Environmental Flows for Hydropower Projects – A Case Study

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ABSTRACT

A large number of river flow diversion type hydropower projects in Himalayan region are in different stages of implementation. Assessment of impact of changed flow regime on river bed and river bank ecology and provision of environmental flows has become necessary in development of hydropower projects. The Nathpa Jhakri Hydroelectric Project (1500 MW), a river diversion project, on Satluj river was completed in the year 2003-04. About 405 cumec of water is being diverted to harness the installed capacity of the project. During lean period, discharge is 100-150 cumec. This implies that river bed could be dry during lean period i.e. November to March. However Satluj river flow is augmented by flow from tributaries joining the river downstream of the dam as well as regeneration of flow along the banks of river. Still, there may be critical reaches in which altered flows are not able to sustain the riverbed ecology and riparian environment existing prior to implementation of the project.

In this paper, a methodology comprising of hydrological and ecological studies has been applied to assess environmental flows in Nathpa-Jhakri reach of Satluj river in the context of Nathpa Jhakri Hydroelectric Project (NJHEP) in Himachal Pradesh. There are almost negligible direct water uses of river due to highly inaccessible terrain. River bank, being rocky, does not support much vegetation up to 100 m height. The main affected phenomenon is river bed ecology. Hydrological (river mapping), hydraulic (cross section, water depth and velocity) and ecological features (river bed and bank flora and fauna) in the study reach have been determined. The assessment of present ecological status of river has been done by field study at selected locations. Available practices for assessment of environmental flow have been applied in case of NJHEP. In addition hydraulic habitat analysis has been carried out. A minimum release of 7.0 cumec from the dam is recommended.

1 INTRODUCTION

Environmental flows are the water that is left in a river eco-system or released into it for the specific purpose of managing the condition of that ecosystem. Failure to maintain such flows may lead to decline in the health of water dependent ecosystem. Minimum flow is a general term used to describe a flow required to maintain some feature of a river ecosystem. The concept of minimum flow originated (in the USA) as a stream flow standard to limit the abstraction of water during the dry season.

No simple figure can be given for the environmental flow requirement of a river. It is related to a number of factors such as hydrologic and biotic character of critical reaches, perceived sensitivity, desired state of the river and the uses to which river flow is put. The desired state is defined in terms of quantity of water through time required to maintain river health in a particular state. It has been given various names such as environmental flow (regime), in stream flow, environmental allocation or ecological flow requirement. Literature study shows that environmental flows have been generally specified in terms of discharge. This alone is not adequate to maintain required hydrologic regime. It is also necessary to specify velocity of flow and wetted perimeter (or width/depth ratio). For same discharge, velocity of flow and wetted perimeter

could vary significantly over short distances and thus affect sediment transport capacity and physical habitat.

Assessment of impact of changed flow regime on river bed and river bank ecology and provision of environmental flows have become necessary in development of hydropower projects [Tennant, 1976, Barkar and Kirmond, 1998, Hughes and Munster, 2000, Souchon and Keith, 2001, Env. Agency, 2002, Hughes and Hannart, 2003, DHI, 2006]. In this paper, a methodology comprising of integrated hydrological and ecological studies has been developed and applied in Nathpa-Jhakri reach of Satluj river in the context of Nathpa Jhakri Hydroelectric Project in Himachal Pradesh.

2 THE STUDY AREA AND BASE LINE DATA

The 1500 MW Nathpa Jhakri Hydroelectric Project (NJHEP) is a run of the river project on the river Satluj with a dam near village Nathpa in district Kinnaur and an underground power house near village Jhakri in district Shimla (Figure 1). The project area is on Hindustan Tibet road NH-22 approximately 150 km from Shimla. The area lies in the lesser Himalayan range which are seismically active zone.

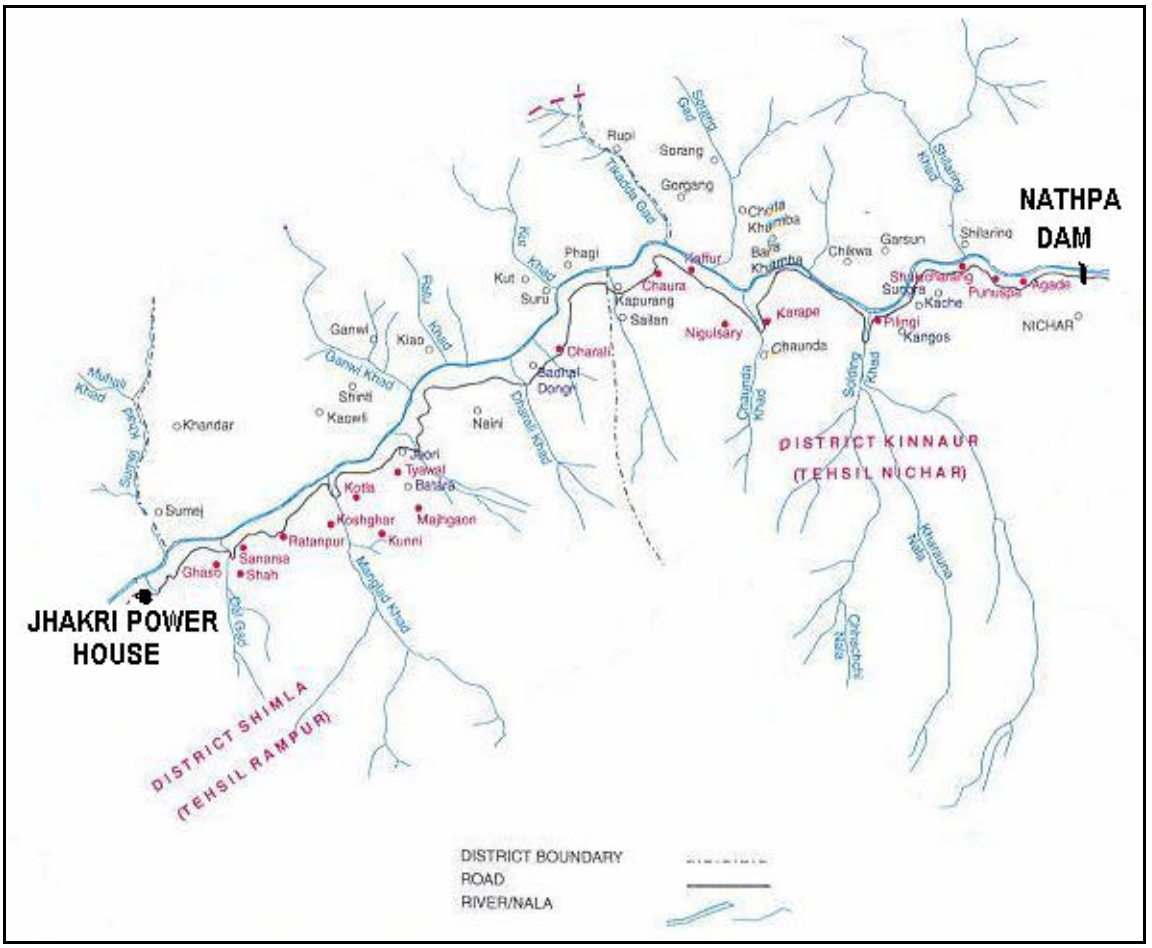

Fig. 1: Study area

About 405 cumecs of water is required to harness the installed capacity of the project. During monsoon, the flow of the river varies from 700 to 2500 cumecs, and from 100 to 150 cumecs during the lean months. In the lean period, the entire water in the river at Nathpa is required for power generation. Flow of Sholding khad is also diverted into HRT during lean period.

The river reach between Nathpa and Jhakri is situated in steep mountain terrain making it almost inaccessible. In elevation, the first 100 m from the river bed is predominantly rocky and do not support

much of the vegetation. 26 small and large tributaries with catchment area ranging from 2.6 sq. km to 127.87 sq. km join Satluj river in the Nathpa-Jhakri reach. Interim catchment area between Nathpa and Jhakri is nearly 866 sq. km.

Field observations (visual documentation and measurements of river bed, soil sampling, sampling of aquatic flora and fauna, village level surveys, monitoring of tributary discharges) were carried out and hydrometeorological data were collected from various agencies. Lean season discharge of tributaries have been monitored on ten daily basis during October 2005 to February 2006 and during December 2006 to February 2007.

When the project was initially accorded environmental clearance by the Department of Science and Technology, submission of a detailed EIA was not required. WAPCOS [1999] studied the social and ecological aspect of area beyond the impact zone of the project to get an idea on the environmental base line data of the impact zone of the project. The impact zone of the project was defined as area within 5 km on either side of Satluj river from Nathpa dam site to Jhakri power house. It did not cover entire tributary catchments between Nathpa and Jhakri.

3 PRECIPITATION IN THE AREA AND ITS EFFECTS

Higher rainfall is received in lower parts compared to upper part. Seasonal as well as annual rainfall in the study area is highly erratic creating situation of meteorological drought as per criteria of India Meteorological experiment. Rainfed agriculture is not sustainable.

Compared to upper catchments of Satluj basin, the study area between Nathpa and Jhakri has significantly much smaller snow covered area (4% in March/April and negligible in September/October). However, snow, ice and glacier fields in upper Satluj basin form natural reservoirs contributing to the perennial water resource at Nathpa and in downstream.

Long-term changes in rainfall and temperature in the region have been studied by Pant et al [2003] and Kumar et al [2005]. These two studies suggest that there is long term decreasing trend in monsoon rainfall which could have major implications with regard to drinking water supply from springs. Rise in post monsoon temperature could lead to increased evaporation. Decreased rainfall and rise in temperature (and hence evaporation) may have adverse effect on soil moisture in the long term.

4 DIRECT/INDIRECT USE OF WATER, SOURCES AND SUPPLY

In the present study, direct use refers to use of Satluj river flows for various purposes and indirect use refers to use of tributary and spring flows. Human habitations vary in size from isolated hamlets to agglomerated settlements mostly along roads (NH-22). These are located on hill slopes at significantly higher elevation compared to Satluj river. Satluj river does not directly contribute as source of water for human and animal population, neither for irrigation. Also no cultural or religions activities are directly related to Satluj river in the reach. Its direct use is mainly as aquatic habitat.

Main sources of water supply to human habitations, animals and for agriculture are hill streams (Khads) and springs. On the left bank side of Satluj where most of the habitations exist there are about 55 streams (13 are perennial) and about 60 cold water springs adjacent is NH-22. Several streams and springs have either dried up or discharge has significantly reduced due to catchment degradation and also due to tunneling operation. Water supply to 22 villages has been affected by the projects construction.

Himachal Pradesh Irrigation and Public Health Department at Rampur and Nichar have taken up 82 schemes for water supply which will supply 3757.5 lpm water (1.975 MCM per year) to 33236 human population. In addition 10 irrigation schemes will cover 590.77 ha land under irrigation. Water availability in springs and khads for these schemes should be regularly monitored

Water need of human and animal population and evapotranspiration demand of vegetation have been estimated as below.

Item	Annual water need
Human population 71099	1.95 MCM
Animal population 116331	0.67 MCM
Vegetation (forest, pasture, agriculture)	64.00 MCM
Total	66.62 MCM

5 AQUATIC BIODIVERSITY AND IMPACT OF ALTERED FLOW REGIME

Sample survey of benthic flora and fauna was carried out during February-April 2006 (four sites) and then again during December 2006 at five sites. Important findings of the study are given below:

Benthic fauna: Two taxomomic groups (Diptera and Ephemeroptera) are found at each site with highest number of species pertaining to Diptera. Abundance of Diptera increase from Nathpa to Jhakri whereas Ephemoroplera shows reverse trend. Percentage abundance of other groups (Trichoptera, Coleoptera and Odonata) do not show any finite trend from upper to lower reach.

Benthic Flora: Dominant group of phytoplanktons found during post project situation are same as existing in pre-project condition. Equisetum plant is found on river banks at all sites. Blue green algae has economic importance.

Diversion of Satluj flow during flood season does not have adverse impact on aquatic flora and fauna as frequency and size of floods in downstream of Nathpa dam is not significantly altered.

Inundation upstream of Nathpa dam is found to be beneficial for many plant species promoting biodiversity.

Alteration in flow regime has not affected macroinvertebrates which have been found in abundance in post-project condition.

Field observations during post-project condition did not indicate abundance of fish and fishery is not practiced. Similar situation prevailed in pre-project condition.

There is a potential lag effect in biological response to flow regulation. Long term observations over several years are required to determine which attributes of the altered flow regime are directly responsible for change in biodiversity. Therefore environmental flows (with limited knowledge on long term hydrologic and biotic response to flow alteration) remains untested hypothesis.

6 FLOW IN TRIBUTARIES AND SATLUJ RIVER MAPPING

Long-term data of Sholding khad and Gaanvi khad have been used for estimation of discharges in other tributaries. For the months of December to February, discharge per unit catchment area of Sholding and Gaanvi khads holds for estimation of discharges occurring in the left and right bank tributaries respectively. For the months of October to November and March to June, discharges for catchments having negligible snow covered area are based on discharge of Sailan khad. For catchments having snow cover area, discharges are based on discharge per unit catchment area of Sholding and Gaanvi khads.

6.1 Low Flow Regime

There exist a variety of low flow indices to analyze low flow regime of a river. Flow duration curve (FDC) is one of the most informative method of displaying the complete range of river discharges. Ten daily flows per unit catchment area (specific discharge) have been used in preparing FDC for Satluj river downstream of Nathpa dam and downstream of Sholding khad confluence. FDCs have also been prepared for Gaanvi khad, Sholding khad, Baspa river and Bhaba khad.

Low flow indices for the four khads and for Satluj river (d/s of Nathpa and d/s of Sholding confluence) have also been worked out using available data. These are mean annual runoff, mean daily flow, absolute min flow, Q_{20}/Q_{90}, Q_{50}/Q_{90}, Q_{90}/Q_{50}, mean annual 10 day minimum flow and 10 day minimum flows corresponding to 10 year and 2 year return periods.

The specific discharge duration curves (SDDC) of Gaanvi and Sholding are similar and are therefore representative of SDDC for other tributaries between Nathpa and Jhakri. Variability of low flow discharge (Q_{50}/Q_{90}) is almost same for the four tributaries placing confidence in consistency and reliability of data of Sholding and Gaanvi tributaries.

Observed long term data (at least 10 years) for post project situation is required for reliable estimation of indices for post project condition.

7 AVAILABLE PRACTICES ON ENVIRONMENTAL FLOWS

Worldwide the most commonly applied method to define target river flows are based on hydrologically defined indices which often can be easily computed. Some of the methods are discussed below.

France: Freshwater fishing law of June 1984 requires that residue flows in bypassed sections of river must be a minimum of 1/40 of the mean flow for existing schemes and 1/10 of the mean flow for new schemes. Since NJHEP is an existing scheme, residue flow d/s of Nathpa dam should be 1/40 of long-term mean flow.

U.K.: Q_{95} (flow which is equalled or exceeded 95% time) should be maintained. Figure of Q_{95} was chosen purely on hydrological ground. However, implementation of this approach (e.g. how much Q_{95} can be reduced) often includes ecological information.

USA (Montana method): Percentages of mean flow are specified that provide different quality habitat for fish eg. 10% for poor quality (survival), 30% for moderate habitat and 60% for excellent habitat. This method is known as Tennant or Montana method. Misleadingly it has been called the Montana method though it is not used in Montana.

The Satluj river reach between Nathpa and Jhakri has low biological productivity. Fishery is not practiced in the reach. Therefore, only survival habitat may be required in the reach for which 10% of mean flow may be specified as per this method.

South Africa: Hughes and Munster [2000] and Hughes and Hannart [2003] used a hydrological index (i.e. coefficient of variation of flows divided by the proportion of total flow that is base flow; CV/BFI). Relationship was developed between this hydrological index (CV/BFI) and the percentage of the mean annual runoff (MAR) required to maintain river flow. Relationship is established by plotting results of individual detailed environmental flow studies on the graph of (CV/BFI) vs %MAR. BFI describes the effect of geology on low flows. BFI may be near about 1 for stream with high base flow.

In the case of Nathpa-Jhakri reach coefficient of variation of flow is expected to be high as C_V of seasonal and annual rainfall is found to be high. However, BFI is also expected to be high due to snow melt contribution to base flow.

UK: The Environment Agency of England and Wales has specified percentages of natural Q_{95} flow that can be abstracted for different environmental weighting bands.

Sensitivity	Env. Weighting band	% of Q_{95} that can be abstracted
Most sensitive av. Score 5	A	0.5%
	B	5 – 10%
	C	10 – 15%
	D	15 – 25%
Least sensitive average score 1	E	25 – 30%
	Others	Special treatment

Environmental weighting four elements of the ecosystem are assessed.

	Score for Satluj river				
	1	2	3	4	5
Physical character	1				
Fisheries	1				
Macrophytes	1				
Macro invertebrates	1				

Sensitivity = (ΣScore)/4 = 1 for Satluj river between Nathpa and Jhakri

Physical Characterization: Rivers with steep gradients score 5 since small reduction in flow result in relatively large reduction in wetted perimeter. River reaches that are narrow and deep are less sensitive to flow reduction and score 1. Physical character is determined by comparing the river with photographs of typical river reaches in each class.

In case of Satluj river, sensitivity score is taken as 1 in consideration of its physical character, low biological productivity and absence of fishery and less sensitivity of macrophytes and invertebrates to reduced flows in post project condition. Therefore, not more than 30% of Q_{95} should be abstracted i.e. downstream release should be at least 70% of Q_{95}.

Hydraulic Rating Method

In this method, relationship between wetted perimeter and discharge is graphically depicted. Break points in slope of curve indicate maximum available habitat for least amount of water until next break point. Alternately top width/depth ratio could be plotted as a function of discharge as has been done in the present study. However, detailed studies should be undertaken on relationship between wetted perimeter (or width/depth ratio) and survival and reproduction of particular species.

HPSEP&PCB Guideline

In the context of NJHEP, the Himachal Pradesh State Environment Protection and Pollution Control Board (HPSEP&PCB) has issued guidelines for minimum releases to be made from the Nathpa dam. It has specified minimum flow of water as 15% threshold value of the minimum flow observed in lean season.

DHI Study for Rampur HEP

DHI Water and Environment [2006] in its study on managed river flow for Rampur Hydro Electric Project has performed hydrodynamic practice analysis to obtain velocity profile of Sutlaj river between Nathpa and Bael so as to determine most favourable flow condition for flushing of sediments, dilution for BOD load and for growth of aquatic life. The different scenarios were simulated for different flow releases varying from 1 cumec to 10 cumec as well as zero release and 1500 cumec release. Table 1 shows velocity and flow requirements as per DHI study.

From aquatic ecological and fisheries point of view the average velocities are of the order of 0.6 to 1.2 m/s for different discharges between the range 1 to 10 cumec which provide conducive environment for fish habitat and spawning etc. Keeping these parameters in view, minimum suitable releases from dam above 5 cumec has been recommended in the DHI study.

Table 1: Velocity and flow requirements as per DHI study

Sl. No.	Purpose	Velocity required	Flow required	Flow suggested
1.	Sediment flushing - for fine sediments - for sand	 0.247 m/s 0.17-0.8 m/s	> 4 cumec	> 5 cumec
2.	DO levels		> 4 cumec for DO above 8 mg/l	> 5 cumec
3.	Aquatic ecology	0.6 – 1.2 m/s	> 4 cumecs for DO above 8 mg/l	> 5 cumec

8 MINIMUM FLOW AS PER AVAILABLE PRACTICES

Low flow characteristics of tributaries and Satluj river between Nathpa and Jhakri have been analyzed. Following parameters are taken for assessment of low flow requirements as per available practices.

	Pre-project flow (cumec)	
	Nathpa dam	D/S of Sholding khad confluence
Long term absolute min flow	62	67.31
95% dependable flow	80	84.66
Mean annual flow	342.17	365.3

Table 2 shows computation of minimum flow requirement in Satluj river d/s of Nathpa and d/s of Sholding confluence according to various country/agency practices. It is seen from Table 2 that specified flow requirement is lowest as per DHI (2006) study. Flow required as per HPSEP&PCB guideline and as per practice in France are similar. Required flow as per criteria in UK and USA are comparatively high. Criteria specified by HPSEP & PCB appears to be reasonable considering, economic status of the state and the country and the demand for power generation and needs of the ecosystem in the study area.

Table 2: Minimum flow requirement in Satluj river

Agency/Country Practice(Reference)	Minimum flow requirement criteria	Minimum flow requirement d/s of Nathpa dam (m^3/s)	Minimum flow requirement d/s of Sholding khad confluence (m^3/s)
France [Souchon and Keith, 2001]	0.025 x mean flow for existing scheme	0.025 x 342.17 = 8.55	0.025 x 365.3 = 9.13
U.K. [Barkar and Kirmond, 1998]	Flow equaled or exceeded 95% of time (Q_{95})	80	84.66
USA (Montana method) [Tennant, 1976]	10% of mean flow for poor quality habitat of fish	0.1x 342.17 = 34.2	0.1 x 365.3 = 36.5
UK [Env. Agency, 2002]	0.7 x Q_{95} for least sensitive ecosystem	0.7 x 80 = 56	0.7 x 84.66 = 59.262
DHI study of Rampur HEP [DHI, 2006]	Flow velocity 0.6 to 1.2 m/s	5	Not specified
HP State Env. Protection and Pollution Control Board	15% of the observed min. flow in the lean season	0.15 x 62 = 9.3	0.15 x 67.31 = 10.1

9 HYDRAULIC HABITAT ANALYSIS

For the purpose of maintaining habitat of aquatic flora and fauna, it is necessary to assess depth of flow, flow velocity and submergence of river bed in terms of top width of flow section for various flow conditions. Initial reach of 10.8 km (downstream of confluence of Chaunda khad with Satluj) is taken as critical reach for hydraulic habitat analysis. Four sections have been chosen for this analysis. Transverse profile of Satluj river bed at following locations has been surveyed.

At each of the four sites, cross sections were surveyed and flow area and related top width of flow and depth of flow (in deepest section) have been worked out. Variation in top width (W), depth in deepest section (D) and ratio of W/D with change in flow area were then estimated.

9.1 Width, Depth and Ratio of Width to Depth for Required Discharge and Velocity

DHI [2006] carried out hydro dynamic study for different flow releases from Nathpa dam (0 to 10 cumec and 1500 cumec). It is seen that the cross sections chosen by DHI do not accurately represent transverse

bed profiles in initial reach of 10 kms which are more important for low flow condition. For the habitat of aquatic life, parameters such as width/depth ratio of flow, bed submergence, velocity of flow are important. For silt flushing, velocity of flow is as important as the discharge. Same discharge on different river bed profiles may produce different habitat conditions due to non-uniformity and irregularity in river bed.

A most favourable velocity from various considerations (flushing, DO, aquatic life) is taken as 1.2 m/s. Required flow area is given by required discharge/required velocity. Then resulting D, W and W/D at various sections for required discharge and flow velocity of 1.2 m/s are found out. These are tabulated in Table 3.

Table 3: Depth (D), top width (W) and W/D ratio for required discharge and flow velocity

Req. discharge	Req. velocity	Req. cross sectional area	Section 1			Section 2			Section 3			Section 4		
			Chainage = 100 m; Total bed width = 40 m			Chainage = 1.7 km; Total bed width = 40 m			Chainage = 3.5 km; Total bed width = 60 m			Chainage = 10.8 km; Total bed width = 60 m		
			Depth	Top width	W/D	Depth	Top width	W/D	Depth	Top width	W/D	Depth	Top width	W/D
cumec	m/s	sq. m	m	m		m	m		m	m		m	m	
2	1.2	1.7	0.38	16 (40.0)	42.11	0.32	12 (30.0)	37.50	0.49	9 (15.0)	18.37	0.37	10 (16.7)	27.03
5	1.2	4.2	0.51	23 (57.5)	45.10	0.45	28 (70.0)	62.22	0.7	14 (23.3)	20.00	0.56	15 (25.0)	26.79
7	1.2	5.8	0.58	29 (72.5)	50.00	0.51	36 (90.0)	70.59	0.8	24 (40.0)	30.00	0.68	19 (31.7)	27.94
10	1.2	8.3	0.65	33 (82.5)	50.77	0.57	39 (97.5)	70.18	0.88	31 (51.7)	35.23	0.78	23 (38.3)	29.49

Note: values in brackets correspond to percentage of total bed width

During the pre-project condition, a major part of river bed used to be in submerged condition. It may not be possible to attain same amount of bed submergence in lean season during the post-project condition. Analysis has been carried out to assess bed submergence at the four sections with different releases from Nathpa dam.

Table 4 shows releases from Nathpa dam and corresponding flows in the downstream. It is seen that with release of 7 cumec the resulting flows at various sections (7, 7.08, 8.59 and 11.26 cumec) will cause bed submergence of 72.5%, 90%, 45.8% and 45% at Section 1, 2, 3 and 4respectively in the month having lowest flow. This amount of bed submergence appears to be satisfactory in consideration of habitat requirement. Bed submergence will be higher in other months. It is therefore suggested that minimum release from Nathpa dam may be 7 cumec.

Table 4: Releases from Nathpa dam and corresponding flows at the four sections

Release from Nathpa dam	Flow at section 1	Flow at section 2	Flow at section 3	Flow at section 4
2	2	2.08	2.59	5.26
5	5	5.08	6.59	9.26
7	7	7.08	8.59	11.26
10	10	10.08	11.59	14.26

10 FLOW MANAGEMENT

For further improvement in hydraulic habitat, flow should be managed as discussed below.

- Rapid flow decreases should be avoided because fish and macro-invertebrates may get trapped in off-channel habitats during rapid flow decreases.

- Flow should be allowed to gradually decline in winter season but not to the extent where river would recede to disconnected pools.
- River bed submergence should not reduce significantly due to reduction in flows. Log weirs or wire gabions may be used to increase river bed submergence and create pool riffle habitat units at 200 m interval from Nathpa dam to Sholding confluence. However, increase in width/depth ratio should be done in such a manner so as not to reduce sediment transportation capacity. These structures will normally get damaged/dislocated in monsoon season. Therefore, only temporary structures need to be provided every year after monsoon season.
- Creation of pool riffle habitat units will also enhance aesthetic condition of river in the critical reach downstream of Nathpa dam.
- Adequate connections between pools and river flow reaches should be maintained wherever it is not possible to increase width / depth ratio of flow section.
- Net primary productivity of the riparian area is mainly influenced by physical site conditions, surrounding land use and composition of terrestrial flora than by river regulation. Surrounding land use and terrestrial flora are not significantly affected by reduction of flows in Satluj river which flows through deep rocky gorge. Annuals (grass and herbs) are observed at few locations. Flow could be channelized along bank having riparian vegetation and in the reaches where width/depth ratio of the flow section can not be increased.
- Due to steepness of bed slope, it is possible to maintain velocity of flow more than 0.6 m/sec even in the critical reach below Nathpa dam. Species which need running water such as hydropsyche will not be affected provided velocity in the range of 0.6 to 1.2 m/sec is maintained downstream of Nathpa.

11 CONCLUSIONS

- A more appropriate term for environmental flow or minimum flow is the managed flow as in addition to discharge, we need to prescribe other hydraulic variables also (velocity of flow, flow variability, depth of flow, submerged width of river bed etc.). These are important for aquatic habitat, silt flushing, water quality, aesthetic river condition etc.

- A simple figure for environmental flow could be misleading. Hydrologic and biotic character of critical reaches also need to be simultaneously analysed. And yet world wide the most commonly applied method to define minimum flow are based on hydrologically defined indices. Available practices have been applied to assess environmental flow in case of NJHEP. DHI recommendation is based on hydrodynamic practice study of Nathpa-Bael reach and is subject to various assumptions.

- Hydraulic habitat analysis of 10.8 km reach d/s of Nathpa (upto confluence of Chaunda khad) has been carried out. Based on the analysis, minimum flow release of 7.0 cumec with velocity about 1 m/s is recommended.

- Temporary measures such as creation of pools at 200 m interval, adequate connections between isolated pools and flowing channel etc. need to be taken after every monsoon season and only in the initial 10.8 km reach.

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