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Assessment of Environmental Flows for Various Sub-Watersheds of Damodar River Basin Using Different Hydrological Methods

Ravindra Kumar Verma[1], Shankar Murthy[2*] and Rajani Kant Tiwary[3]

[1]*Fellow (Doctoral Programme), Environmental Engineering & Management Group, National Institute of Industrial Engineering, Mumbai, Maharashtra - 400087, India*
[2]*Associate Professor, Environmental Engineering & Management Group, National Institute of Industrial Engineering, Mumbai, Maharashtra - 400087, India*
[3]*Senior Scientist, Water Environment Division, Central Institute of Mining and Fuel Research (CIMFR), Barwa-Road, Dhanbad, Jharkhand-826015, India*

Abstract

Environmental Flows (EFs) assessment is a global challenge involving a number of tangible and intangible segments of hydrology, hydraulics, biology, ecology, environment, socio-economics, and several other branches of engineering including the management of water resources. It has consequently led to the development of more than 240 methods available in literature. Required for the longevity of a river, EFs derived from a single method are usually not accepted. In the present study, the EFs variability was assessed using three hydrological methods: (i) Tennant, (ii) Tessmann, and (iii) Graphical and Stochastic Flow Duration Curve (FDC) for various sub-watersheds of Damodar River Basin (DRB), located in the states of Jharkhand and West Bengal. The estimated values from Tessmann and graphical FDC methods were not as reliable as those from Tennant and Stochastic FDC methods. Comparative results indicate that minimum flow should be ranged from 1.04- 16.08 cumec, was required to keep basic river ecosystem functions in different watersheds. Whereas, 7Q series were estimated using stochastic FDC recommended for design flows from low to high. The value of Q95 of 7Q10 and 7Q100 FDC were found appropriate as designed EFs during drought/low flows and normal precipitation years respectively. Similarly, the values recommended for 7Q50 and 7Q100 of probability exceedance of 90% and 95%, will help water resource planner and decision makers for development of new water resources projects such as the design of storage facilities, assessment of water available for municipal, agricultural or industrial purposes and operating rules that satisfy EFs in the DRB.

Keywords: Environmental flows, Damodar river basin, Tennant, Tessmann, Flow duration curve

Introduction

Assessment of EFs is of paramount importance in the present era of modernization/development leading to increasing hydrological alternation through dams and diversions and, in turn, modification to the natural conditions of stream flow and ecosystem as well due to increasing water extraction for meeting human demands for uses such as industry, agriculture, recreation, hydropower generation, domestic water supply [1-3]. It is estimated that more than 60% of the world's rivers are fragmented by hydrological alternation and modify the natural patterns of rivers or stream flow and this figure is projected to increase to 70% by 2025 [4]. The protection of aquatic resources against the impact of dam and water extraction in river is a challenging and elusive issue in sustainable river basin management. Now a day, EFs assessment has undergone a major paradigm shifts from a single hydrologic attribute (i.e. minimum flows) to a full range of flows (floods, average, and low flows) that account for seasonal and inter- and intra-annual variation in stream flow variability. In addition, its magnitude, timing, frequency, and rate of change also plays an important role in long-term sustainability of water resources and their proper utilization with river ecosystem in state of good health and other features (such as fish, wildlife habitat, environmental purposes, water quality) [5,6]. In last two decades, EFs is gaining more attention, because it is required for the longevity of a river, led to the development of more than 240 methods in published literature. Although [7] pointed out that none of developed methodology is considered as best and all methods have importance, depending on objectives for estimating EFs and hydro-geological condition of a watershed. Therefore, comparative approaches is ideal approach to provide an assessment of EFs in a river or stream because all categories of quantitative methods have importance and its use depends on the level of protection, environmental goals, and objectives of the study [8]. Further [8] pointed out that hydrological and hydraulic methods are useful in cases where there is a poor understanding of the ecosystem or where a high level of protection for an existing ecosystem is required. Based on this concept, a number of hydrological based comparative studies have been conducted throughout the world by researcher for different purposes. Table 1 shows only a few of them. In this view the objective of the study is assess EFs variability using three well known hydrological methods: i) Tennant, (ii) Tessman, and (iii) FDC in eight different sub-watersheds of the DRB, India.

Study Area

The DRB has area of about 23,170 sq. km. in the states of Jharkhand and West Bengal, India and lies between 22°15'N to 24°30' N latitude and 84°45' E to 88°30' E longitude Figure 1. The basin has two main rivers Damodar and Barakar, experienced exclusive anthropogenic activity and the riverbed is probably altered The water of the rivers is mainly used for agriculture, industry and domestic purposes and demand for water from these sectors would drastically increase in near future. Details of surface water availability, water use, and demand are summarised in Table 2. The basin hydrology is the product of its climate, geology, land use, topography and drainage systems. The flow response

***Corresponding author:** Shankar Murthy, Associate Professor, Environmental Engineering & Management Group, National Institute of Industrial Engineering, Mumbai, Maharashtra-400087, India; Tel:91-22-28035201; Email: murthyshanker@gmail.com

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Reference	Purpose	EFs methods used	Finding
[9]	In-stream flow methods most often used in North America	IFIM, Tennant, Wetted Perimeter, 7Q10 flow, Aquatic Base Flow (ABF).	Comparing results provide useful update and widest application
[10]	In-stream flow methods used in Australia	Tennant, Flow duration (Q95& Q90), Constant yield.	Suggested different methods are suitable according to different conditions or objectives
[11]	Comparisons of hydrologically based in-stream flow methods in 70 rivers of Atlantic Canada	Tennant, 25% of the MAF, Monthly (Q50, Q90) flow, Aquatic Base Flow (ABF), 7Q10 flow.	Q_{90} and 7Q10 methods predict extremely low in-stream flows during winter and summer months; whereas, Q50 flows recommended for gauged and 25% of the MAF & ABF for ungagged basin.
[12]	Examine impact of temperature on low stream flow for 77 rivers in the Canadian Prairies and trends analysis	Seasonal 7-day low flow, Seasonal 25% of mean flow, Seasonal Q80, Monthly Q50 & Q90.	Decrease in the magnitude and an increase in the frequency of low flow results in poor water quality and negative impact on aquatic life in river, while temperature has an increasing tendency.
[13]	Assessment to fulfilled water requirement for industrial plant located in San and Brah river watershed, India.	50-, 75-, 90- percentile FDC	Only San river met the required water demand
[14]	To protect the fish habitat	MAF, Q50, Q90, 7Q2, 7Q10.	Q50 method provide high level and whereas Q90, 7Q2 and 7Q10 methods low level of in-stream flow in small river.
[15]	Assessment of EFRs in major Indian river basin.	Default FDC	Suggested 6 (From A to F) Environmental Management Classes (EMCs).
[16]	Link EFRs with EFs classes	FDC	Developed a software package named Global Environmental Flow Calculator (GEFC) for desktop assessment of EFs.
[17]	Assess and design EFs in the Brahmani-Baitarani river system, Odissa, India.	FDC	7Q10 FDC and 7Q100 FDC were appropriate methods for designed EFs during drought /low flow periods and normal precipitation years respectively.
[18]	Assess optimal EFs in Tungabhadra river, India	Tennant	Required more water improve water quality and livelihood support base of river ecosystem.
[19]	Computing the minimum water requirement to save biological activity in Safaood river, Iran.	Tennant, Q95 from FDC, Hydraulic	Q95 from FDC gave compatibility results with the rivers condition whereas; Tennant and Hydraulic methods gave overestimated results.
[20]	Comparisons of hydrological based methods for assess EFRs to maintain basic functions in Shahr chai river, Iran.	Tennant, FDC shifting, Low flow index, DRM, GEFC	FDC shifting and DRM methods are more reliable methods in compare to Tennant, 7Q10 and Q90 of AFDC for maintains basic river functions.

Table 1: Comparative studies based on hydrological based methods.

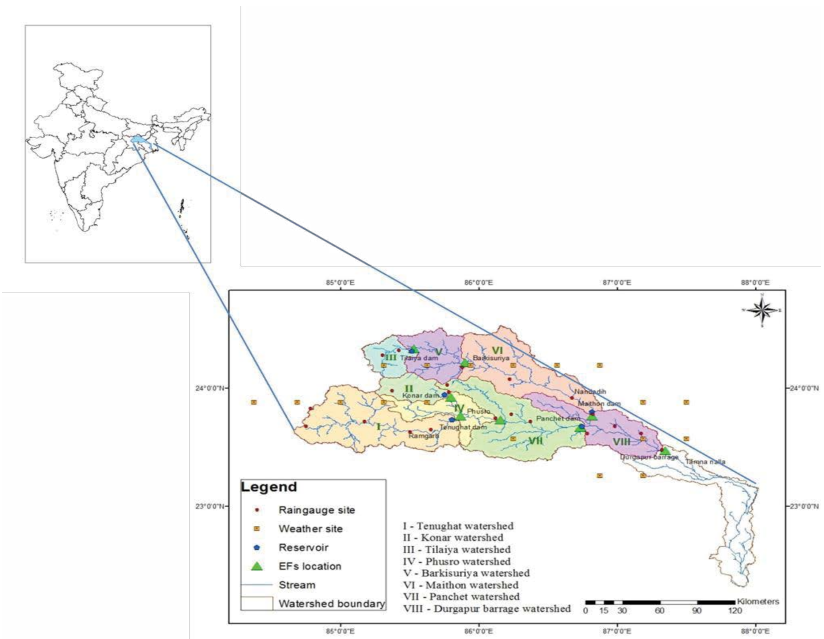

Figure 1: Showing eight sub-watersheds with EFs location.

in the rivers is strongly influenced by the underlying geology and five storage dams that provide a measure of flow regulation. These dams were constructed under Tennessee Valley Authority (TVA) of United States of America project across Damodar and its tributaries at Tilaiya, Konar, Maithon, Panchet, Tenughat and a barrage at Durgapur and four are still proposed at Aiyar, Bermo, Balpahari, and Bokaro, so that the flow can be control in the lower valley and could be better utilized for industry, municipality, agriculture and other sectors. These dams as in case of other dams of the globe have affected the hydrological system of the rivers and altered the natural habitats of the river system. The basin experiences tropical climate; the winters are cold, summers are hot and the temperature difference between the two seasons is significant. Summers are usually very hot and dry with average 30°C, and during May-July month, temperatures can reach upto 48°C. Both rivers Damodar and Barakar are entirely rain fed. Mean annual precipitation over the whole basin varies from 1200-1400 mm (Barakar 1260 mm, Damodar 1272 mm, and lower valley 1329 mm). About 80% of mean annual runoff occurs during monsoon season from June to September. Mean annual precipitation varies from about 765 to 1850 mm. Generally, rainfall is occurring in April to August. The highest annual rainfall is 1650 mm in the southern part of the lower valley. The rainfall gradually decreases to less than 1050 mm in the northern part of the Barakar catchment.

Hydrological Methods Adopted to Assess EFs

Three hydrological methods: Tennant, Tessman, and FDC (traditional and stochastic) were used to assess EFs in eight sub-watersheds of the DRB. Details of Tennant, Tessman, and FDC methods can be found elsewhere, Whereas, described about stochastic FDC. Furthermore, the value of probability of exceedance equal to 95% (Q95) of FDC was chosen as "design EFs" in the DRB, because, the basin has extremely low flows during lean period and the ecosystem (flora and fauna) manages with the severity of flow from high to low flows very well.

Results and Discussion

Firstly, the Tennant method was applied to generate EFs requirements corresponding to different habitat condition in selected each watershed and recommended values are summarized in Tables 3 and 4. It can be noted that required values for optimum habitat status (60-100% of MAF) are maintaining in the DRB except in low flow season from April to July. Analysis shows that excellent habitat condition was maintain in downstream of Phusro, Maithion, and Panchet watersheds. On the other hand, reaches below Konar dam, Tilaya dam and, Barkisuriya did not satisfy required flow even 2.5% of the MAF throughout the year due to heavily flow regulation in Konar and Barakar watersheds (Table 5). To make preliminary flow recommendations that take into consideration the needs of fish and other aquatic life, the Tennant method can be used in the DRB. However, it should be modified by adjusting the season of lowest flow to cover the period from April to July. Secondly, Tessmann method [22-24] was applied that mimic the natural flow on monthly basis and recommended values are shown in Figure 2. In the third method, FDCs of daily and 7-day were drawn for respective stations based on available period of record (POR). Figure 3 shows daily FDC at each monitored site. It has been observed that shape of computed daily FDCs at each sites were different, may be due to different in variability in precipitation, watershed characteristics, meteorological factors, urbanization and water abstraction or demand. The Damodar catchment is highly urbanized and having impervious surface which causes increase in storm water runoff and decrease in infiltration and ground water recharge.

Conclusions and Recommendation

The paper presents the preliminary EFs recommendations using three hydrological methods; (i) Tennant (ii) Tessman, and (iii) FDC in eight sub-watersheds in the DRB, which is the first attempt in this tropical river system. These methods are preliminary approaches, where insufficient ecological and hydraulic data are not available. Lack of eco-hydrological data makes it difficult to determine minimum flow thresholds and tipping points of different freshwater ecosystems across

Source	Amount (MCM)	Offstream User	Water demand (MCM/year)	
			In year 2012	In year 2021
DVC reservoir at 75% dependability (Konar, Tilaiya, Maithon, Panchet, Durgapur barrage)	4,855	Domestic	507.0	-
Less due to decrease in water holding capacity of reservoir	1,030	Industry	663	884
Net available	3,825	Agriculture	652.41	1948
Presently available from other sources	223			
Total water available	**4,048**			

Table 2: Water availability, withdrawal and demand in the DRB.

Station/its characteristics	TG dam	KN dam	TY dam	Phusro	Barkisuraiya	MT dam	PH dam	DB, Burnpur
River	Damodar	Konar	Barakar	Damodar	Barakar	Barakar	Damodar	Damodar
Locatitn	23°44' N 85°55' E	23°43' N 85°30' E	24°19' N 85°31' E	23°45' N 86°00' E	23°13' N 85°54' E	23°78' N 86°81' E	23°40' N 86°44' E	24°06 'N 86°13' E
Drainage area (km^2)	3,393	997.1	984	5,352	2,681	6293.7	10,966	19,555
Annual runoff (Ha-m)	245,500	55,507	43,172	-	-	261,499	453,923	-
Average annual precipitation (cm)	132.08	132.08	111.76	-	-	114.17	114.17	132.08
Total dead storage capacity (Ha-m)	16,096	3,440	7,478	-	-	9,317	11,914	-
Spillway design discharge (cumec)	15,990	6,796	1,348	-	-	13,592	16,608	-

Table 3: Descriptions of selected EFs location characteristics in the DRB

SlNo.	EFs recommendation/ station	Period of record	MAF (cumec)	Flushing or Maximum	Outstanding		Excellent		Good		Fair or Grading		Poor or Minimum	Serve Degradation
				April to September @ 200%	April to September @ 60%	October to March @40%	April to September @ 50%	October toMarch @ 30%	April to September @ 40%	October to March @20%	April to September @ 30%	October to March @ 10%	October to September @10%	April to September @ < 10%
1.	Tenughat dam	1981-2010	69.83	139.66	41.89	27.93	34.92	20.95	27.93	13.96	20.95	6.98	6.98	< 6.98
2.	Konar dam	1981-2010	13.63	27.26	8.18	5.45	6.82	4.09	5.45	2.07	4.09	1.36	1.36	< 1.36
3.	Tilaya dam	1981-2010	10.37	20.79	6.22	4.15	5.19	3.11	4.15	2.08	3.11	1.04	1.04	< 1.04
4.	Barkisuriya	1981-2010	32.16	64.32	19.30	12.86	16.08	9.65	12.84	6.43	9.65	3.22	3.22	< 3.22
5.	Phusro	1988-2010	87.56	175.12	52.54	35.024	43.78	26.27	35.02	17.51	26.27	8.76	8.76	< 8.76
6.	Maithon dam	1981-2010	81.50	163.0	48.9	32.6	40.75	24.45	32.6	16.3	24.45	8.15	8.15	< 8.15
7.	Panchet dam	1981-2010	135.87	271.74	81.52	54.35	67.94	40.76	54.35	27.17	40.76	13.59	13.59	< 13.59
8.	Damodar bridge, Burnpur	1981-2010	168.03	336.06	100.82	67.21	84.02	50.41	67.21	33.61	50.41	16.80	16.80	< 16.80

			MAF (cumec)	Flow Indices from empirical 1day and 7-day POR FDC													
				Q10		Q17		Q40		Q50		Q75		Q90		Q95	
				1-day	7-day	1-day	7-day	1-day	7-day	1-day	7-day	1-day	7-day	1-day	7-day	1day	7-day
1.	Tenughat dam	1981-2010	69.83	187.73	187.74	128.4	133.71	6.37	8.48	5.70	6.25	5.10	5.24	4.68	4.86	4.39	4.51
2.	Konar dam	1981-2010	13.63	21.29	21.18	13.65	13.77	9.26	9.60	8.60	8.79	6.75	6.82	5.55	5.10	4.05	4.52
3.	Tilaya dam	1981-2010	10.37	21.87	21.76	20.2	18.88	9.72	9.54	4.16	4.92	0.075	0.38	0.25	0.35	0.011	0.34
4.	Barkisuriya	1981-2010	32.16	77.06	78.6	45.85	53.27	21.18	22.78	11.39	13.0	0.78	1.24	0.023	0.06	0.01	0.2
5.	Phusro	1988-2010	87.56	176.11	240.13	139.4	153.2	25.08	27.45	19.36	20.5	10.04	10.38	4.52	5.18	1.86	2.14
6.	Maithon dam	1981-2010	81.50	169.09	169.98	126.16	124.4	45.83	46.62	31.46	34.8	14.28	15.90	7.17	9.19	2.89	5.18
7.	Panchet dam	1981-2010	135.87	353.0	354.89	195.2	226.8	58.33	58.07	36.11	38.9	9.95	13.34	2.88	5.44	0.29	0.74
8.	Damodar bridge, Burnpur	1981-2010	168.03	473.12	478.0	282.5	305.1	46.8	52.25	24.0	26.9	4.49	4.86	0.22	1.10	0.22	0.23

Table 4: Comparison of recommended EFs in cumec in various sub-watersheds of the DRB assessed through Tennant, and traditional FDC

Sl. No	Sampling site	Q10 (cumec)				Q25 (cumec)			
		7Q10	7Q20	7Q50	7Q100	7Q10	7Q20	7Q50	7Q100
1.	Tenughat dam	99.79	133.71	192.59	449.04	7.31	25.76	80.86	240.38
2.	Konar dam	9.79	10.76	16.55	65.86	8.10	8.54	10.09	25.81
3.	Tilaya dam	10.52	13.19	18.68	82.49	2.43	4.91	15.49	25.21
4.	Barkisuriya	33.63	40.14	73.2	224.87	17.22	20.99	36.92	90.66
5.	Phusro	106.77	140.8	240.2	891.81	37.12	41.30	114.84	361.0
6.	Maithon dam	77.36	97.22	160.24	540.0	42.70	53.03	86.72	185.86
7.	Panchet dam	194.36	277.35	374.64	786.04	102.7	142.72	177.46	276.22
8.	Damodar bridge, Burnpur	72.29	195.11	507.81	1469.0	11.96	44.61	168.07	567.28
		Q50 (cumec)				Q75 (cumec)			
		7Q10	7Q20	7Q50	7Q100	7Q10	7Q20	7Q50	7Q100
1.	Tenughat dam	5.09	5.31	6.12	39.17	4.86	5.09	5.29	8.32
2.	Konar dam	5.67	6.02	8.38	22.59	4.4	5.65	7.10	10.99
3.	Tilaya dam	0.075	0.14	7.13	22.05	0.05	0.05	0.09	10.86
4.	Barkisuriya	2.49	5.0	13.92	30.59	0.04	0.06	1.25	12.36
5.	Phusro	10.2	15.09	20.34	37.79	3.25	7.25	10.25	24.45
6.	Maithon dam	13.75	23.97	37.68	62.88	7.97	12.91	17.16	29.40
7.	Panchet dam	34.87	57.87	60.62	71.25	15.6	14.25	21.1	22.77
8.	Damodar bridge, Burnpur	1.82	3.13	16.51	193.81	0.22	1.42	5.21	73.49

		Q90 (cumec)				Q95 (cumec)			
		7Q10	7Q20	7Q50	7Q100	7Q10	7Q20	7Q50	7Q100
1.	Tenughat dam	4.40	4.71	4.93	6.52	2.55	4.02	4.56	5.58
2.	Konar dam	3.47	4.56	6.02	10.88	3.40	4.51	5.9	10.88
3.	Tilaya dam	0.03	0.04	0.06	2.26	0.02	0.03	0.05	1.50
4.	Barkisuriya	0.01	0.02	0.10	2.99	0.01	0.02	0.10	1.98
5.	Phusro	1.87	2.89	7.47	21.74	1.23	1.3	6.90	19.31
6.	Maithon dam	2.89	7.28	11.6	20.47	1.67	6.35	8.20	17.23
7.	Panchet dam	9.80	6.22	10.22	14.19	2.76	5.21	8.68	10.44
8.	Damodar bridge, Burnpur	0.22	0.62	3.87	49.35	0.20	0.22	3.71	34.66

Table 5: Comparing the results for selected 7Q flow series in various return periods computed using SFDC analysis.

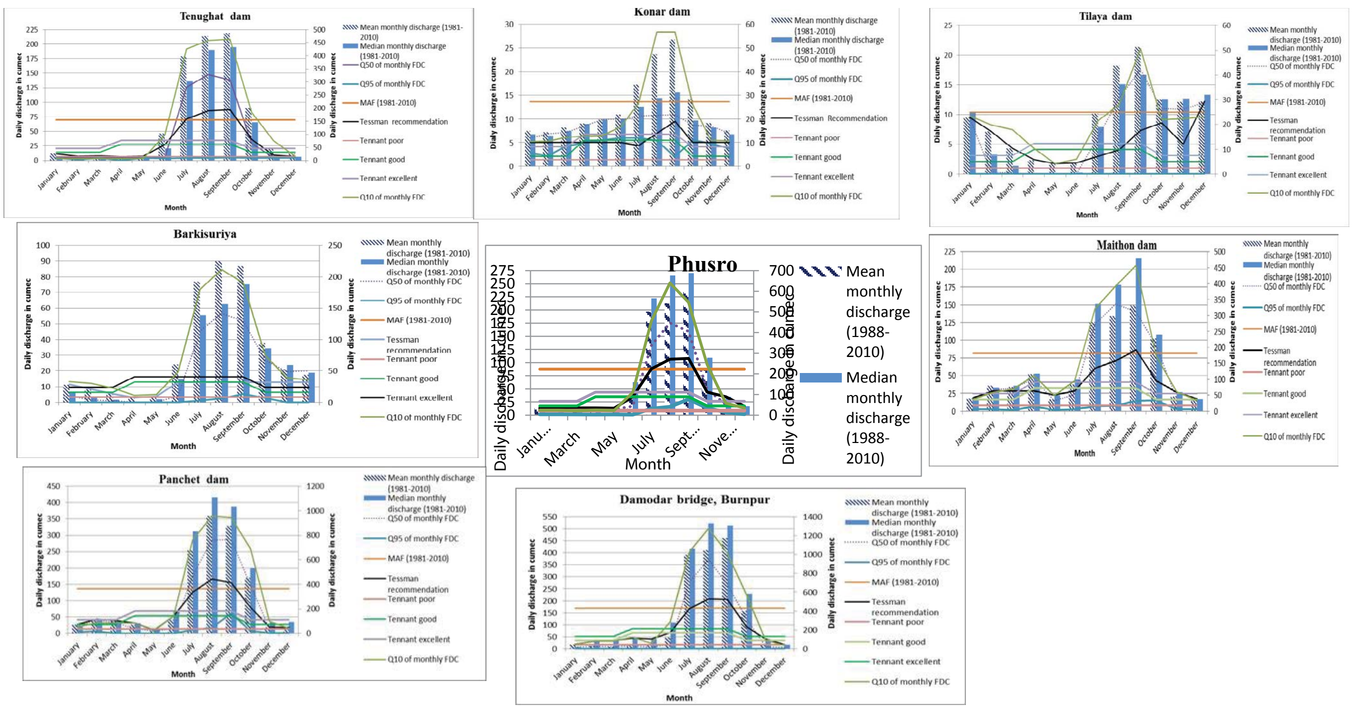

Figure 2: Estimated EFs in different watersheds of the DRB using Tennant method on monthly basis, Tessmann method and flow charecteristics at diffents % time exceedance (i.e Q10, Q50, Q95) on basis of monthly FDC.

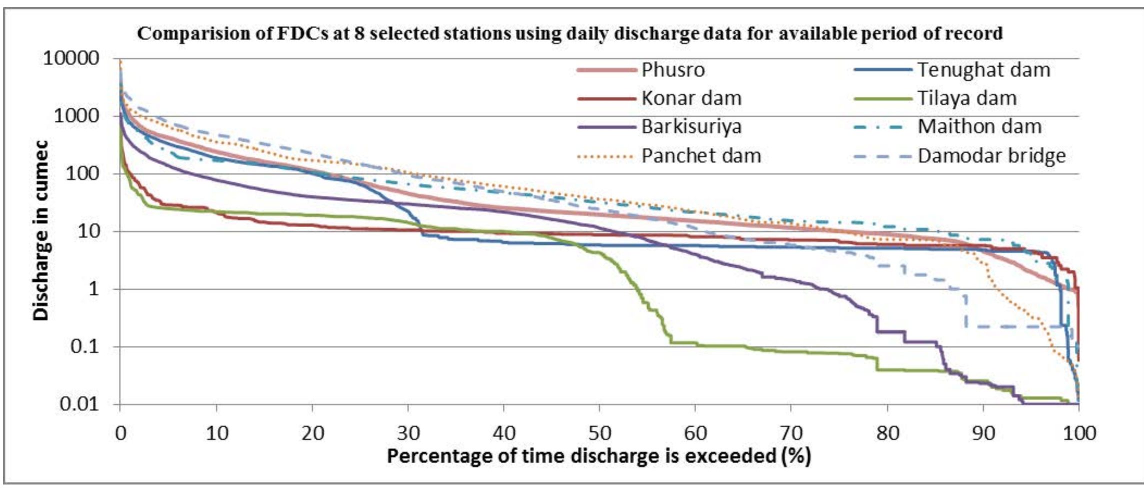

Figure 3: A graphical comparetive representation of daily FDC for selected stations in the DRB.

the world. However, in some cases, hydrological methods gave results that were in agreement with each other, but in other cases different approaches yielded different results and threshold values.

The flow recommendations in this study are often used as firsthand information, because neither a flow as magnitude computed by Tennant and Tessman and duration computed by FDC nor frequency obtained by stochastic FDC analysis has a consistent relationship to habitat or production across a range of stream geomorphology. It is therefore, likely to generate results with low confidence and monotonous and there is no provision to integrate other associated aspects, for instance-the ecology, biodiversity, riverine communities etc. Thus, there is a need for a better methodology that could be implemented and describes relationships between discharge and width, discharge and depth, and discharge and velocity. Hence, simple historical based approaches used in assessing EFs requirements are not found suitable for all types of watershed. However, the results obtained provide detailed information, which can be used for estimating the water supply, the water demand for both anthropogenic and ecological, and the amount available for withdrawal in near future regarding the planned anthropogenic alteration and its consequences. The values recommended for 7Q50 and 7Q100, will help water resource planner and decision makers to develop new water resource projects such as the design of storage facilities, assessment of water available for municipal, agricultural or industrial purposes and operating rules that satisfy EFs in DRB.

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References

1. Crisp DT (1989) Some impacts of human activities on trout Salmo trutta populations. Freshwater Biology 21: 21-33.
2. King J, Brown C, Sabet H (2003) A scenario-based holistic approach to environmental flow assessment for rivers. River research and applications 19: 619-639.
3. Petts GE (2009) Instream flow science for sustainable river management. Journal of the American Water Resources Association 45: 1071-1086.
4. Revenga C, Brunner J, Henninger N, Kassem K, Payne R (2000) Pilot analysis of global ecosystems: freshwater systems. World Resources Institute.
5. Poff NL, Allan JD, Bain MB, Karr JR, Preste-gaard KL, et al. (1997) The natural flow regime. A paradigm for river conservation and restoration. Bio Science 47: 769-784.
6. Postel S, Richter BD (2003) Rivers for life: managing water for people and nature. Island Press Washington DC, USA.
7. Acreman M, Dunbar MJ (2004) Defining environmental river flow requirements-a review. Hydro Earth Sys Sci 8: 861-876.
8. Jowett IG (1997) Instream flow methods: A comparison of approaches. Regulated Rivers: Res Mange 13: 115-127.
9. Reiser DW, Wesche TA, Estes C (1989) Status of instream flow legislation and practices in North America. Fisheries 14: 22-28.
10. Karim K, Gubbels ME, Goulter IC (1995) Review of determination of instream flow requirements with special application to Australia. Water Resour Bull 31: 1063-1077.
11. Caissie D, El-Jabi N (1995) Comparison and regionalization of hydrologically based in-stream flow techniques in Atlantic Canada. Can J Civil Engg 22: 235-246.
12. Yulianti JS, Burn DH (1998) Investigating links between climatic warming and low stream flow in the Prairies region of Canada. Can J Water Resour 23: 45-60.
13. Pandey RP, Ramasastri KS (2003) Estimation of lean season water availability in streams with limited data. Journal of the Institution of Engineers. India, Civil Engineering Division 84:149-152.
14. Caissie D, El-Jabi N, Hébert C (2007) Comparison of hydrologically based instream flow methods using a resampling technique. Can J Civil Engg 34: 66-74.
15. Smakhtin VU, Anputhas M (2006) An assessment of environmental flow requirements of Indian river basins. International Water Management Institute, Colombo, Sri Lanka.
16. Smakhtin VU, Eriyagama N (2008) Developing a software package for global desktop assessment of environmental flows. Environ. Model. Software 23: 1396-1406.
17. Smakhtin V, Revenga C, Döll P (2004b) A pilot global assessment of environmental water requirements and scarcity. Water Int 29: 307-317.
18. Jha R, Sharma KD, Singh VP (2008) Critical appraisal of methods for the assessment of environmental flows and their application in two river systems of India. KSCE J Civil Engg 12: 213-219.
19. Babu KL, Kumara, BKH (2009) Environmental flows in river basins: a case study of river Bhadra. Current Science 96: 475-479.
20. Shokoohi A, Hong Y (2011) Using hydrologic and hydraulically derived geometric parameters of perennial rivers to determine minimum water requirements of ecological habitats (case study: Mazandaran Sea Basin-Iran.). J Hydrolog Process 25: 3490-3498.
21. Karimi SS, Yasi M, Eslamian S (2012) Use of hydrological methods for assessment of environmental flow in a river reach. Int J Environ Sci Technol 9: 549-558.
22. Sugiyama HV, Vudhivanich AC, Whitaker K, Lorsirirat (2003) Stochastic flow duration curves for evaluation of flow regimes of rivers. J Amer Water Resour Assoc 39: 47-58.
23. Tessman SA (1980) Environmental Use Sector Reconnaissance Elements of the Western Dakotas Region of South Dakota Study. Water Resources Research Institute.
24. Kumar SS, Sridhar KT (1998) GIS techniques for carrying capacity study of Damodar River Basin Central.