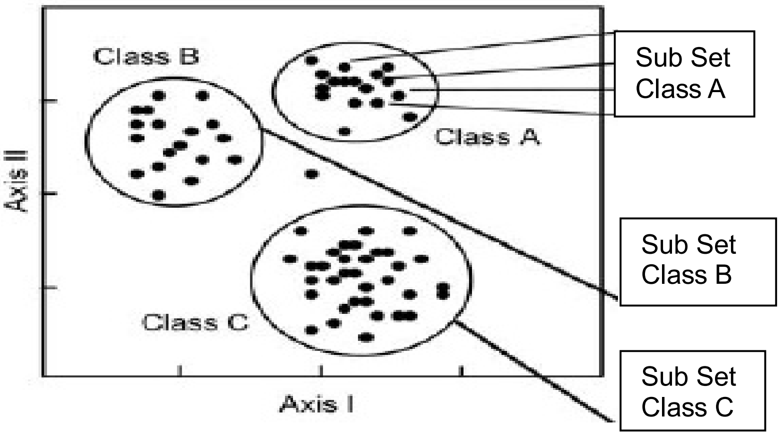

Fig. 1: Reference streams classification based on reference stream flow data.

The fundamental method is to find out natural or "reference" rivers in an area and obtain the natural flow regime. There is wide scope in selecting the adequate flow regime, the data that represent them, the method of classification and the number of river classes to be used for a given area. As a general rule the available literature suggests that measures of flow magnitude (e.g. annual, seasonal, monthly and daily), the frequency, timing, duration and predictability of flow events (e.g. floods and droughts), rate of change from one flow condition to another and the temporal sequencing of flow conditions should be included as they influence many aspects of river ecosystems [7,27,28]. Reference streams are classified into hydrological similar groups according to particular combinations of ecologically important flow variables extracted from the long-term hydrograph. Each class i.e. classes A, B, and C as in Figure 1 [20] is defined by a particular subset of the flow data used in the classification.

2.2. Step 2: Evolution of Frequency Distributions for each Flow Variable in each Class

Each reference river within a class (Class A, B and C) will have a distribution of values for each defining flow variable attained from the flow data. These distributions differ from one river to another but when combined together they represent the actual range of differentiation for all the rivers in the class. If the rivers are ungauged, mathematical modeling can be used to estimate the flow data by using nearby gauges in combination [23,25,29]. Frequency distributions are developed for each flow regime for each class and are combined to represent the natural range of variation in each flow regime across all streams in the class as shown in Figure 2 [20].

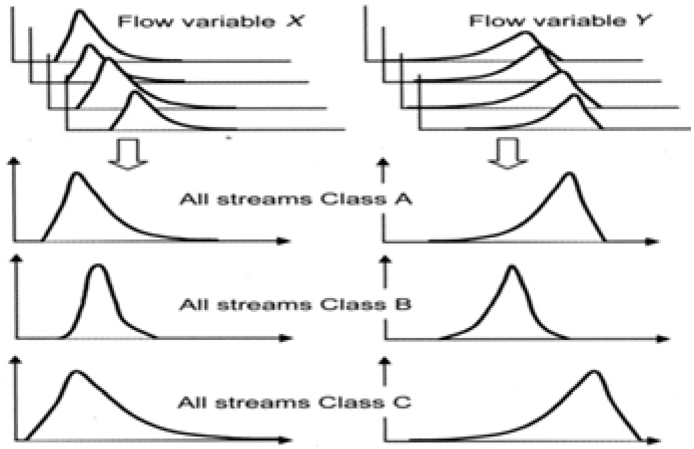

Fig. 2: Frequency distributions for each flow variable in each class.

2.3. Step 3: Compare Frequency Distributions from Flow-Modified Rivers with Reference Condition in the same Class

Flow improvement has to be defined as variations from the reference condition for each class of river. First of all, each flow-stream is assigned to one of the regional flow regime classes both by estimating the pre-disturbance flow data (as mentioned in step 2) and making the assessment based on a statistical model or based on landscape and climatic characteristics. Then, for each low flow rivers, the extent of improvement of any flow can be assessed with respect to the reference condition frequency distribution for that class. In the example as in the Figure 3 for class A [20], reference rivers/streams 4 and 5 clearly lie outside of the natural extent for deviation of this variable and would most probably show ecological degradation. River/Stream 3 exceed than 95% of the natural range and might also be expected to show some ecological degradation's. River/Streams 1 and 2 depict those values which are well within the range of natural flow extent assigned for this class and ecological imbalance/degradation have a very remote possibility.

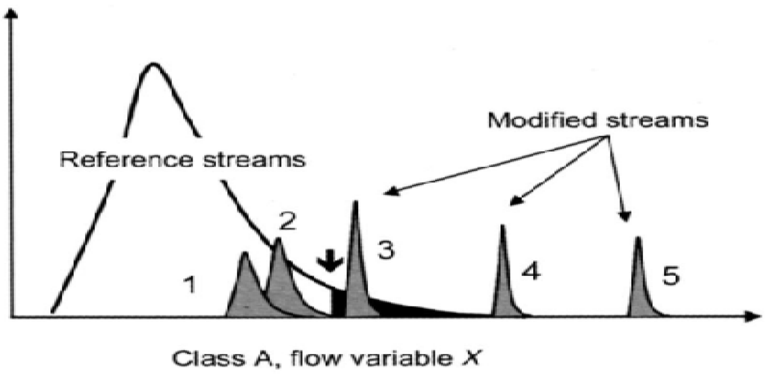

Fig. 3: Comparison of frequency distributions from flow-modified streams with the reference condition frequency distribution for stream class A.

In the absence of ecological data, it is suggested that the "threshold level" for extreme risk condition of ecological damage should be set at the 95% of the reference condition. This certainly reflects "indicators of hydrologic alteration" approach developed by Richter *et al.* [30] and other methods which recommend the flow "standards" based solely on hydrologic alteration [31,32]. It is suggested that this approach should only be utilized as a precautionary method to protect stream ecosystems when ecological data/validation cannot be achieved.

2.4. Step 4: Evolving a Flow-Response Relationships for Ecological Health Data from Reference and Flow Modified Steams or each Low Variable

We believe that ecological validation is important feature of an idol approach. Hence, after the kind and extent of flow modification have been ascertained for the given class of river/streams, the final step is to evolve a relationship between aquatic/ecological condition with reference to natural flowing condition and extent to which flows have been modified. A comparison of flow-ecological relationships across the slopes (downstream) of natural or "reference" river to the degraded flow regimes for each river/stream class is required. By comparing the ecological condition along a flow degraded slopes (downstream), requisite minimum ecologically (environmental) flow standards can be incorporated and validated. Hence it becomes possible to build upon a relation for “flow response” against each of the existing natural asset which hold interest in developing the norms for minimum flow assessment (e.g. habitat, aquatic and riparian vegetation, fish, etc.) and also each “envoirmental flow variable” which defines the stream class (e.g. low flow discharge, frequency of flood flows, duration of low flow, etc.). Expert judgment can also contribute towards the development of “flow-response curves” [33,34].

The main issue is of the functional form of the flow-response relationship. This relationship may be linear as shown in Figure 4 [20], it reflects that there is a decrease in aquatic life from months to years [35]. Hence it may be said that it may be a response as health indicator 2 in Figure 4 [20] which resulted in marked decrease in aquatic habitat with decreased level of flow.

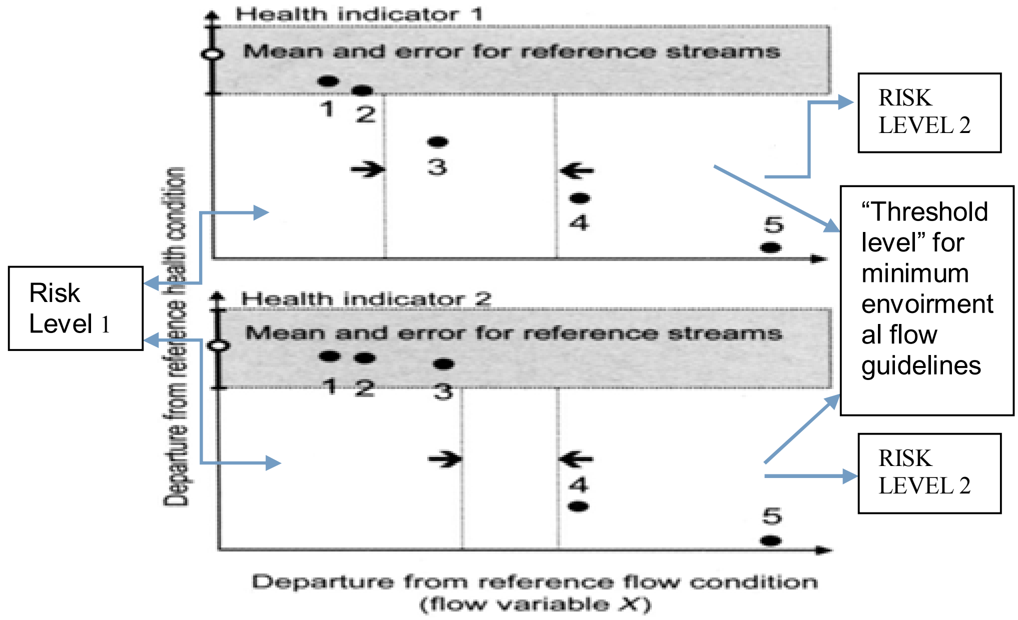

Fig. 4: Flow-ecological response relationships.

From health indicator 1 in the Figure 4 [20], stream 3 falls outside the reference flow values of streams 1 and 2 and thus it is ecologically degraded, but in case of health indicator 2, stream 3 is not degraded as compared to reference flow values in that class. From these health indicators curves, two critical "threshold level" are established to formulate the setting of "environmental flow norms" (dotted vertical lines and arrows in Figure 4). For each flow health indicator, risk level 1 ascertain the limit that is must for flow improvement in order to maintain the ecological balance of the stream or river, whereas risk level 2 represents the change in degree of flow which is associated with severely degraded river conditions. Hence all together, the individual flow-response curves (in both the case of health indicators 1 & 2) and the two risk levels (1 & 2) provide the decision makers with relevant information to formulate the norms for environmental flow for a specific class of river/stream. Realistic flow level can be nominated so that the degree of flow modification does not exceed risk level 1. Furthermore a higher level of risk level can be accepted only by agreeing upon damage of riverine ecological system by allowing a particular hydrological variable to vary upto a greater degree relative to the natural range for that river/stream class. It is proposed that the two risk levels can be regarded as the critical "threshold level" to formulate minimum environmental flow for distinctive river/stream class, as these risk level defines the best and worst case scenarios of ecological response to flow changes. This threshold developing process can be applied in two different contexts: for assessment of ecological changes due to flow modifications for a particular class of river/stream, or for incorporating the guidelines for flow restoration in degraded river/stream of the same class.

3. STRENGTH'S IN COMPARISION TO THE OTHER METHODOLOGIES:

The strength of the proposed methodology are as follows (a) it is "holistic" [4,34] as it deals with the flow requirements of many ecosystem segments; (b) this method can be applied to find out the envoirmental consequences of change in ecological system relevant to flow regime that defines the stream class [7,26]; (c) it evolve two critical risk levels that are the most important "thresholds" required for assessing the minimum environmental flow requirements; (d) with considerations of risk level 1, it is assumed in totality that it will protect the aquatic and biotic regime of the riverine ecosystem, (e) The method is evolved for being utilized for those classes of streams which have a substantial variation in climatic and ecological conditions and can thus can results in environmental flow norms.

4. DISADVANTAGE OF THIS METHOD IN COMPARISION TO THE OTHER METHODOLOGIES

Major and most eminent disadvantage of this method is that it cannot be used for the streams/rivers which stand unaffected by the various activities on and along the river. Thus the method mentioned here is more appropriate as it is a result of flow response relation that gives the "risk level" or "threshold level" beyond which the alter in flow in some manner or other results in the degradation of ecological system in that hydrological class of river/stream.

5. CONCLUSION

The flow regime of the world's rivers has been modified by infrastructure such as dams, weirs, abstractions for irrigation and water supply and inter-basin transfers. Dams have had significant impacts on river systems and the consequential impact on ecological system provided by the rivers.

Modifications to river flows needs to be balanced with the critical need to maintain flow dependent ecological services. This is essential for the maintenance of biodiversity and human livelihoods. Planning environmental releases from dams is complex and context specific and dependent on the dam function, socio-economic conditions, river ecosystem, water users and downstream stakeholders.

The development of large water infrastructure is essential for human survival and economic development. However, it needs to occur within a strategic policy framework for integrated water resource management

Incorporation of area specific flow guidelines for the protection and restoration of the ecological integrity of streams and rivers will certainly help in maintaining the ecological balance of the riverine ecosystem.

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