

Application of Comprehensive Fall Index Method in Water Level-Flow Relation of Main Cross Sections in Middle Reaches of the Yangtze River

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Abstract: The Yangtze River, the longest river in China, is also a famous river in the world. Most regions within its drainage basin are of moderate climate, abundant rainfall, rich resources and dense population, in the meantime, the Yangtze River basin is also a region in which floods frequently happens. In order to launch studies on flood control impact in the middle reaches of the Yangtze River better, this paper selected stage-discharge data of the main fracture surfaces of three control stations-Shashi, Luoshan and Hankou located on middle reaches of the Yangtze River during flood period (from May to September) during 1981~2010, based on analysis of influencing factors on water level-flow relations in three hydrologic sections, it adopted comprehensive fall index method to process these data, by which it obtained the achievement of water level-flow relation curves in these stations, and used principle of least squares to conduct curve fitting and then made a reasonable analysis. Results show that polynomial curves fitting can eliminate the influence of calculated water level-flow relation line to the least, and it has better effect in practical application.

Introduction

The Yangtze River basin is a region in which floods frequently happens within China, especially within 126,000 sq. km. on plain area of the middle and lower reaches of Yangtze River, floods are more frequent and serious. Flood in 1998 and severe flood prevention and control situation in recent years have further revealed problems existing in flood prevention and control on middle reaches of Yangtze River. Hence, it's quite necessary to launch studies on flood control impact on middle reaches of Yangtze River.

In order to adapt to dynamic change process of the Yangtze River and conform to basic principles of hydrological data acquisition, this study adopted measured data at the end of the last century and at the turn of this century, namely daily average water level and flow data of the main cross section of middle reaches of the Yangtze River during flood period (from May to September) during 1981~2010 to conduct analysis and calculation with comprehensive fall index method, obtained water level-flow relation curves in three stations-Shashi, Luoshan and Hankou, and explored change rules by analyzing station characteristics to estimate developmental tendencies in the future.

Study of Influencing Factors on Water Level-Flow Relations of Stations

Shashi Station

Shashi gauging station is 67.4km away to the north of Xinchang station, 76.1km from Ouchikou and 241.9km (324.7km before bend cutting) from Chenglingji. Shashi-Xinchang reach has no branch inflow or dam burst distribution, and calming effect of flood after riverway regulation and storage is slight.

Jingjiang River bend cutting during 1967~1972 caused systematic change of water level-flow relation in this station. According to riverway features, flood composition and cross section analysis

in Jingjiang reach, it's believed that water level-flow relation in Shashi station are mainly influenced by the following factors: cross section scouring and silting variation, Chenglingji water level, backwater jacking of lower-reach variation, fluctuation rate of flood, etc., cross section water level-area relation in Shashi station is the primary factor. Besides above factors, there are also flood composition of Jingjiang River and Dongting Lake, continuous floods, water level of flood rising, flood peak shape, etc.

Luoshan Station

Luoshan hydrological station is 3.5km to the south of outlet of Dongting Lake and it's a control station for Dongting Lake effluent and Jingjiang River inflow. Lushui River, which is 35km downward Luoshan, flows into Yangtze River at Luxikou. Han River, the longest branch of Yangtze River, is 210km away from downstream of Luoshan and it flows into Yangtze River in Wuhan City. In the meantime, there are also Jinshui, Sheshui, Daoshui, Jushui, Fushui, Huiyuanjou, Bashui, Xishui, Qishui and so on in the downstream to uplift it. Fluctuation of these branches has a certain influence on water level and flow in Luoshan station.

According to natural features of Hankou segment, flood composition features and cross sectional water level-area relation in Lianhuatang station and water level-flow relation loop curve analysis, it's found that factors influencing Luoshan water level-flow relation are quite complicated, mainly including scouring and silting variation, river reach scouring and silting variation, downstream variation backwater effect, flood fluctuation, etc.,[1] secondly, flood composition in stem stream and branches as well as evolution of river and lake relation and so on has a certain influence.

Hankou Station

Han River which is 1.4km upward Hankou station flows into Yangtze River at the left bank of Han River, and more upward, there are Dongjing River, Jinshui and Lushui flowing into Yangtze River; Fuhuan River at the left bank which is 9.2km downward Hankou station flows into Yangtze River, and more downward, there are Daoshui, Jushui, Bashui, Xishui, Qishui, Wuhu and Zhangdu Lake flowing into the stem stream, and at the right bank, Liangzi Lake and Fushui joining the stream. Poyang Lake drainage system which is 284 km downward the station flows into Yangtze River at outlet. Downstream branches inflow have a certain backwater effect on water level-flow relation in this station.

Main factors influencing water level-flow relation in Hankou Station include: backwater effect of downstream branch variation, flood fluctuation, cross section scouring and silting variation, and special water regimens like flood encounter of stem stream and branches, continuous multi-peak flood, flood diversion dam burst, etc.[2]

Calculation Principle and Method of Water Level-Relation Curve Fitting

In recent years, in terms of determination of water, there has been a large number of researches which have proposed comprehensive unit hydrograph method, fall index method, downstream water-level parameter method, etc.[3] Traditional establishment of water level-flow relation curve has always used temporary curve method, but this aligning method can be influenced by many human factors. Because of difference in practical working experience, and with different parameters taken into consideration, parameters can't be quantified, consequently, relation curves given by different people will be different. And calculated flow quantities will be of different values, which brings inconveniences to practical work. However, appropriate mathematical model which is used to do curve fitting can solve this problem.

Based on previous researches, this paper, according to practical situation, conducted statistical analysis of water level and flow at 8:00 every day during flood period (from May to September) during 1981~2010 in Shashi, Luoshan and Hankou stations, based on which it used principle of the least squares to do curve fitting. Polynomials used, the influence of individual measuring points with large testing errors was eliminated to the least. As relation lines were calculated by mathematical

formula, flow quantities deducted by relation lines would not be different because of difference in alignment. In practical application, it has better effect.

Shashi Station:

Shashi water level-flow relation is under effect of backwater variations like flood fluctuation, water level of Lianhuatang, effluent of Dongting Lake, etc, hence, fitting of Shashi water level-flow relation in the 90s put emphasis on these factors.

(1) Reform of Flood Fluctuation Influence

Because of the influence of above factors, measured flow points sometimes present as anticlockwise loop curve, and sometimes are quite dispersive, and the two factors are mixed together. In order to differentiate the two kinds of influencing factors, flood in stem stream of Yangtze River is large while Dongting Lake inflow is small, and backwater effect is not obvious. 1981, 1987 and 1989 data were analyzed, correction factor method was used to correct flood fluctuation, floods in above three years presented obvious loop curves. When correction factors were taken among 10000~20000, correction effect was better, high water points were obviously concentrated with densely concentrated point groups. With full consideration of its correction factor $1/UI$, when 15000 was taken, the effect was better. The following equation was used for correction of flood fluctuation rate.

$$Q_c = \frac{Q_n}{\sqrt{1 + \frac{\Delta Z}{\Delta t} \cdot \frac{1}{UI_c}}} \quad (1)$$

Q_c -----steady flow after correction(m^3/s);

Q_n ----- measured flow(m^3/s);

Z ----- rising or falling flood water level of one day(m) ;

t -----time bucket, one day=86400s;

$1/UI_c$ -----correction factor, Shashi station is 15000 after the optimization.

(2) Analysis of backwater effect of Lianhuatang

Through reorganization of measured data in Shashi station and Lianhuatang at the same time, it's found that its water level-flow relation was related to water level in Lianhuatang. When water level in Lianhuatang was low, Shashi station was mainly influenced by flood fluctuation and cross section scouring and silting, and water level-flow point groups were relatively concentrated; when Dongting Lake effluent was large and water level in Lianhuatang was high, Shashi station was mainly influenced by backwater effect with much water level elevation (such as in 1996 and 1998) and dispersive point groups).[4]

Corresponding water levels in Lianhuatang was taken as parameter points to draw diagram of 1981~2003 water level-flow measuring points in Shashi station, and it's found that originally dispersive points presented regular distribution with variation of water levels in Lianhuatang. Measuring points with high water level in Lianhuatang were above and those with low levels were below. We used the following equation to analyze influence of Lianhuatang water level, and obtained water level-flow relation results in Shashi station (as shown in Table 1).

$$Q_c = C(H_s - H_L - 0.21)^n \quad (2)$$

Q_c -----steady flow after correction of Shashi station (m^3/s) ;

C -----correlation coefficient of the relationship between stage and discharge in Shashi station, calculated by the measured data;

H_s 、 H_L -----water level of Shashi and Lianhuatang (m) ;

n -----Coefficient of minimum error calculated by using least square method considering the relationship of H_s and C .

Table1: The stage-discharge relationship results of Shashi(water level: m ; flow rate: m³/s)

$H_s \backslash H_L$	the flow which water level of Lianhuatang station corresponding										
	26	27	28	29	30	31	32	33	34	35	36
33	3560	2350									
34	6330	5060	3810	2590							
35	9400	8170	6830	5620	4350	3060					
36	12670	11420	10170	8750	7420	6080	4930	3640			
37	16580	15170	13940	12330	10920	9580	8250	6920	5420	4000	
38	21000	19490	18050	16500	15000	13420	12080	10670	9170	7580	6100
39	26420	24670	23030	21330	19580	18080	16580	15000	13330	11830	10300
40	32670	30750	28850	26830	24920	23080	21330	19670	18000	16250	14750
41	40080	37830	35590	33330	31170	29170	27170	25080	23250	21420	19830
42	47750	45500	43180	40580	38250	35750	33580	31330	29170	27250	25330
43	56490	53920	51170	48420	45750	43170	40750	38330	35920	33750	31580
44	65750	62920	60000	56920	53830	51000	48500	45920	43420	41000	38670
45	75140	71920	68710	65330	62330	59420	56530	53960	51530	48960	46320
46		81000	77630	74580	71250	68000	65260	62350	59640	56940	54300
47								70510	67690	65240	62350

Luoshan Station and Hankou Station:

Water level-flow relations in Luoshan station and Hankou station are mainly influenced by factors like downstream branches backwater effect, flood fluctuation, etc. which will be analyzed as follows.

Correction of Flood Fluctuation Influence

Influenced by additional gradients of flood waves, measured water level-flow relation in Luoshan station is influenced by flood fluctuation rate and presents as anticlockwise loop curve. Hence, correction factor method can be used to correct water level-flow relation influenced by flood fluctuation rate. Based on analysis of flooding years since the 1980s, we compared correction effects of different correction factors on water level-flow relation loop curves, and we found that optimal correction factors in different years were slightly different. [5]With full consideration of the correction factor $1/UI$, when it was 40,000 in Luoshan station and Hankou station, the effect would be better.

Equation (1) was used to calculate flood fluctuation rate correction, and correction factor $1/UI$ was taken as 40,000 in Luoshan station and Hankou station after optimal selection.

Correction of Backwater Effect of Downstream Branch Inflow

Effluents of drainage systems in the downstream of Luoshan station and Hankou station such as Lushui, Jinshui, Han River, eastern Hubei as well as Poyang Lake, etc. has backwater effect on water levels in the two stations to different degrees. Backwater effects of branches inflow and river channel damming effect elevate water levels in the two stations. [6]Hence, correction of backwater effect should be conducted, and the method is:

$$Q_n = Q_c + \sum k_i q_i \quad (3)$$

Q_n ——backwater jacking flow after correction (m³/s);

Q_c ——the flow after correction of the flood fluctuation rate (m³/s);

q_i ——the jacking flow corresponding with all levels of a tributary from Luoshan to Hukou (m³/s);

k_i ——jacking coefficient of water from tributary;

i ——ordinal number of the tributary.

With full consideration of the two main influencing factors-downstream branches backwater effect and flood fluctuation, water level-flow relations in Luoshan station and Hankou station were deduced as shown in Table 2 and Table 3.

Flow rate Water level	The fluctuation rate of Luoshan												
	-1	-0.5	-0.4	-0.3	-0.2	-0.1	0	0.1	0.2	0.3	0.4	0.5	1
22	10500	12650	13070	13480	13900	14300	14700	15100	15570	15970	16370	16770	18820
24	14500	17200	17630	18110	18700	19190	19700	20150	20650	21100	21550	22100	25000
25	16905	19700	20260	20830	21470	22040	22610	23050	23630	24130	24700	25270	28260
26	19300	22500	23100	23700	24400	25200	25840	26470	27100	27740	28430	29000	32300
27	22100	25500	26300	26900	27700	28500	29450	30140	30780	31540	32300	33060	37145
28	24900	28700	29600	30300	31200	32100	33000	33900	34700	35500	36400	37500	41600
29	27900	32200	33200	34000	34900	35700	36800	37800	38700	39700	40800	42000	46800
30	31400	36100	37000	37900	38900	39900	41100	42000	43200	44500	45700	47100	52900
31	35200	40300	41200	42200	43300	44600	45900	47100	48400	49800	51300	52700	59600
32	39400	45200	46200	47500	48600	50000	51400	52800	54300	55600	57300	59100	67100
33	44500	51600	52900	54300	55800	57300	58900	60400	62100	63800	66000	68100	78000
34	50900	59400	61000	63000	65100	66900	68800	70900	73100	75400	78000	80500	92200

Table2 :The stage-discharge relationship results of Luoshan (water level: m ; flow rate: m³/s)

Flow rate Water level	The fluctuation rate of Hankou							
	-0.8	-0.4	-0.2	0	0.2	0.4	0.6	1
17	13700	14000	14300	14700	15100	15400	15800	16900
19	18100	19000	19500	20000	20500	21000	21600	23100
21	22900	24500	25400	26100	27000	27900	28700	30500
23	28700	30700	31800	33000	34100	35200	36300	39100
25	36200	38800	40100	41700	43200	44600	46000	49400
27	45200	48900	50500	52500	54000	56000	57500	62800
28	51500	55000	57000	59200	61200	63000	64900	71500
29	58300	62000	64200	66900	68900	71000	73400	80000
30	64800	69600	72000	74800	77000	79500	82000	88100
32	80700	85700	88300	91000	93500	95900	98700	104200

Table3 :The stage-discharge relationship results of Hankou (water level: m ; flow rate: m³/s)

Principle of Polynomial Fitting Method

As there was a large quantity of calculation data with large fluctuation, and polynomial fitting method was suitable for analyzing deviations of a large quantity of data, it's even more suitable for situation with large data fluctuation. [7]Therefore, we used principle of the least squares method to establish polynomial fitting equation through deformation regression model:

$$y = b + c_1x + c_2x^2 + c_3x^3 + \dots + c_nx^n \quad (4)$$

In order to select optimal fitting curve, parameter R^2 was taken to characterize reliability of fitted curve.

$$R^2 = 1 - \frac{SSE}{SST} \quad (5)$$

$$SSE = \sum (Y_i - \hat{Y}_i)^2 \quad (6)$$

$$SST = \sum Y_i^2 - \frac{(\sum Y_i)^2}{n} \quad (7)$$

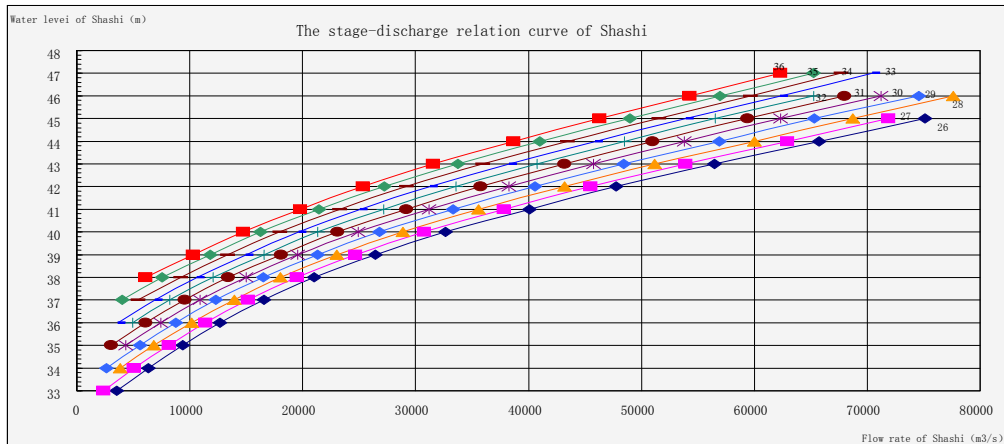
When R square value of fitted curve was equal to or approximate to 1, its reliability was the highest.

Water Level-Flow Relation Curve Results and Reasonableness Analysis in Stations

Shashi Station

The calculation in this paper mainly used flood data during 1981~2003 especially high water level data in Lianhuatang in 1983, 1996, 1998, 1999 and 2001 which could reflect water level-flow relation under current status in Shashi station. Based on measured water flow results in Shashi station, we analyzed and corrected flood fluctuation rate and water level backwater effect in Lianhuatang, after which we finally transformed them into Shashi water level-flow relation cluster which took water levels in Lianhuatang as parameters, [8] and then we obtained water level-flow relation curve results mapped out by hydrological data in Shashi station during 1980~2003 as shown in Graph1.

Graph1: The stage-discharge relationship curve of Shashi

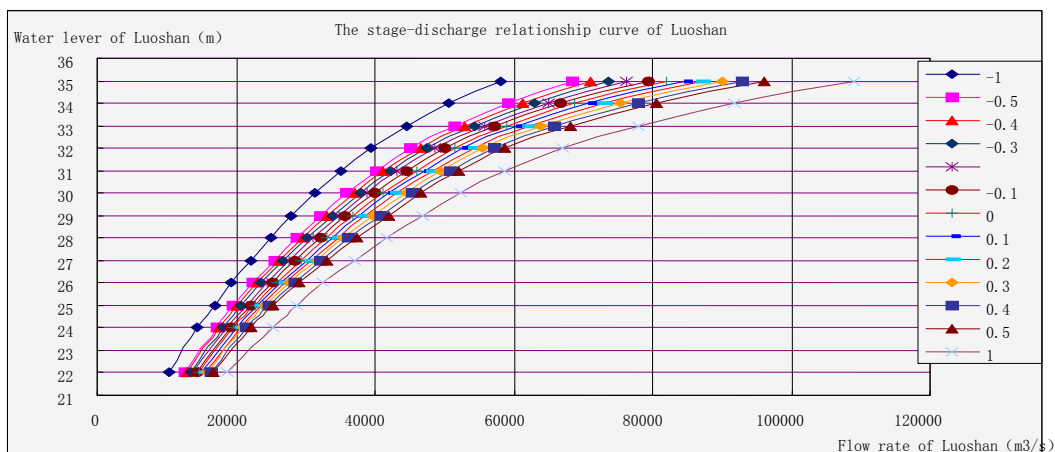


It can be seen from water level-flow relation curve that: when water level in Lianhuatang remained unchanged, Shashi water level-flow relation presented monotonic increasing relation line. When Shashi water flow was unchanged, Shashi water level would increase with water level in Lianhuatang elevated. Under the same water level in Shashi, Shashi water flow would increase as water level in Lianhuatang lowered and then it would tend to be stable.

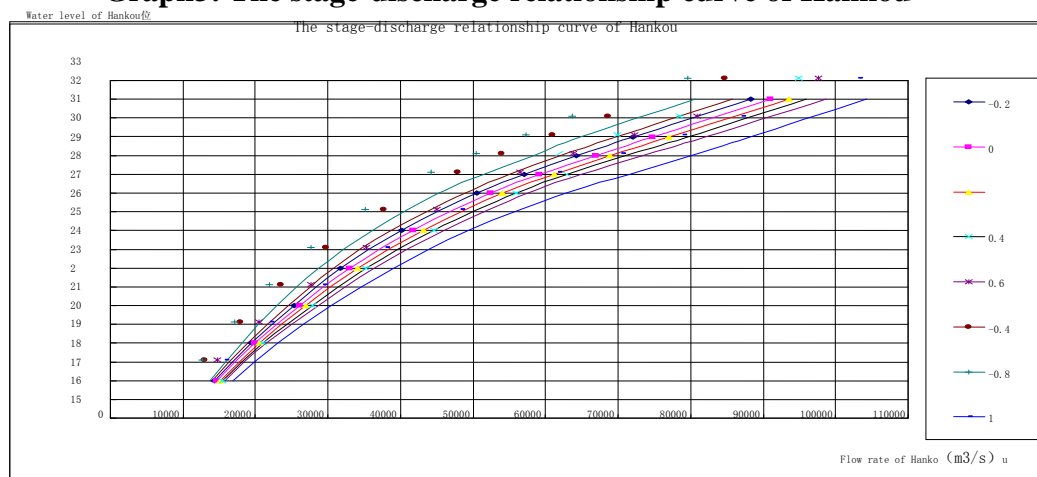
Luoshan Station and Hankou Station

As stated above, there are many factors influencing water level-flow relations in Luoshan station and Hankou station. It's difficult to make quantitative analysis of effects of all factors. Hence, we analyzed main influencing factors of the two stations. We adopted measured water level and flow data over the years, firstly we used correction factor method to eliminate influence of flood fluctuation, then we conducted downstream backwater effect correction, and implemented a statistical analysis of comprehensive lines given by these years, and finally we obtained water level-flow relation curves which took fluctuation rates as parameters as shown in Graph2 and Graph 3.

Graph2: The stage-discharge relationship curve of Luoshan



Graph3: The stage-discharge relationship curve of Hankou



Conclusion

In order to verify reasonableness of water level-flow relation curves in stations obtained above, we selected measured data in 1998 to conduct verifying calculation, and specific verification method was:

(1) According to measured water levels and water level during flood rising as well as relevant parameters in these control stations, we checked and obtained Q through water level-flow relation curves;

(2) We conducted statistical analysis of errors of measured flow duration curves and calculated flow duration curves.

Analysis showed that: calculated flow conformed to measured flow very well, fitted water level-flow relation curves could accord with measured data in 1998, from which it could be seen that water level-flow relation obtained by uniformization processing of comprehensive fall index method was feasible.

The research analyzed hydrological characteristics in the middle reaches of Yangtze River, and it's especially of great significance to major problems such as river-lake relation, hydrological forecasting during flood period, river bed evolution after bend cutting of Jingjiang River, excess flood distribution and dispatch, etc.

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