BUREAU OF INDIAN STANDARD

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पारिस्थितिक संतुलन बनाए रखने के लिए डाउनस्ट्रीम प्रवाह के लिए पैरामीटर और मूल्यांकन मानदंड के लिए दिशानिर्देश

Draft Indian Standard

Guidelines for Parameters and Assessment Criteria for Downstream Flow to Maintain Ecological Balance

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Environmental Assessment and Management of Water Resources Projects Sectional Committee, WRD 24	**Last Date for Comments: 04/10/2023**

FOREWORD
(***Formal Clause of the foreword will be added later***)

Provision for environmental flows is central to integrated water resources management. Environmental Flow Assessment (EFA) methods are still evolving and experience in addressing downstream biophysical and social impacts is limited. Successful mitigation, compensation, and restoration of bio-physiology are more likely to be achieved if a thorough environmental flow assessment is undertaken during the planning of water resources development projects.

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1 SCOPE

This standard outlines the principles behind environmental flow assessments, provides a description of methods that have been used to assist with such assessments, and highlights the features that will enhance the chance of successful implementation of environmental flows.

2 INTRODUCTION

The flows of the world's rivers are increasingly being modified through impoundments such as dams and weirs, abstraction for agriculture and urban supply, maintenance of flows for navigation and structures for flood control. These interventions have significant impacts, reducing the total flow of many rivers and affecting both the seasonality of flows and the size and frequency of floods. In many cases, these modifications have adversely affected the ecological and hydrological services provided by water ecosystems. There is now an increasing recognition that modifications to river flows need to be balanced with the maintenance of water-dependent ecological services. The flows needed to maintain these services are termed 'environmental flows (EF)' or 'environmental flow requirements (EFR)' and the process for determining these flows is termed environmental flow assessment or EFA.

A question generally arises as to what exactly constitutes the environmental flows. And, also, whether the right term is minimum flows or environmental flows. Broadly speaking, 'environmental flows' indicate the flows required to meet the ecological needs while 'minimum flows' indicate the flows required for the environment plus flows needed for other purposes viz. human uses such as bathing, washing, religious needs, etc. Incidentally*,* the terms of reference of this Working Group include Recommend criteria to be followed for minimum flow in different types of rivers from environmental and other considerations. However, the terms 'minimum flows' and 'environmental flows (EF)' or 'environmental flow requirements (EFR)' are generally used to convey the same meaning (just as ecology and environment). Recognition of the escalating hydrological alteration of rivers on a global scale and resultant environmental degradation has led to the establishment of the science of environmental flow assessment whereby the quantity and quality of water required for ecosystem conservation and resource protection are determined.

The quantum of flow in a river and its quality are interrelated. Impact on river water quality resulting from discharges of treated or untreated wastewater into the river will depend upon the dilution offered by the quantum of flow in the river. Even in the most optimistic programme for treatment of wastewaters prior to their discharge into a river, a certain minimum flow in the recipient river would be required in order to maintain the desired water quality. The in-stream uses of water, special to our country, such as religious mass bathing, regular bathing and washing also require adequate flow to be maintained so that the pollution of the rivers caused by such uses can be kept within acceptable limits. Rivers should be looked upon as components of the total environment. Rivers support a chain of life which has to be conserved. Conservation is possible only if an adequate flow of acceptable quality is maintained in the rivers.

3 NEED FOR MINIMUM FLOWS

3.1 Water Requirements

In the modern society, water is put to a variety of uses for the benefit of human population. The following are the important uses.

a) Domestic and municipal supply,
b) Irrigation,
c) Thermal power and Industrial requirement,
d) Generation of hydroelectric power,
e) Navigation,
f) Requirement to maintain natural ecosystem of the water stream, and the pollution control,
g) Growing of fish, crabs and other aquatic animals for food, oil and other purposes,
h) Growing of aquatic plants for food and other applications,
j) Swimming, boating and other recreational uses and
k) Cattle bathing and washing.

3.2 Pollution Loads

The minimum flow in a river for different purposes including maintenance of water quality in the river is going to be different at different places depending upon the actual requirement due to population concentration, industries established and the effluents likely to be discharged in the river. It is, therefore, generally not possible to fix any minimum flow for the entire reach of the river. Ideally, the minimum flow required in the river can only be fixed for a particular stretch. Moreover, the sewage and effluents from the industries have to be treated under the provisions of the Environmental (Protection) Act, 1986, to the specified level before discharging into the river so that the water quality of the river water may be maintained.

4 MINIMUM FLOW ASSESSMENT METHODS

Environmental flow assessment methods fall into two categories, prescriptive and interactive. Several methods have been developed in each category.

RELATIVE DATA AND TIME REQUIREMENTS OF SELECTED FLOW ASSESSMENT METHODS

Output	Method	Data and time requirements	Approximate duration of assessment	Relative confidence in output	Level of Experience
Prescriptive	Tennant Method	Moderate to low	Two weeks	Low	USA/extensive
	Wetted-Perimeter Method	Moderate	2-4 months	Low	USA/extensive
	Expert Panels	Moderate to low	1-2 months	Medium	South Africa, Australia/ extensive
	Holistic Method	Moderate to high	6-18 months	Medium	Australia/ very limited
Interactive	IFIM	Very high	2-5 years	High	USA, UK/extensive
	DRIFT	High to very high	1-3 years	High	Lesotho, South Africa/very limited

4.1 HISTORIC METHODS OR HYDROLOGICAL METHODOLOGIES

Many historic flow methods based on hydrological data have been used to define minimum flows. They are often referred to as fixed percentage or look-up table methodologies, where a set proportion of flow often termed as minimum flow represents the EFR intended to maintain the freshwater fishery, other highlighted ecological features, or river health at some acceptable level, usually on an annual, seasonal or monthly basis. Occasionally, hydrology-based EFMs include catchment variables, are modified to take account of hydraulic, biological or geomorphological criteria or incorporate various hydrological formulae or indices. Three variants of these are described below.

4.1.1 Exceedance Methods

These include flows such as the mean annual, 1 in 5-, 10- or 20-year 7-day (or some other duration) low flow or percentages of those, or a percentage Exceedance flow (i.e. a minimum flow is defined as a flow that is equalled or exceeded for a proportion (e.g. 96 percent) of the time. The principles underlying this technique are very similar to those of the Tennant method but use naturally occurring low flows rather than mean flow to define the minimum flow.

4.1.1.2 Tennant method: Percentage of Average Annual Flow (AAF), required to achieve different objectives (AAF expressed as instantaneous flow)

Tennant recommended specific percentages of mean annual flow based on field observations of the wetted perimeter, cross-sectional area and velocity of North American rivers at a range of flows. The Tennant method (known in New Zealand as the Montana Method) was based on a study of cross-section data from 11 streams in Nebraska and Wyoming in the USA. The study found that stream width, water velocity and depth all increased more rapidly from zero flow to 10 percent of the mean flow, than at flows higher than 10 percent of the mean flow. Habitat for trout formed the basis for Tennant's assessment of minimum flow. He considered that an average depth of 0.3 m and velocity of 0.23 m/s, as provided by 10 percent of the mean flow, were lower limits for the well-being of trout, whereas an average depth of 0.46 m and velocity of 0.46 m/s, as provided by 30 percent of the mean flow were within the good to the optimum range.

From these observations, he recommended that 60-100 percent of mean annual flow would provide optimum flows for most forms of aquatic life, 30 percent would provide good habitat, and that 10 percent was a minimum below which only short-term survival of aquatic life could be expected. Tennant also recommended periodic flushing flows of 200 percent of the mean annual flow.

Change in width, depth and velocity (as a proportion of mean flow) for two-channel types (single thread uniform and single thread non-uniform) is represented as a function of the percentage in mean flow. It can be seen that in general, the hydraulic conditions change at a high rate from zero to approximately 10 percent of the mean flow. However, this is variable and is dependent on the hydraulic parameter and geometry of the channel being considered.

Objective	**Recommended percentage of AAF**	
	Autumn-Winter	**Spring-Summer**
Flushing or maximum flows	200	200
Optimum range of AAF	60-100	60-100
Percentage AAF required to maintain a river condition		
Outstanding	40	60
Excellent	30	50
Good	20	40
Fair or degrading	10	30
Poor or minimum	10	10
Severe degradation	10-zero flow	10-zero flow

4.1.1.3 Modified Tennant method

The Modified Tennant method recommends as an emergency rule-of-thumb that 100 percent of the mean flow for each month be considered optimum, 75-99 percent acceptable, 30-74 percent as poor-fair, and 29 percent or less as unacceptable. This regime could reduce peak flood flows which may be important in maintaining the normal ecosystem in some rivers, and recommended that flushing flows be maintained for optimum and acceptable flow regimes.

4.1.2 HYDRAULIC METHODS OR HYDRAULIC RATING METHODOLOGIES

Hydraulic methods usually consider changes in simple hydraulic variables, such as river width or wetted perimeter. Hydraulic parameters such as width, wetted perimeter and velocity increase with increased flow. This increase is non-linear and a point is

generally reached where the rate of increase in the value of a parameter reduces rapidly. This point is called the point of inflection and marks the point beyond which increased flow will have a diminishing effect on the hydraulic parameter being considered. Water velocity is not usually considered in hydraulic methods, possibly because it shows less clearly defined inflection points.

The wetted perimeter approach provides information on the effects of different flows on the area of wetted river channel which is assumed to provide habitat for aquatic life. For both uniform and non-uniform channel cross-sections, there is a rapid increase in wetted perimeter from zero discharge to the discharge at an inflection point, beyond which additional flow results in only minor increases in wetted perimeter. Minimum flows are set near the inflection point of the wetted perimeter versus discharge curve. Braided channels and some gravel bed channels have very flat cross-sections and ill-defined banks. These channel types do not show a clear inflection point.

Fifteen or more cross-sections should be randomly chosen for the wetted perimeter method. Cross-sections are best placed in riffles and runs because these are areas of the stream most seriously affected by reduced discharges. This technique may be unsatisfactory for identifying minimum flows in uniform steep-banked channels. This is because a very small flow may just cover the bed of the channel between the banks. The shallow depth and low velocity at this point of inflection may be unsuitable for many biotas. However, in rivers with non-uniform channel cross-sections, the irregular channel shape will tend to produce a variety of channel depths across the cross-section when the inflection point is reached.

4.1.3 HABITAT METHODOLOGY

Habitat is an encompassing term used to describe the physical surroundings of plants and animals. Some aquatic habitat features, such as depth and velocity, are directly related to flow, whereas others describe the river and surroundings. Habitat methods are a natural extension of hydraulic methods. The difference is that the assessment of flow requirements is based on hydraulic conditions that meet specific biological requirements rather than the hydraulic parameters themselves. Hydraulic models predict water depth and velocity throughout a reach. These are then compared with habitat suitability criteria to determine the area of suitable habitat for the target aquatic species. When this is done for a range of flows (flow increments), it is possible to see how the area of suitable habitat changes with the flow. The resultant outputs, usually in the form of habitat discharge curves for the biota, or extended as habitat time and Exceedance series, are used to predict optimum flows as EFRs.

4.1.3.1 Habitat Suitability

Instream habitat usually refers to the physical habitat water velocity, depth, substrate, and perhaps cover. Usually, animals are most abundant where the habitat quality is best, in lesser numbers where the habitat is poor, and absent from totally unsuitable habitats. Many aquatic species are commonly found in similar hydraulic conditions in a wide range of rivers. If the characteristic habitat occupied by a species is surveyed, it is possible to determine the relative quality of the different habitats from the abundance of animals in them. Preference curves are the measured variation in the frequency of animals with changes in depth, velocity and substrate. Sampling and

analysis techniques have been developed that allow preference curves to be developed easily and quickly. The locations of animals are found by electro-fishing for small benthic fish, bank observation for large trout and birds, or Surber sampling for invertebrates.

Habitat suitability curves for a particular section of river show the variation in the total quantity of habitat with a change in flow for a particular species. Habitat suitability can vary from zero (unsuitable) to one (optimum). Providing preference curves for a species (or life stage of a species) has been determined, it is possible to quantify the area of suitable habitat available within a river for that species. This area is termed the useable area or weighted useable area (WUA).

4.1.3.2 Habitat retention method

In this method, minimum flow recommendations are based on the retention of hydraulic characteristics in various habitat types (riffles, runs and pools). These criteria consist of average depth, average velocity and wetted perimeter, and instream flow recommendations are set when two or more criteria for the appropriate stream size and habitat are met.

4.1.3.3 Instream flow incremental methodology (IFIM)

Once habitat suitability curves or criteria are defined, they can be applied to habitat survey data and the amount of suitable habitat calculated for a range of flows (flow increments). This is the basis of the instream flow incremental methodology (IFIM). A fundamental criticism of IFIM has been that, although it seemed reasonable to assess stream flow needs on the basis of the amount of suitable habitat, there was no evidence that there was any correlation between species abundance and the amount of suitable habitat. This is not an unreasonable criticism; assessments of habitat should be considered to represent the potential of a river to maintain a population of the target species.

Having said this, studies have found a correlation between habitat availability and animal abundance for many species of benthic invertebrates and fishes. It is also necessary to consider all the requirements for a species’ continued survival. For example, the primary requirements for salmonids are both space and food. Assessing instream flow needs for a river must therefore consider salmonids' space and food production requirements. Requirements for reproduction (spawning) must also be considered in river reaches which are used for this.

4.1.3.4 Hydraulic modelling and prediction of habitat suitability

The standard step method, used to model non-uniform steady flow in natural rivers, is well established in engineering practice. This method is based on the principle of energy conservation and uses the flow, slope, hydraulic roughness, and hydraulic properties of the cross-sections to calculate the longitudinal flow profile. An important assumption in the method is that the distance between cross-sections must be short enough that the hydraulic properties of the cross-sections approximate the hydraulic properties and slope between them. This means that cross-sections should be located sufficiently close that the cross-section area increases or decreases uniformly

between cross-sections and that the change in slope is kept to a minimum. In practice, this means decreasing cross-section spacing at the heads and tails of riffles, where water slopes and cross-section areas change rapidly, and increasing the spacing when the hydraulic conditions are uniform. This sampling procedure is consistent with those used to sample instream a physical habitat.

The hydraulic roughness (Manning's n) is determined from field data on discharge, cross-section area, hydraulic radius, and slope. Manning's n can vary with the flow in an unpredictable manner, and this limits the range of flows for which the roughness calibration is valid.

The distribution of water velocities across a cross-section can be calculated from its conveyance once the water level and flow are known. Each velocity can be adjusted for site-specific features, such as an upstream obstruction which might cause a reduction in velocity or a current on a bend increasing local velocities. Each measurement point represents a cell of the total river area for which the suitability of the velocity, depth, and substrate is evaluated on a scale of 0 (unsuitable) to 1 (optimum).

4.1.3.5 Habitat mapping

Until recently, applications of IFIM involve surveying and hydraulically modelling habitat across a series of contiguous cross-sections over a range of flows in representative reaches of rivers. An alternative approach that requires less knowledge of hydraulic modelling is Meso habitat typing or habitat mapping. This approach better represents the physical habitat in the river over which the survey is intended to apply.

Meso habitat typing first requires that habitat is mapped over the segment of river under study so that the proportions of the different habitats of interest (e.g. pool, riffle, run, etc.) can be calculated. Next, several cross-sections are chosen to represent each of the habitat types. At each cross-section, depths, mean column velocities and substrate composition and recorded at approximately 0.5-1 m intervals, or with enough frequency to characterize the changes in depth and velocity across the section, as for hydraulic modelling. Flow and water level are recorded for each cross-section and repeated at two or more other flows to establish a stage-discharge relationship. Water velocities and depths over each cross-section can then be predicted for a range of flows, using the stage-discharge relationships and channel geometry. This prediction is usually more accurate than predictions made by water surface profile modelling. The area of suitable habitat (weighted useable area, WUA) can be calculated for each species of interest. The WUA at each cross-section is multiplied by the proportion of the total river length that each cross-section represents. The total WUA is then the sum WUA of all the cross-sections. The computer programme RHYHABSIM has been extended to evaluate habitat surveys based on habitat modelling and includes useful tools for the derivation and comparison of rating curves at cross-sections.

4.1.4 HOLISTIC METHODOLOGIES

Holistic methodologies emerged from a common conceptual origin to form a distinct group of EFMs focused from the outset on addressing the EFRs of the entire riverine ecosystem. In a

holistic methodology, important or critical flow events are identified in terms of selected criteria defining flow variability, for some or all the major components or attributes of the riverine system. This is done either through a bottom-up or a top-down or combination process that requires considerable multidisciplinary expertise and input. The basis of most approaches is a systematic construction of a modified flow regime from scratch (i.e. bottom-up), on a month-by-month or element-by-element basis, where each element represents a well-defined feature of the flow regime intended to achieve particular ecological, geomorphological, water quality, social or other objectives in the modified system. In contrast, in top-down, generally scenario-based approaches, environmental flows are defined in terms of acceptable degrees of departure from the natural flow regime, rendering them less susceptible to any omission of critical flow characteristics or processes than their bottom-up counterparts.

4.1.5 HYBRID METHODOLOGIES

A diverse array of methodologies that bear characteristics of more than one of the above four basic types, including partially holistic EFMs which incorporate holistic elements, but within insufficiently developed methodological frameworks can be recognized. These methodologies are classed as ‘combination’ or ‘hybrid’ approaches alongside various other approaches not designed for EFAs from first principles, but adapted or with the potential to be used for this purpose. These latter approaches are termed ‘other’ EFMs.

4.2 Conceptual differences between minimum flow assessment methods for habitat

The following sections explain the conceptual differences between the different assessment methods and the suitability of applying them to meet management goals.

4.2.1 Historic flow methods

Historic methods are easy to apply because they are based on simple hydrological calculations. Factors like food, habitat, water quality, and temperature are not considered explicitly, but are assumed to be satisfactorily provided for because the aquatic species have survived such conditions in the past. These methods attempt to produce a “low risk” approach to minimum flows by specifying flows that are in the historic range. The methods also provide some choice of the level of protection in terms of flow. However, flow acts as a surrogate for biological response and cannot be quantified biologically.

4.2.1.1 Exceedance flows

Use of an exceedance flow (e.g. annual, 5-year or 10-year 7-day low flow) will tend to preserve the status quo. The level of protection given by these methods is clearly associated with the recurrence of the minimum flow under natural conditions. That is, there is a higher level of protection for the biological community if the minimum flow is the same as a frequently occurring natural low flow. The choice of exceedance period

should therefore reflect the significance of the biological community at risk, with communities of higher significance being afforded greater protection by setting more frequently occurring natural low flows as minimum flows.

4.2.1.2 Tennant methods

The Tennant and modified Tennant methods also attempt to maintain the status quo. The assumption that a proportion of the mean flow will maintain the instream environment is reasonable and the use of these methods is well established. The modified Tennant method offers a range of minimum flows with a descriptive measure of their acceptability. This offers some ability to consider the significance of the biological community at risk and level of environmental protection offered. For the same aquatic community, small streams will be more “at risk” than large streams, because velocity and depth are already relatively low.

4.2.2 Hydraulic methods

The aim of hydraulic methods is to describe how full the river channel is for given flows. It is assumed that a full channel will maintain the food-producing capacity of the river. If the inflection point method is used as the flow requirement, the resulting water depth, velocity, and ecological response will depend on channel geometry. For example, in uniform channels, only a small and shallow flow is required to maintain water across the full stream width. Under such conditions, the water depth and velocity may be unsuitable for many species. However, in many non-uniform channels, the water depth and velocity will be characteristic of those at natural flow, thus retaining both the character and ecology of the natural system.

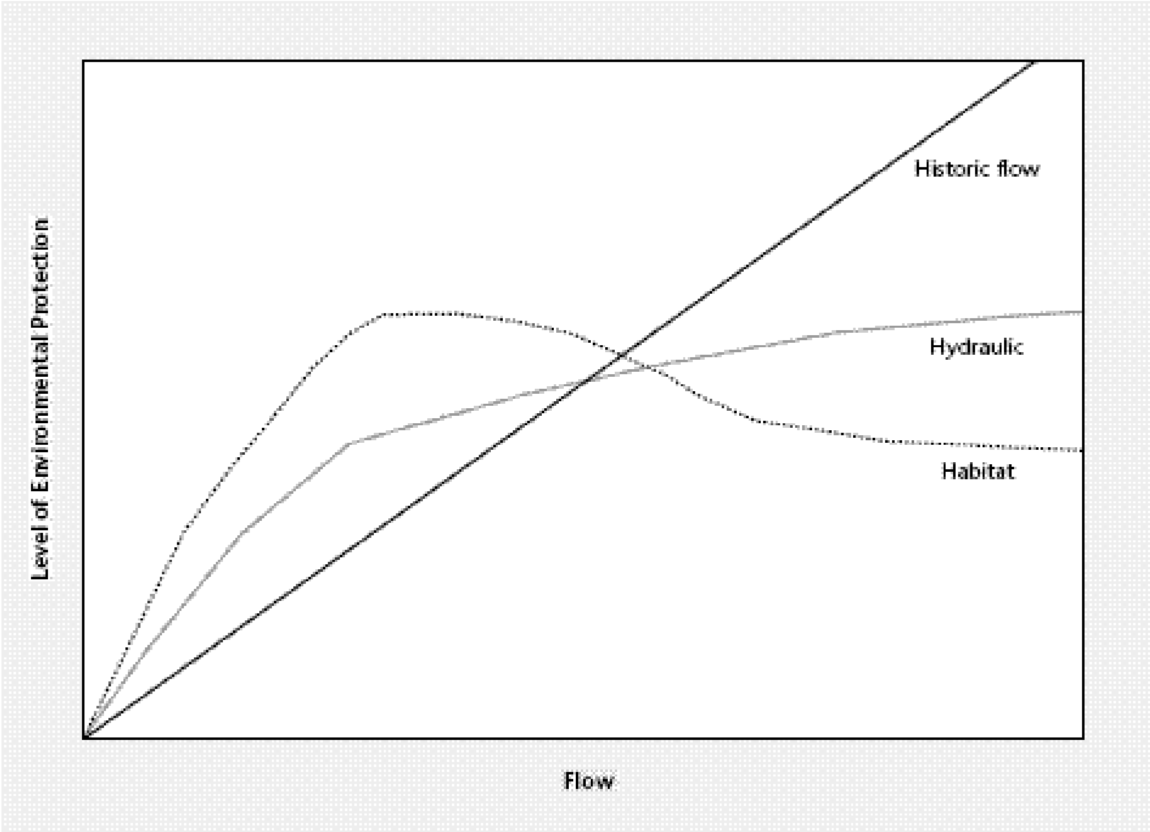
4.2.3 Habitat methods

The ecological goal of habitat methods is to provide or retain a suitable physical environment for the aquatic organisms that live in a river. With the focus of habitat methods on target species, there is a risk of failing to consider other essential components of a stream ecosystem. The selection of appropriate habitat suitability curves and consideration of other factors, such as food, temperature, and water quality is crucial. The key to successful minimum flow recommendations is to provide sufficient habitat for the maintenance of all life stages of the target species and to consider the requirements of the stream ecosystem as a whole.

Habitat methods aim to preserve, or even improve, habitat, in terms of depth and velocity, rather than river character. For example, a swift-flowing river may contain large areas of deep, high-velocity water that are not utilized by most aquatic species. A minimum flow based on habitat would suggest that the area of suitable habitat could be increased by reducing flows so that water velocities and depths were in the range of those preferred by a target species.

This would result in a loss of the high-velocity areas that lend character to a river. Flow assessments based on habitat tend to reduce rivers to a common denominator the habitat used by the target species.

Habitat methods provide the most flexible approach to minimum flow assessments, but can be difficult to apply and interpret. Because of this, the outcome depends critically on how the method is applied: what species or uses are considered and what suitability curves are used. When using habitat methods, there are more ways of determining flow requirements than in either historic flow or hydraulic methods. The relationship between flow and the amount of suitable habitat is usually non-linear. Flows can be set so that they maintain optimum levels of fish habitat, retain a percentage of habitat at average or median flow, or set so that they provide a minimum amount of habitat. Flows can also be set at the point of inflection in the habitat/flow relationship. This is possibly the most common method of assessing minimum flow requirements using habitat methods. While there is no percentage or absolute value associated with this level of protection, it is a point of diminishing return where proportionally more habitat is lost with decreasing flow than is gained with increasing flow. Habitat methods are therefore useful for investigating and presenting the relative levels of protection offered by different minimum flow options.



The level of environmental protection is measured in terms of the surrogate measures for biological response: flow for historic flow methods, wetted perimeter for hydraulic methods, and weighted useable area for habitat methods. (Source: Jowett, 1996).

FIG-1 Relationships Between Flow and The Level of Environmental Protection Offered by the Different Biological Assessment Methods for a Hypothetical River

Habitat-based methods differ from both historic and hydraulic methods in that they make no *a priori* assumptions about the state of the natural ecosystem. Historic and hydraulic methods assume that lower than natural flows will degrade the stream ecosystem, whereas habitat methods accept the possibility that a natural ecosystem, or at least some particularly valued target species, could be enhanced by other than naturally occurring flows.

4.2.4 Levels of environmental protection

Method	**Data and time requirements**	**Approximate duration of assessment**	**Relative confidence in output**	**Level of experience**
Tennant Method	Moderate to low	Two weeks	Low	USA/extensive
Wetted perimeter method	Moderate	2-4 months	Low	USA/extensive
Expert Panels	Moderate to low	1-2 months	Medium	South Africa, Australia/extensive
Holistic Method	Moderate to high	6-18 months	Medium	Australia/very limited
IFIM	Very high	2-5 years	High	USA,UK/extensive

The use of surrogate measures for biological response means that the level of environmental protection offered by biological assessment methods does not necessarily increase linearly with minimum flow. Historic flow methods assume that the biological response, and hence the level of protection, is directly related to flow, with the level of protection increasing with the flow. Hydraulic methods assume that biological response is related to a hydraulic parameter such as wetted perimeter. Hydraulic parameters have a non-linear relationship with flow which is a function of channel geometry. Hydraulic methods therefore assume that environmental protection increases with increasing flow but that this relationship exhibits the law of diminishing returns.

Habitat methods have a non-linear relationship with flow which is a function of channel geometry and preferred habitat of the target species. Habitat methods therefore assume that environmental protection for the target species will be optimized at some flow and that increased or decreased flows will reduce the level of environmental protection.

Levels of protection for different biological assessment methods

Biological assessment method	Assumed relationship between level of protection and flow	Level of protection specified by:	Examples of increasing levels of protection
Historic methods • Exceedance	Linear increase with flow	Exceedance flow	10 year, 5 year, Mean annual low flow
• Tennant	Linear increase with flow	% of mean flow	10% of mean flow 30% of mean flow
Hydraulic methods	Non linear increase with increasing flow	Hydraulic parameters	Increasing percentage retention of hydraulic parameter values
Habitat methods	Optimum conditions at a given flow Reducing protection for flows greater than or less than optimum	Habitat quantity	Minimum habitat Inflection points Optimum

4.3 COMPONENTS OF MINIMUM FLOWS

There are four components that constitute minimum flows;

a) Low flows
b) Flushing flows
c) Special purpose flows
d) Maintenance of impoundment levels

4.4 Low Flows – Aquatic ecosystems are assumed to be adapted to periods of low flow or no flow. Such conditions are presumed to have occurred before human intervention and still occur in pristine catchments. It has been argued that natural low or no flow periods play an important role in stressing ecosystems, permitting re-colonization and succession. However, this stress should not be exacerbated by unnatural long periods of low or no flow. Ecosystems are particularly sensitive to impact when stressed and further stress will result in harmful impacts. Low flows need to be maintained as close to natural levels as possible.

4.5 Flushing Flows — These are flushes of fresh water following storm events, which are necessary for the maintenance of aquatic ecosystems and channel structure. Flushing flows are of particular importance in streams downstream of water supply dams. Water supply requirements often drastically change natural flow regimes, causing damage to downstream aquatic communities and stream structures.

4.6 Special purpose flows – These are flood flows for specific ecosystem requirements, for example, the inundation of wetlands.

4.7 Maintenance of impoundment levels – These are flows required to maintain the water level of urban lakes and ponds and to prevent the water level from lowering too far below the spillway level for a significant period.

5 METHODOLOGY TO BE ADOPTED FOR COMPUTING MINIMUM FLOWS

Several methodologies have been described above for the computation of minimum flows, along with their data requirements, limitations, adaptability, dependability, etc. Any suitable methodology may be adopted, depending on data availability, accuracy desired, manpower available, etc. Minimum flows have to be worked out river-wise, reach-wise and season-wise.

5.1 Suggested Approach for Assessment and Implementation of E-Flows

On perusal of the recommendations of various research studies that are available in India on E-flows, hydrological characteristics of rivers and dependence of the society on river water, the suggested approach for assessment and implementation of E-flows consisting of a combination of hydraulic rating and habitat simulation methods may be adopted as follows.

a) There is a need to identify critical reaches in our river basins that are likely to be impacted due to diversion or impoundment of water in the reservoirs.
b) In the case of a hydropower project, such critical reach shall be from the point of diversion or dam to the outfall of the tailrace or joining of a tributary as shown in Figure 2. After the outfall of the tailrace, all the water diverted to the powerhouse comes back to the river system.
c) In case of diversion for consumptive uses like irrigation, the critical reach shall be from the point of diversion or dam till the location where the flow is augmented by a tributary contributing significantly to the river as shown in Figure 2.

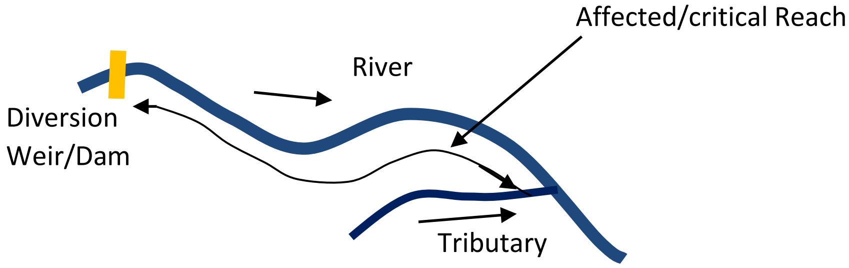


FIG. 2 Critical Reach an a River from E-Flows View Point

Implementation of E-flows should be taken up in adaptive mode. As shown in Fig. 3, this consists of assessment, implementation, monitoring and then modification based on feedback.

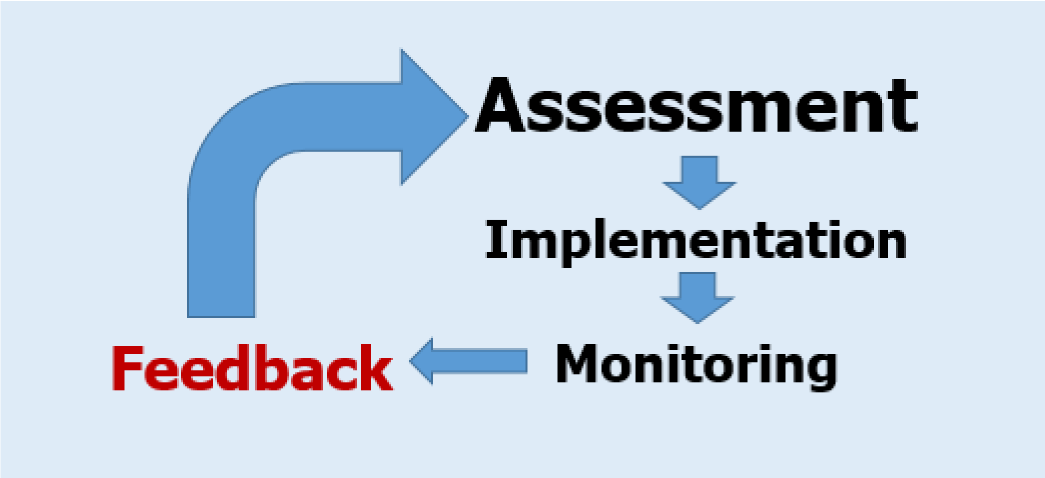


FIG. 3 Adaptive Mode of E-Flows Assessment and Implementation.

Accordingly, the following methodology/framework for assessing the E-flows is proposed:

5.1.1 Methodology and Computational Procedure for Assessing Environmental Flows

There is a wide range of methodologies available for assessing the E-flows. However, there are lack of both the understanding of and quantitative data on relationships between river flows and the ecological characteristics of rivers. In the majority of the assessments of E-flows, hydraulic cum habitat simulation methodology has been implied wherein the requisite flows are assessed based on minimum ecological flow characteristics such as flow depth, flow velocity, perimeter, top width, etc. at the given location of a river. This methodology (Hydraulic cum Habitat simulation) for assessing E-flows appears to be simple and explicit and is capable of reflecting the requisite E-flows with a reasonable confidence levels, particularly during the lean period. Accordingly, the methodology and procedure for assessing the E-flows are proposed as under:

(a) Assess the aquatic habitat characteristics and ecological status of the identified reaches. This assessment may be carried out by expert agencies such as the Wildlife Institute of India **(**WII), Dehradun, Central Inland Fishery Research Institute (CIFRI), Kolkata, State Government Fishery Research Institutes etc. A biodiversity survey would document the baseline ecological status of these reaches and will be of immense value.

(b) Identify the critical reach which is likely to be impacted due to any diversion or impoundment of water in the river. In the case of a hydropower project, such critical reach shall be from the point of diversion or dam to the outfall of the tailrace or joining of a tributary. In case of diversion for consumptive uses like irrigation, the critical reach shall be from the point of diversion or dam till the location where the flow is augmented by a tributary contributing significantly to the river.

(c) Take river cross-sections at regular intervals say 200 m to 1000 m depending upon variability in river geomorphology.
(d) Carry out hydraulic simulation using a hydrodynamic model such as HEC-RAS, MIKE11, etc. for various inflow discharges.
(e) Assess the requisite discharges corresponding to hydraulic parameters fulfilling the ecological requirements in different seasons. Generally, simulations may be carried out corresponding to three seasons that is High flow period or the Monsoon season (June to Sep), the average flow period (April, May, October and November) and the lean or dry period from December to March.
(f) The requisite discharges in different seasons may be expressed as a percentage of average flows or 90 percent dependable flows in that season for ease of implementation.
(g) Biodiversity surveys may be repeated again after say, 5 years, and results be compared with the baseline. Depending upon the outcome, the E-flow assessment may be repeated.

Though the above approach takes care of the assessment of E-flow requirements in all seasons, it is generally seen that river flows are adequate during the monsoon season and the ecological needs of the rivers are naturally fulfilled. Thus the issue of E-flows is critical largely during the lean period only.

For the time being, the above method for assessing the E-flow requirements may be adopted. When the understanding and data availability on relationships between river flows and ecological characteristics of river improves, comprehensive methods such as a holistic approach may also be used.