MODIFIED FREQUENCY COMPUTATION METHOD FOR OPTIMAL ENVIRONMENTAL FLOWS

by

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The paper describes a modified frequency computation method to calculate the optimal environmental flows. This method was used to design monthly environmental flows in Lancang river. The environmental flows calculated by the method are compared with those by the ecological flow method and the Tennant method, revealing its effectiveness.

Key words: *optimal environmental flows, modified frequency computation method, Tennant method, ecological flow method, Lancang river*

Introduction

The environmental flows (EF) evolving from the concept of "minimum flows" describe the quantity, timing, and quality of water flows. Since 1990s, the EF have become a significant part in water resources and environmental fields. Many methods are used to prescribe EF [1-3]. Currently researches are focusing on four main parts: hydrological methods, hydraulic methods, habitat rating methods, and holistic methods [4]. Also there are many methods proposed and improved by China scholars, which are more suitable to concrete condition of China.

The frequency computation method, which can imitate nature process of river runoff, has been proposed to calculate the EF in Luanhe basin [5, 6]. However, in this method only seasonal variation was taken into consideration, interannual variation has been ignored.

Considering the diversity of the influencing factors and the variation of the interannual EF in Lancang river, a modified frequency computation method (MFCM) is presented in this paper. We use it to calculate the optimal EF in Lancang river.

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Modified frequency computation method

MFCM has taken interannual variation of EF into consideration firstly, which is an important influencing factor to river ecosystem. By resembling natural flow patterns, the monthly EF of rivers for different situations can be calculated. MFCM includes the following four steps.

Step 1: Dividing year's time into three levels (dry/normal/wet year).

According to natural yearly runoff series, flow frequency curve has been drawn from large to small order. Considering interannual variation of EF, the curve divides year's time to three parts: wet year, normal year, and dry year. The frequency of the flows which is lower than 25% is classified to wet year, the frequency higher than 75% belongs to dry year, the other is normal year.

Step 2: Classifying three levels year's time respectively as three parts (dry/normal/wet season).

The calculation of EF should take seasonal variation into consideration for different level years. Based upon the historical annual hydrographic data, the average monthly environmental flows for the station can be obtained. Then one-year time can be divided to three levels: wet season, normal season and dry season.

Step 3: Making sure the guarantee rates of the different seasons.

In view of the distribution law of runoff, different guarantee rates are taken to calculate the environmental flows. For example, the guarantee rates are 80% for dry season, 75% for normal season, and 50% for wet season respectively.

Step 4: Calculating the monthly environmental flows.

According to the guarantee rates of the different seasons, calculated runoffs are considered as the monthly environmental flows.

Application and results

The method described in this paper is applied to a reach of Lancang river which has been influenced strongly by social and economic development. Lancang river, originating in Qinghai province of China, is located in southwest China, between 21°36 '-33°50'N and 93°-102°E. The length of the river is 2161 km (including Sino-Burma frontier section 31 km), and the total basin area is $16.74 \cdot 10^4$ km^2.

As an important international river connecting China with Southeast Asia, Lancang river has a high value for balancing the ecosystem. The huge hydropower resources and rich biodiversity resources also attract lots of attention. Since the mid 1980s, the construction of Man-wan Dam started, the engineering for hydropower development in Lancang river basin has been in steady progress.

The paper chooses three stations as control sections: Jiuzhou station, Jiajiu station and Yunjinghong station, and the locations are in upper, middle and lower reaches, respectively. The runoff data from 1956 to 1985 in three stations above are used to study the monthly EF.

The pre-dam annual runoff data from 1956 to 1985 for three stations are divided into three level years (dry/normal/wet year) based on *step* 1 of MFCM.

According to *step* 2 of MFCM, one-year time was divided into three parts: dry season, normal season, and wet season. Based on thirty years average monthly runoff data, the classification of three stations is shown in tab. 1.

Table 1. The divisions of the dry, normal and wet seasons

Station	Dry season	Normal season	Wet season
Jiuzhou	Dec., Jan.~Mar.	Apr. May. Oct. Nov.	June.~Sept.
Jiajiu	Jan.~Mar.	Apr. May. Nov. Dec.	June.~Oct.
Yunjinghong	Jan.~Apr.	May. June. Nov. Dec.	July.~Oct.

By *step 3* and *step 4*, the guarantee rates are taken with three various seasons, respectively, 80% is for dry season, 75% is for normal season, and 50% is for wet season. By calculating monthly runoff with relevant guarantee rate, combination of outcome is the monthly EF for different level years. The results are shown in fig. 1 and tabs. 2, 3, and 4.

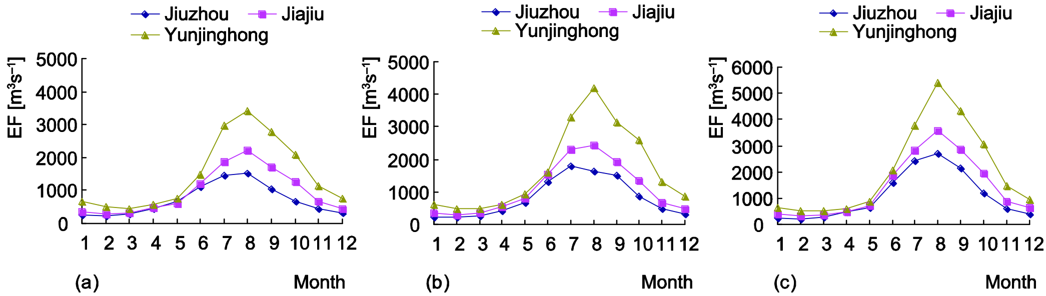

Figure 1. The monthly EF by MFCM in Jiuzhou, Jiajiu, and Yunjinghong for three level years; (a) dry year, (b) normal year, (c) wet year

Based on three level years, we also calculated the monthly EF by the ecological flow method (EFM) [4], which are expressed in tabs. 2, 3, and 4.

Table 2. Monthly EF calculated by EFM and MFCM in Jiuzhou [m^3s^{-1}]

Month	Dry year		Normal year		Wet year	
	EFM	MFCM	EFM	MFCM	EFM	MFCM
1	242	244	218	240	243	254
2	212	224	196	208	193	215
3	255	280	214	265	265	286
4	434	453	331	425	402	463
5	595	672	452	675	581	641
6	895	1115	726	1305	1214	1608
7	1061	1445	1336	1789	1723	2424
8	1387	1517	1203	1642	2029	2686
9	888	1032	1026	1493	1115	2141
10	654	672	744	859	1081	1185
11	434	455	451	473	584	615
12	301	305	310	331	380	390

Table 3. Monthly EF calculated by EFM and MFCM in Jiajiu [m^{3}s^{-1}]

Month	Dry year		Normal year		Wet year	
	EFM	MFCM	EFM	MFCM	EFM	MFCM
1	333	339	325	364	360	400
2	274	285	265	294	301	320
3	281	309	334	350	321	346
4	364	459	456	537	419	478
5	475	589	679	814	643	707
6	987	1208	836	1538	1470	1867
7	1417	1857	1846	2308	2141	2825
8	1927	2204	1744	2432	2763	3591
9	1303	1721	1441	1922	1539	2867
10	1020	1261	1004	1341	1458	1964
11	629	656	614	688	850	892
12	417	442	427	474	563	637

Table 4. Monthly EF calculated by EFM and MFCM in Yunjinghong [m^{3}s^{-1}]

Month	Dry year		Normal year		Wet year	
	EFM	MFCM	EFM	MFCM	EFM	MFCM
1	669	669	574	607	618	654
2	510	502	442	467	463	510
3	443	450	440	490	479	498
4	474	557	512	611	524	581
5	626	754	603	916	752	871
6	1322	1475	1066	1601	1974	2062
7	2631	2985	2315	3309	3314	3766
8	2937	3430	3396	4188	4293	5388
9	2645	2798	2408	3129	3414	4323
10	1836	2103	1785	2588	2386	3055
11	1086	1155	1076	1305	1470	1460
12	739	756	743	877	907	942

Compared with the calculation of EFM, it is clear that the monthly EF of MFCM is universal higher, especially in wet season. For the brood period of aquatic organism is mainly in wet season, the EF calculated by MFCM is more rational. Also in dry and normal year, MFCM offers more EF, which is more benefit to sustain the river ecosystem. Relative errors [3] of EFM and MFCM compared with Tennant method [7, 8] for the EF are shown in tab. 5.

From tab. 5, we can see that relative errors of MFCM are smaller than that of EFM compared with Tennant method for the EF. Adopting Tennant method to assess the monthly EF calculated by EFM and MFCM, the result shows that both of methods can meet the basic demand of river ecosystem. But EFM only offers the minimum EF to guarantee the development of ecosystem without irreversible damage. The effects of MFCM on keeping the balance of the aquatic ecosystem are better from the viewpoint of relative errors.

Conclusions

MFCM is presented in this paper, in which the interannual variation of EF has been firstly taken into consideration. The application results indicate that the relative errors of MFCM are smaller than that of EFM compared with Tennant method for the EF. The result reveals that the EF designed by MFCM is more optimal. This method can be used to make sure the optimal EF in different restoration objective for Lancang river. This paper will provide a guide for the optimal EF calculation in complex river systems.

Table 5. Relative errors of EFM and MFCM compared with Tennant method

Station	Level year	Relative error (%)	
		EFM	MFCM
Jiuzhou	Dry year	41	30
	Normal year	51	29
	Wet year	48	27
Jiajiu	Dry year	46	33
	Normal year	49	31
	Wet year	49	29
Yunjingh	Dry year	48	37
	Normal year	52	36
	Wet year	47	34

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