Analysis on Calculation Methods and Influence Factors of Bankfull Discharge

Sihan Chen¹, Ya Liu¹*, Jinyou Lu¹ and Qiming Yao²

¹Key Laboratory of River and Lake Regulation and Flood Control, Ministry of Water Resources, Yangtze River Scientific Research Institute, Wuhan 430010, China
²Changjiang River Preventive Maintenance Center, Yueyang, China
Email: Newyar@live.cn

Abstract. Rivers are constantly changing under the combined influence of nature and human activities. When exploring the evolution law and morphological characteristics of natural rivers, scholars at home and abroad have introduced many characteristic parameters for quantitative analysis, and the bankfull discharge has always been an important index in the study of riverbed evolution. This paper compares the different calculation methods of bankfull discharge and analyzes the influence factors that lead to the fluctuation of bankfull discharge, and draws two conclusions. On the one hand, in the future, when optimizing and improving the method of calculating bankfull discharge, two points can be mainly grasped: reducing subjective error and improving accuracy. On the other hand, there are many factors that affect the flow of the bankfull discharge, so the accuracy and effectiveness of the basic parameters must be paid attention to in the determination.

Keywords: Bankfull discharge, Water and sediment conditions, Calculation methods, Influence factors

1. Introduction

Natural changes and human activities constantly influence the movement and evolution of rivers. At home and abroad, the artificial control of rivers is dominated by reservoirs [1]. While large and medium-sized reservoirs play a role in flood control, power generation, water supply, navigation, ecology and other aspects, they will also have a certain impact on the downstream river water and sediment conditions and river evolution. The adjustment of scouring and silting of the flat channel downstream of the dam after reservoir operation is the most obvious. Therefore, the study of the characteristic indexes of the flat channel downstream of the dam after reservoir operation can best reflect the influence of the corresponding river directly. The bankfull waterlevel with the surface elevation of river floodplain, which is of great significance in the analysis of river exercise. Each section of a river usually produces a phenomenon that the water level of a characteristic reaches the height of its floodplain before and after the flood season. As an important factor to describe the flow capacity of a river, many extrapolation methods of bankfull discharge have been proposed by scholars at home and abroad [2].

2. Calculation Method of Bankfull Discharge

At present, there are two kinds of methods for estimating bankfull discharge at home and abroad: one is based on the geometry of cross-section, the other is based on runoff and sediment conditions. The method of cross-section geometry is to find the bankfull water level first and then calculate the
bankfull discharge according to the water level. The core of the method for determining the geometric shape of section is to deduce the bankfull water level and find out the relationship between water level and discharge [3-4]. As shown in table 1: one is field observation method, which is mainly based on the geomorphic characteristics of the cross-section, simple and fast, only suitable for regular surfaces; the other is based on the cross-section morphology of the river bed, using certain geometric standards for estimation, and it is only applicable to the specific section of the reach in non-equilibrium state; the third is based on the river scale and through weighted average processing to obtain the results, but needs a lot of section data support [5-6].

Table 1. Comparison of calculation methods of different bankfull water level.

| Method         | Author                  | Derivation method                                         |
|----------------|-------------------------|-----------------------------------------------------------|
| Field observation | Navratil et al (1994-2006) | The abrupt point of geomorphology                         |
| Geometric criteria | Wolman (1955)          | Ratio of minimum river width to average water depth         |
|                 | Williams (1978)          | Important change points in the relationship between discharge area and water surface width |
|                 | Riley (1972)            | From high to low, the first maximum bank slope value       |
|                 | Wang (2013)             | Extremum of breadth depth ratio                            |
| River scale     | Harman (2008)           | Geometric average of logarithmic transformation            |
|                 | Xia et al (2014)        | Geometric average of logarithmic transformation combined with weighted average of section spacing |

He [7] introduced the convergence method and put forward the optimized WOL method. As shown in figure 1, the new method can be applied to the case of more complicated rivers, so it significantly improves the rationality and adaptability of the derivation process.

![Figure 1. Comparison of bankfull discharge at the reach scale with measured data (L. He).](image)

The commonly used methods to determine the relationship between water level and discharge are as follows:

1. Manning's formula method, which is only suitable for the calculation of constant uniform flow [6].
2. As shown in figure 2, the calculation method of measured data is to conduct mathematical analysis based on the measured section data, includes "Average daily water level - Discharge" method, "Measured water level - Discharge" method and "Water level - Velocity - Discharge" method.
(3) One-dimensional hydrodynamic model method. This method can accurately calculate the bankfull discharge value of any selected cross-section, including the lower reaches of the river, which significantly improves the rationality of the water level - discharge relationship [5].

Shi et al. [7] proposed the estimation method based on the viewpoint of nonlinear dynamic system, it is not only suitable for the section without measured data, but also can reflect the effect of time on flat discharge. Li et al. [8] derived by using artificial neural network method of bankfull discharge relatively close to the actual value. Recently, some researchers equate the dominant discharge with the bankfull discharge [9]. Such as Makaviev method [10]. After classifying the flow rate, the probability p of each stage of flow occurrence is counted, and finally the peak value of QmJP~Q curve is the dominant discharge. Geomorphic curve method [11] can draw different relation curves according to different sediment transport conditions, and does not need the data of water surface gradient coefficient. Analytical method [12], when the product of the two Qsf (Q) or the partial derivative of Qs* f(Q) to Q is 0, the peak value of sediment transport efficiency curve is obtained, that is, the dominant discharge. Flow assurance rate method [9] has strong experience and poor rationality, so the first three methods are more widely used in engineering examples.

The basic observation data such as water and sand conditions are the premise of this method, while the bankfull discharge corresponds to the mapping relationship between the section characteristics and its various water and sand characteristic values or the critical points and interpolation points on the relationship curve [13-14].

3. Factors Affecting the Bankfull Discharge

Even if there is only a small change in the shape of the channel, the bankfull discharge will be greatly affected. Different water and sand collocation conditions have different shaping effects on the riverbed, which leads to great difference in the bankfull discharge. There are many factors that promote the fluctuation of bankfull discharge. Objectively, they are mainly discharge process, water and sediment and boundary conditions, time scale change of hydrological system, evolution law of riverbed and boundary conditions of riverbed, etc.; subjectively, there are mainly two types: the subjectivity in calculating the bankfull water level and the subjectivity in calculating the discharge through the water level.
3.1. Water and Sediment Conditions

3.1.1. Influence of Runoff and Sediment Coefficient and Inflow. The condition of incoming water and sediment is always in dynamic change, and the form of riverbed scouring and silting is also changing constantly, thus forming different channel forms, which is also the reason for the great change of bankfull discharge [15-16]. The proportional trend between bankfull discharge and average discharge in flood season in a single year is not strong. Wu et al. [17] found that there is a high correlation between the four-year average flow in flood season and the bankfull discharge in flood season, they pointed out that the adjustment time of bankfull discharge in the feedback of incoming water and sediment is quite different, and the reaction process of its impact on inflow conditions is shorter. In addition, the discharge process will also lead to the change of bankfull discharge. Under the effect of the flood season discharge process, the real-time bankfull discharge increases temporarily. If the annual bankfull discharge is calculated based on the topographic data at this time, it is generally larger than the actual one [18]. In addition, Zhang et al. [19] pointed out that the bankfull discharge has the characteristics of multi time scale evolution. As shown in figure 3, Xia et al. [20] found that the influence of water and sediment conditions on the regulation of bankfull areas in the braided reach is about 4 years.

![Figure 3. Relationships of the reach-scale bankfull areas (X J. Li).](image1.png)

3.1.2. The Influence of Water and Sediment Process and Degree. Different water and sediment processes affect the bankfull discharge through the effect on the main channel range and beach lip elevation. Even if they are in the state of high sediment concentration, the bankfull discharge after large flood and medium flood will be different. Moreover, the corresponding flood season processes in different years are different in terms of duration, scope of action, and flood plain intensity, resulting in the constant change of the bankfull discharge. Xia et al. [21] took the wandering reach of the lower Yellow River as the research object, and obtained the relationship between the change trend of bankfull discharge and the accumulated erosion and deposition amount of the reach, that is, "decrease after silting, increase after scouring", and the two have negative correlation.

3.2. Impact of Estimation Methods

The subjective factors that affect the bankfull discharge are mainly reflected in the evaluation differences brought about by different estimation methods, such as the deviation of artificial judgment or selection of calculation parameters and the error of calculation method itself. The subjective process involved in various methods can bring uncertainty.

3.2.1. Determination of Bankfull Water Level. At present, the level of bankfull beach is mainly determined according to the geometric shape standard, and in the stage of beach channel division, the
determination rules directly affect the accuracy of various characteristic indexes, as shown in figure 4. Therefore, it is necessary to control the subjective error of artificial judgment of topography, so as to obtain more accurate bankfull discharge.

![Figure 4. Influence of the specified main channel width on bankfull characteristics (L. He).](image)

3.2.2. Computing Method. When the cross-section data are reasonable, simple arithmetic average and geometric average based on logarithmic transformation are two common numerical average methods in the process of normalizing the shape characteristic data of main channel. Since natural river channels are randomly distributed in space, the weighting method for cross-section spacing is more suitable for uneven cross-section distribution. After all, the accuracy of each characteristic value is related to the number and proportion of measured sections, so the weighted calculation result is more reasonable [21].

3.2.3. Calculation Parameters - Section Spacing and Quantity. Changing the number of cross-sections of the study reach will also cause the fluctuation of bankfull discharge. Therefore, ensuring that the measured data meet the requirements is the premise of accurately analyzing the discharge capacity of the reach. As shown in figure 5, He [13] deduced the bankfull characteristics by selecting the transverse spacing of different sub sections. Although the bankfull discharge values under different spacing are not equal, the overall results have little difference, and the influence degree is low.

![Figure 5. Influence of cross-section spacing on bankfull characteristics (L. He ).](image)

3.2.4. Uncertainty of Water Level - Discharge Relationship. If the water and sediment process occurs in the condition of high sediment concentration and medium flood period, only the "One-dimensional hydrodynamic model calculation" method is better, and the results obtained by other methods are smaller. As shown in table 2, all the methods are suitable for less sediment or less scouring and silting changes of cross-section in flood season, especially the "Measured water level - Discharge" method and "One-dimensional hydrodynamic model calculation" method, the values obtained by the two methods are almost equal.
Table 2. Calculated bankfull discharge after different flood processes by the four methods.

| Flood type | Bankfull discharge /m³·s⁻¹ |
|------------|-----------------------------|
|            | Average daily water level-Discharge | Measured water level-Discharge | Water level-Velocity-Discharge | One-dimensional model |
| 1977       | 15300                        | 8300                         | 14200                        | 8120                     |
| 1992       | 5360                         | 4680                         | 5230                         | 6210                     |
| 1999       | 2940                         | 2850                         | 5600                         | 2800                     |
| 2006       | 7850                         | 5540                         | 6760                         | 7260                     |

4. Conclusion and Prospect

This paper classifies and compares the conventional methods and innovative ideas of estimating the bankfull discharge at home and abroad, and summarizes the influence of various factors on the estimation, so as to optimize the calculation method according to the applicable situation of each method for the researchers to calculate the bankfull discharge. The main conclusions are as follows:

(1) In the future, when optimizing and improving the method of calculating leveling discharge, we can mainly grasp two points: reducing subjective error and improving accuracy.

(2) There are many factors that affect the bankfull discharge, so we must pay attention to the accuracy and validity of the basic parameters.

Acknowledgements

This study was financially supported by the National Key Research and Development Program of China (No. 2016YFC0402305), the National Natural Science Foundation of China (No. 51609011,41701007), and the Ministry of Finance Project of China (No. 12610100000018J129-5).

References

[1] Qian L, Zhang R, Zhou Z D 1987 *Fluvial Process* Beijing: Science Press.
[2] Xie J H, Ding J S, Wang Y H 1989 *Fluvial Process and Regulation* Beijing: Water Conservancy and Electric Power Press.
[3] He L, Yan Y X, Yan M 2015 Analysis on the definition of bankfull stage by geometric criterion *Journal of Sediment Research* 34(5): 114-118.
[4] Wang W J, Fu X D, Zhang Y F, et al. 2013 Temporal change in bankfull characteristics of the Yellow River, single-thread versus multiple-thread reach *Proceedings of 2013 IAHR World Congress*.
[5] Xia J Q, Wu B S, Li W W 2009 Comparison of different approaches to determine bankfull discharge in the Lower Yellow River *Journal of Sediment Research* (3): 20-29.
[6] Sun Z Y, Lu J R, Qu S J, et al. 2007 Practical new method on bankfull discharge calculation of major bed of the Lower Yellow River channel *Yellow River* 29(2): 22-23, 26.
[7] Shi W, Wang G Q 2003 Estimate of bankfull discharge rate based on nonlinear dynamic system theory *Journal of Tsinghua University* 43(11): 1563-1566.
[8] Li W W, Wu B S, Xia J Q, et al. 2010 Application of the method artificial neural network in calculating bankfull discharge in the Lower Yellow River *Journal of Sediment Research* (3): 17-23.
[9] Bao W N, Guo W D, Li X, et al. 2018 Study on dominant discharge, bankfull discharge and effective discharge of Liaohе River *Journal of Sediment Research* 43(2): 55-60.
[10] Doyle M W, Shields D, Boyd K F, et al. 2007 Channel-forming discharge selection in River Restoration Design *Journal of Hydraulic Engineering* 133(7): 831-837.
[11] Ma Y, Huang H, Xu J, et al. 2010 Variability of effective discharge for suspended sediment transport in a large semi-arid river basin *Journal of Hydrology* 388:357-369.

[12] Wu B S, Deng Y 2005 Adjustment of longitudinal bed profile of riverbed in Sanmenxia reservoir *Journal of Hydraulic Engineering* 36(5): 549-554.

[13] He L 2016 Estimation of bankfull discharge at reach scale and influence factor analysis *Journal of Hydroelectric Engineering* 35(4): 47-54.

[14] Navratil Q, Albert M B, Herouin E F, et al. 2006 Determination of bankfull discharge magnitude and frequency: comparison of methods on 16 gravel-bed river reaches *Earth Surf. Process and Landforms* 31(11): 1345-1363.

[15] Yang Z Y, Xia J Q, Zhou M R, et al. 2019 Adjustments in reach-scale bankfull channel geometry and bankfull discharge in the Yellow River Estuary *Advances in Water Science* 30(3): 305-315.

[16] Chen L, Hu C H, Chen X J 2018 Relationship between bank-full discharges and processes of flow-sediment in Lower Yellow River *Journal of Sediment Research* 43(4): 1-7.

[17] Wu B S, Xia J Q, Zhang Y F 2007 Response of bankfull discharge to variation of flow discharge and sediment load in the lower reaches of Yellow River *Journal of Hydraulic Engineering* 38(7): 886-892.

[18] He L 2018 Effects of discharge hydrograph on bankfull discharge *South to North Water Transfers and Water Science &Technology* 16(3): 38-44.

[19] Zhang Y Y, Zhong D Y, Wu B S 2012 Multiple time scales of bank-full discharge in the Yellow River *Advances in Water Science* 23(3): 303-309.

[20] Li X J, Xia J Q, Zhang X L, et al. 2014 Recent variations of reach-scale bankfull channel geometry in the braided reach of lower Yellow River *Journal of Hydroelectric Engineering* 33(5): 86-92.

[21] Xia J Q, Wu B S, Wang Y P, et al. 2010 Estimating of bankfull discharge in the Lower Yellow River and analysis of its variation processes *Journal of Sediment Research* (2): 6-14.