Impact of Water Diversion of the South-to-North Water Diversion Middle Route Project on the Hydrological Characteristics at the Junction of Yangtze River and Poyang Lake

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Abstract. To research change rule of relationship between Poyang Lake and Yangtze River under the influence of water diversion of Middle Route Project (“MRP”) Phase I of the South-to-North Water Diversion Project (“SNWDP”), this paper use an entry point that hydrological characteristic changes of the inflow water of main stream of Yangtze River, takes the minimum abandoned water as the objective function and establishes an optimal dispatching model base on the structure “water diversion - adjustment capacity”. The influence of water diversion of SNWDP on the hydrological characteristics at the junction of the Yangtze River and Poyang Lake are comparatively analyzed. The results show that the annual water diversion quantity of South-to-North Water Diversion Project has very little impact on the annual runoff, runoff in dry season and minimum monthly runoff of the downstream Jiujiang hydrological station after the regulating of Danjiangkou, which are without obvious influence on the downstream river-lake relation.

Introduction

The term of river-lake relationship has gradually become a term of water conservancy industry in the 20th century. It is first used to describe the relationship between the Yangtze River and Dongting Lake. However, the concept has expanded as the interactive and mutual restrictive relationship between large lakes like Poyang Lake and Tai Lake and basins has become a research hotspot. In 2014, Wan R et al. (2014) defined the “river-lake relationship” as the interaction between the interconnected river and lake basins, including the water exchange between river and lake basins, natural evolution of the underlying surface of river and lake, and the exchange of mass and energy produced.

Complex river-lake relationship between lakes and large rivers affects the safe utilization of water resources like regional flood disaster prevention and control, water resources utilization, water environmental protection and aquatic ecology safety maintenance. Therefore its change law is one of the core studies on the river-lake water issues in river basins (Wan R et al. 2014). In China, many studies focused on the relationships between Yangtze River and the two lakes (Dongting Lake and Poyang Lake) from the aspects of water and sediment exchange, flood control (Hankman D et al. 2003), ecology (Dmnova I et al. 2011; Liu C et al. 2011) and hydrological regime change (Hu X et al. 2011; Guo H et al. 2012).

Du et al. (2011) used the remote sensing method to analyze the area changes of Dongting Lake and their causes in the past century. The results showed that the area of Dongting Lake in 2000 was reduced by 58.06% compared with that in 1930s, while the fastest lake shrinking rate appeared in the period of 1950s~1970s as a result of large-scale land reclamation and other human activities. Zhang et al. (2012) pointed out that since the 20th century the water level of Poyang Lake had been determined by the water level of Yangtze River and its upstream inflow water. As a result, the flood control safety of Poyang Lake would be affected in case of high Yangtze River water level due to the flood season delay. The overseas studies concerning the river-lake relationship mostly focus on the aspects of ecological environment, regional flood control as well as water and sediment exchange (Bonnet M et al. 2008; Lesack L et al. 1995). While, with more and more river-basin
hydraulic complexes built and put into operation, the impact of human activities on downstream hydrological regime and the impact of upstream hydraulic complex on the river-lake relationship change rule is increasingly serious. Through analyzing the impoundment and operation process of Three Gorges Reservoir during 2003–2008 with a dam-river-lake model, Guo et al. (2012) systematically studied the impact of the regulation and storage of Three Gorges hydraulic complex on the river-lake relationship with Poyang Lake.

However, the aforementioned studies mostly focused on the impact of reservoir on the river-lake relationship, and few studies were involved in analyzing the impact of inter-basin water diversion project on the downstream river-lake relationship. Therefore, it is urgent to study the impact factors of the inter-basin water diversion on the downstream river-lake relationship. In this paper, the MRP in the Han River basin, a comprehensive development and utilization inter-basin project, was taken as an example to establish the optimal dispatching model for Danjiangkou Reservoir. Different dispatching cases were set up. The natural inflow runoff series of Danjiangkou Reservoir in 1956–2010 was used to simulate optimal dispatching of Danjiangkou Reservoir and study the impact of water diversion of MRP on the hydrological situations at the downstream Poyang Lake area.

This paper is structured as follows: Section 2 describes the object and methods of study, namely the material and methods; Section 3 is the case analysis; and Section 4 is conclusions.

Material and Methods

Study Area

This paper took “MRP of SNWDP in Han River basin - Danjiangkou Hydraulic Complex Project - Poyang Lake” as the objects of study, the runoff change rule at the Junction as the entry point of analysis, and Jiujiang hydrological station on the main stream at the upstream of the Junction as the control cross-section. This paper studied the discharge process of Jiujiang hydrological station at the upstream of the Junction under the condition of water diversion of upstream MRP, and also compared and analyzed the impact of water diversion of MRP Phase I on the hydrological characteristics of the Junction. The geographical locations and topological structures of the MRP, Danjiangkou hydraulic complex project, Poyang Lake and Jiujiang hydrological station are as shown in Figure 1. The characteristic parameters of Danjiangkou are shown in Table 1.

![Figure 1. The geographical locations and topological structures of the MRP.](image-url)
Table 1. Characteristic Parameters of Danjiangkou Hydraulic Complex.

<table>
<thead>
<tr>
<th>Engineering Characteristics</th>
<th>Unit</th>
<th>Characteristic Value</th>
<th>Engineering Characteristics</th>
<th>Unit</th>
<th>Characteristic Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catchment area</td>
<td>km²</td>
<td>95217</td>
<td>Dead water level</td>
<td>m</td>
<td>150.0(145.0)</td>
</tr>
<tr>
<td>Average annual discharge</td>
<td>m³/s</td>
<td>1230</td>
<td>Flood control limited water level</td>
<td>m</td>
<td>160.0(163.5)</td>
</tr>
<tr>
<td>Average annual runoff</td>
<td>0.1 billion m³</td>
<td>381</td>
<td>Design flood level</td>
<td>m</td>
<td>172.2</td>
</tr>
<tr>
<td>Design flood peak discharge</td>
<td>m³/s</td>
<td>79000</td>
<td>Check flood level</td>
<td>m</td>
<td>174.35</td>
</tr>
<tr>
<td>Check flood peak discharge</td>
<td>m³/s</td>
<td>118000</td>
<td>Normal water level</td>
<td>m</td>
<td>170.0</td>
</tr>
<tr>
<td>Total reservoir capacity</td>
<td>0.1 billion m³</td>
<td>339.1</td>
<td>Dam-crest elevation</td>
<td>m</td>
<td>176.6</td>
</tr>
<tr>
<td>Reservoir regulation capacity</td>
<td>0.1 billion m³</td>
<td>111.1~140.9</td>
<td>Maximum dam height</td>
<td>m</td>
<td>70.6</td>
</tr>
<tr>
<td>Dead reservoir capacity</td>
<td>0.1 billion m³</td>
<td>100~126.9</td>
<td>Power station firm output</td>
<td>10k kw</td>
<td>25.8(23.1)</td>
</tr>
<tr>
<td>Regulation storage coefficient</td>
<td>%</td>
<td>40~46</td>
<td>Installed capacity</td>
<td>10k kw</td>
<td>90</td>
</tr>
</tbody>
</table>

Optimal Dispatching Model (Water Diversion - Adjustment Capacity)

In this study, the minimum surplus water of Danjiangkou Reservoir was taken as the main optimal object. The actual expression is as follows:

$$\min W_d = \min \left( \sum_{t=1}^{T} Q_{\text{d},t} \cdot \Delta t \right)$$

where $Q_{\text{d},t}$ represents the surplus water discharge of Danjiangkou at Period $t$.

The constraints of the above model are as follows:

(1) Upper and lower limit constraints of reservoir capacity (water level):

$$Z_{t,\text{min}} \leq Z_t \leq Z_{t,\text{max}} \quad t=2,3,\ldots,T$$

where, $Z_{t,\text{min}}$, $Z_{t,\text{max}}$ and $Z_t$ represents the allowable minimum water level, maximum water level and water level confronted in Period $t$ respectively.

(2) Reservoir water quantity balance constraints:

$$V_t = V_{t-1} + (I_t - Q_t - S_t^{\text{eq}} - S_t^{\text{ex}}) \Delta t \quad t=2,3,\ldots,T$$

where, $V_t$, $I_t$ and $Q_t$ are the reservoir capacity, reservoir inflow discharge and discharge respectively; $S_t^{\text{eq}}$ and $S_t^{\text{ex}}$ are the headwork diversion discharge of Qingquangou and Taocha respectively.

(3) Reservoir discharge constraint:

$$Q_{\text{min}} \leq Q_{\text{out},t} \leq Q_{\text{max}} \quad \text{and} \quad |Q_{\text{out},t} - Q_{\text{out},t-1}| \leq \Delta Q$$

where, $Q_{\text{out},t}$ is discharge at Period $t$, $Q_{\text{min}}$ and $Q_{\text{max}}$ are the minimum and maximum discharge; and $\Delta Q$ is the maximum variation amplitude of discharge.

《Water Dispatching Scheme for Middle Route Project Phase I of South-to-North Water Diversion Project》 are reviewed and approved by the State Council in 2014, which conducted partition dispatching according to water levels of Danjiangkou Reservoir.
**Case Study**

**Natural Runoff Series**

In this paper, the long-series natural runoff data of 55 years (1956~2010) of Danjiangkou Reservoir inflow runoff and Jiujiang hydrological station was selected to simulate the operation of Danjiangkou Reservoir. The annual average runoff process of Danjiangkou Reservoir and Jiujiang hydrological station are as shown in Figure 2 and Figure 3 respectively.

![Figure 2. Annual Average Natural Reservoir Inflow Runoff of Danjiangkou Reservoir.](attachment:fig2.png)

![Figure 3. Annual Average Natural Reservoir Inflow Runoff of Jiujiang Hydrological Station.](attachment:fig3.png)

**Comparison and Analysis of Simulation Results**

This study analyzed the historical runoff data of monthly long-series natural inflow runoff series in 1956~2010, applied the DP algorithm for solution and the reservoir dispatching model described in Section 2, and set two kinds of dispatching cases for Danjiangkou Reservoir. Case 1 didn’t consider the water diversion of MRP Phase I after the heightening of Danjiangkou dam, while Case 2 considered the water diversion of SNWDP. The optimal dispatching schemes for corresponding cases were developed, and the comparative analysis on the runoff process of Jiujiang hydrological station in the dispatching scheme and the natural runoff process was made to quantify the impact of MRP on the runoff process at the Junction after Danjiangkou Reservoir regulation and storage. The annual runoff processes of Jiujiang hydrological station in different cases are as shown in Figure 4.

![Figure 4. Annual Discharge Process Diagram of Jiujiang Hydrological Station.](attachment:fig4.png)

It can be seen from above figure that after the water diversion of MRP, the runoff in the annual runoff process of Jiujiang hydrological station changes very little, and the maximum annual runoff variation amplitude does not exceed 2%. Therefore, the water diversion of MRP has very small
impact on the annual runoff of Jiujiang hydrological station, and there is no obvious fluctuation occurring between each year.

In order to analyze the impact of water diversion of SNWDP on the annual runoff process of the downstream Jiujiang hydrological station in detail, the annual monthly runoff processes of Jiujiang hydrological station under different inflow frequency conditions of the rainy, normal and dry seasons (5%, 50% and 95%) were selected to conduct comparative analysis in this paper.

![Figure 5. Monthly Discharge Process Diagram of Jiujiang Hydrological Station in a Rainy, Normal and Dry Year Respectively.](image)

From Table 2 and Figure 5, after the water diversion of MRP, the runoff of the downstream Jiujiang hydrological station in the dry season is 2.2%, 1.4% and 1.6% respectively. Therefore, through the regulation and storage by Danjiangkou hydraulic complex, the water diversion quantity of MRP has a slight impact on the runoff of the downstream Jiujiang hydrological station in the dry season.

<table>
<thead>
<tr>
<th>Case</th>
<th>Frequency</th>
<th>Item</th>
<th>Year</th>
<th>Dry Season</th>
<th>Flood season</th>
<th>Minimum Value</th>
<th>Maximum Value</th>
<th>Ratio of Dry Season in 1 Year (%)</th>
<th>MWD(×10⁸m³)</th>
<th>TC</th>
<th>QQG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural</td>
<td>Average annual</td>
<td>Discharge</td>
<td>23105</td>
<td>12161</td>
<td>33872</td>
<td>8112</td>
<td>44327</td>
<td>26</td>
<td>0</td>
<td>5.0</td>
<td></td>
</tr>
<tr>
<td>Natural</td>
<td>5%</td>
<td>Discharge</td>
<td>28530</td>
<td>15923</td>
<td>41000</td>
<td>9201</td>
<td>48106</td>
<td>28</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Natural</td>
<td>50%</td>
<td>Discharge</td>
<td>23038</td>
<td>12941</td>
<td>32971</td>
<td>7175</td>
<td>42988</td>
<td>28</td>
<td>0</td>
<td>1.3</td>
<td></td>
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<tr>
<td>Natural</td>
<td>95%</td>
<td>Discharge</td>
<td>18535</td>
<td>9407</td>
<td>27514</td>
<td>6479</td>
<td>37870</td>
<td>25</td>
<td>0</td>
<td>3.9</td>
<td></td>
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<tr>
<td>Case1</td>
<td>Average annual</td>
<td>Discharge</td>
<td>23105</td>
<td>12564</td>
<td>33457</td>
<td>8757</td>
<td>43734</td>
<td>27</td>
<td>0</td>
<td>5.0</td>
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<tr>
<td>Case1</td>
<td>5%</td>
<td>Discharge</td>
<td>28640</td>
<td>16531</td>
<td>40618</td>
<td>10298</td>
<td>46773</td>
<td>29</td>
<td>0</td>
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<tr>
<td>Case1</td>
<td>50%</td>
<td>Discharge</td>
<td>23057</td>
<td>13123</td>
<td>32829</td>
<td>7414</td>
<td>40946</td>
<td>28</td>
<td>0</td>
<td>1.3</td>
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<tr>
<td>Case1</td>
<td>95%</td>
<td>Discharge</td>
<td>18427</td>
<td>9630</td>
<td>27081</td>
<td>6707</td>
<td>38554</td>
<td>26</td>
<td>0</td>
<td>3.9</td>
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<tr>
<td>Case2</td>
<td>Average annual</td>
<td>Discharge</td>
<td>22816</td>
<td>12289</td>
<td>33171</td>
<td>8443</td>
<td>43222</td>
<td>27</td>
<td>92.8</td>
<td>5.0</td>
<td></td>
</tr>
<tr>
<td>Case2</td>
<td>5%</td>
<td>Discharge</td>
<td>28376</td>
<td>16270</td>
<td>40350</td>
<td>10020</td>
<td>46674</td>
<td>29</td>
<td>106.8</td>
<td>0</td>
<td></td>
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<tr>
<td>Case2</td>
<td>50%</td>
<td>Discharge</td>
<td>22805</td>
<td>13123</td>
<td>32330</td>
<td>7416</td>
<td>39908</td>
<td>29</td>
<td>80.1</td>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td>Case2</td>
<td>95%</td>
<td>Discharge</td>
<td>18168</td>
<td>9560</td>
<td>26636</td>
<td>6707</td>
<td>37681</td>
<td>26</td>
<td>74.3</td>
<td>3.9</td>
<td></td>
</tr>
</tbody>
</table>
According to the analysis from the angle of minimum monthly runoff, after the water diversion of MRP, the minimum monthly runoff of the downstream Jiujiang hydrological station increases by 8.9%, 3.7% and 4.1% respectively. Therefore, after the water diversion of MRP, under the regulation and storage by Danjiangkou hydraulic complex, the minimum monthly runoff of the downstream Jiujiang hydrological station increases slightly.

In conclusion, although according to comparative analysis with large time scales (annual and inter-annual rainy and dry seasons), after the annual water diversion of SNWDP and through the regulation and storage by Danjiangkou hydraulic complex, the annual runoff and runoff in dry season of the downstream Jiujiang hydrological station is slightly affected and the minimum monthly runoff increases slightly. However, there are still some months in the dry season where the runoff of Jiujiang hydrological station decreases.

Conclusions

For this purpose of analyzing the changes of water exchange rules between Poyang Lake and main stream of Yangtze River under the condition of water diversion of MRP Phase I, an optimal dispatching model was established for Danjiangkou Reservoir. The minimum surplus water was taken as the objective function. The natural inflow runoff series of Danjiangkou Reservoir in 1956~2010 was used to simulate the optimal dispatching of Danjiangkou Reservoir, and ascertain the discharge process of Jiujiang hydrological station at the upstream of the Junction under the condition of water diversion of MRP. Through comparative analysis with large time scales (annual and inter-annual rainy and dry seasons), the results showed that the annual water diversion quantity of SNWDP had very little impact on the annual runoff, runoff in dry season and minimum monthly runoff of the Jiujiang hydrological station after the regulation and impoundment of Danjiangkou hydraulic complex, and would not exert obvious impact on the downstream river-lake relationship.

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