Study of flood protection water levels for railway projects in the plains river network area

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Abstract. The Taihu Lake basin is characterised by a developed water system and a longitudinal river network, which is prone to flooding during the flood season. This poses a threat to the construction and operation of river-related railways, bridges, and other infrastructures, and therefore the design value of the water level of the river channel must be provided prior to the construction of roads and bridges in the basin. The Yanyi Railway traverses numerous river systems without the benefit of measured hydrological data. In order to address this deficiency, two methods were constructed using the Taihu Lake basin model: the historical water level frequency analysis method and the typical design storm method of the basin. These methods were employed to calculate the flood protection water level of each river under different design schemes and to analyze the reasons for the differences in the results. The results indicate that the water level results of the historical water level frequency analysis method are also applicable to the construction of the Yanyi Railway, provided that an economic perspective is taken.

Keywords: Taihu Lake basin model; Flood protection water level; Frequency analysis; Design storm.

1. Introduction

The Yanyi Railway is an important regional railway link in the national high-speed railway network, passing through several important rivers in the Taihu Lake basin along the route, which often suffers from flooding due to the combined effects of the rainy season, typhoons, and coastal flooding along the river, leading to major disaster losses in the region [1]. With the rapid urbanization in recent years, and a large number of water conservancy projects, the hydrological characteristics of the basin have a greater impact on precipitation, and water levels are showing a rising trend[2, 3], the frequency of flooding is also a significant increase in trend [4]. To meet the requirements of the Yanyi Railway project design, it is necessary to calculate and research the flood protection water level along the railway project near the river.

Currently, there are several methods for analyzing and calculating the flood protection water level of a river. Zhang Shuohan and others[5]have calculate the flood protection water level of a railway station based on the principle of water balance; some scholars have also built models, such as machine learning models[6], one-dimensional river network models[7], to model the river level. There are also scholars who statistical methods such as the Monte Carlo method and the Copula function[8, 9]to deduce the flood protection water level of rivers. The above methods are only limited to solving the level of a river, and there are fewer studies on the water level derivation for continuous water bodies in the river network area.

In the plains river network area of the Taihu Lake basin, river system connectivity is better[10]. However, due to the uneven distribution of hydrological stations, a considerable number of rivers do not have monitoring stations, and there is a lack of hydrological information on these rivers in the actual research process. To solve this problem, Mao Rui et al [11] mapped the ecohydrological line of rivers and lakes in the Taihu Lake basin during the rainy season, which was used to interpret the water conditions in the basin during the flooding period as well as the development of the water level process. Other scholars have coupled the MIKE model with techniques such as BP neural networks[12]; or directly on the study area to build hydrological and hydrodynamic models[13], water level and flooding process simulation of the river in the watershed without information, to provide a reference for solving the problem of river flood control water level.

This paper is based on the current situation of waterways in the Taihu Lake Basin, selecting the Taihu Lake Basin model, and designing two different methods In the current situation of the Taihu Lake Basin, based on the land use, water conditions, and water conservancy facilities scheduling, calculating the flood protection water level of the Yanyi Railway through the river with no information in the different scenarios, to solve the problem of calculating flood protection water level of river cross-section with lack of measured data in Taihu Lake Basin.

2. Study area

Yan-Yi Railway (South Jiangsu section) along the route mainly includes the Taihu Lake Basin Water Conservancy sub-district of WuChengXiYu District and the West Lake District. The two sub-areas are the north of the central subtropical to the north subtropical south over the humid monsoon climate zone, the average annual precipitation of 1100mm.

There are 6 hydrological stations distributed near the railway line, and a total of 22 river channels. A significant portion of the river cross-section lacks the deployment of monitoring stations, necessitating the use of suitable technical means to simulate the water level of uninformative rivers in the course of scientific research or actual production.

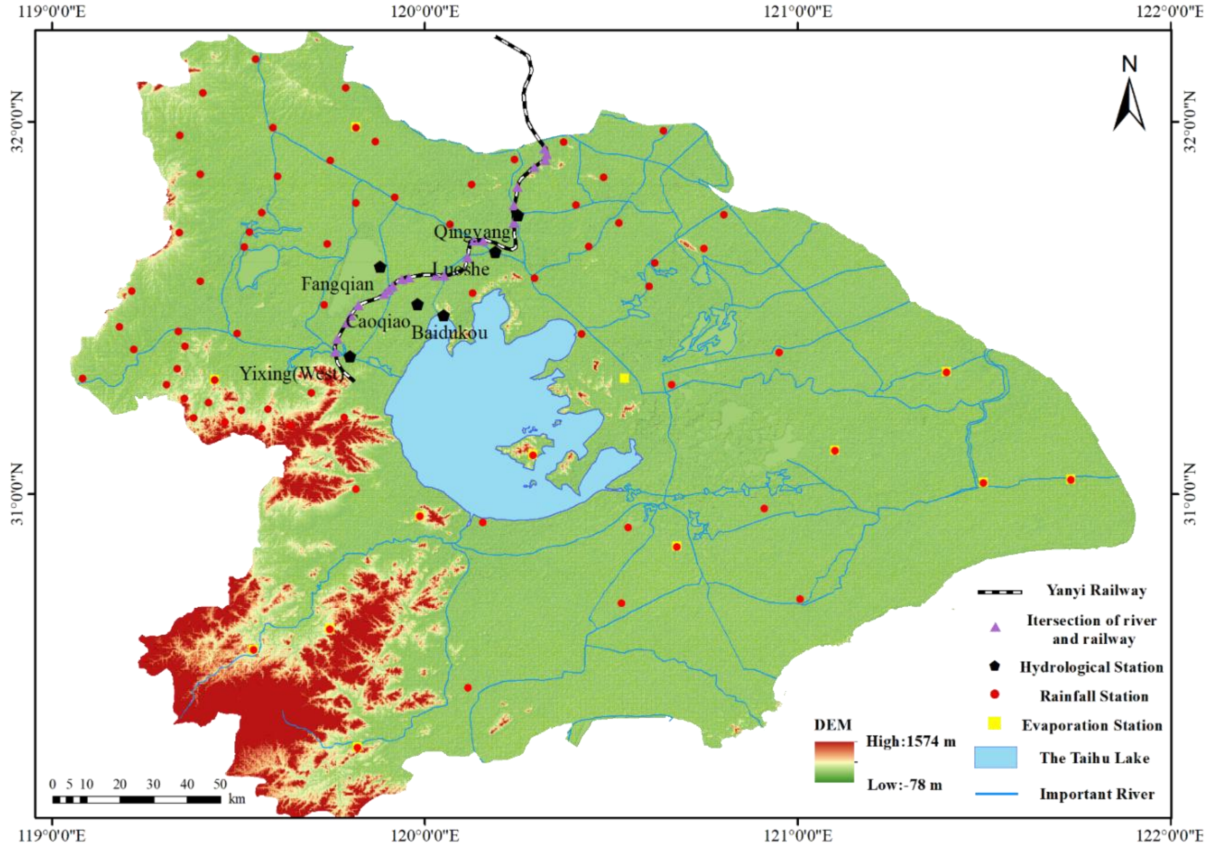

Fig.1. Map of location of the Yanyi Railway and monitoring stations and river layout

3. Methodology

3.1 Water level modelling methods

The Taihu Lake Basin Model is adopted in this paper to analyze and calculate the flood protection water level of the river without data. The model consists of a rainfall-runoff model and a river network water quantity model, and it is applied to the entire Taihu Lake basin for calculation purposes.

3.1.1 Model Principles and Structures

The rainfall-runoff model is designed to simulate the rainfall-runoff relationship and the confluence process of runoff in the watershed. The watershed is divided into three distinct areas: the western Zhejiang hill area, the western lake hill area, and the plain area. The three water sources of the Xin’anjiang model are used in the hilly area of western Zhejiang. The western hill area of the Taihu Lake and the plain area are according to the characteristics of each surface and the different flow production rules, the production and surface confluence calculations are carried out separately for each surface.

The water quantity model for the river network uses the flow yields for each sub-district derived from the rainfall runoff model to calculate water level and flow results in a generalized river network based on the Saint Venant system of equations that describes one-dimensional non-constant flow of water in a prismatic open channel.

3.1.2 Model parameter rates and verification

The measured runoff from hydrological stations in the mountainous areas of western Zhejiang was used to rate the Xin'an River model for the three water sources, and then the rainfall runoff model was synchronized with the parameters of the river network water quantity model for the plains and the hilly areas of western Zhejiang. The measured data of 1998 and 1999 were used to verify the process of model water level change, and they basically coincided with each other.

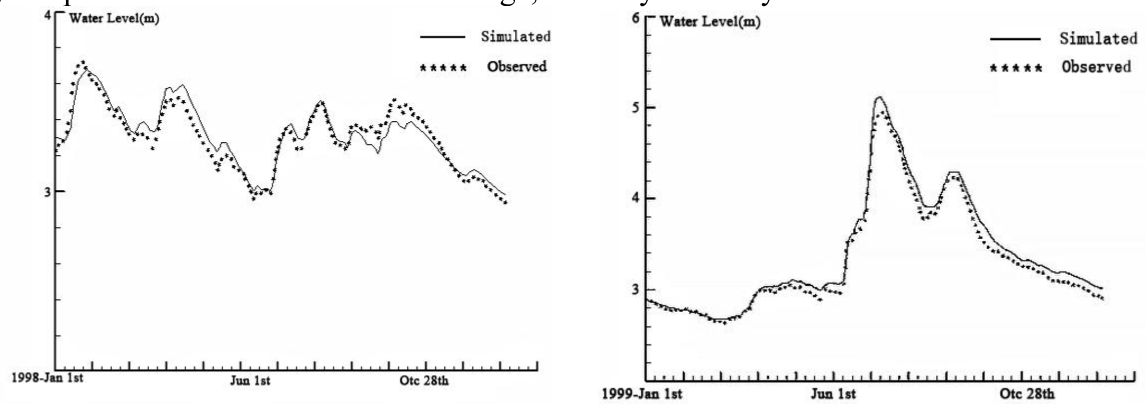

Fig.2. Results of fit between measured and modelled water levels

3.2 Water levels simulation design schemes

3.2.1 The historical water level frequency analysis method

Based on the day-by-day rainfall and evaporation data from 1981 to 2019 at some stations within the Taihu Lake basin, the average surface rainfall and evaporation of each hydraulic computation subsection were calculated and inferred using the Tyson polygon method and put into model-driven calculations to simulate the process of water level change of each river over the years, and to count the highest water level of each river over the years.

The P-III curve was employed to fit the highest water level sequence observed in each river in previous years. The parameter optimization was conducted in accordance with the minimum criterion of outlying sum of squares (OLS) in order to calculate the 100-year flood protection water level of the river along the railway.

3.2.2 The typical basin design storm method

In accordance with the regional storm flood peak-making characteristics, the storm data from various historical periods were counted and the P-III curve was selected for fitting in order to derive the design storm under different calendar times in the region.

In the typical rainstorms in the Taihu Lake basin, the center of the 1991 rainstorm was located in Huxi District and Wucheng Xiyu District, which is the design rainfall pattern that has been used in the upstream flood control planning of the Taihu Lake basin. Scaling the 1991-type live storm process by the same-frequency method to obtain a 1-in-100-year design storm process[14]。

In the model, Wucheng Xiyu District and Huxi District utilize the 100-year design storm after scaling for a typical year, while other sub-districts employ the typical annual real rainfall process to calculate the 100-year flood protection water level of the river along the railway under this design scheme.

4. Results and Discussions

4.1 Calculation results of flood protection water level analysis

By calculating the historical water level frequency analysis method and the typical design storm method of the watershed, the results of the 100-year flood protection water level of the Yan-Yi Railway (South Jiangsu Section) crossing the river under different design standards were obtained.

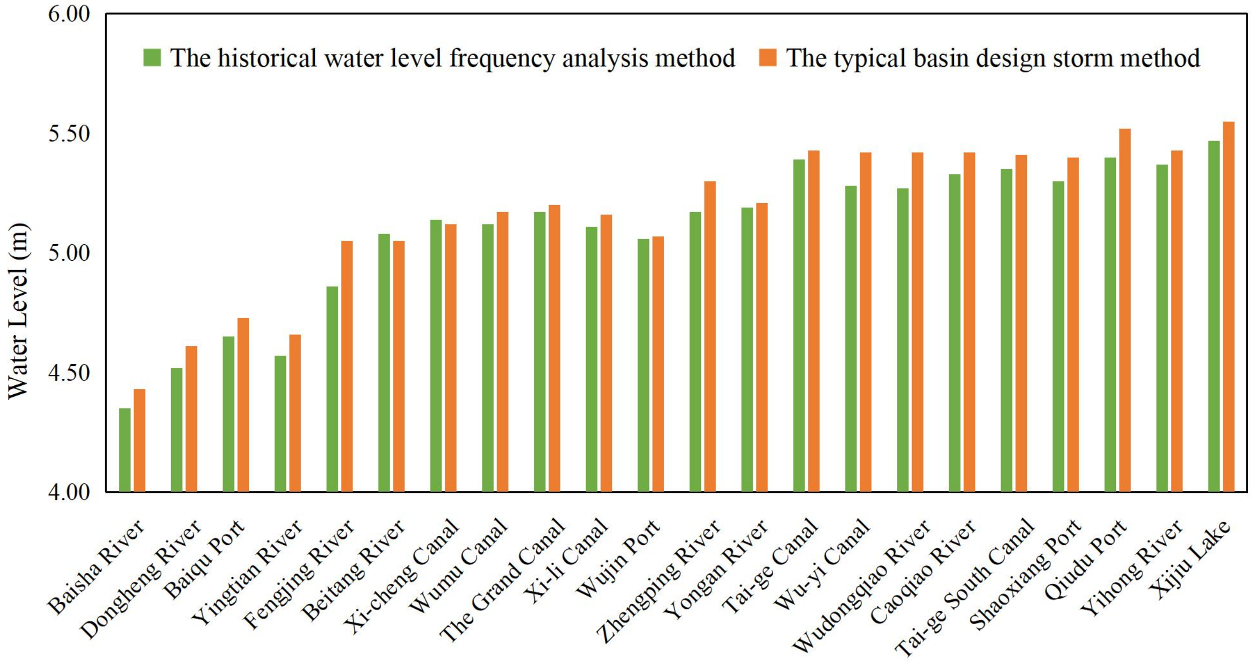

Fig.3. Comparison of river flood protection water level results

The average stream level calculated by the historical water level frequency analysis method is 5.10m and the average stream level calculated by the typical watershed design storm method is 5.17m, with a difference of 0.07m between the two methods. River levels show a gradual increase from north to south. Among them, the average flood protection water level is 4.59m and 4.70m for the five channels from Baisha River to Fengjing River in the northern section of the railway near the Yangtze River; The average flood protection water level of rivers near the Grand Canal in the middle section of the railway, from the Beitang River to the Xili Canal, is 5.12m and 5.14m; in the southern part of the railway, the river from Wujin Port to Xijiu Lake, the average flood protection water level is 5.30m and 5.38m.

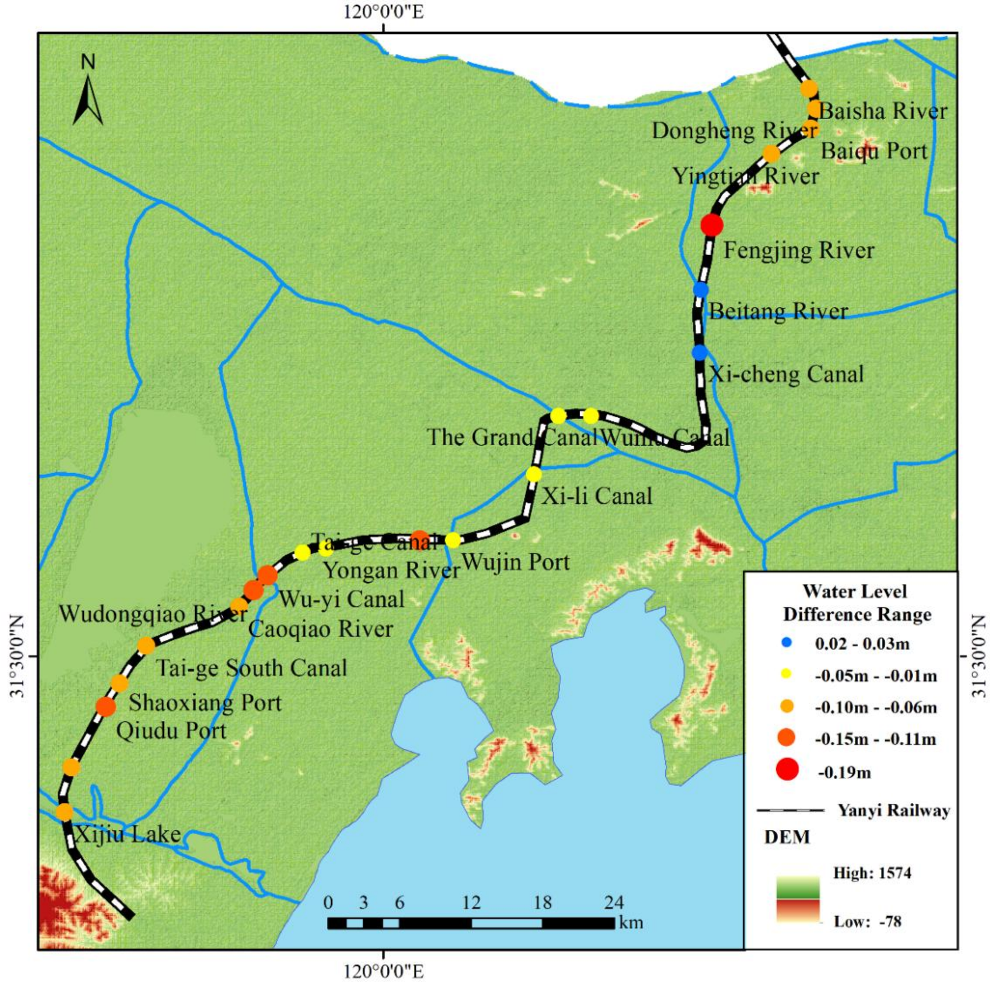

Fig.4. Distribution of river flood protection water level difference ranges

Comparing the flood protection water level results of the two calculation methods in terms of the number of rivers, the water level results of the historical water level frequency analysis method, only the Beitang River and Xi-cheng Canal are higher than the water level of the typical basin design storm method, with a difference of 0.03m and 0.02m. The flood protection water levels in the remaining 20 rivers (lakes) were lower than the typical design storm method for the basin, with the range of lows ranging from 0 to 0.19 m, and the average range of lows being about 0.07 m. Among them, the number of channels with water level difference ranging from -0.10m to -0.06m was the highest with 9 rivers; this was followed by 6 rivers with differences ranging from -0.05m to 0m.; there are 4 rivers with difference values ranging from -0.15m to -0.11m. The river with the largest difference in water level is Fengjing River, with a difference of 0.19m.

Comparing the results of the design water level spatially, the four rivers along the railway that pass closest to the Yangtze River have a difference between -0.10 and -0.06m. These five rivers between Xi-cheng Canal and Wujin Port are the ones with the closest calculated flood protection water level results, with the difference ranging from -0.05 to -0.01m. Between Tai-ge Canal and Xijiu Lake, the difference in water level ranges from -0.15 to -0.06m.

4.2 Discussion of reasons for differences in water level results

In the comprehensive reference to the construction of hydraulic structures in the region where the Yan-Yi Railway (South Jiangsu Section) passes through, as well as the analysis from the perspective of considering the design scheme, the differences between the two calculation methods mainly come from the following three aspects:

(1) As depicted in the figure, notable disparities exist in flood protection water levels calculated by various design schemes near the Yangtze River and Taihu Lake, the two principal water bodies.

Conversely, along the central railway section traversing the river, particularly in the vicinity of the Beijing-Hangzhou Canal, the design level differences between the two schemes are relatively minor. These rivers are equipped with water locks at their junctions with the Yangtze River, the Grand Canal, and Taihu Lake to regulate water level and river flows. The advent of the rainy season in the Yangtze River Basin has resulted in a notable increase in the water levels of the Yangtze River and Taihu Lake. Rivers in the hilly regions upstream of Taihu Lake play a pivotal role in modulating the lake's water level. Therefore, the discharge rate and flow from rivers into the Yangtze River and Taihu Lake will be controlled as necessary, resulting in higher water levels around these water bodies during extreme rainfall events.

(2) Different rainfall scenarios for railway have been considered in the design of the program. The historical water level frequency analysis method is based on measured precipitation evaporation data over the past 39 years and reproduces the actual water level conditions over the years through model simulations, focusing on analyzing the general changes in water levels during the flood season and taking into account the prevalent rainfall conditions faced by the river rather than extreme conditions. The typical basin design storm method is by calculating the size of the 100-year storm, and then The most unfavorable spatial and temporal combinations of storms are selected from the successive flooding processes to be scaled up or down., to derive the flood protection water level of the river along the railway, focusing on the analysis of extreme, rare rainfall conditions under the changes in the water level of the river in this very unfavorable to the normal operation of water conservancy projects in the watershed, the calculated water level value will be on the high side.

(3) The model is refined and parameterized using the current year's hydraulic facilities and scheduling rules, which are more complete than in historical years, therefore, the water level results from the simulated historical rainfall are theoretically lower than the actual values for that year. In the long run, as the planning, construction, and management of water conservancy projects in the Taihu Lake basin become more perfect, and the scheduling rules become more reasonable, the water level of the river in the face of extreme rainfall will also be maintained at a safer interval. Therefore, from the consideration of the economy of railway projects, using the historical water level frequency analysis method to determine its flood protection water level has its rationality and applicability.

5. Conclusions

This paper presents an improved Taihu Lake basin model based on the current subsurface conditions and water conservancy engineering and scheduling rules. Two design schemes were adopted to simulate and calculate the 100-year flood protection water level of the river. Two methods were used to determine the flood protection water level of each river channel. The first is the historical water level frequency analysis method, the calculated water level is between 4.35m and 5.47m; the second is the typical basin design storm method, the calculated flood protection water level of the river ranges from 4.43m to 5.55m. The water level generally increases gradually from north to south.

The results of the two different calculation methods are compared and analyzed from the perspectives of river number and spatial distribution. It was found that the water level results of the historical water level frequency analysis method are slightly lower than the typical basin design storm method, the difference is between 0~0.19m, and the largest difference in water level is Fengjing River, and the average magnitude of the difference in water level is 0.07m. Rivers near the Yangtze River and connection between Ge Lake and Taihu Lake, the difference in flood protection water level of different design schemes is larger, while the difference in water level results of rivers near the Grand Canal in the middle section of the railway is very small within 0.05m.

There are three reasons for the difference in the results of flood protection water levels:(1) Under extreme rainfall conditions, the river draining to the Yangtze River and Taihu Lake, may experience limited drainage. (2) The scheme design considers changes in water level for both general and extreme rainfall situations. (3) The water conservancy project profiles used in the calculation of the historical water level frequency analysis method are all from the current year. Therefore, the historical water level frequency analysis method is a more economical way to calculate the flood protection water level of railway projects.

The presented data furnish essential technical support for the engineering design and construction of the aforementioned railway. Concurrently, the findings of this study will serve as a point of reference for the design of flood protection water levels for analogous related projects in the Taihu Lake basin.

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