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Evaluation of hydrological criteria of Environmental Flow

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Abstract: *EF in India has usually been understood as the minimum flow to be released downstream from a dam as compensation for riparian right without considering impacts on river ecosystem.Daily discharge data converted into monthly flow data between the periods of 1988 to 2011 were used for determining environmental flow requirement in Tennant (Montana) Method, Modified Tennant and BBM (Building Block Method). The modified Tennant method recommends environmental flow on monthly basis for Kotul, Mula Dam and Panegaon gauging sites. Therefore EFR at Kotul site for the months of June to September need to be 1212.19, 1347.33, 486.86 and 75.58 m^3/sec, respectively. For Mula Dam site EFR for the months of June to December are 1.94, 15.49, 17.78, 10.81, 19.17, 0.010, 0.0045 m^3/sec, respectively and for Panegaon site EFR for the months of June to October are 2.93, 39.77, 288.89, 237.08, 226.54 m^3/sec, respectively.*

Keywords:*Environmental Flow, Tennant (Montana) Method, Modified Tennant, Building Block Method and Mula River.*

INTRODUCTION

Due to high water demand, the scarcity of water resources and complexity of water allocation, environmental flow is an integral part of water basin management. The environmental flow problem is beset with challenges for water resource planning. In particular, the knowledge base with which to evaluate the ecological impact of changes in flow regime is poor. Environmental water requirement also referred as environmental flow are a compromise between water resources development and the maintenance of a stream in ecologically acceptable or agreed condition. Managing environmental water flow is a complex task because the change of quality of water occurs as the flow moves downstream. An environmental flow refers to water considered sufficient for protecting the structure and function of an ecosystem and its dependent species. Environmental flows describe the quantity, quality and timing of water flows required to sustain freshwater and estuarine ecosystem and the human livelihoods and well-being that depend on these ecosystems.

MATERIALS AND METHODS

In the present study Hydrological index method and Building Block Methodology has been used for assessment of environmental flow.

Tennant (Montana) Method

Discharge data for 24 years (daily discharge data converted into monthly data) (1988-2011) was used to estimate Environmental flow requirement (EFR) at Kotul and Panegaon located on the Mula Stream. Under lookup Tables, the recommendation of WCD2000, UK-Q_{95}, 75% of Q_{95} have been used. In lookup Tables 10 % of MAF is considered as per

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WCD2000. Tennant proposed that certain flow could achieve the maintenance of particular amounts of habitat and this method uses a percentage of the mean annual flow (MAF) for two six months periods to define conditions of flow related to fishery, wildlife, recreation and environmental resources as per Table 1. The conditions of a particular habitat given by Tennant(1976) means that if the quantity of water that the basin managers can provide for EFR is < 10% of MAF during April to September and 10% during October to March then the environmental quality of the habitat in that reach will be "severe degradation" . And if a "Good habitat" is desired, then at least 60% of the MAF must be allocated for EFR, 40% during April – September and 20% during October to March. The Tennant method is dependent on the provision of extensive flow data and the relationship between habitat suitability and proportions of mean annual flow, which forms the basis of this method. Tennant (or Montana) method (1976) is the most common method applied worldwide and has been used by at least 25 countries (Tharme, 2003). Its appeal is in its simplicity ease of use. Tennant (1976) used original headings of "recommended base flow regimens Oct-Mar. and Apr-Sept". The percentage of mean annual flow is assumed to roughly describe aquatic habitat conditions. For example, 10 % of the mean annual flow offer "poor" habitat conditions, 30 % is "fair" and 40 % or more is "good" [Pyrce, 2004].

Table 1
Tennant (Montana) method (1976)

Description of general condition of flow	*Recommended flow regimens (% of MAF) October to March*	*Recommended flow regimens (% of MAF) April to September*
Flushing flow (from 48-96 hours)	Not Applicable	200%
Optimum range	60-100%	60-100%
Outstanding	40%	60%
Excellent	30%	50%
Good	20%	40%
Fair or degrading	10%	30%
Poor or minimum	10%	10%
Severe degradation	<10%	< 10%

Modified Tennant (Tessman) method

The Tennant method was further modified by Tessman method called as Modified Tennant Method or Tessman Method. Tessman adopted Tennant seasonal flow recommendation to calibrate the percentage of Mean Annual Flow (MAF) to local hydrologic and biological conditions including monthly variability. The description is shows as below:

i) Monthly minimum equals the Mean Monthly Flow (MMF), if MMF < 40% of MAF
ii) If MMF > 40% of MAF, then monthly minimum equals 40% MAF
iii) If 40% MMF > 40% of MAF, then monthly minimum equals 40% MAF
iv) The flushing flow criterion is still a requirement to be met on an annual basis.

Building Block Method

The Building Block Method (BBM) is essentially a prescriptive approach, designed to construct a flow regime for maintaining a river in a predetermined condition. The objective of BBM is to determine ecologically acceptable, modified flow regimes for impounded rivers and other situations where flows are regulated (Arthington, 1998). An environmental flow regime is then constructed (month by month basis) through separate consideration of different components of the flow regime. Each component of flow being specified in terms of magnitude, time of year, duration and rate of rise and fall of flood flows. Each flow component is intended to achieve a particular ecological, geo-morphological or water-quality objective (Brown, 2006). The BBM is holistic, but issues such as water quality and the flow requirements of water-dependent wildlife require more development and stronger linkages into the methodology. The BBM has advanced the field of environmental flow assessment in an entirely new direction, being an holistic methodology that addresses the health (structure and functioning) of all components of the riverine ecosystem, rather than

focusing on selected species as do many similarly resource-intensive international methodologies.

Environmental Water Requirement Using Building Block Methodology

The BBM methodology assesses the requirements, which needs to be fulfilled throughout the year for estimation of Environmental flows. The requirements considered are:

1. Irrigation and Drinking water requirements

   The Panegaon site is located in a downstream side of Mula reservoir in an area with low population density with no major sources of pollution. The major source of water for meeting irrigation and drinking requirements in the project area are rivers which flow adjacent to the habitations. The water is conveyed to the point of consumption. Thus, no water is abstracted from this site.

2. Flow required maintaining water quality
3. Flow required to sustain riverine ecology including species

The BBM methodology used in this study constructs a synthetic hydrograph which must satisfy the water requirements in the river for maintaining a desired condition. The hydrograph simulates the natural conditions in the river to fulfill the different flow regimes present throughout the year. The identification and incorporation of these important flow characteristics will help to maintain the river's channel structure, diversity of the physical biotopes and processes. Four main seasons are identified along the year:

Season I This season is considered as high flow season influenced by monsoon. It covers the months from May to September. The minimum flow during this period is assumed as 30% of average flow (monthly).

Season II This season is considered as average flow period. It covers the month of October in which the proposed minimum flow is taken as 20% of average flow. This period is a transitional period between the wet and dry period.

Season III This season is considered as low or lean or dry flow season. It covers the months from November to March. The proposed minimum flow is taken as 15% of average flow during this period.

Season IV This season is considered as average flow period and is same as that of season II. It covers the month of April in which the proposed minimum flow is taken as 20% of average flow. This period is a transitional period between the dry and wet period.

The proposed minimum flows and Environmental flow requirements using Building Block Methodology are estimated for the case: For this case in which number of years monthly average flow data is considered.

RESULTS AND DISCUSSION

Hydrological characteristics have a direct effect on ecological and geomorphological processes that occur within the river channel and riparian environments. The hydrological regime is of major importance in the functioning of a river although the nature of its influence will differ for different components of the abiotic and biotic environment. The regime includes and describes all aspects of the hydrological character of a river.The Environmental Flow Requirement (EFR) of Mula River at Kotul, Mula Dam and Panegaon gauging sites was estimated using Lookup Tables, Table 1 (WCD 2000; UK-Q_{95}; 75% of Q_{95}), Tennant method (Table 2) and Tessman method (Table 3).

Tennant Method

For the determination of environmental flow requirement for the Tennant method there is necessity of lookup tables and therefore the lookup tables were developed. It is revealed from the Table 4.8 that the variation of environmental flow requirement (EFR) from 173.50 to 119.83 cumec for Panegaon gauging site of the Mula River. Similarly for Kotul site, the results reveal variation of environmental flow requirement (EFR) from 468.29 to 98.96 cumec (Table 1).

It is evident from Table 2, that a flow of the order of 694.02 cumec during April to September

Table 1
EFR at Kotul, Mula Dam and Panegaon gauging site of Mula River using Lookup Tables

Gauging sites	*MAF (cumec)*	*10% MAF (cumec) according to 'WCD'*	*Q_{95} (cumec) according to 'UK'*	*75% of Q_{95} (cumec)*
Kotul	4682.96	468.29	131.94	98.96
Mula Dam	111.83	11.83	13.13	9.8
Panegaon	1735.05	173.50	159.78	119.83

and 347.01 cumec during October to March would be necessary to maintain a "good habitat" at Panegaon gauging site of the river. Similarly to maintain an "Excellent habitat" at Panegaon a flow in the order of 867.52 cumec during April to September and 520.51 cumec during October to March has been estimated using Tennant method. Table 2 also indicates that flushing flow for a period of 48-96 hours should be provided once in a year during April to September of the order of 3470.1 cumec at Panegaon gauging site, which would be essential for breeding, regeneration of flora and fauna of the river. Similarly from Table 2, that a flow of the order of 1873.18 cumec during April to September and 936.59 cumec during October to March would be necessary to maintain a "good habitat" at Kotul gauging site of the river. Similarly to maintain an "Excellent habitat" at Kotul a flow in the order of 2341.48 cumec during April to September and 1404.88 cumec during October to March has been estimated using Tennant method. Table 2 also indicates that flushing flow for a period of 48-96 hours should be provided once in a year during April to September of the order of 9364 cumec at Kotul gauging site, which would be essential for breeding, regeneration of flora and fauna of the river.

Modified Tennant (Tessman) Method

According to Modified Tennant method, Environmental Flow Requirement at Kotul and Panegaon gauging site was also estimated. The results are given in Table 3, which indicate that MAF of river at Panegaon gauging site in the order of 1735.05 m^3/s and 40% of MAF becomes 694.02 m^3/s .As per the modified Tennant method, if MMF less than 40% of MAF then EFR should be equal to MMF of that particular month i.e.; MMF of Panegaon station in June month is 2.93 m^3/s which is less than 40% of MAF (694.02 m^3/s), therefore, EFR for the month of June should be 2.93 m^3/s. If MMF of a month is greater than 40% of MAF then EFR of that particular month should be 40% of MAF for that month. Similarly for the Kotul gauging site in Table 3, which indicate that MAF of river at Kotul gauging site in the order of 4682.96 m^3/s and 40% of MAF becomes 1873.18 m^3/s. As per the modified Tennant method, if MMF less than 40% of

Table 2
EFR estimated by Tennant method at Kotul, Mula Dam and Panegaon station

Description of Flow	*Kotul*		*Mula Dam*		*Panegaon*	
	April to September (cumec)	*October to March (cumec)*	*April to September (cumec)*	*October to March (cumec)*	*April to September (cumec)*	*October to March (cumec)*
Flushing flow(from 48-96 hours)	9364	Not Applicable	223.66	Not Applicable	3470.1	Not Applicable
Optimum range of flow	2809.77– 4682.96	2809.77– 4682.96	67.09- 111.83	67.09- 111.83	1041.03 – 1735.05	1041.03 – 1735.05
Outstanding habitat	2809.77	1873.18	67.09	44.73	1041.03	694.02
Excellent habitat	2341.48	1404.88	55.91	33.54	867.52	520.51
Good habitat	1873.18	936.59	44.73	22.36	694.02	347.01
Fair or degrading habitat	1404.88	468.29	33.54	11.18	520.51	173.50
Poor or minimum habitat	468.29	468.29	11.18	11.18	173.50	173.50
Severe degradation	< 468.29	< 468.29	<11.83	<11.83	< 173.50	< 173.50

MAF then EFR should be equal to MMF of that particular month i.e.; MMF of Kotul station in June month is 1212.19 m^3/s which is less than 40% of MAF (1873.18 m^3/s), therefore, EFR for the month of June should be 1212.19 m^3/s. If MMF of a month is greater than 40% of MAF then EFR of that particular month should be 40% of MAF for that month.

Mean monthly flow (MMF) is not available in Kotul, and Panegaon site during October to May and November to May however if the mean monthly flow is available in future the environmental flow requirement (in cumec) during October to May and November to May should be taken as per criteria of Modified Tennant method (Table 3).

Environmental Water Requirements for Panegaon and Kotul Site Using Building Block Methodology

The BBM methodology assesses the requirements, which needs to be fulfilled throughout the year for estimation of Environmental flows. The requirements considered are:

1. Irrigation and drinking water requirements
2. Flow required maintaining water quality
3. Flow required to sustain riverine ecology including vegetation species

The flow required for sustaining riverine ecology for average flows for Mula Dam site for the month of June to December are shown in Table 4. No flow is available in Mula Dam site during January to March, however if the flow is available in future the flow requirement (in cumec) during January to March should be 15% of average flows. Also the discharge was not available in March and May however if it is available then flow requirement (in cumec) for sustaining the riverine ecology at Mula Dam site will be 30% and 20% of

Table 3
Monthly EFR of Kotul, Mula Dam and Panegaon gauging site in Mula River by Tessman

Month	*Kotul*		*Mula Dam*		*Panegaon*	
	MMF	*EFR*	*MMF*	*EFR*	*MMF*	*EFR*
Jun	1212.19	1212.19	1.94	1.94	2.93	2.93
Jul	1347.33	1347.33	15.49	15.49	39.77	39.77
August	486.86	486.86	17.78	17.78	288.89	288.89
September	75.58	75.58	10.81	10.81	237.08	237.08
October	-	-	19.17	19.17	226.54	226.54
November	-	-	0.010	0.010	-	-
December	-	-	0.0045	0.0045	-	-
MAF	4682.96		111.83		1735.05	
40% of MAF	1873.18		44.73		694.02	

Table 4
Flow required to sustain riverine ecology for average flows for the period of 1988 to 2011(Mula Dam site)

Month	*Discharge(cumec)*	*Percentage*	*Flow required (cumec)*
June	1.947437	30	0.584231
July	15.49853	30	4.649558
August	17.78923	30	5.336768
September	10.81268	30	3.243804
October	19.17378	20	3.834755
November	0.010984	15	0.001648
December	0.004512	15	0.000677

average discharge for March and May respectively.

The environmental flows required as per Building Block Methodology for average flows for the Mula Dam site during the period of 1988 to 2011 are shown taken in Table 5. In this site there is irrigation water requirement, drinking water requirement, urban and industrial water requirement and other losses are available. Therefore they are included in the total flow.

SUMMARY AND CONCLUSION

In Hydrologic criteriaEnvironmental Flow (EF) of Mula River, at Kotul, Mula Dam and Panegaon gauging site, was estimated using various hydrological index methods, viz. Lookup Tables (WCD 2000; UK-Q_{95}; 75% of Q_{95}), Tennant as well as Modified Tennant methods and BBM (Building Block Methodology) was used to determine Environmental flow only for the Mula Dam site. According to lookup tables variation of flow from 119.83 to 173.50 cumec for Panegaon gauging site and 98.96 to 468.29 cumec for Kotul was observed. The results of lookup Tables may not be appropriate to recommend as EFR because these results were hardly found to represent even the poor flow condition (10% of MAF) of Tennant method. The Tennant method gives relatively more choices to recommend EFR varying from outstanding habitat to inferior habitat based on field condition and project priorities, however, Modified Tennant method appears to be preferred to estimate the environmental flow requirements, which is more acceptable and allocating EFR on monthly basis. Environmental water requirements at site of Mula Dam were also worked out using BBM.

Table 5
Environmental Flows required as per Building Block Methodology for average flows for the period of 1988 to 2011 (Mula Dam site)

Month	*Irrigation water requirement (cumec)*	*Drinking water requirement (cumec)*	*Urban and industrial water requirement (cumec)*	*Other losses (cumec)*	*Flow required to sustain riverine ecology (cumec)*	*Total flow (cumec)*
May	32.01336	0.016246	0.046927	9.316192	-	41.39273
June	27.42016	1.019331	0.706914	3.401834	0.584231	33.13247
July	29.33329	0.148642	0.996275	3.363499	4.649558	38.49126
August	51.58882	0.252329	0.727352	6.175601	5.336768	64.08087
September	24.74575	0.407735	1.199756	2.03403	3.243804	31.63107
October	38.87763	1.582278	1.481258	2.647995	3.834755	48.42392
November	23.77493	0.034855	0.046748	16.54511	0.001648	40.40329
December	31.97163	0.254106	0.136121	3.839317	0.000677	36.20185
January	29.54003	0.036969	0.047875	4.362142	-	33.98702
February	27.55728	0.048195	0.04473	5.596505	-	33.24671
March	22.4622	0.036112	0.046755	7.095635	-	29.6407
April	27.33176	0.020856	0.047056	8.557043	-	35.95672

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