Research on runoff variation trend and hydrological situation variation in Wujiang River Basin

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Abstract. This paper selected the Wujiang River Basin as the study area, and restored the runoff process at Wulong station through complicated calculation. By using Mann-Kendall, Kendall rank correlation test and other test methods, there was no significant trend for the runoff in the Wujiang River Basin. The RVA method was applied to analyze the influence degree for the existing cascade reservoir operation on the hydrological regime of the Wujiang River, and it was concluded that the overall hydrologic indicators alteration degree of Wulong Station was high. By simulating the operation scenarios of the cascade reservoirs, future hydrological regime alteration of Wulong station was predicted. Compared with the current situation of Wulong station, the results showed that the inflow will decrease in flood season, and the inflow will increase in dry season.

1. Introduction
The construction of water conservancy projects has a greater impact on the natural hydrological regime of downstream rivers. It changes the inter-annual and intra-year distribution of water resources, and affects the migration and spawning of downstream fish due to the regulation of floods. In order to quantitatively assess the degree of this influence, many scholars have carried out a lot of research. By constructing the hydrologic indicator set of studying river, the RVA method (Range of Variability Approach)[1-2] can analyze the changes of hydrologic indicator values in different periods to indirectly reflect the degree of river hydrologic alteration, and has a large number of applied studies in different basins. Li[3] used the RVA method to assess human-induced hydrologic alteration in the control reach of Yichang hydrometric station on Yangtze River. Yu[4] analyzed the alteration of the ecological hydrologic characteristics of Lanzhou station in the upper Yellow River, and found that the operating modes of different reservoirs have different degrees of alteration in the hydrologic regime for the Lanzhou section of Yellow River. Zhang[5] analyzed the environmental impact of hydropower development on the main stream of Wujiang River in Guizhou. Wang[6] analyzed the influence of joint operation of reservoirs on the hydrologic regime of Dongfeng reservoir in the upper Wujiang River.
River. Duan[7] used the RVA method to analyze the impact of large cascade reservoirs on hydrologic regime of Yichang station in the upper Yangtze River.

Based on the analysis of runoff evolution trend by using MK test[8-10], Kendall test and other methods, this paper used the RVA method to evaluate the hydrological regime alteration of lower Wujiang River. The aim and main contents of research to explore the evolution law of basin water resources, evaluate the current situation of the basin and future hydrological regime of Wujiang River, and provide a reference for the optimal operation and adjustment of the basin control water conservancy projects.

2. Study area
The Wujiang River is the largest tributary on the right bank of upper Yangtze River, with a catchment area of 87,900 km², a length of 1037 km, and a total natural drop of 2124 m. It originates from the eastern foot of Wumeng Mountain in the northwestern of Guizhou Province and flows through four provinces (or municipalities) of Yunnan, Guizhou, Chongqing and Hubei. Since 1959, the mainstreams and tributaries of Wulong station in the upper Wujiang River have successively built many hydropower stations, such as Hongjiadu, Dongfeng, Wujiangdu, Goupitan, Pengshui, and Jiangkou, and the natural runoff process have been changed.

The schematic diagram of Wujiang River system, reservoirs and hydrological stations is shown in Figure 1.

3. Analysis on the Evolution Trend of Runoff in Wujiang River Basin

Figure 1. Wujiang River Basin

Figure 2. The monthly average flow changes of Wulong station before and after restoring calculation from 1997 to 2016
3.1. Restoring calculation on the Runoff of Wujiang River

In order to eliminate the impact of reservoirs on runoff regulation and meet the requirements of “consistency” in hydrological analysis samples, the impact of reservoir regulation and impoundments in the upstream of Wujiang station was restored: the runoff propagation time from Hongjiadu to Wujiangdu was generalized in 3 days; the runoff propagation time from Wujianqiu to Wujiangdu is considered as 2 days; due to the short distance from Pengshui to Wulong station, the runoff propagation time is not considered, and only the Wulong station is carried out runoff restoring calculation.

The statistics of the annual average monthly flow changes before and after the restoration of Wulong station from 1980 to 2016 are shown in Figure 2. It can be seen that due to the impact of upstream cascade reservoirs on regulation and impoundments, the annual average monthly flow of Wulong station from May to July and October is slightly reduced compared with the natural flow, the flow from August to September and November to April is increased, and the flow in January is increased by 21.9%. In terms of runoff, the distribution of runoff at Wulong station before and after restoring calculation changed little, indicating that the cascade reservoirs above Wulong station have little impact on runoff.

3.2 Prediction of runoff evolution trend for Wujiang River

The runoff series from 1952 to 2016 at Wulong station were used to conduct Mann-Kendall nonparametric test, Kendall rank correlation test, Spearman rank correlation test and linear regression test, and the results are shown in Table 1.

At the significance level of $\alpha=0.05$, $U_{0.02}=1.96$, $t_{0.02}(59-2)=2.002$. The statistical test results of annual runoff at Wulong station show that there is no significant trend in this runoff series.

4. Analysis on hydrological regime alteration of Wujiang River based on RVA method

The principle of the RVA method (Range of Variability Approach) is to select a controlling hydrological station or a controlling hydrological section of a river, and collect the daily-scale long series of runoff data. Through the statistical analysis of these data, an IHA (Indicators of Hydrologic Alteration) set of 32 indicators is constructed, including 5 groups of indicators on monthly flow, extreme flow, occurrence time of extreme flow, frequency and duration of flow pluses, rate and frequency of water flow. By confirming the abrupt change time point, the alteration of control station or control section affected by upstream human activities or water conservancy projects is evaluated. Many scholars have applied this method to the hydrological variation analysis of rivers, and the evaluation effect is big. Therefore, the RVA method is used to analyze and assess the current status of Wujiang River and the future hydrological variation.

4.1. Current hydrological variation status of Wulong station based on the RVA method

Wulong hydrological station is the control station of Wujiang River basin, and the main upstream large-scale reservoirs with strong regulating capacity are Hongjiadu, Dongfeng, Wujianqiu, Goupitan, Pengshui, Jiangkou, etc. Wujianqiu Reservoir began to store water at the end of 1979, and the flow of Wulong station was affected by the regulation and impoundments of upstream reservoirs after 1980. Therefore, this study selected 1980 as the initial time from the year when Beibei station was affected by water conservancy projects, and assessed the variation of hydrologic indicators at Wulong station from 1980 to 2016. The results show that 23 indicators have changed in high degree, the overall hydrological alteration degree is 0.75 which belongs to a high level. The alteration in the IHA indicators of Wulong station from 1980 to 2016 are shown in Figure 3.

### Table 1. Test results of annual runoff trend at Wulong Station

| Station | M-K test | Kendall test | Spearman test | LRT test |
|---------|----------|--------------|---------------|---------|
| Wulong  | -0.20    | -0.31        | 0.13          | -0.84   |
In Figure 3, the first group of monthly flow indicators from 1 to 12 changes in high degree; in the second group of annual extreme flow and base flow indicators from 13 to 23, 1-day maximum flow, 30-day maximum flow and base flow index change in middle and low degree, and other indicators all change in high degree; the third group of occurrence time of extreme flow indicators from 24 to 25 changes in high degree; in the fourth group of frequency and duration of flow pluses indicators from 26 to 29, only high pulse duration changes in high degree; the fifth group of rate and frequency of water flow indicators from 30 to 32 changes in middle and middle degree.

Figure 3. Indicators of hydrologic alteration at Wulong Station

The indicators of February median flow, March median flow, November median flow, December median flow, 3-day minimum flow, 7-day maximum flow have changed in high degree. In order to analyze the impact of water conservancy projects on the hydrologic regime alteration of downstream rivers, the long series of measured and natural process for these indicators are shown in Figure 4.
4.2 Prediction of hydrologic alteration in Wulong station based on RVA method

The joint operation simulation of large-scale reservoirs on the Wujiang River was carried out on the scale of ten days, and the changes in the hydrological regime of the lower Wujiang River can be predicted. Table 2 shows the alteration of hydrological indicators at Wulong Station from 1970 to January to December 2016. It can be seen that after the joint operation of cascade reservoirs, the average flow from January to December in the hydrological IHA indicators changes in low degree.

| Indicators      | Nature Discharge 1970-2016 (m³/s) | Modified Discharge (m³/s) |
|-----------------|-----------------------------------|---------------------------|
|                 | Median Value | Upper limit of RVA | Lower limit of RVA | Median Value | Alteration Degree |
| January Flow    | 413         | 471                | 336                | 514          | L                |
| February Flow   | 455         | 584                | 358                | 590          | L                |
| March Flow      | 583         | 725                | 433                | 741          | L                |
| April Flow      | 1258        | 1490               | 972                | 1467         | L                |
| May Flow        | 2284        | 2760               | 1750               | 2379         | L                |
| June Flow       | 3499        | 4390               | 2600               | 3226         | L                |
| July Flow       | 3373        | 4520               | 1957               | 3068         | L                |
| August Flow     | 1999        | 2640               | 1130               | 1878         | L                |
| September Flow  | 1664        | 2203               | 1010               | 1595         | L                |
| October Flow    | 1407        | 1800               | 863                | 1358         | L                |
| November Flow   | 975         | 1176               | 630                | 1020         | L                |
| December Flow   | 518         | 577                | 428                | 599          | L                |
Figure 5. Comparative analysis of monthly average flow of Wulong station in February

The annual average flow of Wulong station from June to October will be reduced by 4%-9% compared with the natural flow. For example, the average flow in July is 3068 m³/s, which is 306 m³/s less than the natural flow of 3373 m³/s, with a decline of 9%. The annual average flow from November to May of the next year will increase compared to the natural flow. For example, the average flow rate in February increased by 136 m³/s, with a growth of 30%. In order to analyze the alteration in the hydrologic indicators of Wulong Station, the long series of runoff after modified calculation and the natural runoff processes in the dry period of February at Wulong Station are selected for comparative analysis. The results are shown in Figure 5.

From the comparison result in Figure 5, without new large-scale reservoir in the upstream of Wulong station, the hydrologic indicators of Wulong station changes in low degree, and it shows that the upstream cascade reservoirs have little impact on runoff during the flood season and impoundment period.

5. Conclusion
In this study, a restoring calculation was adopted for the long series data of water storage capacity of cascade reservoirs in the Wujiang River, and the natural runoff process of Wulong station was obtained. Through the analysis of annual average monthly flow changes in Wulong station before and after the operation of reservoirs, the hydrologic regime alteration of upstream cascade reservoir regulation and storage was concluded. Compared with the natural flow, the actual monthly average flow of Wulong station from May to July and October decreased slightly, and the flow from August to September and November to April of next year increased, of which the average flow of January increased by 21.9%. At the significance level of α=0.05, the runoff series from 1952 to 2010 at Wulong station passed the Mann-Kendall non-parametric test and Kendall rank correlation test. The test results show that there is no significant change trend.

By analyzing the alteration of hydrological indicators for the runoff series at Wulong station after the operation of upstream reservoir, it is concluded that 23 indicators have changed in high degree, and the overall hydrological alteration degree is 0.75 which belongs to a high level. Based on the prediction of hydrologic regime alteration at Wulong Station, the annual average flow of Wulong station from June to October will be reduced by 4%-9% compared with the natural flow. The annual
average flow from November to May of the next year will increase compared to the natural flow. For example, the average flow rate in February increased by 136 m³/s, with an growth of 30%.

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