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The analysis on the influence of heavy rain and flood on the design flood of Liqingdian Hydrological Station

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ABSTRACT

With climate change, many places have experienced extreme heavy rain and flood recently, which has a certain impact on the design flood in local areas. After analyzing the characteristics of extremely heavy rain and flood in 2010 and 2021 at Liqingdian Station in Nanzhao, Henan Province, this thesis determines the return periods of two major floods in 2010 and 2021 by using the flood data of regional survey. The design floods of various schemes are analyzed and calculated, including different flood series and historical flood recurrence periods at Liqingdian Station. According to the results, after the major floods in 2010 and 2021, the design peak flow of each frequency increased by 3.2% to 50.1%, and the design 24-h flood volume increased by 9.4% to 42.2%. The recent major floods have a significant impact on the design flood of Liqingdian Station. Therefore, the analysis and calculation of design flood should be made based on the full use of heavy rain and flood that have occurred and the surrounding survey data to fully demonstrate and determine the design flood.

Keywords: Liqingdian Station; Heavy rain and flood in 2010; Heavy rain and flood in 2021; Return period; Design flood

1. Introduction

Due to global climate change, many regions have experienced extreme heavy rain and floods. The extreme heavy rainfall or rainstorm rainfall accounts for an increasing proportion of the total rainfall in China, the precipitation intensity of extreme heavy rain or rainstorm has gradually increased, and the clustered heavy rain has also increased in intensity and frequency [1,2]. Located in the middle of China, Henan Province belongs to the transition zone between the semi humid and warm temperate zone of China and is featured by subtropical climate. It is also a geomorphic transition zone in the west of the Yellow River and Huaihe River. It is adjacent to Taihang Mountain in the north, Funiu Mountain in the northwest southeast direction in the west, the upper reaches of the Huaihe River basin in the south, and the southern edge of the North China Plain in the east [3]. Henan Province mainly can be divided into four high value areas with short-term heavy rainfall, namely the north of the Yellow River in northern Henan, Shangqiu of eastern Henan, the south of Funiu Mountain in southwestern Henan, and the area along the Huai River and its south in southern Henan; The terrain has increasingly significant impact on precipitation is significant, which is mainly achieved by increasing the frequency of short-term strong rainfall occurrence [4].

Located in the southwest basin of Henan Province, Liqingdian Station belongs to the rainstorm peak area in the south and east of Funiu Mountain. In 2010 and 2021, this place experiences heavy rainfall floods. In this paper, the impact of heavy rain and floods on the design flood results of Liqingdian Station is analyzed in combination with the characteristics of typical heavy rain and floods.

2. Overview of River Basin and surveying stations

The Huangya River is a tributary of the Tangbai River system in the Yangtze River Basin. Originating from the

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southern foot of Funiu Mountain at the junction of Nanzhao County, Song County, and Ruyang County in Henan Province, it flows into the Bai River from west to southeast, with a drainage area of 681 km^2 and an asymmetric fan-shaped basin. The main tributary is distributed on the left bank. Liqingdian Station is a control station for the Huangya River and an important control station for the downstream Yahekou Reservoir. It was established on January 1, 1977, and is in charge of basin area of 613 km^2. The main rainfall observation stations in this basin include Jiaoyuan and Mashiping, and there are downstream stations such as Liushan. The distribution of river system and observation stations in the watershed is shown in Fig. 1.

3. Overview of recent typical heavy rain and flood

3.1. Rainstorm and flood in 2010

Heavy rain and flood occurred in the Huangya River basin from July 18 to 19, 2010. On July 19th, the annual maximum peak flow of Liqingdian Station reached 5,670 m^3/s (the second among the measured series). The rainfall for each duration of representative stations and downstream Liushan Station in the basin is shown in Table 1. The center of heavy storm is located in Erdaohe River, a tributary near Liqingdian at the lower reaches of the basin. According to the data and the location of the observation station, Jiaoyuan, Mashiping, Yangmaping and Liqingdian are taken as representatives to analyze the process of rainfall in the areas above Liqingdian. The corresponding process of flood is illustrated in Fig. 2.

3.2. Heavy rain and flood in 2021

From September 24 to 25, 2021, there was heavy rain in Henan Province. The center of the heavy rain was located in Yangxizhuang at the upstream of Baihe River in Nanzhao County. The lower reaches of the Huangya River basin belong to the central radiation range of the heavy storm. Table 2 demonstrates the maximum rainfall of Jiaoyuan, Mashiping, Liqingdian and Liushan stations in the lower reaches above Liqingdian. The rainfall of each duration is relatively large, and the rainstorm increases from the upstream to the downstream. The maximum 24 h rainfall of Jiaoyuan, Mashiping and Liqingdian was 128.5, 298 and 327.5 mm, respectively. The maximum 24-h rainfall of Liushan,

Table 1
Heavy rain of short duration on July 18–19, 2010

Observation station	Rainfall (mm)					
	1 h	2 h	3 h	6 h	12 h	24 h
Jiaoyuan	15.25	30.5	38.6	55.9	73.7	91.65
Mashiping	27.8	55.6	72.15	105.7	112.62	126.08
Li Jiangzhuang				101	120.2	
Caiyuan		62.5		131.5	156.2	164.5
Yangmaping		70.5		155.5	161.6	167.8
Erdaohe				151.1	180.7	185
Li Qingdian	65.2	103.4	113.8	158.5	167.92	171.9
Liushan	52	84.3	91.9	113	126.6	132.5

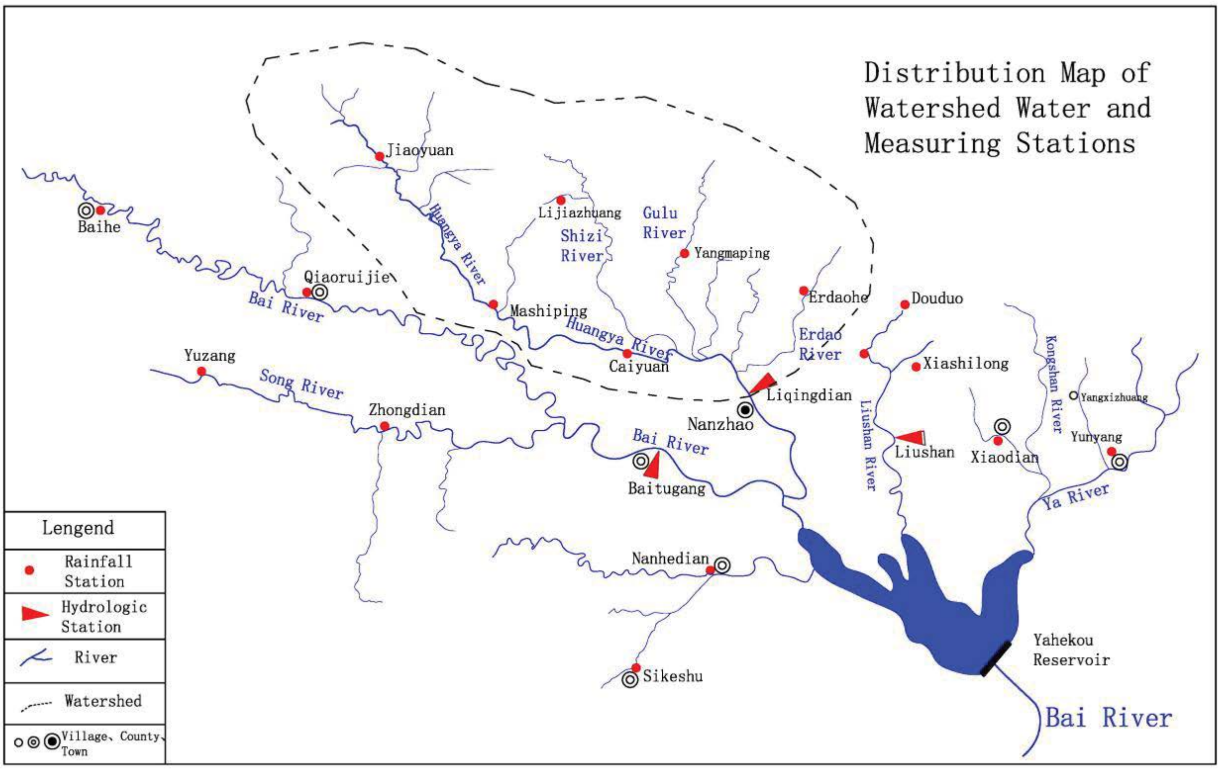

Fig. 1. Sketch map of river system and station distribution.

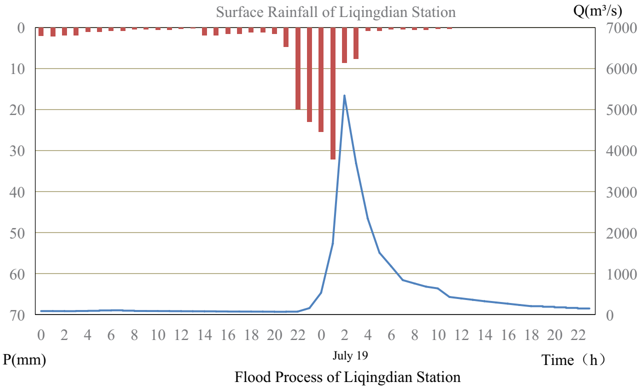

Fig. 2. Heavy rain and flood process at Liqingdian Station on July 18–19, 2010.

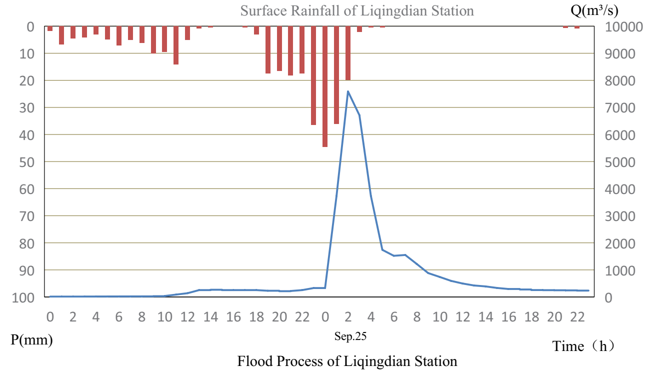

Fig. 3. Heavy rain and flood process at Liqingdian Station on Sep. 24–25, 2021.

Table 2
Heavy rain of short duration on Sep.18–19, 2021

Observation station	Rainfall (mm)					
	1 h	2 h	3 h	6 h	12 h	24 h
Jiaoyuan	39	63.5	72.5	81	82	128.5
Mashiping	88	133	183	226	230	296.5
Liqingdian	80.5	146.5	179.5	234.5	242	327.5
Liushan	77.2	108	139	178.4	295.2	378.4

Guanzhuang, Xiashilong, and Doudou in the tributary of the Baihe River downstream of Liqingdian Station, were 380.8, 404, 448.5, and 298.5 mm, respectively.

The maximum short duration of the 1 and 3 h heavy rain was detected at Mashiping Station, and the maximum 6 h rainfall at Mashiping Station was equivalent to that at Liqingdian Station. The maximum duration of the rainstorm above 12 h happened in the downstream Liushan Basin and nearby, and the maximum 32 h rainstorm was detected at 485 mm at Yangxizhuang Station. At around 2 o'clock on September 25th, the Huangyahe Liqingdian Station experienced the maximum flood peak of 7,620 m^3/s since measurement. Based on the data and the location of the observation stations, the rainfall process in the basin above Liqingdian was analyzed using Jiaoyuan, Mashiping, Liqingdian, and Liushan as representatives. The corresponding flood process is illustrated in Fig. 3.

3.3. Features of heavy rain and flood in 2010 and 2021

The years 2010 and 2021 mark the measured maximum and secondary floods at Liqingdian Station. The common characteristics of the two floods and the corresponding heavy rain are as follows: (1) The center of the rainstorm was near Liqingdian, the center of the rainstorm in 2010 was near Erdaohe River in the upstream tributary near Liqingdian, and the center of the short duration heavy rain in 2021 was near the downstream of Liqingdian. (2) Before the occurrence of the maximum heavy rain and flood, small amount of rainfall occurred in the basin. (3) Heavy rainfall was very concentrated, with 1-h rainfall accounting for 26% and 27% of 6-h rainfall in 2010 and 2021, and 6-h rainfall accounting for 60% and 84% of 24-h rainfall. (4) The main peak of heavy rain happened later, and the flood was a single peak flood with steep rise and fall.

4. Analysis of flood characteristics

The measured flood peak and 24-h flood volume series from 1977 to 2021 are depicted in Figs. 4 and 5. Compared with the 1977 to 2021 series, which includes the major floods in 2010 and 2021, the 1977 to 2021 series of the first 31 y showed a significant decrease in recent small and medium-sized floods, but the major floods were very prominent. The average annual flood peak flow from 1977 to 2021 was 1,014 m^3/s, with the maximum and second largest flood peaks being 7,620 m^3/s in 2021 and 5,670 m^3/s in 2010, respectively, which were 7.5 and 5.6 times the annual average. From 1977 to 2021, the average 24-h flood for many years was 257 million·m^3, with the maximum and second largest 24-h floods of 121 million·m^3 (2021) and 81.8 million·m^3 (2010), respectively, which were 4.7 and 3.2 times the annual average.

5. Analysis of return periods of extraordinary floods

5.1. Necessity

If the first (or the first few) measured floods were much larger than the one that ranked after it, and after checking the historical flood investigation we confirm that it could be ranked in a period longer than n years, we can infer that its return period is greater than the one estimated on the basis of n years, then this extraordinary flood (or several extraordinary floods) should be taken into account [5,6].

According to the measured series data by Liqingdian Station, floods in 2021 and 2010 had flows 7.5 and 5.6 times higher than the multi-year average, and they are 2.4 and 1.8 times higher than the peak of the 3rd-ranking 1991 flood, which was 3,110 m^3/s. In accordance with related standards, such extraordinary values should be analyzed to decide the return period and consider the representativeness of the series parameters.

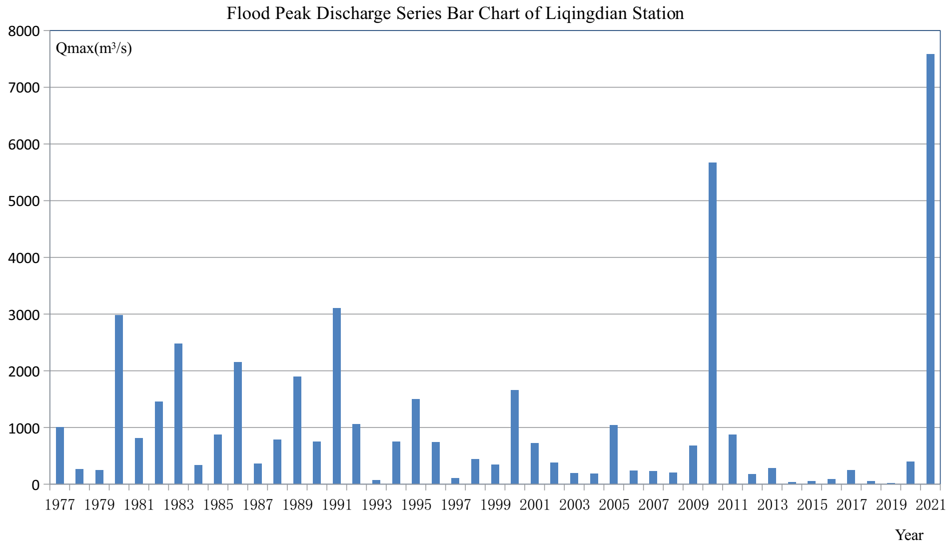

Fig. 4. Column diagram of the annual maximum peak flow of Liqingdian Station.

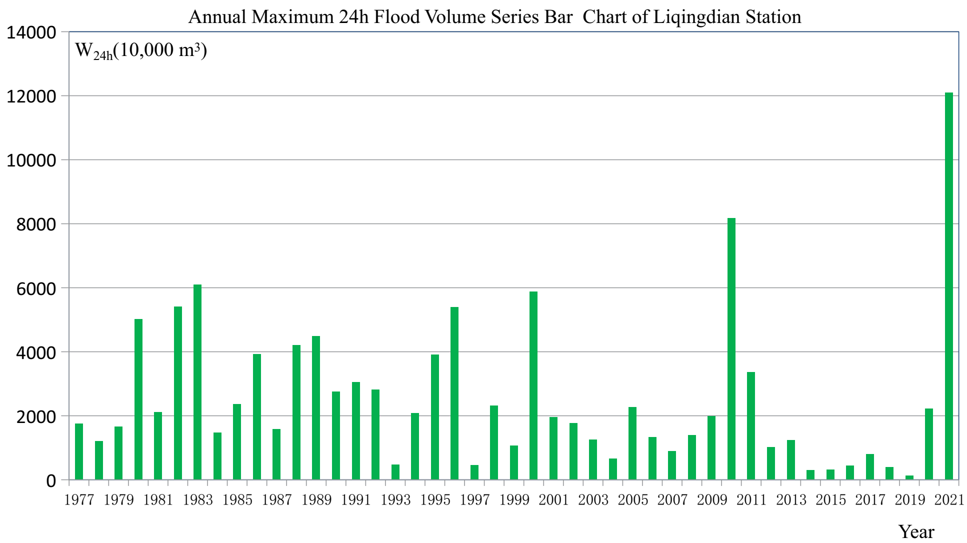

Fig. 5. Column diagram of the annual maximum 24 h flood volume of Liqingdian Station.

5.2. Based on information

From 1953 to 1971, Changjiang Water Resources Commission, China Railway Siyuan Survey and Design Group, Nanyang City Hydrology Bureau carried out several flood surveys at the main tributaries of the Tangbai River, and after 1991, Changjiang Water Resources Commission also conducted flood surveys of rivers that intersect along the trunk canal in the middle route of the South-to-North Water Diversion Project [7]. Surveys by the main hydrological stations near Liqingdian and cross-sectional-studies of the Bai River basin confirmed the results of the 1919 flood survey [8], and further improved the accuracy and reliability. Nevertheless, the Huangya River still lacked historical flood survey information.

During the past 300 y, there were three major floods occurred at downstream Yahekou Reservoir (control basin area 3,025 km^2) and they happened in 1,676; 1,749 and 1,919 (10,000 m^3/s), respectively. Since the establishment of Yahekou Reservoir in 1958, an extraordinary flood peak occurred in 1975, with an inflow of 11,600 m^3/s [7]. Moreover, according to the collected information, the maximum flood peak that flowed into the Yahekou Reservoir happened in 2021, which was 18,200 m^3/s. Based on this, we can trace the 2021 Yahekou Reservoir flood back to 1919.

5.3. Analysis of return period

After analyzing the influencing area of the 2021 storm flood, we find that the Huangya River Basin and other nearby basins were affected by the same weather system, which belonged to the storm-scale and mesoscale weather systems. As a result, a certain magnitude of storm flooding was formed. According to the analysis of the 1919 historical flood survey, the Huangya River and the Liushan River would be within same weather system during the flood of this scope and magnitude. Thus, a certain magnitude of storm flooding was also formed. According to historical flood survey data by different institutions from 1953 to 1971, there were no other recorded larger floods since 1919. Therefore, the return period of the 2021 measured large flood at Liqingdian Station and others can be calculated at least from 1919 onwards.

According to the historical data about floods near Liqingdian Station in 1919, we investigated the relationship between the peak flow of 1919 flood and the catchment area. (Fig. 6). Based on the correlation, the peak flow of 1919 flood at Liqingdian Station was estimated to be 4,520 m^3/s,

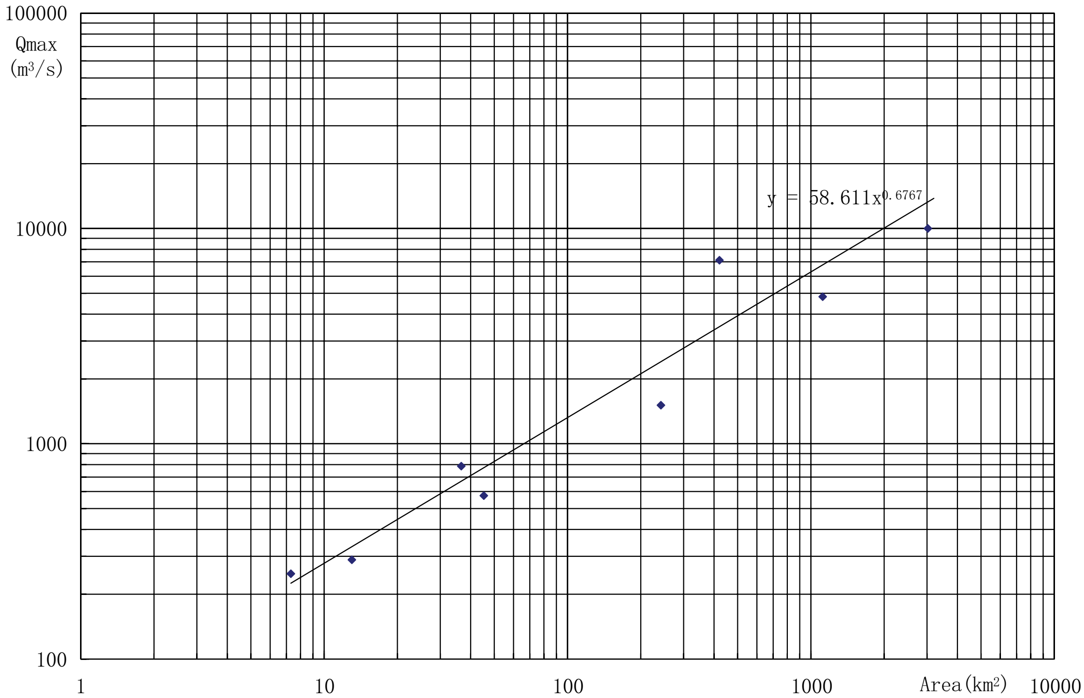

Fig. 6. Relation map of peak area of historical flood in 1919.

Fig. 7. Frequency curve of annual maximum flow rate at Liqingdian Station (1977–2007 measured series).

which was smaller than that in 2021 (the first measured flood) or 2010 (the second measured flood). Therefore, the flood in 2021 near Liqingdian can be ranked as the largest flood since 1919. This is in line with the fact that the magnitude of 2021 flood at the Yahekou Reservoir can at least rank first since 1919.

6. Design flood analysis

6.1. 1977 to 2007 series design floods

The 31-y series from 1977 to 2007 has no extraordinarily large values, and the measured series is used to calculate the design flood peak and 24-h design flood at Liqingdian

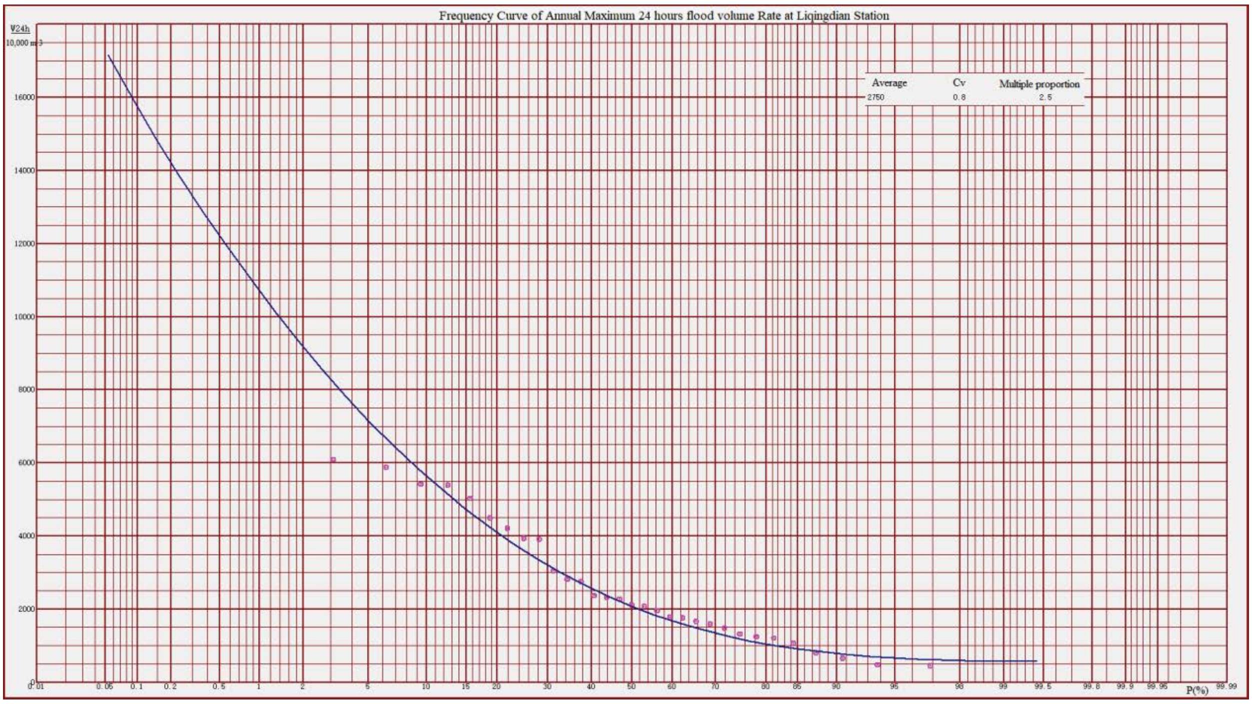

Fig. 8. Frequency curve of annual maximum 24 h flood volume rate at Liqingdian Station (1977–2007 measured series).

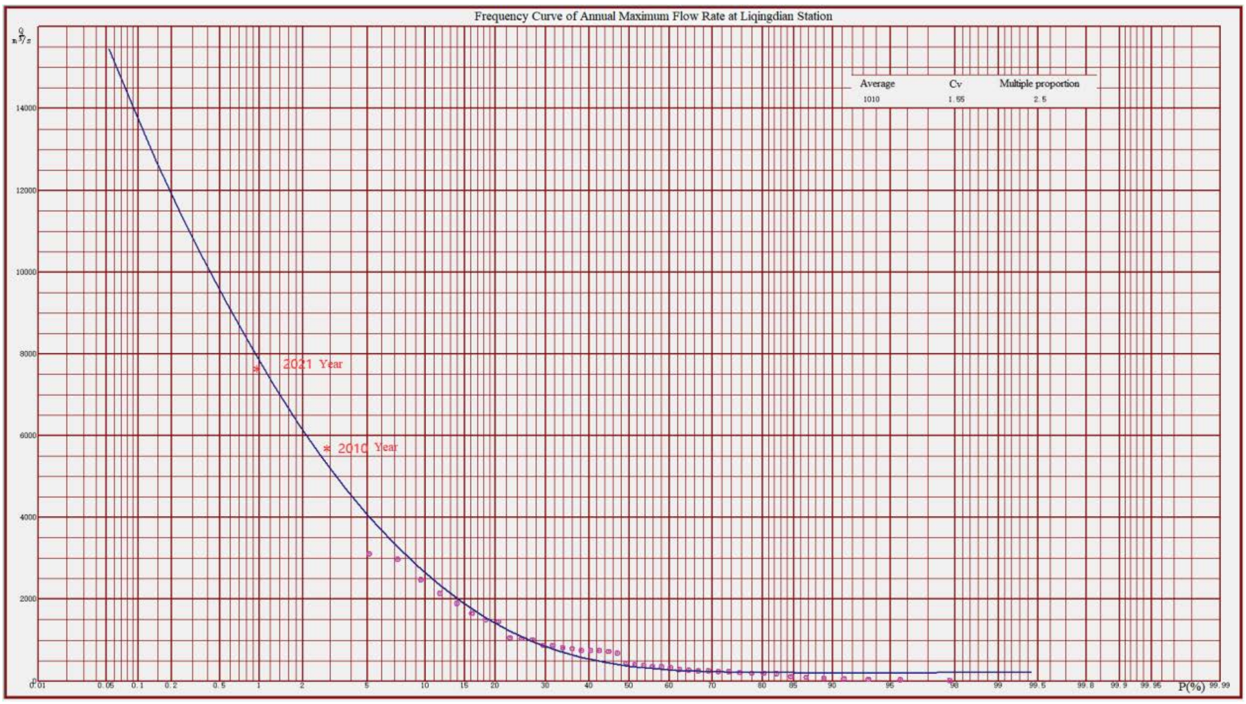

Fig. 9. Peak flow frequency curve of Liqingdian (2021, 2010 up to 1st and 2nd since 1919).

Station (Figs. 7 and 8). The results are shown in Q_1 and W_1 in Table 3.

6.2. 1977 to 2021 series design floods

To analyze the flood peak series at Liqingdian Station between 1977~2021, we took the flood return period as the basis. The flood values in 2021 and 2010 were upgraded as the extra-large values. The return period started from 1919, in which 2021 ranked the first, 2010 ranked the second, and 1919 ranked the third. Due to the absence of flood survey data at Liqingdian Station in 1919, we set a void space for data in 1919. The peak flow frequency curve is shown in Fig. 9. The results are shown in Table 3 of Q_2. To analyze the impact of the extra-large values on the design flood, we calculated the measured series of design flood volume from 1977 to 2021. The frequency curves are shown in Fig. 10 and the results are shown in Table 3 of Q_3. Comparing the results of the two, the 10% to 0.05% design flood peak of the former is smaller than that of the latter by 4.1% to 33.6%. When measured series included extraordinary floods, the analysis of the return period based on standards is very necessary and has a significant impact on the results of the design flood.

There are no particularly prominent oversized values regarding to the maximum 24 h flood of Liqingdian Station (1977~2021 series). Fig. 11 shows the based on the measured series of frequency fitness line curve is shown in, the design flood is shown in Table 3 of W_2.

Table 3 compares the design floods of 1977 to 2021 series (Q_2, W_2) that have taken into account the information of the large flood, with the design floods of 1977 to 2007 series (Q_1, W_1) that have

Table 3
Design flood results of Liqingdian Station

Project		Parameters			Design flood of various frequencies							
		Mean value	C_V	CS/C_V	0.05%	0.1%	0.2%	0.5%	1%	2%	5%	10%
Flood peak (m³/s)	Q_1	1,100	1.02	2.5	9,460	8,520	7,580	6,360	5,440	4,530	3,360	2,500
	Q_2	1,010	1.45	2.5	14,200	12,500	10,900	8,800	7,250	5,760	3,880	2,580
	Q_3	1,030	1.9	2.5	21,400	18,600	15,900	12,400	9,900	7,490	4,580	2,690
Comparison (%)	$(Q_2–Q_1)/Q_1 \times 100$	–8.2	42.2	–	50.1	46.7	43.8	38.4	33.3	27.2	15.5	3.2
	$(Q_2–Q_3)/Q_3 \times 100$	–1.9	–23.7	–	–33.6	–32.8	–31.4	–29.0	–26.8	–23.1	–15.3	–4.1
24 h flood volume (10,000 m³)	W_1	2,750	0.8	2.5	17,300	15,700	14,200	12,200	10,700	9,160	7,140	5,620
	W_2	2,650	1.08	2.5	24,600	22,100	19,600	16,300	13,900	11,500	8,410	6,150
Comparison (%)	$(W_2–W_1)/W_1 \times 100$	–3.6	35.0	–	42.2	40.8	38.0	33.6	29.9	25.5	17.8	9.4

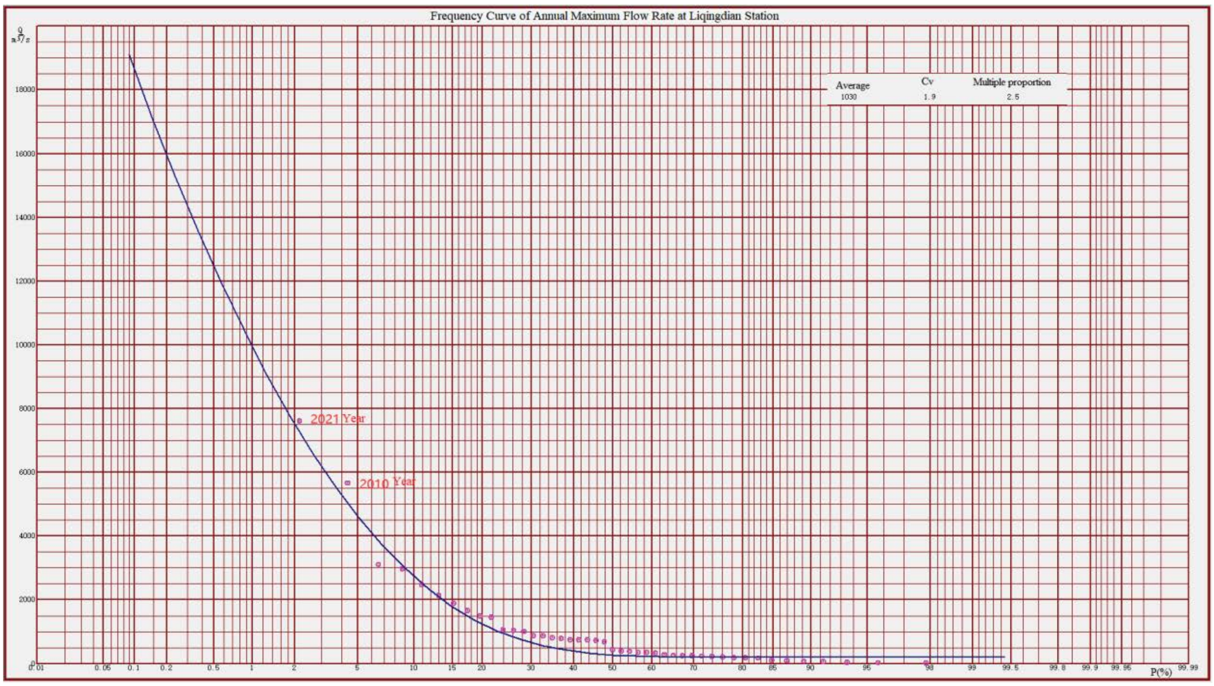

Fig. 10. Peak flow frequency curve of Liqingdian (1977–2021 series).

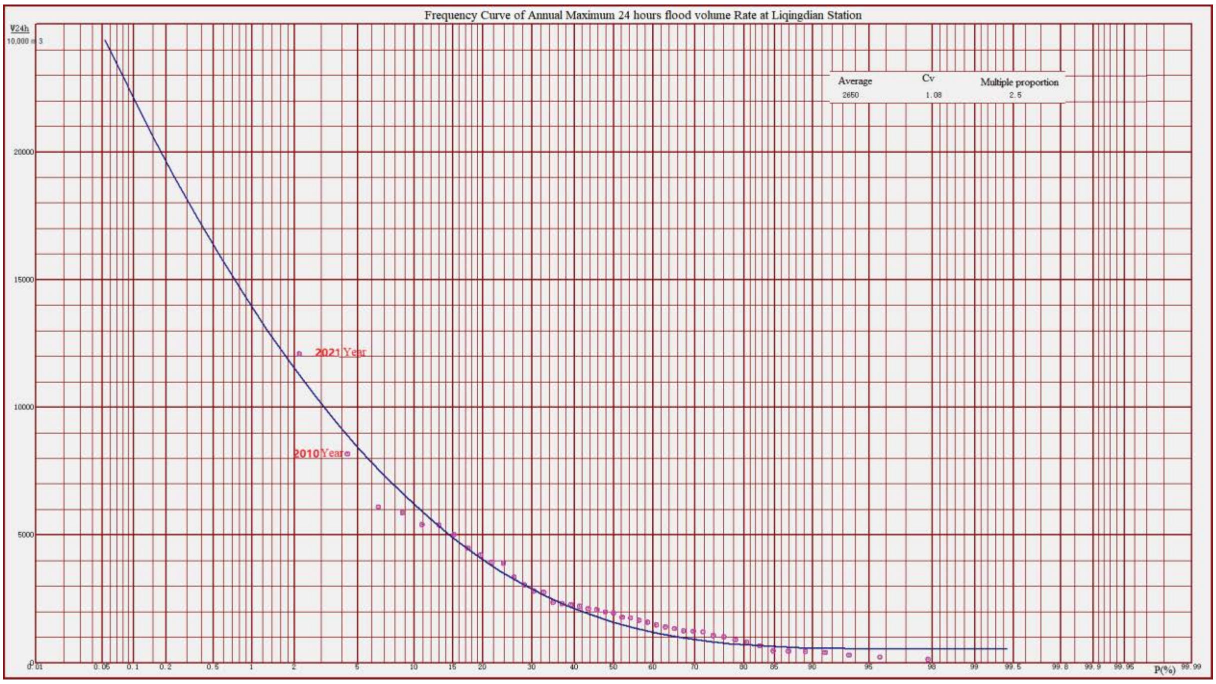

Fig. 11. Frequency curve of the annual maximum 24 h flood of Liqingdian (1977–2021 series).

not contained the information. According to the comparison, the mean values of the flood peaks and the 24-h flood volumes decrease but the CVs increase more. The 10%~0.05% design flood volumes increase by 3.2% to 50.1%, and 10% to 0.05% of the 24-h design flood volume increased by 9.4%~42.2%. According to Q_1, which does not contain information about the large flood, the return periods of the flood with the magnitudes of the 2010 flood (5,670 m^3/s) and 2021 flood (7,620 m^3/s) are about 100 and 500 y, respectively. In comparison, according to Q_2, which considers the information about the large floods, the return periods change to 50 and 100 y, respectively. The results show that information about recent large floods has a significant impact on the design floods, especially floods with very rare frequencies.

7. Conclusion

- Since we have the measured data, the largest flood and second largest flood near the Liqingdian Station happened in 2021 and 2010, respectively. The center of rainstorm was located near Liqingdian. The initial part of the rainfall was smaller, followed by heavy rainfall and the main peak. The flood hydrograph was single-peak, with steep rises and falls.
- After the comparison of the long series design flood that includes recent major floods with the short series design flood that does not include recent the major floods, we find that the mean values of the flood peak and the 24-h flood volume decrease, but the CV increases more. The 10%~0.05% design flood volume increases by 3.2%~50.1%, and the 24-h 10%~0.05% design flood volume increases by 9.4%~42.2%.
- According to the results, after adding the recent large flood data to the series, the design flood of Li Qingdian Station increased more. When the extra-large values differ, the solutions for return periods and design flood results will change greatly. The analysis and calculation of the design flood should take into account the survey data of severe rainstorms and large floods at the nearby sites to improve the accuracy of the results. The methodology and results of this paper provide a certain reference to flood analysis by nearby stations and related engineering design.

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