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Research Article

DESKTOP APPROACH FOR ENVIRONMENTAL FLOW ASSESSMENT OF A RIVER

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ABSTRACT
Environmental flows are the water that is left in a river, or released into it in order to maintain valued features of the ecosystem. It refers to the water considered sufficient for protecting the structure and function of an ecosystem and its dependent species. In the recent advancement, there has been a rapid proliferation of methods for assessing the environmental flows, ranging from relatively simple, low-confidence, desktop approaches, to resource-intensive, high-confidence approaches. Each of these has some merits and limitations. In the present study, the environmental flow has been assessed using desktop approach based on environmental management classes (EMCs) at various stretches of Cauvery river in Karnataka state. The results are compared with other hydrological index methods. The minimum and maximum range of magnitude of flow estimated based on these methods are recommended as environmental flow, which can be used for future planning of water resource development and hydropower projects in the Cauvery basin.

Key Words: *Environmental Flows, River, Desktop Approach, Environmental Management Classes*

INTRODUCTION
In the 1970s, the concept of minimum flow in the rivers came into practice. It was based on the premise that the health of a river ecosystem deteriorates if the flow falls below a certain minimum value. Hence, as long as the discharge in the river exceeds a critical value, the river ecosystem will be able to function satisfactorily. Subsequent detailed studies on the different components of river ecosystems led to the understanding that ensuring minimum flow alone is insufficient and all elements of a flow regime, including high, medium and low flows are important (Poff *et al.*, 1997). It is now widely accepted that a naturally variable regime of flow, rather than just a minimum low flow, is required to sustain freshwater ecosystems (Poff *et al.*, 1997; Bunn and Arthington, 2002; Postel and Richter, 2003; Annear *et al.*, 2004; Poff, 2009), and this understanding has contributed to the implementation of environmental flow management on thousands of river kilometers worldwide (Postel and Richter, 2003).Thus, any changes in the flow regime will have some influence the river ecosystem and if the natural river ecosystem is to be maintained in a pristine condition, the environmental flow will have to be set to closely follow the natural flow regime. However, this will not always be possible and most river ecosystems are managed to different degrees to meet the needs of the society. Certain needs, e.g., water supply for municipal uses, irrigation, require removal of water from the river. Societal needs such as bathing in the river do not require that water be removed from the river. Generation of electricity by the use of stream flows may require diversion of water or may be accomplished without diversion, depending upon the topographic conditions.
Environmental flows are the water that is left in a river, or released into it (e.g. from a reservoir), in order to maintain valued features of the ecosystem (Tharme and King, 1998). Environmental flow requirement (EFR) is needed to help maintain downstream ecosystem, renewable natural resource production system and associated livelihood. As such, EFR is a compromise between water resources development and maintenance of a river in ecologically acceptable or agreed conditions. Realizing the importance of EFR, several countries have made ensuring environmental flows mandatory through legislations to ensure required minimum flow in the river system to sustain ecosystem services. The practice of EFR's began as a commitment to ensuring a 'minimum flow' in the river, often arbitrarily fixed at 10% of the mean

annual runoff (World Commission on Dams, 2000). However, this 'minimum flow' approach may not be appropriate for safeguarding essential downstream environmental conditions of the river system.

In recent years, there has been a rapid proliferation of methods for estimating environmental flows, ranging from relatively simple, low-confidence, desktop approaches, to resource-intensive, high-confidence approaches. The comprehensive methods are based on detailed multi-disciplinary studies that often involve expert discussions and collection of large amounts of geo-morphological and ecological data (e.g. King and Louw, 1998). Typically they take many months, sometimes years, to complete. A key constraint to the application of comprehensive methods, particularly in developing countries, is the lack of data linking ecological conditions to specific flows. To compensate for this, several methods of estimating environmental flows have been developed that are based solely on hydrological indices derived from historical data (Tharme, 2003). Initially, Tharme (2003) reviewed the status of environmental flow methodologies worldwide and revealed the existence of 207 individual methodologies, recorded for 44 countries within six world regions. Application of methodologies is typically at two or more levels. (1) Reconnaissance-level initiatives relying on hydrological methodologies are the largest group (30% of the global total), applied in all world regions and (2) At more comprehensive scales of assessment, two avenues of application of methodologies exist.

As such, the preliminary studies on environmental flow requirements of Indian River Basins have been carried out by IWMI (2006) using a flow duration curve (FDC)– a cumulative distribution function of monthly flow time series. Smakhtin and Erivagama (2008) described FDC based method and software package for desktop assessment of environmental flows. The method uses monthly flow data and is built around a FDC, which ensures that elements of natural flow variability are preserved in the estimated environmental flow time series. The curve is calculated for several categories of aquatic ecosystem protection -from 'largely natural' to 'severely modified'. Mazvimavi *et al.,* (2007) used desktop hydrological method to assess EFR for river basin planning in Zimbabwe. Kashaigili *et al.,* (2007) also used desktop approach to determine maintenance high and low flows, and drought low flow requirements within the Ruaha National Park. Yang *et al.,* (2008) Environmental flow requirements for integrated water resources allocation in the Yellow River Basin. Shofiul Islam (2008) presented a methodology deals on human well being, river functions and their relation with river flow based in Asian environment. Babu and Harish Kumara (2009) studied environmental flows and its importance. Due to the construction of big dam across the river Bhadra which alter its natural flow using Tenant method. Assessment of Environmental Flows Baitarni and Brahmani River Systems is carried out by Jha *et al.*, (2008) to estimate low-flow and high-flow discharges for ecological river maintenance and recommended stochastic Flow duration curve (SFDC) approach as most suitable technique for estimating environmental flows. Recently, Mathew *et al.,* (2009) carried out a study to estimate the environmental flow requirements downstream of the Chara weir by using Desktop approach.

As we all aware that Karnataka State was in a comfortable position in the power sector till 1972. From 1973 onwards, there was a shortage as the addition to the capacity failed to keep pace with the growth in demand, which affects not only industrial development but also the other sectors of economy including agriculture. Hydropower, which is perpetual clean power with least running cost. It contributes about 63.4% of the Karnataka power system. Karnataka state large deficit in peak power demand and energy availability, hence, there is a scope for its development of Hydropower. Prior to planning of hydropower project, it is necessary to carry out the environmental flow assessment. Hence, the present study has been conducted to assess environmental flow requirements in selected river stretches/reaches of Cauvery River in Karnataka state using various desktop approaches.

MATERIALS AND METHODS

The baseline maps of Cauvery basin was collected from Water Resources Development Organization (WRDO) Bangalore. The various sub-basins within Cauvery basin were demarcated using the open source GIS namely Integrated Land and Water Information System (ILWIS 3.8.1) software of ITC

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Netherlands. There exist a potential to economically harnessed (HPS) in Cauvery river basin. KPCL planned for HPS. Run-of-the river power generation at proposed site of HPS requires a weir for creating small pondage. The River Cauvery is one of the important east flowing river of Karnataka. It rises in the Western Ghats and flows in eastwardly direction passing through the states of Karnataka, Tamil Nadu, Kerala and Pondicherry before it drains into Bay of Bengal. The basin lies between longitudes $75^0$30’ E to $79^0$45’ E and latitudes $10^0$05’ N to $13^0$30’ N. It is bounded on the west by the Western Ghats, on the east and south by the Eastern Ghats and on the north by the ridges separating it from the Tungabhadra (Krishna) and Pennar basins. The total length of the river from source to its outfall into Bay of Bengal is about 800 km. Of this, 320 km is in Karnataka, 416 km is in Tamil Nadu and 64 km forms the common boundary between Karnataka and Tamil Nadu States. The Cauvery basin extends over an area of 81,155 km2, which is nearly 24.7% of the total geographical area of the country. The sub-basin wise map of Cauvery basin is generated using ILWIS software as shown in figure 1. The locations of various gauge-discharge sites were also demarcated as shown in figure 1.

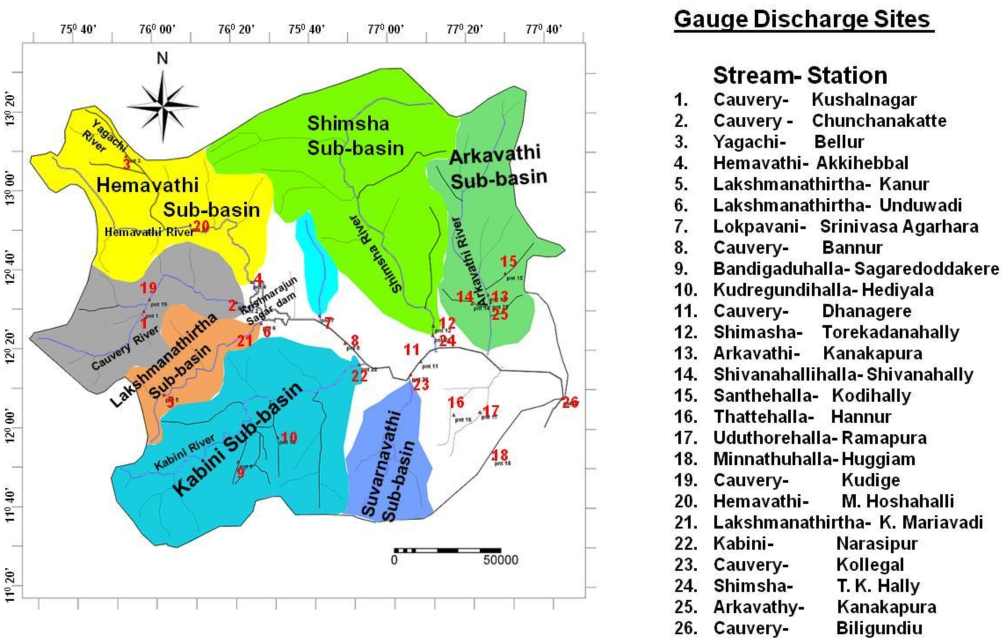

Figure 1: Location map of Cauvery basin and gauge-discharge sites

The long term stream flow data was procured from WRDO, Bangalore for the selected sites as per availability. The table 1 shows the details about gauging sites selected in the present study.

Table 1: Details of gauging sites on Cauvery basin selected in the present study

Sr. No.	Gauging station	River	District	Location	Catch-ment area (sq. km)	Period of data availability	Elevation (m) from m.s.l.
1.	Belur	Yagachi	Hassan	$75^0$52’E $13^0$40’N	522	1992-1999	750.52
2.	Hadige	Hemavathi	Hassan	$75^0$44’E $13^0$00’N	365	2004-2010	750.12
3.	Akkihebal	Hemavathi	Mandya	$76^0$25’E $12^0$38’N	5198	1992-2003	752.84
4.	Kollegal	Cauvery	Mysore	$77^0$08’E $12^0$12’N	21627	1971-2006	613.77

The EFR analysis has been carried out for various river reaches up to the gauging sites on Cauvery river in Karnataka state. The desktop approach is used for the assessment of EFR.

Desktop Approach

It can be sub-divided into (i) those based purely on hydrological data, and (ii) those that employ both hydrological and ecological data.

Desktop Methods based on Hydrological Data

Flow Duration Curve (FDC) based method: A flow duration curve is a plot of flow vs. percentage time equaled or exceeded. FDC can be prepared using the entire time series data of flow or the flow data pertaining to a specific period (such as a month) in different years. Further, it can be developed for a particular site or combining data for different sites on per unit catchment area basis in a hydro meteorologically homogeneous region.

Environmental Management Class (EMC) based FDC approach (EMC-FDC): Smakhtin and Anputhas (2006) reviewed various hydrology based environmental flow assessment methodologies and their applicability in Indian context. Based on the study, they suggested a flow duration curve based approach which links environmental flow requirement with environmental management classes.

This EFA method is built around a period-of-record FDC and includes several subsequent steps. The first step is the calculation of a representative FDC for each site where the environmental water requirement (EWR) is to be calculated. In this study, the sites where EF is calculated coincide with the major flow diversion. The sites with observed flow data are further referred to as 'source' sites. The sites where reference FDC and time series are needed for the EF estimation are referred to as 'destination' sites. All FDCs are represented by a table of flows corresponding to the 17 fixed percentage points. For each destination site, a FDC table was calculated using a source FDC table from either the nearest or the only available observation flow station upstream. To account for land-use impacts, flow withdrawal, etc., and for the differences between the size of a source and a destination basin, the source FDC is scaled up by the ratio of 'natural' long term mean annual runoff (MAR) at the outlet and the actual MAR calculated from the source record.

Environmental flow aim to maintain an ecosystem in, or upgrade it to, some prescribed or negotiated condition/status also referred to as "environmental management class (EMC)". The higher the EMC, the more water will need to be allocated for ecosystem maintenance or conservation and more flow variability will need to be preserved. Generally, six EMCs are used and corresponding default levels of EWR may be defined. The set of EMCs is similar to the one described in DWAF (1997) and replaced below. Placing a river into a certain EMC is normally accomplished by expert judgment using a scoring system. Alternatively, the EMCs may be used as default 'scenarios' of environmental protection and corresponding EWR and EF- as 'scenarios' of environmental water demand.

RESULTS AND DISCUSSION

In the present study, the long term daily stream flow data at various stream gauging stations collected from WRDO, Bangalore were analyzed for flow characterization as tabulated in Table 2.

Table 2: Statistical analysis of daily flows (average 10 daily) observed at gauging sites

Sr. No.	Flow Characteristics		Gauging Sites			
			Belur	Hadige	Akkihebal	Kollegal
1	Minimum	Month	Apr	May	March	June
		Value (cumec)	0.02	0.27	8.49	12.30
2	Maximum	Month	Nov	July	August	August
		Value (cumec)	93.43	515.91	618.81	31369.90
3	Mean (MAF)	(cumec)	14.34	85.79	49.27	912.21

The primary data on collection of biotic valued ecosystem components (macro invertebrates, fish and fish otter) were made after visiting all the selected river zones of study area. The secondary data related with biotic components were also collected from the published literature. The data on fishes and fish otter were collected through primary and secondary sources. Hydrological requirements (water depth and water velocity) of macro invertebrates, fish and fish otter were also collected on the analysis of the characteristics of their natural habitat and their life activities in the Cauvery basin. Based on the various approaches as stated earlier for classifying the rivers on the basis of biotic communities or various basin ecological indicators, the selected reaches in the present study were classify into different environmental management class (EMC) of the rivers.
In the EMC-FDC desktop approach based on hydrological data seventeen fixed percentage points are taken for the computation of dependable flows. The reference flows at each point are computed by using the reference-flow duration curve. The EFR values computed considering 17 fixed points of probability of exceedence for six defined EMCs at selected sites are presented in Table 3.

Table 3: Computed EFR at 17 fixed points of probability for various EMC classes

% probability levels	Environmental Management Classes (EMCs)						
	REF	A	B	C	D	E	F
				Belur			
0.01	175.00	175.00	146.00	118.00	89.60	66.20	56.20
0.1	175.00	146.00	118.00	89.60	66.20	56.20	38.40
1	146.00	118.00	89.60	66.20	56.20	38.40	28.90
5	118.00	89.60	66.20	56.20	38.40	28.90	24.00
10	89.60	66.20	56.20	38.40	28.90	24.00	4.71
20	66.20	56.20	38.40	28.90	24.00	4.71	1.23
30	56.20	38.40	28.90	24.00	4.71	1.23	0.30
40	38.40	28.90	24.00	4.71	1.23	0.30	0.15
50	28.90	24.00	4.71	1.23	0.30	0.15	0.08
60	24.00	4.71	1.23	0.30	0.15	0.08	0.07
70	4.71	1.23	0.30	0.15	0.08	0.07	0.07
80	1.23	0.30	0.15	0.08	0.07	0.07	0.07
90	0.30	0.15	0.08	0.07	0.07	0.07	0.07
95	0.15	0.08	0.07	0.07	0.07	0.07	0.07
99	0.08	0.07	0.07	0.07	0.07	0.07	0.07
99.9	0.07	0.07	0.07	0.07	0.07	0.07	0.07
99.99	0.07	0.07	0.07	0.07	0.07	0.07	0.07
				Hadige			
0.01	887	887	887	651	613	362	300
0.1	887	887	651	613	362	300	210
1	887	651	613	362	300	210	119
5	651	613	362	300	210	119	94.3
10	613	362	300	210	119	94.3	75.6
20	362	300	210	119	94.3	75.6	49.7
30	300	210	119	94.3	75.6	49.7	38.8
40	210	119	94.3	75.6	49.7	38.8	11.1
50	119	94.3	75.6	49.7	38.8	11.1	0.793
60	94.3	75.6	49.7	38.8	11.1	0.793	0.327

70	75.6	49.7	38.8	11.1	0.793	0.327	0.3
80	49.7	38.8	11.1	0.793	0.327	0.3	0.274
90	38.8	11.1	0.793	0.327	0.3	0.274	0.251
95	11.1	0.793	0.327	0.3	0.274	0.251	0.23
99	0.793	0.327	0.3	0.274	0.251	0.23	0.21
99.9	0.327	0.3	0.274	0.251	0.23	0.21	0.192
99.99	0.3	0.274	0.251	0.23	0.21	0.192	0.176
			Akkihebal				
0.01	990	990	881	469	359	177	116
0.1	990	881	469	359	177	116	95.1
1	881	469	359	177	116	95.1	69.6
5	469	359	177	116	95.1	69.6	56.2
10	359	177	116	95.1	69.6	56.2	41.1
20	177	116	95.1	69.6	56.2	41.1	30.8
30	116	95.1	69.6	56.2	41.1	30.8	24.6
40	95.1	69.6	56.2	41.1	30.8	24.6	23.5
50	69.6	56.2	41.1	30.8	24.6	23.5	5.86
60	56.2	41.1	30.8	24.6	23.5	5.86	0.623
70	41.1	30.8	24.6	23.5	5.86	0.623	0.498
80	30.8	24.6	23.5	5.86	0.623	0.498	0.398
90	24.6	23.5	5.86	0.623	0.498	0.398	0.318
95	23.5	5.86	0.623	0.498	0.398	0.318	0.254
99	5.86	0.623	0.498	0.398	0.318	0.254	0.203
99.9	0.623	0.498	0.398	0.318	0.254	0.203	0.162
99.99	0.498	0.398	0.318	0.254	0.203	0.162	0.13
			Kollegal				
0.01	61073	61073	32014	13171	6020	1927	1228
0.1	61073	32014	13171	6020	1927	1228	711
1	32014	13171	6020	1927	1228	711	484
5	13171	6020	1927	1228	711	484	334
10	6020	1927	1228	711	484	334	201
20	1927	1228	711	484	334	201	154
30	1228	711	484	334	201	154	116
40	711	484	334	201	154	116	94.9
50	484	334	201	154	116	94.9	66.7
60	334	201	154	116	94.9	66.7	45.1
70	201	154	116	94.9	66.7	45.1	44.2
80	154	116	94.9	66.7	45.1	44.2	43.2
90	116	94.9	66.7	45.1	44.2	43.2	42.2
95	94.9	66.7	45.1	44.2	43.2	42.2	41.3
99	66.7	45.1	44.2	43.2	42.2	41.3	40.4
99.9	45.1	44.2	43.2	42.2	41.3	40.4	39.5
99.99	44.2	43.2	42.2	41.3	40.4	39.5	38.7

The environmental flow requirement as a percentage of mean annual flow (MAF) are also computed and presented in Table 4.

Table 4: Computation of EFR at selected gauging sites for various EMC classes

EMC Class	EFR (%) of MAF			
	Belur	**Hadige**	**Akkihebal**	**Kollegal**
A	75.0	75.0	71.8	53.2
B	53.5	53.3	49.4	26.4
C	36.4	36.5	34.6	14.5
D	23.5	24.9	25	9.2
E	13.6	16.8	18.2	6.3
F	6.9	11.0	13.0	4.6

Table 5: Range of EFR computed using various EFA methods

EFA Method	EFR (Cumec day)			
	Belur	**Hadige**	**Akkihebal**	**Kollegal**
WCD (2000)	2.26	8.35	4.90	91.22
France	0.47	2.09	1.22	22.81
CWC (2007)	0.57	1.67	1.18	18.24
EMC-FDC	5.32	20.79	12.24	83.92
UK	0.29	4.08	8.90	36.14
Minimum	0.29	1.67	1.18	18.24
Maximum	5.32	20.79	12.24	91.22

The environmental flow has also been assessed based on various hydrological index methods such as the recommendation of World Commission of Dam (WCD), France, Central Water Commission (CWC) India, UK methods as presented in Table 5. The minimum and maximum values at selected gauging station have computed as an environmental flow requirement for the stretches upstream of gauging station.

Conclusion

In the present study, **t**he environmental flows have been assessed using desktop (EMC-FDC) approach at various river stretches of Cauvery basin. The look up table used in the various countries such as France, and USA are area specific. Hence, the values of environmental flow based on look up table may not appropriate for Indian condition. Therefore, the present study suggested the minimum and maximum range of environmental flow requirement at various stretches considered for the present study of Cauvery basin, which can be used for planning any water resources or hydroelectric projects in these stretches.

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