Analysis on Reasonable Operation Mode of Newly Built Sediment Laden Reservoir

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Abstract. The operation mode of the reservoir should be selected according to the task, Reservoir type, Reservoir capacity, reservoir runoff and sediment of the reservoir. For the river with much sediment, the different Operation mode of reservoir will affect the Sediment deposition pattern and sedimentation rate of the reservoir, and have a great impact on the difference of the reservoir. The selection of operation mode of newly-built reservoir with sediment is directly related to the operation period and operation benefit of the reservoir. How to select the operation mode of the reservoir to maximize the benefit of the reservoir has been discussed and studied by water conservancy workers in recent years. Taking Gahaishan reservoir in Kulun banner of Inner Mongolia as an example, the paper uses one-dimensional reservoir sediment mathematical model, combined with suspended load unbalanced sediment transport equation, flow sediment carrying capacity formula and resistance formula suitable for sediment laden rivers, and uses existing sedimentation data of reservoirs in similar basins for verification. This paper briefly describes how to calculate the sediment deposition for the newly-built sediment laden reservoir and how to reasonably select the appropriate operation mode.

1. Overview
Liuhe river is a sediment laden river in North China, known as the "Small Yellow River". Due to the special geographical location and the cross erosion of wind and water, the Liuhe River Basin in Kulun banner is extremely serious, which is the key area of soil and water loss in China. Serious soil and water loss has caused the land of Kulun to be fragmented, ravines crisscrossed, yellow sand hazy and frequent flood and drought disasters. The slope of the lower reaches of Liuhe river is small and the siltation is serious, which causes serious siltation to Xinmin estuary and Liaohe River Estuary, and causes serious damage to the upper and lower reaches of the region. The effective measures to reduce soil erosion and sediment deposition are to carry out soil and water conservation projects and build sand retaining dams or reservoirs. However, it is a key problem that how to regulate the sediment laden reservoir and make it play its role of sediment retention and benefit for a long time. Taking the proposed Gahaishan reservoir on the Yangxumu River as an example, this paper analyzes how to select a reasonable operation mode for the reservoir.
The newly built Gahaishan reservoir with a control area of 350 km² is located 30 km upstream of Sanjiazi station, a national hydrological station on the Yangxumu river. The main tasks of the reservoir include flood control, water supply, sediment retention and irrigation, as well as fish culture[1].

The sediment of the river where the reservoir is located mainly comes from flood, so the interannual and annual variance of the sediment discharge is greatly. The sediment volume generally increases with the increase of water volume. The sediment mainly concentrates in the flood season from June to September, in which July to August account for a large proportion, and there is a great difference between the interannual sediment discharge.

According to the results, the interannual and annual variation of sediment in the reach where Sanjiazi station is located is very significant. The annual average sediment discharge is 1.52 million t/a, and the maximum annual sediment discharge is 153 times of the minimum one. The sediment discharge from June to September accounts for more than 80% of the annual sediment discharge, and July August accounts for more than 65% of the annual sediment discharge. The annual variation of sediment concentration is large. The measured maximum sediment concentration is 1475 kg / m³ higher than the minimum section, and the sediment erosion modulus is 3725 T / km².

2. Establishment of Sediment Mathematical Model

The mathematical model of non-uniform flow unsaturated full sediment reservoir which is mature calculation method and complete functions is proposed for the calculation of sediment deposition and sediment discharge of the reservoir. The model has been widely used in the calculation of reservoir sediment deposition in the Yellow River Basin. It has been verified by practice that the calculation results of the model are highly reliable. The calculation results have high practical value.

2.1 Basic Equations and Numerical Solutions

The flow equation and sediment movement equation used in the model calculation are as follows: Flow continuity equation:

\[
\frac{\partial A_i}{\partial t} + \frac{\partial Q_i}{\partial x} - q_{Li} = 0
\]

Equation of flow motion:

\[
\frac{\partial Q_i}{\partial t} + \frac{\partial}{\partial x} \left( \alpha_i \frac{Q_i^2}{A_i} \right) + \alpha_i \frac{Q_i}{A_i} q_{Li} + g A_i \left( \frac{\partial Z_i}{\partial x} + \frac{Q_i^2}{K_i} \right) = 0
\]

Silt transport equation:

\[
\frac{\partial}{\partial t} (A_i S_{ij}) + \frac{\partial (A_i V_{ij} S_{ij})}{\partial x} + \sum_{j=1}^{m} (K_{ij} \alpha_{ij} f_{ij} b_j S_j \omega_{ij}) - \sum_{j=1}^{m} (K_{ij} \alpha_{ij} b_j S_{ij} \omega_{ij}) - S_{ij} q_{Li} = 0
\]

Deformation equation of riverbed erosion and deposition:

\[
\frac{\partial Z_{hij}}{\partial t} - \frac{K_{ij} \alpha_{ij}}{\gamma_0} \omega_{ij} (f_{ij} S_j - S_{ij}) = 0
\]

2.2 Some Key Parameters

2.2.1 Sediment carrying capacity. Gahaishan reservoir is a river blocking reservoir on the Yangxumu river. The peak value of sediment concentration in the river is high and the overall amplitude changes greatly in the period. Therefore, the general formula suitable for different sediment concentration should be selected for the calculation of sediment carrying capacity. Professor Zhang Hongwu's bed
load transport rate formula is chosen to calculate the flow sediment carrying capacity of this model[2]. The formula is as follows:

\[
S_* = 2.5 \left[ \frac{(0.0022 + S_V)V^3}{\kappa \frac{\gamma_s - \gamma_m}{\gamma_m} gH\omega} \ln(H/6D_{50}) \right]^{0.62}
\]

(5)

In the formula, \(S_V\) — the volume specific sediment concentration; \(D_{50}\) — middle diameter of river bed silt; \(\kappa\) —Carmen constant of muddy water; \(\omega\) —Settling velocity of sediment in muddy water; \(\gamma_m\) —Bulk density of muddy water.

\[\text{Figure 1. Verification of the Formula of Sediment Carrying Capacity}\]

\[\text{Figure 2. Relationship between } \theta, \theta' \text{ in a alluvial river}\]

2.2.2 Current movable bed resistance. The calculation of Current movable bed resistance will directly affect the results of the location, distribution and amount of sediment deposition in the reservoir, so a reasonable calculation method with wide application range and high accuracy must be chosen.

The resistance research results proposed by Wang Shiqiang are used in this calculation. \(\theta, \theta'\) — Parameters reflecting flow intensity, It is expressed as follows:

\[
\theta = \gamma J (\gamma_s - \gamma)D_{50}
\]

(6)

\[
\theta' = \gamma' J (\gamma_s - \gamma)D_{50}
\]

(7)

In the formula, \(h\) —Water depth , \(h'\) —Water depth related to sand resistance; \(J\) —Nengpo; \(D_{50}\) —Middle diameter of river bed silt; \(\gamma\) —Bulk density of silt, \(\gamma'\) —Bulk density of water. When taking the same \(\theta'\), In the low energy state, \(f\) has little change with the decrease of \(D_s\).

2.2.3 Dry bulk density of sediment. The selection of suitable dry bulk density in the calculation of reservoir sedimentation is very important to the calculation results. The dry weight of this calculation is selected as 1350kg/m³.
3. Calibration and Validation of the Model
By collecting and sorting out the hydrological data of several typical flood processes and sediment concentration measured at Sanjiazhi hydrological station on Yangxumu River, the verification of the model is realized[3].

3.1 Calibration of Initial Storage Capacity of the Model
In order to verify the reliability of the boundary conditions of the model, 208 sections with a spacing of 100m are used to analyze and calculate the reservoir capacity. The reservoir capacity obtained by the calculation is compared with that obtained by the measured topographic map method, The two results are similar, which indicate that the boundary conditions selected in this numerical simulation are reasonable.

3.2 Verification of Flow Resistance and Sediment Carrying Capacity
Considering that the geological characteristics of Derisubaoieng water reservoir is similar to Gahaishan reservoir, the model movable bed resistance under the action of flood is verified and calculated by using the measured rating current of several typical large floods at Daban hydrometric station at the end of the reservoir[4]. After verification, the calculated results have a good relationship with the measured data, which shows that the simulation calculation of the resistance of the current movable bed is in accordance with the actual situation consistent weight etidy. The calibrated parameters can be directly used in model calculation.

4. Determination of Operation Mode

4.1 Types of Primary Operation Mode
Five different operation schemes are proposed to analyze the sediment discharge mode of the reservoir, and the change of reservoir capacity caused by each sediment discharge mode and the effect after the change of reservoir capacity are analyzed. Finally,a reasonable operation mode is recommended for the reservoir [4]. Combined with the hydrological and sediment conditions, five different operation modes are proposed: scheme 1: for storing water 20 years before the completion of the reservoir; 2: storing water for 20 years after the completion of the reservoir; and starting to discharge sediment from July 20 to 31 of each flood section 2: storing water for 20 years before the completion of the reservoir, and starting to discharge sediment from August 1 to 20 of each flood season; scheme 3: storing water 30 years after the completion of the reservoir and discharging sediment from July 20 to 31 each year; Scheme 4: storing water 30 years before the completion of the reservoir and discharging sediment from August 1 to 20 in each flood season; scheme 5: storing water after the reservoir for 50 years.

4.2 Calculation Process of Operation Mode

4.2.1 Storage capacity curve under different operation modes. According to the five operation modes of the reservoir, the relationship between water level and storage capacity of the reservoir after 50 years of operation is simulated[5]. Various schemes are described as follows:

Scheme 1: In the 20 years before the completion of the reservoir, the period of open discharge and sediment discharge of the reservoir is from July 20 to 31 According to the relationship in different years, and the correlation between incoming and outgoing sediment volume and sediment discharge ratio, the accumulated sedimentation amount of reservoir in 10, 20, 30 and 50 years of operation is 617 ten thousand tons, 2044 ten thousand tons, 2353 ten thousand tons, 4160 ten thousand tons. The remaining storage capacity below the normal water level is:5474.2, 5011, 4658.5, 3886.9 ten thousand m3.

Scheme 2: In the 20 years before the completion of the reservoir, the period of open discharge and sediment discharge of the reservoir is from August 1 to 20. The relationship between water level and reservoir capacity of Gahaishan reservoir at different levels is simulated. According to the relationship in different years, and the correlation between incoming and outgoing sediment volume, and
sediment discharge ratio, the accumulated sedimentation of the reservoir in 10, 20, 30 and 50 years of operation is 6.17 million tons, 20.44 million tons and 42.35 million tons. The remaining storage capacity below the normal water level is 54742.2, 5011, 45.844 and 34.604 ten thousand m³.

Scheme 3: 30 years before the completion of the reservoir, the period of open discharge and sediment discharge of the reservoir is from July 20 to 31. The relationship between water level and storage capacity of Gahaishan reservoir in different level years is simulated. According to the relationship in different years, and the correlation between incoming and outgoing sediment volume, and sediment discharge ratio, the accumulated sedimentation amount of reservoir in 10, 20, 30 and 50 years of operation is 6.17 million tons, 20.44 million tons and 41.6 million tons. The remaining effective storage capacity below Xingli water level is 5475, 5011, 47.328 and 40.421 ten thousand m³.

Scheme 4: During the 30 years before the completion of the reservoir, the period of open discharge and sediment discharge of the reservoir is from July 1 to 20. According to the relationship in different years, and the correlation between incoming and outgoing sediment volume, and sediment discharge ratio, the accumulated sedimentation amount of reservoir in 10, 20, 30 and 50 years of operation is 6.17 million tons, 20.44 million tons and 41.6 million tons. The remaining effective storage capacity below Xingli water level is 5475, 5011, 47.328 and 35.097 ten thousand m³.

Scheme 5: 50 years before the completion of the reservoir, the relationship between water level and storage capacity of Gahaishan reservoir in different level years is simulated. According to the relationship in different years, and the correlation between incoming and outgoing sediment volume and sediment discharge ratio, the accumulated sedimentation amount of reservoir in 10 years, 20 years, 30 years and 50 years is 6.17 million tons, 20.44 million tons, 23.52 million tons and 41.61 million tons. The remaining effective storage capacity below Xingli water level is 5475, 5011, 47.328 and 42.428 ten thousand m³.

4.2.2 Comparison and selection results of different schemes. Based on the model calculation results of scheme 1 to scheme 5, the open discharge and sediment discharge schemes of Gahaishan reservoir within 10 years, 20 years, 30 years and 50 years are analyzed, and the sedimentation amount and residual storage capacity are compared. The comparison results under different operation conditions are shown in Table 1 and table 2. After 50 years, the sedimentation profile under different operation conditions of the reservoir is shown in Fig. 2 ~ Fig. 4. From the above conclusions, we can draw the following conclusions:

In this paper, the open discharge and sediment discharge of the reservoir in the same period of the year are simulated, and the sediment deposition amount and deposition form of the first 20 years and the first 30 years after the completion of the reservoir are analyzed. The results show that the amount of sediment deposition is basically the same, and the center of gravity of the latter sedimentation is inclined to the fired of the reservoir.

When the storage years are the same, it is found that the former has more sediment deposition after 50 years by comparing the two schemes of open discharge and sediment discharge in the flood season from July 20 to July 31 and from August 1 to August 20 each year. From the deposition morphology, the center of gravity of sediment deposition tends to the dam site when the sediment is discharged before August 20.

Through the comparison of scheme 1 and scheme 3, it is found that the results of reservoir sedimentation morphology and sedimentation volume of the two schemes after 50 years are basically similar; though the comparison of scheme 2 and scheme 4, it is found that the results of deposition morphology and sedimentation volume after 50 years of the two schemes are basically similar; comprehensive analysis shows that the sediment deposition amount of 50 years of scheme 5 is the largest, but the overall center of gravity of sedimentation form is inclined to the end of the reservoir, The sediment deposition is the minimum under the design flood level and normal water level.

Under the condition of open discharge and sediment discharge in the same period, the sedimentation amount of 20 years storage operation and 30 years storage operation is the same. However, from the deposition morphology, the center of gravity of sediment deposition tends to the tail of the reservoir after 30 years of storage.
Under the same storage year operation conditions, the sediment discharge of 50 years after July 20 is slightly more than that before August 20. From the deposition morphology, the center of gravity of sediment deposition tends to the dam site when the sediment is discharged before August 20.  

50 years later, the amount of sedimentation and the deposition morphology are similar in scheme 2 and scheme 4, and similar in scheme 1 and scheme 3. In scheme 5, the siltation volume is the largest in scheme 5, but the overall center of gravity of sedimentation is inclined to the end of the reservoir, and the sedimentation volume is the minimum below the design flood level and normal storage level.

**Table 1. Comparison of sediment deposition 5 of scheme 1 to scheme Unit: 10000 tons**

| Scheme | 10 year | 20 year | 30 year | 50 year |
|--------|---------|---------|---------|---------|
| Scheme 1 | 616.9 | 2043.5 | 2352.7 | 4160.3 |
| Scheme 2 | 616.9 | 2043.5 | 2352.7 | 4134.8 |
| Scheme 3 | 616.9 | 2043.5 | 2352.7 | 4160.3 |
| Scheme 4 | 616.9 | 2043.5 | 2352.7 | 4127.3 |
| Scheme 5 | 616.9 | 2043.5 | 2352.7 | 4160.2 |

**Table 2. Comparison of remaining storage capacity of different schemes Unit: 10000 tons**

| Scheme | 10 year | 20 year | 30 year | 50 year |
|--------|---------|---------|---------|---------|
| Scheme 1 | 5474.2 | 5011.0 | 4658.5 | 3886.9 |
| Scheme 2 | 5474.2 | 5011.0 | 4584.4 | 3460.4 |
| Scheme 3 | 5474.2 | 5011.0 | 4732.8 | 4042.1 |
| Scheme 4 | 5474.2 | 5011.0 | 4732.8 | 3509.7 |
| Scheme 5 | 5474.2 | 5011.0 | 4732.8 | 4242.8 |

![Figure 3. Initial storage capacity curve](image)

![Figure 4. 50 year siltation profile of scheme 1 and 2](image)

![Figure 5. 50 year siltation profile of scheme 3 and 4](image)

![Figure 6. 50 year siltation profile of scheme 5](image)

**5. Conclusion**

(1) Using the daily discharge and sand content data of Sanjiazi Hydrological Station, five reservoir operation modes were simulated for Gahaishan Reservoir. The results show that: the sedimentation results of the first 20 years of water storage operation and the first 30 years of storage operation of the reservoir are basically the same, but the center of gravity of sediment deposition is inclined to the end of the reservoir.  

(2) The sedimentation amount after 50 years of open discharge after the last ten days of July is slightly more than that before the end of August, and the sedimentation center tends to the dam site; the sedimentation amount and deposition morphology form of 50 years II and scheme 40 and 50 years later are similar, and that of scheme 1 and scheme 30 are similar. The deposition amount of scheme 5 is the largest after 50 years, but the overall center of gravity of sedimentation is inclined to the end of the reservoir, the sedimentation volume below the design flood level and normal storage level is the minimum.

(3) The operation scheme of the reservoir should be determined according to the reservoir benefit target and sediment deposition. Reservoir operation plan needs to be specifically determined according...
to the profitability goal of the reservoir and the situation of sedimentation. According to the calculation results, the total amount of sediment deposition in the five operation schemes is similar, but the deposition position is obviously different. The longer the storage operation time is, the closer the sedimentation center is to the end of the reservoir, and vice versa, it is close to the front of the dam. In addition, the timing of open discharge and sediment discharge also has a significant impact on the location of sediment deposition. The sediment discharge starting from August is beneficial to sediment discharge, but the sediment deposition is forward; the sediment discharge from July is close to the end of the reservoir and the amount of sediment deposition is large.

(4) The water-sediment series calculated by this model is the converted value after considering the effect of the upstream reservoir to intercept the sediment, but the conversion does not consider the fact that the increase of the sediment intercepting function in the later period of operation of the upstream reservoir will increase the amount of sediment into the reservoir. Therefore, in summary the specific operation scheme should comprehensively consider the factors of flood control pressure caused by sediment deposition and the benefit of the reservoir. It is suggested to store water in the early stage, detect the sedimentation situation of the reservoir, and timely carry out flushing in late July or late August to maintain long-term effective storage capacity. Therefore, the reservoir adopts the operation mode of open discharge and sediment discharge from August 1 to August 20 after 30 years of storage operation.

(5) Through the mathematical model to simulate the relationship between water and sediment movement, it can accurately predict the distribution of sediment deposition in the reservoir, which has played a positive guiding role in the reasonable selection of application mode and the maximum play of the role of water supply and sediment discharge of Gahaishan reservoir, and can also extend the service life of the reservoir to the maximum extent, making the economic benefits brought by the national capital investment maximum. At the same time, it also conserves local water resources, reduces soil erosion, and adds a beautiful ink to the construction of the most beautiful scenery in Northern China.

6. Reference Significance
Taking the operation mode selection of the proposed Gahaishan reservoir in Liuhe River Basin as an example, this paper describes how to select the operation mode of the sediment laden reservoir, so as to play the role of the reservoir to the extreme. The operation mode of Gahaishan reservoir which storing clear water draining muddy water the first 20 years and storing flood in the later 30 years is of certain guiding significance to the operation mode of water conservancy projects on the sediment river laden river in the North.

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