A numerical simulation study on the sedimentation dredging in Lushui Reservoir, part 2: influence and its back siltation

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Abstract. A well-verified two-dimensional mathematical model for vertical averaged flow was used to calculate the influence on the flow after the sedimentation dredging in Lushui Reservoir. The numerical simulation results show that the influence of dredging works on the flow in the dredging reach is limited, and the influence is mainly concentrated in the local area near the dredging area, while the influence on the velocity flow pattern and the overall river regime in the main channel of the dredging reach is relatively small.

1. Introduction
In recent years, reservoir desilting, as an effective way to solve the problem of shortening reservoir life caused by the reduction of reservoir capacity and the shortage of sand and stone resources around the reservoir, has attracted the attention of many experts and scholars [1-5]. After the sedimentation is dredged, the water level, flow velocity, flow pattern, and the evolution of the river reach will be changed, which may bring adverse effects to the flood control safety, navigation safety, water ecology and environment of the cleaned river reach. In this paper, a numerical simulation study on the sedimentation dredging in Lushui Reservoir was carried out by using a plane two-dimensional mathematical model for vertical averaged flow.

2. Data and method

2.1. Calculation boundaries
For the reservoir operation, the flood control is an important task. As a result, any activities in the reservoir that may have an impact on flood control must be taken seriously. Therefore, the movement and changes of water flow under the designed flood discharge must be analysed.

In addition to flood control, the reservoir operates at normal water level all the year round, and the flow changes under this water level also needs to be analysed. During normal operation period, multi-year average flow discharge is a very important flow condition. It reflects the long-term flow conditions of the reach.

Therefore, the designed flood discharge and multi-year averaged flow discharge were selected as two flow boundary conditions to calculate and analyse the impact of sediment desilting on the flow in Lushui Reservoir.

According to the design data of Lushui Reservoir, the designed flood level of Lushui Reservoir is once in 100 years, the corresponding inflow flow is 9390m³/s, and the water level in front of the dam is 56.5m. The multi-year-averaged inflow is 2.71 billion m³, with a corresponding inflow flow of 86m³/s, and a normal water level 55m in front of the dam. The details of boundaries were shown in table 1.
During the calculations, the terrain measured in December 2017 was adopted. The terrain was shown in figure 1.

Table 1. Boundaries of the mathematical model for calculation on the influence of sedimentation dredging

| No. | Condition                               | Flow discharge (m$^3$/s) | Down water level (m) |
|-----|-----------------------------------------|--------------------------|----------------------|
| 1   | designed flood discharge                | 9390                     | 56.5                 |
| 2   | multi-year-averaged flow discharge      | 86                       | 55                   |

2.2. Selection of the dredging area

Based on the analysis of the sediment deposition carried out in [6-8], 4 dredging area were selected as the pilots to give a trial. Considering the safety of river regime and the thickness of deposition since the building of the reservoir, the proposed dredging thickness of 1-4 dredging areas is about 6-7m respectively. Table 2 is the dredging volume of each dredging area, and the location of the dredging area was shown in figure 2.

Table 2. Boundaries of the mathematical model for calculation on the influence of sedimentation dredging

| Zone | Area ($10^4$m$^2$) | Dredging elevation (m) | Annual mining volume($10^4$m$^3$) |
|------|--------------------|------------------------|-----------------------------------|
| 1    | 11.33              | 39.0                   | 110.9                             |
| 2    | 13.44              | 38.5                   | 124.7                             |
| 3    | 14.22              | 38.0                   | 157.4                             |
| 4    | 19.31              | 37.0                   | 133.3                             |

2.3. Analysis method

During the calculations, 12 sections were arranged to carry out the comparative analysis of water level and velocity before and after dredging. The location of these sections were shown in figure 2. At the same time, according to the calculation results, the contour map of water level and velocity changes before and after dredging was also drawn.

In addition, in order to predict the sediment back siltation after dredging, the Luo Zhaosen formula [9] was used to give a prediction of the sediment siltation thickness in the dredging area. The empirical formula was as follows:

\[
Ps = \frac{\alpha \omega S_T T}{\gamma'} \left[ I \left( \frac{H_1}{H_2} \right)^m \left( 1 + \frac{\Delta q}{q_i} \right)^{3m} \right]
\]

(1)

Where, \( Ps \) is average silting strength of unit area in t period, \( \alpha \) is settling probability of sediment in moving water, \( \omega \) is settling speed of sediment in still water, \( S' \) is sediment carrying capacity of water flow in natural state, \( T \) is the calculation period, \( \gamma' \) is dry bulk density of sediment, \( H_1, H_2 \) is averaged water depth before and after dredging, \( \Delta q \) is single width discharge before and after dredging, \( m \) is index in the sediment carrying capacity formula.
3. Results

3.1. Water level changes after dredging

Figure 3 is the contour map of water level changes before and after dredging. It can be seen from the map that after dredging, the water level changes were mainly limited in the dredging area, while the water level in the upstream and downstream of the dredging area decreases to a certain extent. Under the condition of designed flood discharge, the maximum damming height of water level in the dredging area is about 3.3cm, the maximum lowering value of water level in the upstream and downstream of the dredging area is about 13.5cm, and the damming height of water level in the nearshore of the dredging side is about 2cm. The influence of water level is limited within the range of 3470m upstream to 560m downstream of the dredging area.

Under the condition of multi-year-averaged flow discharge, the rule of water level change is basically the same as that under the condition of designed flood flow, but the change value and influence range of water level are reduced. The maximum damming height of water level in the dredging area is 0.3cm, the maximum reduction value of water level in the upstream and downstream of the dredging area is about 0.7cm. The influence of water level is limited within the range of 1420m upstream to 380m downstream of the dredging area.
3.2. Flow velocity changes after dredging

Figure 4 is the contour map of velocity changes before and after dredging. Figure 5 is the map of velocity distribution change of monitor sections before and after dredging. From the above chart, it can be seen that after dredging, the flow velocity changes are mainly limited in local areas, which generally shows that the flow velocity in the dredging area and the outside of the dredging area decreases, while the flow velocity in the upstream and downstream of the dredging area increases to a certain extent. Under the condition of designed flood discharge, the maximum value of velocity decrease in desilting area and outside is about 1.4m/s, the maximum value of velocity increase in upstream and downstream of the dredging area is about 0.3m/s, the value of velocity increased in nearshore is about 0.1m/s. The range of velocity influence is limited in the range of 3490m upstream to 580m downstream of desilting area.

Under the condition of multi-year-averaged discharge, the rule of flow velocity changes is basically the same as that under the condition of designed flood flow, but the changed value and influence range of flow velocity are reduced. The maximum value of flow velocity decreased in the dredging area and the outside is about 0.02m/s, the maximum value of flow velocity increased in the upstream and downstream of the dredging area is about 0.01m/s. The flow velocity near the shore is basically unchanged, and the influence range of flow velocity is limited in the dredging area within 1450m upstream to 410m downstream of the silting area. From the change of flow direction before and after dredging, the change of flow direction is mainly manifested in the local area of desilting area, and the maximum change value of flow direction under the design flood discharge is about 10.5 °.
Figure 4. Contour map of velocity changes before and after dredging.
3.3. Flow velocity changes after dredging

Based on the two-dimensional mathematical model, the water depth and flow velocity in the desilting area were obtained. Then according to the empirical formula above, the maximum desilting thickness in the flood period in the desilting area is about 0.73m. And the thickness of upstream dredging zone is larger, and downstream dredging zone is smaller. Considering the sediment retention effect of the middle and small reservoirs in the upper reaches in the future, the amount of sediment coming from the up reach will be kept at a low level for a long time, and the back silting intensity in the future dredging area may be further reduced.

4. Conclusion

The numerical simulation results show that the influence of dredging works on the flow in the dredging reach is limited, and the influence is mainly concentrated in the local area near the dredging area, while the influence on the velocity flow pattern and the overall river regime in the main channel of the dredging reach is relatively small. The Due to the sediment retention effect and small reservoirs in the upper reaches in the future, the amount of sediment coming from the up reach will be kept at a low level for a long time, which will result in a reduced silting intensity in the future, even smaller than 0.73m/a.

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References

[1] CHEN Yin, WANG Yangui, CHEN Kang. (2018) Principle of utilizing reservoir sediment as natural resource and its engineering approaches. Journal of Hydroelectric Engineering, 37: 29-38.

[2] Xu jiaji. (2020) Analysis on the necessity and influencing factors of reservoir desilting. Agricultural Science- technology and Information, (4): 107-108.

[3] Dong S, Li JQ, Chen LQ. (2019) Summary of reservoir desilting Technology. EWRHI, 40: 49-52.

[4] LIU Zenghui, NI Fusheng, XU Liqun, etc. (2020) A Review of Reservoir Dredging Technology. YELLOW RIVE R, 42: 5-10.

[5] Guo C, JIN Z W, YAN X, etc. (2019) Preliminary study on reservoir desilting in the Yangtze River Basin. EWRHI, 40: 53-55.

[6] LIN Qiusheng, LI Ronghui, DAI Xiaolin, etc. (2011) analysis on sedimentation law in Lushui Reservoir in recent period. Yangtze River, 42(10): 7-9.

[7] Wu Fei. (1993) Analysis on the sedimentation of Lushui reservoir in 30 years. Yangtze River Water Conservancy Education, 10(4): 53-56, 78.

[8] Mao Rong sheng, WU Fei. (1994) A Study on Sedimentation in Lushui Reservoir in 30 Years. Water Resources and Hydropower Engineering, (5): 40-44.

[9] Luo Zhaosen. (1987) Computation of siltation in dredged channels in estuaries. Journal of sediment research, (2): 13-20.