Analysis on the influence of reservoir group on the runoff of Datong station in dry season

Ming Zeng1*, Jiqiong Li2,3, Yaowu Min1*, Shanshan Yang4, Jie Li1
1Bureau of Hydrology, Changjiang Water Resources Commission of the Ministry of Water Resources of China, Wuhan 430010, China
2Changjiang River Scientific Research Institute, 430010, Wuhan, China;
3Wuhan Changjiang Kechuang Technology Development Co.Ltd, Wuhan 430010, China;
4Chinese Hydraulic Engineering Society, Beijing 100053, China;
* correspondence: zengm@cjh.com.cn (M Zengi); 459087311@qq.com (Y Min)

Abstract. Datong Station is an important controlling station in the lower reaches of the Yangtze River. Analysis on the influence of upstream reservoir group on the runoff change characteristics can provide theoretical support for the utilization and sustainable development of water resources in the lower reaches of the Yangtze River and the Yangtze River Estuary. Based on in-situ observation and mathematical statistics, this paper analyzes the runoff composition of Datong Station and the influence of reservoir group on the runoff of Datong Station in dry season. The main conclusions are as follows: the water inflow from Yichang and above is the main component of Datong Station runoff. The operation of upstream reservoir group adjusts the water inflow distribution of Datong Station to a certain extent. The water replenishing of reservoir group increases the runoff of Datong station obviously from November to March of the following year (dry season), which has a positive effect on resisting the saline water intrusion in the Yangtze River estuary.

1. Introduction
The Yangtze River estuary is a densely populated and economically developed area in China. It is economic, transportation, technology, industrial, financial, trade, exhibition, and shipping center. With the development of the national economy and the rapid increase in population, water supply of Shanghai has become increasingly tight [1]. The saline water intrusion in the Yangtze River estuary in dry season every year seriously threatens the water intake of water source in Shanghai [2]. The various production and living water safety problems caused by saline water seriously restrict the development and utilization of water resources and economic development in the Yangtze River estuary [3].

The degree of saline water intrusion in the Yangtze River estuary is closely related to the main stream runoff amount of Yangtze River, tides, wind stress, estuary morphology and underwater topography. Water diversion is one of the more common and effective methods to prevent and resist saline water intrusion. According to the overall layout of the comprehensive plan for the Yangtze River Basin, Datong Station, as the main controlling station on the lower reaches of the Yangtze River, has a control index threshold of 10000m³/s [4]. After the cascade reservoirs in the upper and middle reaches of the Yangtze River are constructed and put into operation, analysis on the influence of their scheduling
operations on the runoff of Datong Station, can provide a constraint boundary for the upstream reservoir group scheduling in dry season.

2. Study Area
Datong Station is an important hydrological station in the middle and lower reaches of the Yangtze River. It is located in Meigeng Town, Guichi District, Chizhou City, Anhui Province. It is 642km from the sea entrance of the Yangtze River, and the control basin area accounts for 94% [5]. The station is the nearest hydrological controlling station with long-term observation data in the lower reaches of the Yangtze River from sea entrance. The runoff change directly affects the water quantity change in the lower reaches of the Yangtze River basin, the development of fan delta geomorphology, the saline water intrusion and the change of flood disasters. The operation of the upstream reservoir group, especially the Three Gorges Reservoir, is bound to have a certain impact on the runoff of Datong Station [6].

3. Data and Methodology

3.1. Data
In this study, the daily runoff data of Datong Station from 1950 to 2018 and the multi-year daily data of tributaries controlling stations in the upper reaches of Datong Station were collected. The relevant data are derived from the hydrological yearbook of the Yangtze River Basin.

3.2. Methodology
In this study, in-suit observation data was used to analyze annual runoff composition and runoff composition in dry season of Datong Station, clarifying water inflow proportion above the Three Gorges. Based on the reservoir operation data, runoff change characteristics of Datong Station in dry season (from November to April of the following year) before and after reservoir operation was analyzed and reduction analysis was performed.

4. Results and Discussion

4.1. Analysis on runoff composition of Datong Station

4.1.1 Analysis on multi-year annual runoff composition
To analyze runoff composition of Datong station, runoff sources were divided into Yichang and above, Dongting Lake, Yichang to Hankou interval, Poyang Lake and Hankou to Datong interval. Multi-year annual runoff of each region was analyzed (from 1986 to 2015).

The multi-year average annual runoff composition of Datong Station in the Yangtze River main stream is shown in Table 1. It can be seen that the catchment area above Yichang accounts for 59% and the multi-year average annual runoff accounts for 46.9%. The catchment area of Dongting Lake located in heavy rain area in north Xiangxi and Poyang Lake located in heavy rain area in Jiangxi is 15.4% and 9.5% respectively, and the runoff accounts for 28.9% and 17.4% respectively, which is larger than the catchment area ratio. The water inflow in Yichang to Hankou interval and Hankou to Datong interval accounts for 2.6% and 4.2% respectively. It can be seen that in the annual runoff composition of Datong Station, the proportion of water inflow from Yichang and above is nearly half, which is the main component of runoff of Datong Station.
Table 1  The runoff composition of areas above Datong Station in the Yangtze River

| River, interval, station | Catchment area | Annual runoff |  |
|-------------------------|----------------|---------------|---|
|                         | Area (km²)    | percentage    | runoff (m billion³) | percentage |
| Yangtze River           | 1005501       | 59.0          | 4172                 | 46.9       |
| Qili Mountain           | 262823        | 15.4          | 2565                 | 28.9       |
| Yichang to Hankou       | 219712        | 12.9          | 230                  | 2.6        |
| Hukou                   | 162225        | 9.5           | 1548                 | 17.4       |
|Datong                   | 51522         | 3.2           | 371                  | 4.2        |
| Yangtze River           | 1705383       | 100           | 8886                 | 100        |

4.1.2 Analysis on multi-year monthly runoff composition in dry season

In order to clarify the changes in runoff composition of Datong Station in dry season, partition analysis on the multi-year monthly average runoff composition from November to April of the following year was performed according to the annual runoff, which is shown in Table 2.

The Table 2 show that the monthly runoff has gradually decreased since November entering the dry season, the monthly runoff is the smallest in February, which is $3.246 \times 10^{11}$ m³. Since then, the runoff has gradually increased with the increase of water inflow from the two lakes. The water inflow from Yichang and above accounts for 28.1~40%, water inflow from Dongting Lake accounts for 20.8%~33.4%, water inflow from Poyang Lake accounts for 14.2~29%, water inflow from Yichang to Hankou interval accounts for 5.5~13.9%, water inflow from Hankou to Datong interval accounts for 2.1~8.7%. The water inflow from Dongting Lake and Poyang Lake changes greatly, and the runoff in March and April increases significantly, which is related to the water inflow increase in the south of the two lakes in March and April since entering the spring flood season. Except that the water inflow from the two lakes increases and the runoff proportion becomes larger, among the runoff composition in November, December, January and February, the water inflow from Yichang and above accounts for above 1/3, the water inflow from Dongting Lake and Poyang Lake accounts for 21~28% and 14~21% respectively. The total runoff of the two lakes accounts for nearly half.

The results show that the runoff is the the smallest in February, followed by January and December. Among the runoff composition of Datong Station in dry season, the water inflow from Yichang and above is stable. Except that the water inflow accounts for 30% and below in March and April, the water inflow in the other drier months accounts for above 1/3. It is the important component of runoff of Datong Station. The water inflow from Dongting Lake and Poyang Lake increases significantly in March and April entering the spring flood season, the runoff in the other drier months is relatively stable. The runoff of Dongting Lake and Poyang Lake is $8.16~12.37 \times 10^{10}$m³ and $5.96~7.73 \times 10^{10}$m³ respectively. The total runoff of the two lakes accounts for nearly half among the water inflow of Datong Station, which indicates that the water inflow from the two lakes has important influence on the degree of abundance and drought of Datong Station in dry season. The water inflow from Yichang to Hankou interval accounts for 5.5~13.9% and the monthly runoff is $3.42~5.84 \times 10^{10}$m³. The water inflow from Hankou to Datong interval accounts for 2.1~8.7% and the monthly runoff is $1.33~4.09 \times 10^{10}$m³. The water inflow from the two sections is relatively small, accounting for a small proportion of the water inflow of Datong Station. If the water inflow of other major runoff sources decreases, the superimposed effect of the water inflow of the interval will affect the runoff of Datong Station to a certain extent.
Table 2 Multi-year monthly runoff composition of Datong Station in dry season

| River, interval, station | January | February | March | April | November | December |
|--------------------------|---------|----------|-------|-------|----------|----------|
|                          | runoff  | percent  | runoff | percent | runoff   | percent  |
|                          | (10^4 m^3) | (%)     | (10^4 m^3) | (%)     | (10^4 m^3) | (%)     |
| Yangtze River           | 130.8  | 38.8    | 111.8 | 34.4    | 137.7 | 28.1 |
| Yichang                 | 81.6   | 24.2    | 91.7  | 28.2    | 155.9 | 31.8 |
| Dongting Lake           | 47.0   | 13.9    | 38.1  | 11.7    | 45.6  | 9.3  |
| Qidi Mountain           | 59.6   | 17.6    | 67.4  | 20.8    | 132.9 | 27.1 |
| Yichang to Hankou       | 18.5   | 5.5     | 15.7  | 4.8     | 17.9  | 3.6  |
| Poyang Lake             | 337.5  | 100     | 324.6 | 100     | 489.9 | 100  |
| Hankou to Datong        | 337.5  | 100     | 324.6 | 100     | 489.9 | 100  |

4.2. The influence of water replenishing by reservoirs on the runoff of Datong Station in dry season (from November to April of the following year)

4.2.1 Runoff changes of Datong Station before and after Reservoir Operation

Based on operating year of the Three Gorges as the node, the monthly average runoff of Datong Station before and after the Three Gorges operation was calculated (from November to April of the following year). The water inflow of Datong Station increases from December to April of the following year after the Three Gorges operation. The average runoff of Datong Station in 2003~2018 was 17800 m^3/s, increasing 1100 m^3/s compared with years from 1950 to 2002, and the increase range is 6.59%. The monthly average runoff increases 2500~3400 m^3/s from January to March and the increase range is 21.3%~24.5%. The increase range is the smallest in December. The monthly average runoff increase is 1100 m^3/s and the increase range is 7.69%. The water inflow decreases slightly by 14.6% and 1.24% respectively in November and April compared with years from 1950 to 2002.

Table 3 Monthly Average runoff and its variation of Datong Station in dry season

| Category | runoff and its variation (runoff: m^3/s, percentage: %) |
|----------|----------------------------------------------------------|
|          | November | December | January | February | March    | April    | November~April |
| 1950~2018 | 22500    | 14500    | 11600   | 12300    | 16700   | 24000    | 16900            |
| ①1950~2002 | 23300    | 14300    | 11000   | 11700    | 16000   | 24100    | 16700            |
| ②2003~2018 | 19900    | 15400    | 13700   | 14200    | 19400   | 23800    | 17800            |
| ①-②      | -3400    | 1100     | 2700    | 2500     | 3400    | -300     | 1100             |

4.2.2 Runoff reduction analysis

According to the river system where the reservoir group is located, the influence of the reservoir operation on the multi-year monthly average runoff of Datong Station from November to April of the following year was calculated, and the results are shown in Table 4.

Table 4 shows that the influence of the main controlling reservoirs on the water inflow of Datong Station in dry season from November to April of the following year is mainly reflected in the water replenishing, increasing the water inflow of Datong Station in dry season to a certain extent. The water replenishing influence of reservoir group is little in November, only increasing 81.5 m^3/s. The water replenishing influence of reservoir group has become significant since December and the water
replenishing amount is the largest in February. The runoff of Datong Station increases 1140m$^3$/s, 2470m$^3$/s, 2490m$^3$/s, 2310m$^3$/s and 1940m$^3$/s respectively from December to April of the following year.

For the months in which salt tide occurred easily in the past years, such as the period from December to February of the following year, the reservoir group has obviously replenished the downstream river runoff since its operation, which has a positive effect on resisting the saline water intrusion in the Yangtze River estuary. The Three Gorges has significantly increased the runoff of Datong Station by 254m$^3$/s, 658m$^3$/s, 1090m$^3$/s respectively from December to February of the following year since its operation, accounting for 22.3%, 26.6% and 43.8% of the total amount of reservoir group. Secondly, the operation of reservoir group in Hanjiang also plays a better role in water replenishing, increasing the runoff of Datong Station by 327m$^3$/s, 451m$^3$/s, 501m$^3$/s from December to February of the following year, respectively, accounting for 28.7%, 18.3% and 20.1% of the total amount of reservoir group.

Table 4 Influence of Reservoir Group Operation on water inflow of Datong Station in dry season (November ~ April of the following year)

| Reservoir Group                  | Runoff (m$^3$/s) |
|----------------------------------|------------------|
|                                  | November | December | January | February | March  | April  |
| Middle reaches of Jinsha River   | 59.9     | 5.74     | 18.8    | 9.18     | 14.7   | -38.7  |
| Yalong River                     | 16.8     | 26.9     | 392     | 355      | 416    | 202    |
| Lower reaches of Jinsha River    | 16.6     | 72.6     | 34.8    | -11.8    | 40.0   | 217    |
| Minjiang River                   | 19.9     | 119      | 137     | 181      | 158    | 164    |
| Jialing River                    | 2.58     | 98.5     | 79.3    | 62.6     | 75.4   | 39.0   |
| Wujiang River                    | -28.3    | 18.1     | 33.6    | 37.2     | 19.8   | 65.9   |
| Three Gorges                     | -41.2    | 254      | 658     | 1090     | 713    | 1130   |
| Total of Upper reaches           | 46.4     | 595      | 1350    | 1720     | 1440   | 1780   |
| Qingjiang                        | -6.22    | 68.7     | 140     | 44.9     | 21.5   | 2.93   |
| Dongting Lake                    | -88.5    | 68.2     | 350     | 203      | 274    | 20.2   |
| Land water                       | 3.28     | 15.2     | 9.46    | -0.21    | -1.39  | -10.4  |
| Hanjiang River                   | 102      | 327      | 451     | 501      | 397    | 183    |
| Poyang Lake                      | 24.7     | 67.6     | 169     | 21.3     | 180    | -38.1  |
| Total of Middle reaches          | 35.1     | 546      | 1120    | 770      | 872    | 158    |
| Total of Reservoir group         | 81.5     | 1140     | 2470    | 2490     | 2310   | 1940   |

Note: the statistical year is 2003-2018;"+" is reservoir water replenishing ,"-" is reservoir storage

5. Conclusions

(1) Water inflow from Yichang and above is the main component of the runoff of Datong Station. The operation of upstream reservoir group adjusts the water inflow distribution of Datong station to a certain extent. The water replenishing of reservoir group increases the runoff of Datong station obviously from November to March of the following year (in dry season), which has a positive effect on resisting the saline water intrusion in the Yangtze River estuary.

(2) The Three Gorges obviously replenishes water to Datong Station in dry season, and has increased the runoff of Datong Station by 254m$^3$/s, 658m$^3$/s and 1090m$^3$/s from December to February of the following year, accounting for 22.3%, 26.6% and 43.8% of the total amount, respectively.

(3) This study only uses in-situ observations for statistical analysis, and the difference in flood propagation time has not been considered. The next research is to consider the use of hydrodynamic models to verify the results of this study.

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