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Environmental Flow Assessment of Marsudar River in Chenab Basin using HEC-EFM

Seerat Magray [1], Thokar Subiaya Bashir[2], Shakil Ahmad Romshoo[3]

1 Department of Earth Sciences, Annamalai University, Tamil Nadu, (India)

2 Department of Earth Sciences, Annamalai University, Tamil Nadu, (India)

3 Department of Earth Sciences, Kashmir University, (India)

ABSTRACT

Traditionally, water has been managed according to the supply viewpoint with most of the stress on immediate cost-effective growth from the use of the water. In this respect many authorities try to supply water in plenty to their community resulting into unprecedented environmental degradation. For ecosystem conservation and resource protection the quantity and quality of water necessary are to be determined which lead to the development of the idea of environmental flow assessment. There is a danger of environmental degradation in Marsudar river of Chenab basin. To maintain the health of the ecosystem of river the water-resources planners should understand the necessity of implementation of environmental flows. The main aim of this study is to understand the e-flow requirements in the Marsudar River for the functions of hydrology and ecology. This paper describes use of HEC- EFM open source software for recommending environmental flows for river targeted for water-management activities. The model is used to identify the critical minimum flows required for Fish survival in streams .The environmental indicators employed for the research are fish (Brown Trout, Mahseer, Rainbow Trout and Snow Trout).

KEY WORDS: Environmental flows, Fish, HEC-EFM, Hydrological alteration

I.INTRODUCTION

Rivers have been extremely useful to human being in all parts of the earth as they sustain numerous services that no other ecosystem can. Since the world came to existence rivers have sustained ecosystems supporting biodiversity. There are many organisms which are sustained by rivers. Some are not only supported by rivers but they also serve are their only habitats. Increase of population density, industrialization, urbanization and agricultural activities cause major impacts on rivers.

Korsgaard (2006) stated that through impoundments such as dams and weirs which are constructed to serve many purpose the flows of the world's rivers are increasingly being altered. This does not only threaten the water quantity requirements of rivers but also impacts the quality of the rivers (Postel and Richter, 2003).

Thus, it is essential to find the ideal flow that has to be maintained within a river in order to sustain the riverine ecosystem as well as to get the maximum benefits from a river. Implementation of environmental flow does not only mean to identify the river health and to manipulate river flow regimes, but also to get the full harvest of free flowing waters. Environmental flows study needs information on the relationship between river hydrology and key aspects of species biology (Pusey, 1998; Kennard et al., 2000; Metsi Consultants, 2000b).

Environmental flow has been given several names, including the environmental flow (regime), instream flow, environmental allocation of ecological flow requirement etc. (Acreman and Dunbar, 2004).

Dissanayake *et al.* (2010) stated that environmental flows are a set of discharges of a specific magnitude, frequency and timing that are necessary to ensure a certain range of benefits from a river which are important to sustain elements of natural aquatic ecosystem and maintain ecosystem (such as fish management). This term is used in the context of rivers which have been dammed, with most or all of the flow trapped by the dam — the failure to provide an e-flow can have severe ecological consequences.

O'Keeffe & Le Quesne, (2009) stated that, environmental flow is the amount of water that is kept flowing down a river in order to maintain the river in a desired environmental condition The rivers can be, and are used for many things e.g. industries, hydropower, infrastructure, irrigation, fishing, drinking water, fishing, boating, recreation, cultural activities etc. Water is needed for all these activities and enough amount should be left for human use also.

In 1960s the main focus of water management developed nations was on maximizing hydropower generation, flood protection and water supplies. During 1970s scientists had to alter the dam operations to maintain fish species due to the ecological and economic effects of these projects focusing mainly on the determination of minimum flow which is necessary to preserve individual species in river e.g., Trout.

By the 1990s, scientists realisedc social and biological systems are complex to be described by single minimum flow (Bunn et al., 2002; Richter et al., 2008). Since 1990s preserving and restoring environmental flow has increasingly gained support. More implementation has developed from dam reoperation (Richter et al., 2008) to an integration of all aspects of water management (Dyson et al., 2003) including surface and groundwater water diversions.

1.1 Importance of Environmental Flows

A large number of river flow diversion type Hydro Electric Projects in Himalayan region are in different stages of planning and implementation. Assessment of effect of changed flow regime on river bank and river bed ecology and establishment of environmental flows has therefore become a critical constraint in development of Hydro Electric Projects.

In Detailed Environmental Impact Assessment (DEIA), modeling of environmental flows is one of the main studies that is needed to be delivered in the report. The model is important to the project proponent to engage suitable designs that can be suited to environmental needs. Environmental Flow Assessment (EFA) is used to estimate the quantity and timing of flows to sustain the ecosystem values (Mohd Ekhwan Toriman, 2010).

1.2 Modeling of e-flows

As global hydrologic models become more and more sophisticated, gradually finer spatial and temporal resolution of river flow will become available. To talk about the questions of flow alteration in streams and rivers around the world and to guide the development of basin-specific environmental flow requirements these hydrological simulations can be used. These simulated flows will be useful for application in an e-flows framework if they capture the seasonal and short-term variation in the hydrology of ungauged rivers. The sensitivity of different components of the flow regime should be assessed to expected climate change and to specific human involvements in the hydrologic cycle. Attention must also be paid to other sources (beyond climate change), like land use practices and increasing human demand for freshwater and other resources.

By modeling these responses we can model the river vulnerability to climate change and other human-derived environmental change. Hydrologic models linked to other global databases, such as fish species diversity can provide visions into how future flows will be translated into ecological responses and human well-being, across a range of governance contexts. Global analyses that show the intersection of water stress; industrial, agricultural and personal human demand; ecosystem services; management of dams; regional vulnerability to climate change; etc. can be used to inform water infrastructure planning and development. They can also be used to show where ecosystem service facility is greatest or where aquatic and riparian biodiversity is likely to find refuge. This kind of information can guide global conservation efforts and inform what kind of infrastructure design are required. The e-flows framework can act in these situations to integrate on-the-ground planning efforts with global biodiversity conservation policies and plans.

II.STUDY AREA

The biggest tributary of Chenab river is Marsudar. Originating from Nunkun glacier in Warwan valley from Higher Himalayas Marsudar river meets Chenab at Bhandarkot. The geographical extent of the Chenab sub-basin lies between 74°2' to 77°46’ East longitudes and 32°0’ to 34°15’ North latitudes of the country. In India, the 49 watersheds of the Chenab sub-basin cover parts of two states viz. J&K and Himachal Pradesh (CGWB, 2013). The part of Chenab falling in J&K state is covered by brown hill and sub-montane soils in Doda district, mountain meadows in Udhampur district while in Jammu district it is covered by brown hill and alluvial soils. The soils of the high Himalayas in the north are subject to continuous erosion and a thick silt sediment layers are deposited to form a wide valley plain.

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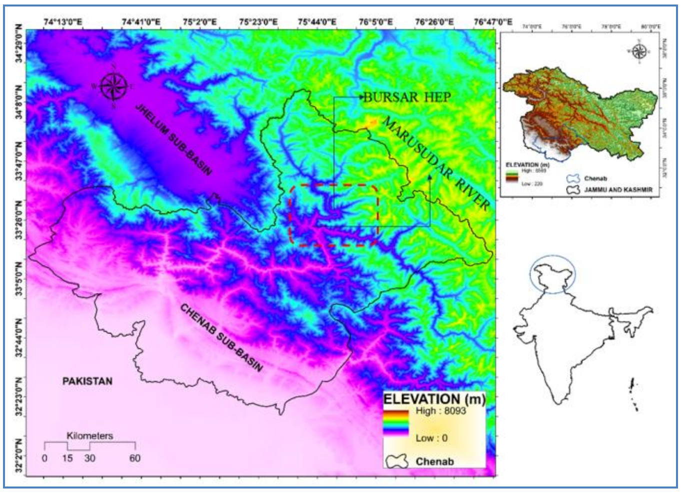
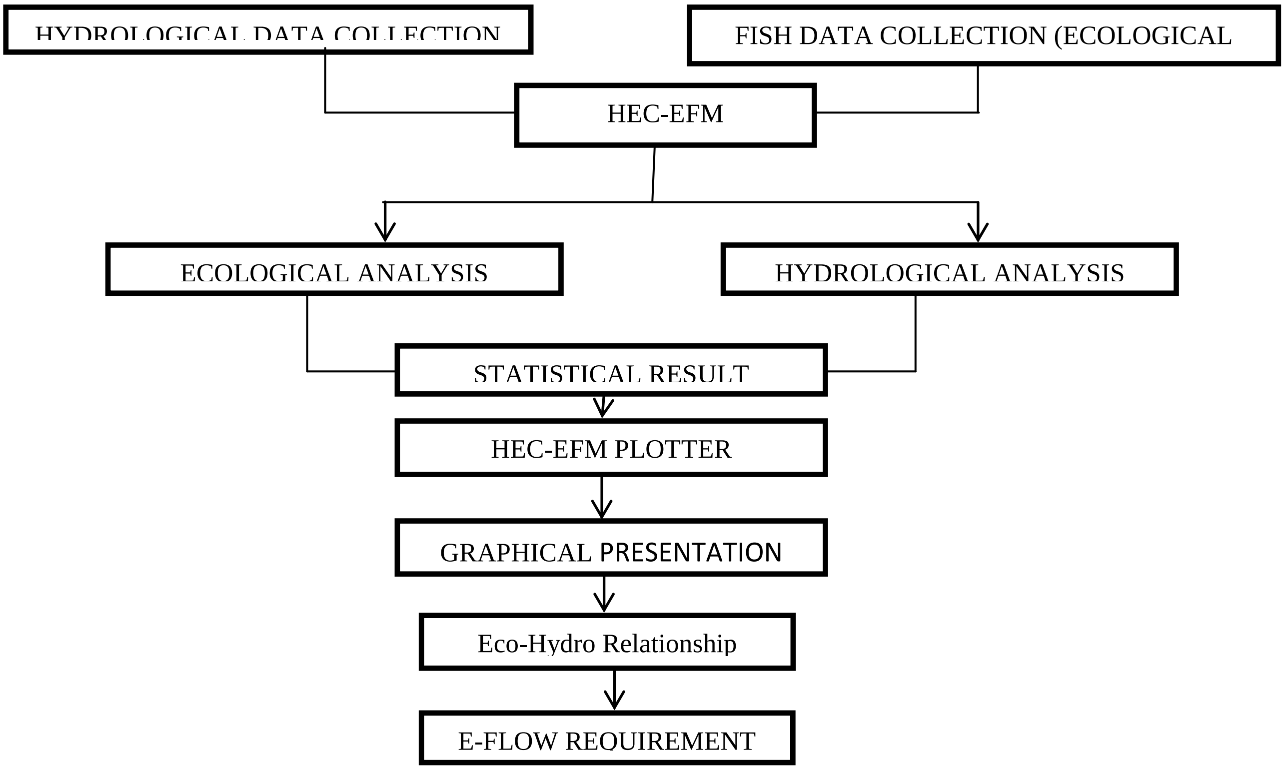


Fig. 1.1 Study Area

III.MATERIALS AND METHODOLOGY

Long-term discharge data of about last three decades (1975-2014) was used for environmental flow assessment of the Marsudar River. The average 10-daily discharge series was obtained from Pakal site for the period of Jun 1975 – May 2014.



3.1 Fish Data

It was hard to carry out full-fledged field survey on fish in the Marsudar River as the river stretch is fast and most often turbulent. Therefore, in addition to the field identification, literature survey of the fish particularly from the EIA reports in the surrounding of the proposed Bursar project was done to identify all the fish species in the river. The fishes identified in river are; Brown trout (*Salmo trutta*), Mahseer (*Tor putitora*), Snow trout (*Schizothorax richardsonii*) and Rainbow trout (*Oncorhynchus mykis).* The e-flow assessment study was done on the four fishes as detailed below:

3.2 HEC-EFM-Ecosystem Functioning Modelling

HEC-EFM is a planning tool that aids in analyzing ecosystem response to changes in flow regime. The Hydrologic Engineering Centre (HEC) of the U.S. Army Corps of Engineers has developed HEC-EFM to support project teams to visualize current ecologic conditions, highlighting promising restoration sites, and assess and rank alternatives according to the relative variation in ecosystem aspects (Hickey & Fields, 2009). Central to HEC-EFM analyses are "functional relationships." These relations link characteristics of hydrologic and hydraulic time series (flow and stage) to elements of the ecosystem by combining four basic criteria: 1) season, 2) flow frequency, 3) duration, and 4) rate of change. No limitation is there to the number or category of relationships that may be developed and it has an interface to enable entry and inventory of criteria. HEC Ecological Functioning Model (HEC-EFM) uses hydrological and hydraulic data as key parameters for simulation. The habitat flow requirements are set and used as surrogate for copying breeding and feeding behavior of each species and taxa considered. Like that of habitat models, this model is used to estimate the effects, in terms of usable physical habitat, of historical or future expected changes in flow caused by dam construction. HEC-Ecological Functioning model is somehow similar to the Habitat model but; the model does not consider other parameters such as wetted perimeter or velocity but rather uses flow and water depth only. In general, HEC-EFM is more advanced and complex than those of the purely hydrological/Hydraulic methods. (John T. Hickey, Rochelle Huff, Christopher N. Dunn 2015).

3.3 Stream Flow Data Analysis

The overall mean of the data series is 4089.69, highest mean 6243 is in the year 1975 and the lowest mean 1853 is in the year 2014. The overall median of the time series is 1836.12, highest median 5049 in 1975 and lowest 847 in 2014. The overall standard deviation of the time series is 4258.8 highest standard deviation 5512 is in the year 1986 and the lowest 204 in 1981. The analysis of the standard deviation of the data indicates that the stream flow data has large inter-annual variation. The minimum value of the time series of the annual stream flow is 1853 cfs and the maximum value observed in the time series of the annual stream flow data is 4264.21 cfs indicating a large range in the observed annual stream flow. **Fig. 1.2** shows the decreasing trend of the stream flow in the area.

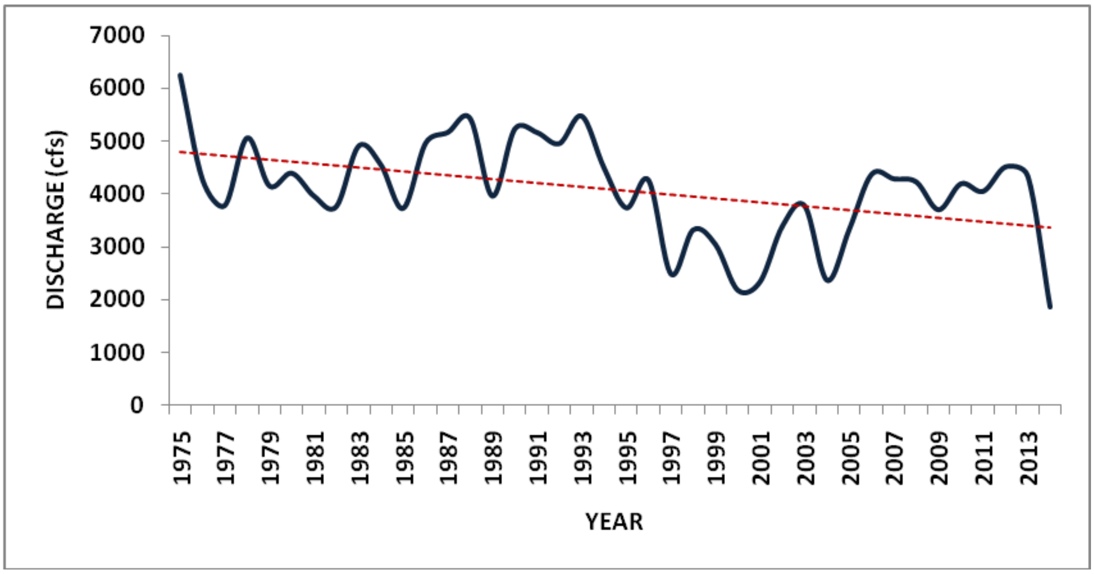


Fig. 1.2 Annual analysis of stream flow data from 1975 – 2014

IV.RESULTS AND DISCUSSION

Fish stock is reducing at an alarming rate in the tributaries of Chenab River because of the change in environmental conditions. Close observation depicts that certain fish species have decreased in number over the years and some species have been termed "endangered". Most literature suggests that using the conditions within spawning seasons that generate the largest extent of effective spawning habitat as an indicator of success for each year's spawn. Further, literature suggests that good spawning conditions do not need to occur every year-it would be sufficient if there were good conditions in 25% of years, so that, on average, each of these fishes would have a chance to spawn in their lifespan. The e-flow requirement for various fish species is discussed in the following sections.

BROWN TROUT (Salmo trutta)

HEC-EFM Relationship

- ✓ Season: October to December
- ✓ Duration: 30 days, minimums (sustained highs) and then Maximum (largest extent)
- ✓ Percent exceedance: 25% (4 yr) – flow frequency
- ✓ Hypothesis tracking : Increased flow will improve (+) floodplain spawning

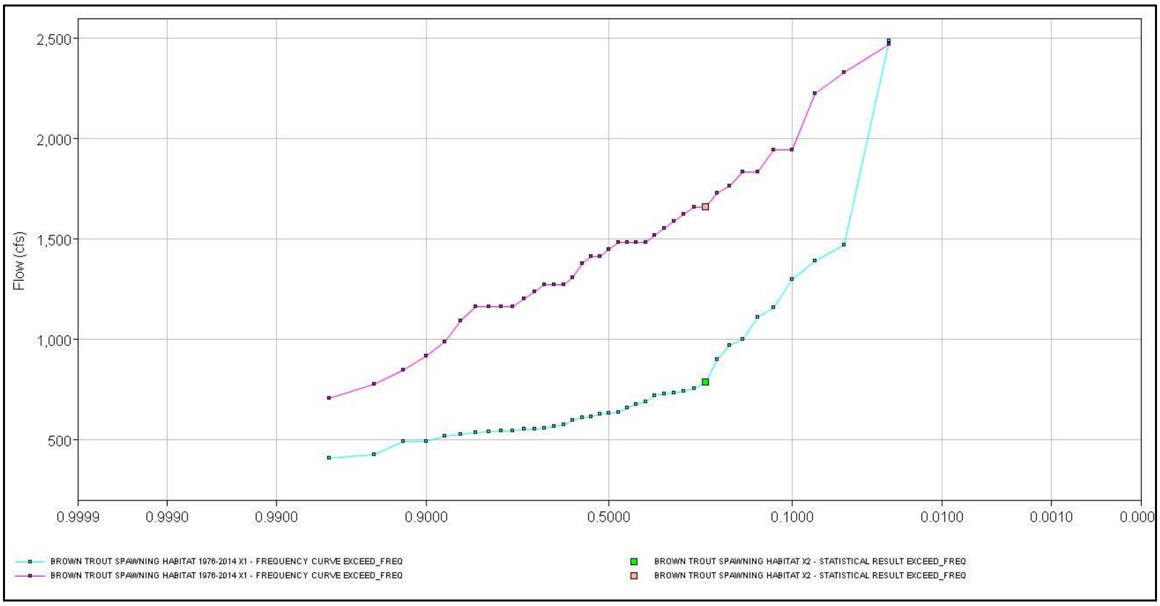


Fig. 1.3 Graph showing the average minimum environmental flow for Brown Trout for the natural and gauged flow from 1976-2013

MAHSEER (Tor putitora)

HEC-EFM Relationship

- ✓ Season: July – September
- ✓ Duration: 24days, minimums (sustained highs) and then Maximum (largest extent)
- ✓ Percent exceedance: 25% (4 yr) – flow frequency
- ✓ Hypothesis tracking : Increased flow will improve (+) floodplain spawning

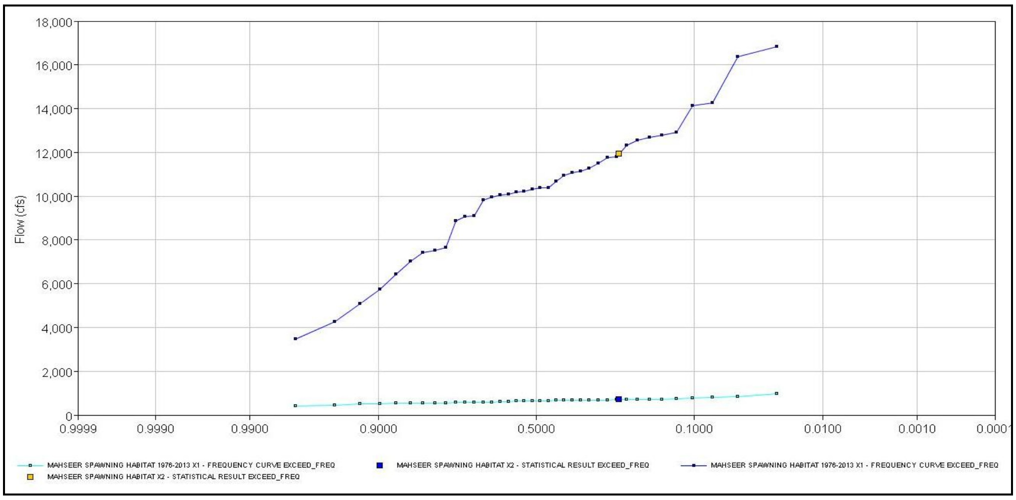


Fig. 1.4 Graph showing the average minimum environmental flow for Mahseer for the natural and gauged flow from 1975-2014

RAINBOW TROUT (Oncorhynchus mykis)

HEC-EFM Relationship

- ✓ Season: March - May
- ✓ Duration: 24days, minimums (sustained highs) and then Maximum (largest extent)
- ✓ Percent exceedance: 25% (4 yr) – flow frequency
- ✓ Hypothesis tracking : Increased flow will improve (+) floodplain spawning

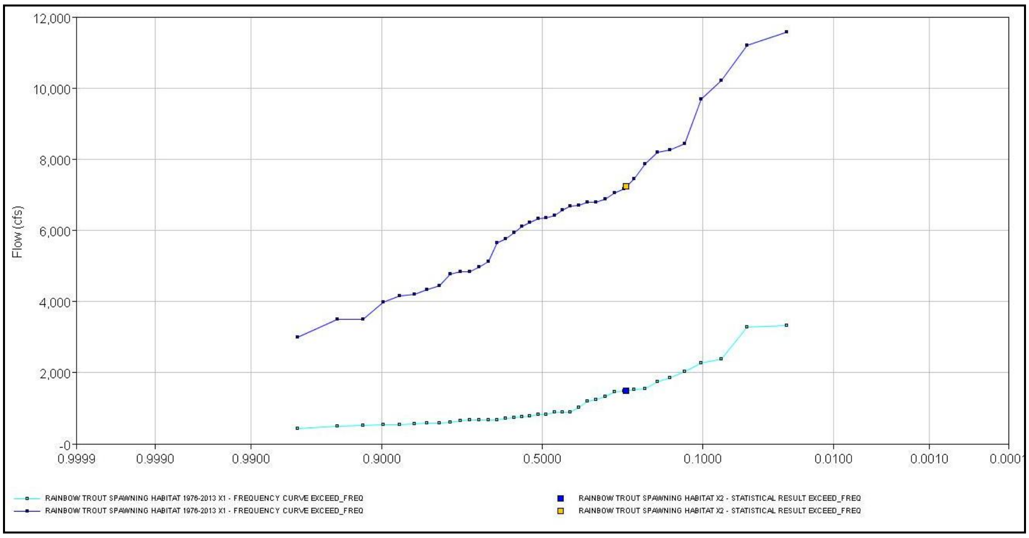


Fig. 1.5 Graph showing the average minimum environmental flow for Rainbow Trout for the natural and gauged flow from 1975-2014

SNOW TROUT (Schizothorax richardsonii)

HEC-EFM Relationship

- ✓ Season: August – October
- ✓ Duration: 10 days, minimums (sustained highs) and then Maximum (largest extent)
- ✓ Percent exceedance: 25% (4 yr) – flow frequency
- ✓ Hypothesis tracking : Increased flow will improve (+) floodplain spawning

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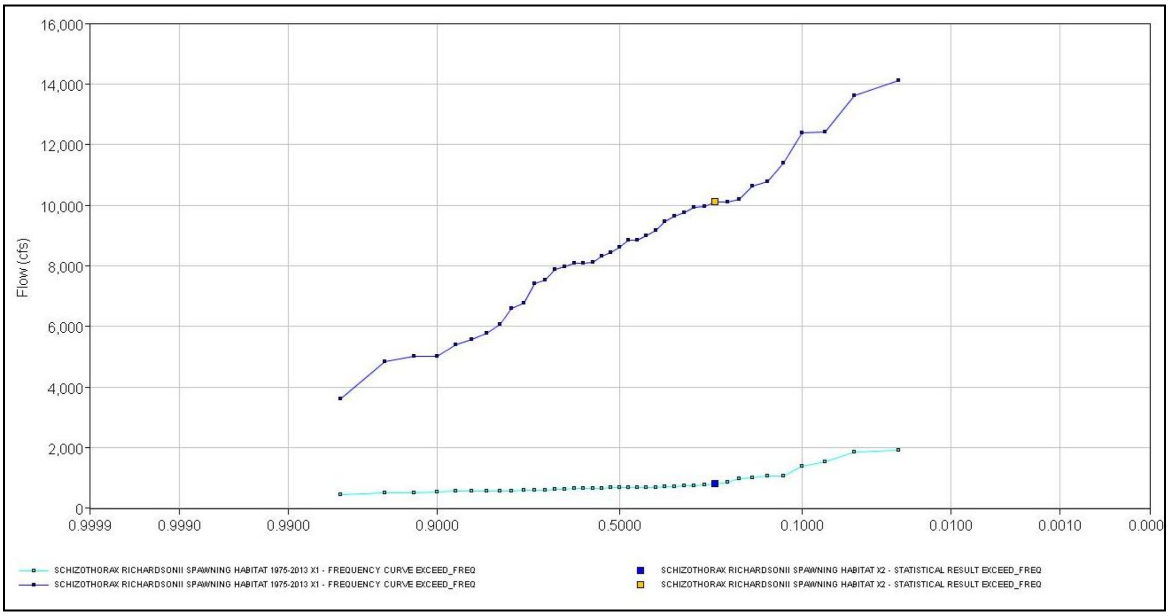

Fig. 1.6 Graph showing the average minimum environmental flow for Snow Trout for the natural and gauged flow from 1975-2013

The analyses of the minimum environmental flow requirement for various fish species (Brown Trout, Mahseer, Rainbow Trout and Snow Trout) observed/reported in the Marusudar river was worked out using HEC-EFM model. The comparative analyses of the minimum environmental flow requirement for the four species is given in the Fig. 1.3, 1.4, 1.5 and 1.6.

- The min. environmental flow requirement for Mahseer for Natural Flow regime is11926 cfs and for Gauged Flow regime 699 cfs. For better spawning and to maintain good ecological conditions it requires is11926 cfs of water for Natural flow regime and 699 cfs for Gauged flow regime.
- The min. environmental flow requirement for Brown Trout for Natural Flow regime is1660 cfs and for Gauged Flow regime 785 cfs. For better spawning and to maintain good ecological conditions it requires 1660 cfs of water for Natural flow regime and 785 cfs for Gauged flow regime.
- The min. environmental flow requirement for Snow Trout for Natural Flow regime is10099 cfs and for Gauged Flow regime 800 cfs. For better spawning and to maintain good ecological conditions it requires 10099 cfs of water for Natural flow regime and 800 cfs for Gauged flow regime.
- The min. environmental flow requirement for Rainbow Trout for Natural Flow regime is 7239 cfs and for Gauged Flow regime 1485cfs. For better spawning and to maintain good ecological conditions it requires 7239 cfs of water for Natural flow regime and 1485cfs for Gauged flow regime.

So the Mahseer is the keystone species in case of natural flow regime and Rainbow Trout for Gauged flow regime. Therefore from the analysis of the HEC-EFM model output, it is concluded that a minimum flow of 11926 cfs should be maintained for natural flow regime and minimum flow of 1485 cfs should be maintained for gauged flow to safeguard the environmental concerns regarding the fish life observed and reported in the Marusudar river.

Table 1.1 Min. flow (E- Flow) requirement for all Fishes

Fish	Natural(cfs)/Stat. Result	Gauged(cfs)/Stat.Result
Mahseer	11926	699
Brown Trout	1660	785
Snow Trout	10099	800
Rainbow Trout	7239	1485

V.CONCLUSION

The concept of environmental flows is quite new. For taking this concept to advanced stage several methods have been developed and are being developed.

The science of the environmental flow was established because of the rise in the hydrological alteration of rivers on a global scale and its impact on degrading the environment. The most dominant form of hydrological alteration is mostly due to the construction of impoundments. According to most recent estimations, presently over 45 000 (and probably far closer to 48 000) large dams in over 140 countries (WCD, 2000); a further 800 000 small dams exist globally.

Environmental flow assessment (EFA) is a comprehensive approach for managing water resources and should be a priority for any water related plan that can guide more sustainable use of rivers. This concept provides new information to decision makers that was not previously available. The EFA approach makes river condition a priority management issue (Watson 2006) and wants water managers to become holistic managers of aquatic ecosystems.

For this study we used HEC-EFM. During the modeling process, model results and survey methods were employed to investigate the environmental flows in the Marsudar River.

The four environmental indicators employed for the research are fish (Brown Trout, Mahseer, Rainbow Trout and Snow Trout).

The environmental conditions required by fish to spawn and complete their life cycles can greatly contribute to an understanding of the functioning of that river. It can also guide requirement of the flows necessary to meet their needs, and be useful in the monitoring and management of those flows.

From the result of the analysis it can be easily concluded that the construction of Hydropower projects and change in flow regime will have negative impact on fishes. The result presented here shows that there will be drastic environmental changes in Marsudar River because of the planned intake/diversion weir. Fish species can be affected by the related effects that dam operations have on flow, water quality and physical habitat. Due to the impact of the diversion/alteration there will be significant migration of fishes from the river and it will also impact their spawning behavior.

There is no one method of environmental flow for rivers – the use of method will depend on what people want from a river. Now there are more than 200 methods for assessing environmental flows (Tharme, 2003). Some methods are very quick modelling or extrapolation methods which need no or least extra work; some need years of fieldwork and specialists from a number of disciplines. The choice of method will depend on:

•The type of the problem
•Resources available for the analysis
•The importance of the river
•Difficulty of implementation
•The complexity of the system

In any kind of situation, implementation of environmental flows should be the priority, in which flows may be successively changed in the light of changing priorities, increased knowledge and changes in infrastructure (e.g. removal of dams) over time.

From this viewpoint, for legislation it may be more suitable to require implementation but allow flexibility in choosing the methods of assessment.

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