The Flood Forecasting Scheme of Pudu River Leading Power Station

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Abstract: Pudu River is the largest tributary of the Jinsha River Basin in Yunnan Province, with a runoff area of approximately 11700 km². The upstream is Dianchi Lake, and the flood forecasting has been less studied in Yunnan Province. The purpose of this paper is to do some flood forecasting research for downstream lead plant power stations based on the data conditions and relevant theories. According to the conventional flow algorithm, corresponding water level method and synthetic flow method, the flood of the downstream lead plant power station is forecasted, and the prediction accuracy of each method is evaluated. After analysis, the flow algorithm is not suitable for forecasting the flood of the lead plant, and the accuracy of the synthetic flow law is not high. Finally, the corresponding water level method is selected as the forecast method suitable for the local river section.

1. Overview

The lead plant hydropower station is located in the canyon section of the lower reaches of the Pudu River in Zhongping Township, Luquan County, Kunming. The power station dam site is located in the valley section of the 0.4km upstream of the Sanjiangkou hydrological station of the Pudu River. The control area (9523km²) is close to the Sanjiangkou hydrological station (9529km²). The site is located on the left bank of the Pudu River main stream about 3.5 km below the intersection of the Xima River. The controlled runoff area of the site is 10926 km².

The Pudu River is a primary tributary of the right bank in the lower part of the Jinsha River, most of which belong to the Kunming area. Originated in the west side of Liangming Mountain, Kunming City, Kunming, the north of Liangwang Mountain, Aziying Township, Duojia Village, Shangyu Laibai Baishapo (2600m elevation), through the Songhuaba Reservoir (Big (2) type), it is injected into the Kunming Basin to the south and into the Dianchi Lake. Later, it passes through the DianChi Haikou to Anning, Fuming, Luquan to Jinsha River. The drainage area is 11,751km², the river length is 364km, and the average slope decrease of the river is 4.5‰.

According to statistics, the flooding process in the middle and lower reaches of the Pudu River is slow and the flood time is generally about 15 days. The secondary flooding process is dominated by bimodal, followed by unimodal, and again continuous multimodal.

Due to the storage of Dianchi Lake, the water supply process at the Caijiacun Station in the upper reaches of the Pudu River is relatively smooth, and it has little corresponding to the peak of the downstream Sanjiangkou Station. The flood peak of the tributary Yuantang station basically corresponds to the Sanjiangkou, but after the construction of the Yunlong Reservoir, the original good correlation will not necessarily exist. The Caijiacun station has a relatively small magnitude of flood peaks. In the 50-year measured records of the station, the maximum peak flow is only 405m³/s, and the flood peak modulus is usually lower than the downstream.
2. Basic information

According to the current situation of the Pudu River Area and the location of the project section, the flood forecasting research is mainly based on the measured hydrological data of the dry and tributary hydrological stations in the Pudu River Area. Specifically, it involves the Haikou Station in the upstream of the main stream, the Caijiacun Station in the middle reaches, the Sanchahe River and the Sanjiangkou Hydrological Station in the downstream, and the tributary of the Zhangjiu River Yuantang Station. The specific location is shown in Figure 1. The observations and other conditions are shown in Table 1.

| Station name | area (km²) | time       | Observation content |
|--------------|------------|------------|---------------------|
| sanjiangkou  | 9529       | 1953—2000  | √  √                |
| sanchahe     | 8037       | 1954—1966  | √                   |
| caijiacun    | 5163       | 1953—2000  | √  √                |
| yuantang     | 1925       | 1953—1960  | √  √                |
| haikou       | 2920       | 1953—2000  | √                   |

Description: The observation project after Sanjiangkou Station after 1962 is the water level and rainfall; the Sanchahe station only observes the water level during the period from 1961 to 1966.

Fig.1 Schematic diagram of the distribution of the Pudu River water system and hydrological station

Fig.4 Forecast map of the synthetic flow method of Sanjiangkou station
3. flood forecast

3.1 Forecast method

According to the flood characteristics of the Pudu River and the distribution of the main hydrological stations, the flood forecasting is carried out by the corresponding water level (flow) method.

The Sanjiangkou hydrological station (now the water level station) is located 1.4km downstream of the dam site of the lead plant power station. The plant is located on the left bank of the Pudu River main stream about 9km downstream of the dam site. The runoff area of the power station dam site is 9523km$^2$, which is less than 1% difference with Sanjiangkou Station. Therefore, the flood of the power station dam site can directly adopt the Sanjiangkou station value.

There are Caijia Village and Sanchahe Hydrological Station on the upper reaches of Pujiang River Sanjiangkou Station (which has been revoked), and the upstream tributary of Zhangjiu River has Yuantang Hydrological Station (which has been revoked). From Sanjiangkou Station to the upstream of Caijiacun Station, the distance is 102km, to Sanchahe Station is 49km, to Yuantang Station of the Zhizhong River is 54km.

According to the analysis of flood excavation data, the flood peak flow of Yuantang Station and Sanchahe Station basically corresponds to the downstream Sanjiangkou Station. The Caijiacun station is relatively far from the lead factory power station. The storage of the Dianchi Lake has a great impact on the flood process of the Caijiacun Station. The correspondence between the Caijiacun station flood and the downstream station is poor. Yuantang Station and Sanchahe Station can be used as upstream stations for flood forecasting of lead plant power stations.

3.1.1 Corresponding water level method

According to the process map of the water level (flow) of the same flood data at the Sanjiangkou and Sanchahe stations, the flood process of the Sanjiangkou station has a good correspondence with the upstream station. For the case of upstream water, the flooding time can be clearly seen from the flood process, and the downstream peak flow increases less than that of the upstream. For the case where the surface rainstorm is evenly distributed, the situation of the upstream and downstream flood peaks is also better, but the flood peak propagation time is relatively difficult to determine, sometimes the propagation time is very short, and even the downstream peak current time is earlier than the upstream. This situation generally occurs when the continuous flood time is long and the water level is always high. For example, the 7.19 flood in 1957 (the largest flood in the flow measurement period), the peak time of Sanjiangkou station is 13:19 on the 19th, the flood peak flow is 990m$^3$/s; the peak time of Sanchahe station is also 13th on the 19th, and the flood peak flow is 908m$^3$/s. During the flooding process, the peak was peaceful and slow. The flow volume of Sanchahe Station remained above 800m$^3$/s from 8:00 to 15:00, and the flow volume of Sanjiangkou Station did not drop to 900m$^3$/s from 11:00 to 18:00. Due to the timely intervention of the interval flood, the flood peak can no longer analyze its propagation time, but from the perspective of the flood process, the propagation time should be around 3h. If the incoming water is mainly produced in the two-station interval, there is no obvious flood peak corresponding to the downstream station. This situation is generally less frequent and the flood level is smaller.

According to statistics, during the peak time, the average velocity of the Sanchahe and Sanjiangkou sections is generally between 1.02 and 2.24 m/s. According to the relationship between the wave velocity of the general prismatic channel and the average velocity of the section and the comparison of several measured floods, the wave velocity of this section should be between 1.7~3.74m/s (wave velocity $C_k=dQ/dA$, wave velocity coefficient $\eta$ is 1.67). That is, the propagation time from Sanchahe to Sanjiangkou should be 8~3.6h. Since the statistical data is small, the relationship between the wave velocity and the average flow velocity of the section is an empirical value, so that the propagation time slightly exceeds the above range is also treated according to the same flood.

According to the flood process map of Sanjiangkou and Sanchahe stations, the maps of the upstream flood level and the downstream peak water level and the upstream peak water level and flood peak
propagation time are extracted from the 20 flood points corresponding to the upstream and downstream flood processes (see Figure 2). The figure shows that the water level of the upstream and downstream flood peaks has a good correlation and is linearly related. The relevant equation:

\[ H_{\text{Sanjiangkou}(t+\tau)} = 0.861 H_{\text{Sanchahe}(t)} - 169.19 \]

The correlation between the flood peak water level and the propagation time is also obvious, but it is nonlinearly correlated. The point cluster center is estimated to be aligned, as shown in Figure 2. The propagation time decreases with the increase of the water level of the flood peak. When the water level rises to a certain extent, the variation of the propagation time correlated to the change of the water level decreases, and the propagation time is gradually constant.

It can be seen from Figure 2 that when the water level of the upstream Sanchahe station is known, the water level of the Sanjiangkou station after a few hours can be predicted.

The tributary Yuantang station and the downstream Sanjiangkou station also have the following relationship, but the correlation is obviously not as good as the former, as shown in Figure 3. Caijiacun Station and Sanjiangkou Station have basically no relationship, but when the water level is higher than 1743m (equivalent to a flow rate of 83.0m³/s), it can be roughly concluded that the flood propagation time is between 8~12h.

Figure 2 The corresponding flood peak water level forecast map of the Pujiang River Sanjiangkou Station (upstream Sancha River)
3.1.2 Synthetic flow method

In order to increase the foreseeing period of flood forecasting, this method considers the upstream station to use the Caijiacun station and the tributary of the Yuantang station to forecast the flood of the lead plant power station.

The upstream station of the forecasting scheme moved up, resulting in the influx of a large flooded tributary, the Palm River. In considering the river section where the tributary flows, the flood at the downstream station is the result of flooding of the upstream dry and tributary stations. According to the previous analysis, it is known that the flooding of the Caijiacun station to Sanjiangkou is 4–5h behind that of the Yuantang station. Due to the adjustment of the Dianchi Lake, the water supply process at the Caijiacun Station in the upper reaches of the Pudu River is gentle, and the flood process does not correspond to the downstream. The flood peak flow of Yuantang Station has a certain correlation with Sanjiangkou Station. When establishing the relationship between the upstream and downstream flood peaks, the flood peak flow of Yuantang Station plus the first 4–5h flow in Caijiacun Station is used as the independent variable of correlation. The correlation is shown in Figure 4. Forecast correlation equation: \( Q_{\text{Jiang}}(t+\tau) = 1.605(Q_{\text{yuan}}(t) + Q_{\text{Cai}}(t-4)) - 32.9 \). Because the flood process of Caijiacun Station is relatively peaceful and slow, the flood of Sanjiangkou Station mainly comes from the Caijiacun to Sanjiangkou section. Therefore, this method didn’t precisely deal with the flood propagation time of Caijiacun Station.

3.1.3 Flow Algorithm

In the measured flow series of Sanjiangkou and Sanchahe stations, the upstream and downstream flood peaks were selected, and the flood calculation process with relatively small inflow was carried out to flow calculation by using Musking method. Due to the low flow data during the same period, only 5 floods were taken. According to the flood peak propagation time, the calculation period \( \Delta t \) takes 2h, and the parameters \( k \) and \( x \) are determined according to the test algorithm. Except for 580,616 floods with \( k=2.94 \), \( x=0.45 \) and 570,627 floods with \( k=2.71 \) and \( x=0.48 \) in the range of values, the x-values of the

Figure 3 The corresponding flood peak water level forecast map of Pujiang River Sanjiangkou Station (upstream Yuantang)
other floods are greater than 0.5, and the S–Q’ relationship is basically linear. According to the flow calculation formula established by the two floods k and x values, other floods are predicted, and the accuracy is poor.

From the current data analysis, the Sanchahe–Sanjiangkou section does not have the conditions for flood forecasting by using the Muskingum method, and the calculation results of the characteristic river length also illustrate this point. The characteristic river length calculation was carried out for the floods with different flow levels in the river section. When the flow rate is 80m³/s, the characteristic river length is 97km; when the flow rate is 120m³/s, the characteristic river length is 114km; When the flow rate is 160m³/s, the characteristic river length is 127km. The length of the Sanchahe–Sanjiangkou section is only 49km, which means that the length of the forecasted section is less than one unit.

3.2 Determination of accuracy and determination of forecasting methods

In the previous section, the prediction formulas of the corresponding water level method and synthetic flow method were introduced. In order to preliminarily test its accuracy, it also extracts more floods of the field and compares the measured values with the predicted values. See Table 2–Table 3.

The corresponding water level method has a good accuracy for the downstream water level forecast. In the more than 40 floods extracted, the maximum error of the forecast is 0.25m, 58% of the forecast value error is within 0.1m, and 96% of the forecast error is within 0.2m. The relative error is almost within 10%. For the foreseeable period, the error is relatively large. The main reason is that the intervention of the interval flood has a greater influence on the judgment of the propagation time. The second is that for some floods, it is not necessarily appropriate to determine the flood propagation time based on the upstream and downstream peak time, such as the 7.19 flood in 1957 mentioned above.

The test results predicted by the synthetic flow method are shown in Table 3. The method takes the upstream and downstream peak time, such as the 7.19 flood in 1957 mentioned above.

The 580,716 forecast floods and the measured flood peaks, the floods in other sites have better forecasting accuracy.

The 580,716 flood was the largest flood in Yuantang Station in 1958, and the Sanjiangkou and Sanchahe stations in the published flood element table missed the flooding process in mid-July of that year. The measured flood peak flow of Sanjiangkou Station in the table is 352m³/s, which is extracted from the daily flow meter. There is no corresponding date in the early yearbook. That is, the flood peak flow of Sanjiangkou is 352m³/s, but it is still not sure that it is the 500716 flood.

| Table 2 List of flood forecast results of corresponding water level method at Sanjiangkou Station |
|---|---|---|---|---|---|---|
| n | flood | H_sanchahe(m) | Actual measurement | forecast | Absolute error | Relative error(%) |
|---|---|---|---|---|---|---|
| 1 | 560714 | 1545.47 | 1161.47 | 3 | 1161.46 | 4.2 | 0.01 | -1.2 | 2.47 | 0.42 |
| *2 | 560724 | 1546.93 | 1162.58 | 3 | 1162.72 | 3.3 | -0.14 | -0.3 | 3.58 | -3.82 |
| 3 | 560813 | 1545.11 | 1161.11 | 6 | 1161.15 | 4.8 | -0.04 | 1.2 | 2.11 | -1.88 |
| 4 | 560821 | 1545.9 | 1161.79 | 5 | 1161.83 | 3.9 | -0.04 | 1.1 | 2.79 | -1.43 |
| 5 | 561017 | 1545.48 | 1161.47 | 4 | 1161.47 | 4.2 | 0.00 | -0.2 | 2.47 | 0.07 |
| 6 | 570627 | 1546.95 | 1162.58 | 3 | 1162.73 | 3.3 | -0.15 | -0.3 | 3.58 | -4.30 |
| 7 | 570708 | 1547.29 | 1163.12 | 4 | 1163.03 | 3.15 | 0.09 | 0.85 | 4.12 | 2.26 |
| 8 | 570806 | 1547.31 | 1162.88 | 3 | 1163.04 | 3.15 | -0.16 | -0.15 | 3.88 | -4.22 |
| *9 | 580617 | 1545.52 | 1161.34 | 3.5 | 1161.50 | 4.1 | -0.16 | -0.6 | 2.34 | -6.95 |
| 10 | 580801 | 1545.57 | 1161.52 | 6 | 1161.55 | 3.9 | -0.03 | 2.1 | 2.52 | -1.02 |
|   |   |   |   |   |   |   |   |   |   |   |   |   |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11 | 580906 | 1544.7 | 1160.78 | 6 | 1160.80 | 5.9 | -0.02 | 0.1 | 1.78 | -0.94 |
| 12 | 580917 | 1545.06 | 1161.09 | 6 | 1161.11 | 4.9 | -0.02 | 1.1 | 2.09 | -0.80 |
| 13 | 580920 | 1545.26 | 1161.23 | 6 | 1161.28 | 4.6 | -0.05 | 1.4 | 2.23 | -2.19 |
| 14 | 590624 | 1544.51 | 1160.48 | 6 | 1160.63 | 6.3 | -0.15 | -0.3 | 1.48 | -10.35 |
| 15 | 590802 | 1544.99 | 1160.98 | 5 | 1161.05 | 5 | -0.07 | 0 | 1.98 | -3.35 |
| 16 | 590807 | 1545.04 | 1160.93 | 5 | 1161.09 | 4.9 | -0.16 | 0.1 | 1.93 | -8.26 |
| 17 | 590813 | 1545.53 | 1161.45 | 4 | 1161.51 | 4.1 | -0.06 | -0.1 | 2.45 | -2.50 |
| 18 | 600711 | 1544.31 | 1160.46 | 6 | 1160.46 | 7.2 | 0.00 | -1.2 | 1.46 | -0.06 |
| 19 | 600720 | 1544.93 | 1160.88 | 6 | 1160.99 | 5.2 | -0.11 | 0.8 | 1.88 | -6.10 |
| 20 | 600722 | 1545.04 | 1161.13 | 6.5 | 1161.09 | 4.9 | 0.04 | 1.6 | 2.13 | 1.90 |
| *21 | 600729 | 1546.58 | 1162.58 | 3 | 1162.42 | 3.4 | 0.16 | -0.4 | 3.58 | 4.60 |
| 23 | 600914 | 1544.55 | 1160.58 | 5 | 1160.67 | 6.3 | -0.09 | -1.3 | 1.58 | -5.54 |
| 24 | 610610 | 1545.16 | 1161.07 | 5.2 | 1161.19 | 4.7 | -0.12 | 0.5 | 2.07 | -5.93 |
| 25 | 610710 | 1544.57 | 1160.76 | 6 | 1160.68 | 6.2 | 0.08 | -0.2 | 1.76 | 4.27 |
| 26 | 610730 | 1545.44 | 1161.36 | 5 | 1161.43 | 4.6 | -0.07 | 0.4 | 2.36 | -3.13 |
| 27 | 611024 | 1546.16 | 1162.05 | 4 | 1162.05 | 3.7 | 0.00 | 0.3 | 3.05 | -0.12 |
| *28 | 620701 | 1547.24 | 1162.73 | 3 | 1162.98 | 3.3 | -0.25 | -0.3 | 3.73 | -6.80 |
| *29 | 620827 | 1546.37 | 1162.09 | 4 | 1162.23 | 3.6 | -0.14 | 0.4 | 3.09 | -4.68 |
| *30 | 630731 | 1544.38 | 1160.45 | 6 | 1160.52 | 6.7 | -0.07 | -0.7 | 1.45 | -4.91 |
| *31 | 630820 | 1544.21 | 1160.26 | 7 | 1160.37 | 6.7 | -0.11 | 0.3 | 1.26 | -9.11 |
| *32 | 630828 | 1544.55 | 1160.59 | 6 | 1160.67 | 6.2 | -0.08 | -0.2 | 1.59 | -4.88 |
| *33 | 630627 | 1544.57 | 1160.82 | 4.9 | 1160.68 | 6.2 | 0.14 | -1.3 | 1.82 | 7.43 |
| *34 | 640510 | 1545.47 | 1161.33 | 4.4 | 1161.46 | 4.2 | -0.13 | 0.2 | 2.33 | -5.57 |
| *35 | 640612 | 1544.99 | 1161 | 4.5 | 1161.05 | 5 | -0.05 | -0.5 | 2 | -2.32 |
| 36 | 641007 | 1545.76 | 1161.55 | 3 | 1161.71 | 3.9 | -0.16 | -0.9 | 2.55 | -6.25 |
| 37 | 650630 | 1546.4 | 1162.23 | 4 | 1162.26 | 3.5 | -0.03 | 0.5 | 3.23 | -0.94 |
| *38 | 650629 | 1547.43 | 1162.93 | 3.5 | 1163.15 | 3.3 | -0.22 | 0.2 | 3.93 | -5.53 |
| 39 | 650826 | 1546.63 | 1162.39 | 3.7 | 1162.46 | 3.5 | -0.07 | 0.2 | 3.39 | -2.02 |
| 40 | 651024 | 1546.77 | 1162.54 | 4 | 1162.58 | 3.4 | -0.04 | 0.6 | 3.54 | -1.10 |
| 41 | 660612 | 1544.7 | 1160.68 | 5.5 | 1160.80 | 5.9 | -0.12 | -0.4 | 1.68 | -6.95 |
| 42 | 660618 | 1546.43 | 1162.45 | 4 | 1162.29 | 3.5 | 0.16 | 0.5 | 3.45 | 4.75 |
| *43 | 660711 | 1547.44 | 1163.08 | 3.5 | 1163.16 | 3.2 | -0.08 | 0.3 | 4.08 | -1.86 |
| 44 | 660812 | 1546.04 | 1161.95 | 5 | 1161.95 | 3.9 | 0.00 | 1.1 | 2.95 | -0.01 |
| *45 | 660725 | 1545.39 | 1161.37 | 5 | 1161.39 | 4.3 | -0.02 | 0.7 | 2.37 | -0.88 |

Note: The number in the table with the number * is used to establish the forecast equation using flood. According to the above-mentioned accuracy evaluation results and the unstable relationship of the water level flow at Sanjiangkou Station, the corresponding water level method should be adopted for flood forecasting.
4. Conclusion
Through the above analysis, the flood propagation time from the Sanchahe to Sanjiangkou station of the Pudu River is more than 3.6h. According to the corresponding water level method, the Sanchahe station has a certain accuracy in forecasting the flood of the downstream Sanjiangkou station.

The Pudu River is quite special. There is Dianchi regulation in the upper reaches. The tributary of the Zhangjiu River is regulated by the Yunlong Reservoir. Both the main stream and the tributaries have a regulation delay effect on the flood peaks. Therefore, the peak of the lead plant power station mainly depends on the flood generated in the middle and lower reaches. This will result in a low accuracy of the synthetic flow method or flow calculus.

In short, the flood characteristics of the Pudu River are that the upstream flood peak modulus is smaller than the downstream, and the floods in the lead plant are mainly generated by the downstream and interval tributaries. Suitable forecasting methods elsewhere are not necessarily applicable in the mainstream of the Purdue River. Although the upward movement of the upstream forecasting station increases the forecasting time, the accuracy of the forecasting will be greatly affected without controlling the largest tributary river. Although the upward movement of the upstream forecasting station increases the forecasting time, the accuracy of the forecasting will be greatly affected without including the largest tributary river, Zhangjiuhe. The most ideal way to forecast the flood of the lead-plant power station is to restore or reconstruct the Sanchahe hydrological station in the Sancha River area (downstream of the Zhangjiu River estuary), and the corresponding water level method can meet the requirements.

Yunnan Province does not do much work on flood forecasting, and the local rivers and rainstorms conditions are relatively complex. This article only hopes to do some exploration in this aspect.

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References
[1] Ray K.Linsley,Jr.max A.Kohler Joseph L.H.Paulhus Hydrology for Engineers translator:Guanwen Liu zhihao Zhou Zencyuan Shen Jiyan Liu (1981.5 BeJing) [K]
[2] Hydrological forecasting.4th ed Hohai Universty Weimin Bao[K]
[3] Feasibility study report of qianchang hydropower station[R]