

Simulation of water temperature in two reservoirs with Delft3d

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Abstract. The proposed Guanjingkou and Fengdou reservoir will be constructed at Chongqing city and Muling city in China respectively. The water temperature in the reservoir, in the downstream, and the aquatic ecosystem would be altered by the construction of the reservoirs. This paper simulates the water temperature in the two reservoirs by using the Delft3d z-layer model, which uses the fixed elevation for layers. According to the simulation results, the temperature profile in the reservoirs can be divided into three layers: the upmost epilimnion layer, the beneath thermocline layer, and the constant temperature layer at bottom. The temperature effects can be reduced by measurements of stoplogs gates and multiple gates, respectively. Based on the simulation results in the wet, normal, and dry year, the temperature of water released from the stoplogs gates at Guanjingkou reservoir can be respectively increased by 5.7°C, 6.8°C, 9.6°C, and 5.5°C in the irrigation season from May to August. The temperature of water released from the multiple gates at Fengdou reservoir can be respectively increased by 7.7°C, 1.9°C, 9.5°C, and 10.1°C from May to August. The negative impacts from the water with lower temperature on the related ecosystem can be significantly alleviated.

1. Introduction

The construction of reservoirs would form the vertical stratification of water temperature profile in front of the dam. The changes of water temperature have impacts on the growing, spawning, and propagation of fishes [1-2]. The biome in the river [3], aquatic ecosystem [4-5], and the crop yield [6] can be altered by the water with lower temperature. Hence, the downstream ecosystem can be improved by studying water temperature profile in the constructed reservoir and the corresponding measures.

The researches of reservoir water temperature have been conducted since 1970s in China. The estimation of reservoir water temperature with statistically summarized formulas started in 1980s.



These experimental formulas include Zhang's formula [7], Zhu's formula [8], and statistical formula [9]. The disadvantages of the experimental estimation for the reservoir water temperature are large estimation variations in individual reservoir, ignoring the meteorological conditions and the effect from reservoir operations.

The methods adopted in this paper use numerical method with Delft3d software package to simulate the reservoir water temperature in Guanjingkou and Fengdou reservoir, which takes the reservoir operation, heat exchange, and the meteorological conditions into consideration. The simulation results provide the water temperature profile in the reservoirs, the temperature of water released from proposed gates, and the count measures effects on the temperature of released water. The negative impacts of the water with lower temperature will be alleviated.

2. Material and method

2.1. Method

The Delft3d software package (version 4.10, Deltares, the Netherlands) was selected for simulation the water temperature in the two reservoirs. The governing equations are:

$$\begin{aligned} & \frac{\partial u}{\partial t} + \frac{u}{\sqrt{G_{\xi\xi}}} \frac{\partial u}{\partial \xi} + \frac{v}{\sqrt{G_{\eta\eta}}} \frac{\partial u}{\partial \eta} + \frac{w}{d+\zeta} \frac{\partial u}{\partial \sigma} - \frac{v^2}{\sqrt{G_{\xi\xi}}\sqrt{G_{\eta\eta}}} \frac{\partial \sqrt{G_{\eta\eta}}}{\partial \xi} + \frac{uv}{\sqrt{G_{\xi\xi}}\sqrt{G_{\eta\eta}}} \frac{\partial \sqrt{G_{\xi\xi}}}{\partial \eta} - fu \\ & = -\frac{1}{\rho_0 \sqrt{G_{\xi\xi}}} P_{\xi} + F_{\xi} + \frac{1}{(d+\zeta)^2} \frac{\partial}{\partial \sigma} \left(v_v \frac{\partial u}{\partial \sigma} \right) + M_{\xi} \end{aligned} \quad (1)$$

$$\begin{aligned} & \frac{\partial v}{\partial t} + \frac{u}{\sqrt{G_{\xi\xi}}} \frac{\partial v}{\partial \xi} + \frac{v}{\sqrt{G_{\eta\eta}}} \frac{\partial v}{\partial \eta} + \frac{w}{d+\zeta} \frac{\partial v}{\partial \sigma} + \frac{uv}{\sqrt{G_{\xi\xi}}\sqrt{G_{\eta\eta}}} \frac{\partial \sqrt{G_{\eta\eta}}}{\partial \xi} - \frac{u^2}{\sqrt{G_{\xi\xi}}\sqrt{G_{\eta\eta}}} \frac{\partial \sqrt{G_{\xi\xi}}}{\partial \eta} + fv \\ & = -\frac{1}{\rho_0 \sqrt{G_{\eta\eta}}} P_{\eta} + F_{\eta} + \frac{1}{(d+\zeta)^2} \frac{\partial}{\partial \sigma} \left(v_v \frac{\partial v}{\partial \sigma} \right) + M_{\eta} \end{aligned} \quad (2)$$

The transport equation is :

$$\begin{aligned} & \frac{\partial(d+\zeta)c}{\partial t} + \frac{1}{\sqrt{G_{\xi\xi}}\sqrt{G_{\eta\eta}}} \left\{ \frac{\partial[\sqrt{G_{\eta\eta}}(d+\zeta)uc]}{\partial \xi} + \frac{\partial[\sqrt{G_{\xi\xi}}(d+\zeta)vc]}{\partial \eta} \right\} + \frac{\partial \omega c}{\partial \sigma} = \frac{d+\zeta}{\sqrt{G_{\xi\xi}}\sqrt{G_{\eta\eta}}} \bullet \\ & \left\{ \frac{\partial}{\partial \xi} \left(D_H \frac{\sqrt{G_{\eta\eta}}}{\sqrt{G_{\xi\xi}}} \frac{\partial c}{\partial \xi} \right) + \frac{\partial}{\partial \eta} \left(D_H \frac{\sqrt{G_{\xi\xi}}}{\sqrt{G_{\eta\eta}}} \frac{\partial c}{\partial \xi} \right) \right\} + \frac{1}{d+\zeta} \frac{\partial}{\partial \sigma} \left(D_v \frac{\partial c}{\partial \sigma} \right) - \lambda_d (d+\zeta)c + S \end{aligned} \quad (3)$$

In which the ξ 、 η 、 ω are coordinates, ζ is the water level, d is water depth, $\sqrt{G_{\xi\xi}}$ is transfer coefficient in ξ direction, $\sqrt{G_{\eta\eta}}$ is transfer coefficient in η direction, u is velocity in ξ direction, v is velocity in η direction, w is velocity in ω direction, ρ is water density, P_{ξ} is static pressure in

ξ direction, P_η is static pressure in η direction, f is K's coefficient, F_ξ is turbulence flux in ξ direction, F_η is turbulence flux in η direction, M_ξ is energy transfer in ξ direction, M_η is energy transfer in η direction, ν_v is vertical eddy viscosity.

The z-layer model was selected for simulating the water temperature profiles in reservoirs, which uses the constant layer thickness to provide the suitable layers for stoplogs gates better than the that provided by σ -layer model. The heat transfer package in the Delft3d consists of five input model, which can be decided with the data availability.

2.2. Study area

The proposed Guanjingkou reservoir (E106°52', N29°25') is located in the Wubu River, which is the first tributary of Yangze River in the Banan district of Chongqing city. The total area of the watershed is 439 km². The meteorological conditions in the watershed are: the average air temperature is 18.3°C, the annual average sunshine time is 1134 hours, the relative humidity is 81%, average evaporation is 702 mm/a, the average precipitation is 1104 mm/a. The total water capacity of the proposed Guanjingkou reservoir is 152 million cubic meter with useful storage of 119 million cubic meter. The characteristic water levels are normal water level of 281 meters, the minimum water level of 254 meters, and the average water level of 276 meters above sea level.

The proposed Fengdou reservoir (E130°16', N44°28') is located in Muling city, Heilongjiang province. The watershed covers 1740 km². The meteorological conditions in the watershed are: the average air temperature of 4.2°C, the annual average sunshine time of 2613 hours, the relative humidity of 75%, the average precipitation of 500 mm/a. The average annual discharge in Muling river is 263 million cubic meter. The total water capacity of the proposed Muling reservoir is 165 million cubic meter with useful storage of 153 million cubic meter. The characteristic water levels are normal water level of 382 meters above sea level and the minimum water level of 362 meters.

2.3. Model setup

The simulation models were set up based on the proposed reservoir, the data availability and the research objects. The Digital Elevation Model with resolution of 30×30m from the International Scientific & Technical Data Mirror Site, Computer Network Information Center, Chinese Academy of Sciences (<http://www.gscloud.cn>) was selected for grid generation in Rgrid package. The total 164×8 grids for Guanjingkou reservoir and 40×8 grids for Fengdou reservoir were applied, respectively (figure 1).

The inflows of the model are the discharges at the upstream boundary of the two models while the outflows of the model were set at the downstream of the model domain. The 19 layers for Guanjingkou and 12 layers for Fengdou reservoir were selected based on the proposed project and the measures, respectively. Since the historical meteorological data are rare in the region, the monthly average air temperature could be used as excess temperature in the heat exchange package. The inflow and outflow discharges in normal, wet, and dry year are collected from the hydrological stations at 20%, 50%, and 75% frequency. In addition, one year date was also collected for special dry year at 95%

frequency for water temperature prediction at Fengdou reservoir. The initial temperatures for the two reservoirs were 10°C and 2.3°C for Guanjingkou and Fengdou reservoir from the observation in the nearby reservoirs, respectively. The roughness for Guanjingkou and Fengdou reservoir were 0.18 and 0.2 by trial and error with the water stage and capacity, respectively. The calibration of the model for two reservoirs was achieved by comparing the temperature observations at different depth in the nearby reservoirs with similar conditions and the simulated results.

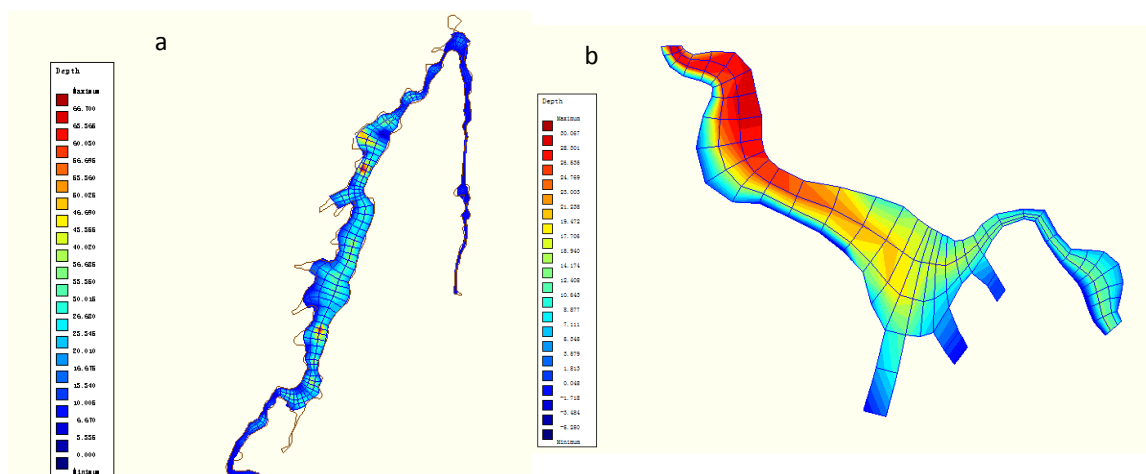


Figure 1. The computation grid for Guanjingkou (a) and Fengdou (b) reservoir.

2.4. Simulation scenarios

The original proposed water diversion scheme is single gate at two reservoirs, which were simulated at the bottom of the reservoir in the model. The proposed measures for water temperature are the stoplogs gates for the Guanjingkou and the three multiple gates for Fengdou reservoirs, respectively. Thus, the effects of stoplogs gates and the three multiple gates are simulated as that the water is released from the available upmost gate according to the predicted water level in the reservoir. The scenarios can be finalized as the water released from single gate and multiple gates during the normal, wet, and dry (special dry) year.

3. Results and discussion

The simulated water temperature profiles in front of the dam at the two reservoirs under normal, wet, and dry conditions are illustrated in figure 2. The comparison of water temperature with non-measures (single gate) and measures (multiple gates) at two reservoirs is shown in figure 3.

According to the simulation results, the water temperature profile in front of the Guanjingkou reservoir can be separated into three layers. The maximum depth of upmost epilimnion layer is 20 meter. The depth of thermocline layer is between 20 and 35 meter. The constant temperature layer is below 35 meter. The minimum water temperatures released from single gate are 9.7°C, 9.7°C, and 9.5°C in January under wet, normal, and dry year. The water temperature can be increased by releasing the water from upmost gate in stoplogs gates system. During the main irrigation season from May to August, the water temperature could be increased 5.7°C, 6.8°C, 9.6°C, and 5.5°C, respectively.

Since the proposed Fengdou reservoir is located in north China, where the water is frozen during winter. So only the water temperatures from spring to autumn were selected for analysis. Based on the

simulation results, the water temperature profile in front of the Fengdou reservoir can be separated into three layers. The maximum depth of upmost epilimnion layer is 15 meter. The depth of thermocline layer is between 15 and 25 meter. The constant temperature layer is below 25 meter. The minimum water temperatures released from single gate are 2.5°C, 2.3°C, and 2.3°C in April in wet, normal, and dry year. The water temperature can be increased by releasing the water from upmost gate in three gates system. During the main irrigation seasons from May to August, the water temperature could be increased by 7.7°C, 1.9°C, 9.5°C, and 10.1°C, respectively.

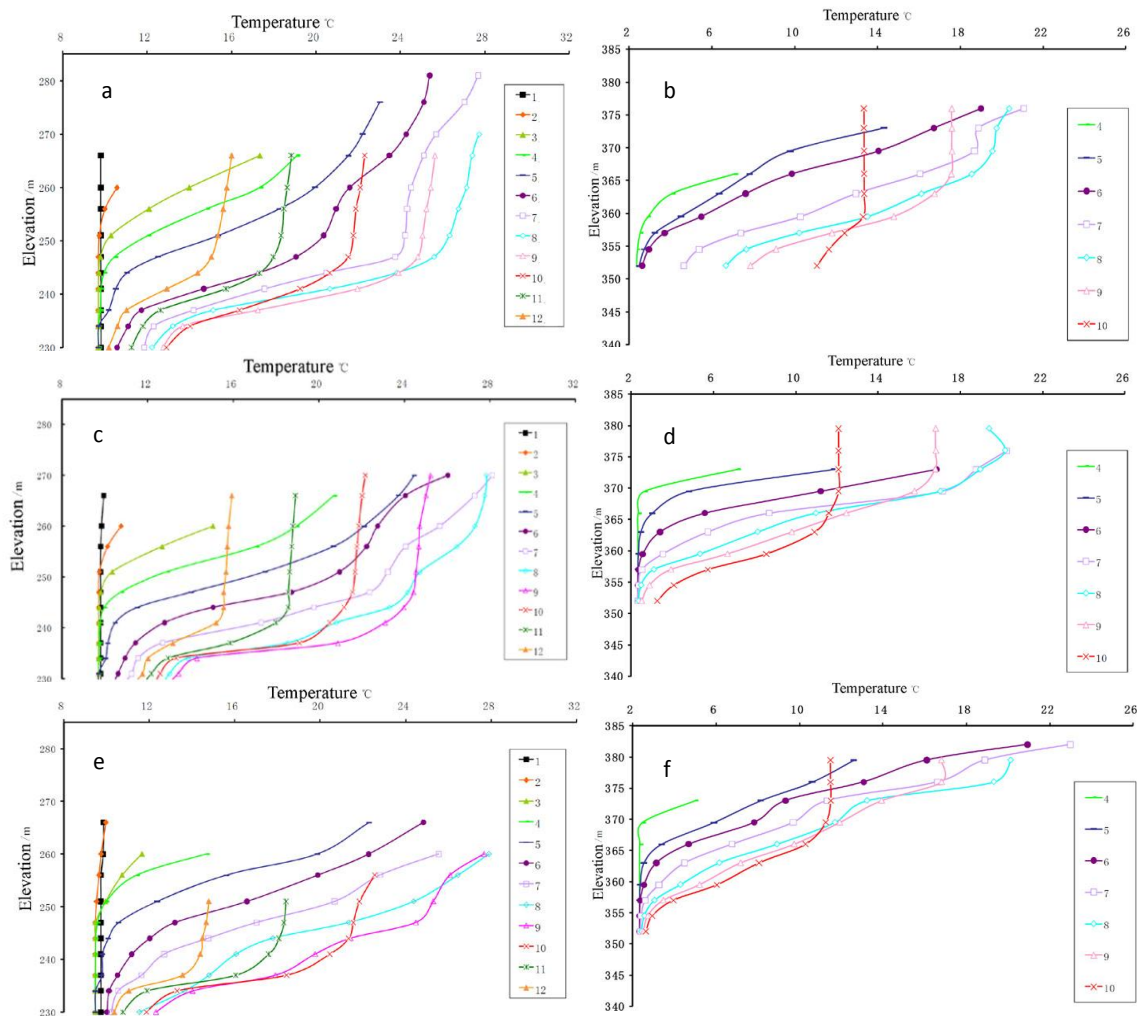


Figure 2. The simulated water temperature profiles in front of dam at Guanjingkou reservoir under normal (a), wet(c), and dry (e) condition and in front of dam at Fengdou reservoir under normal (b), wet (d), and dry (f) condition. The numbers are the different month.

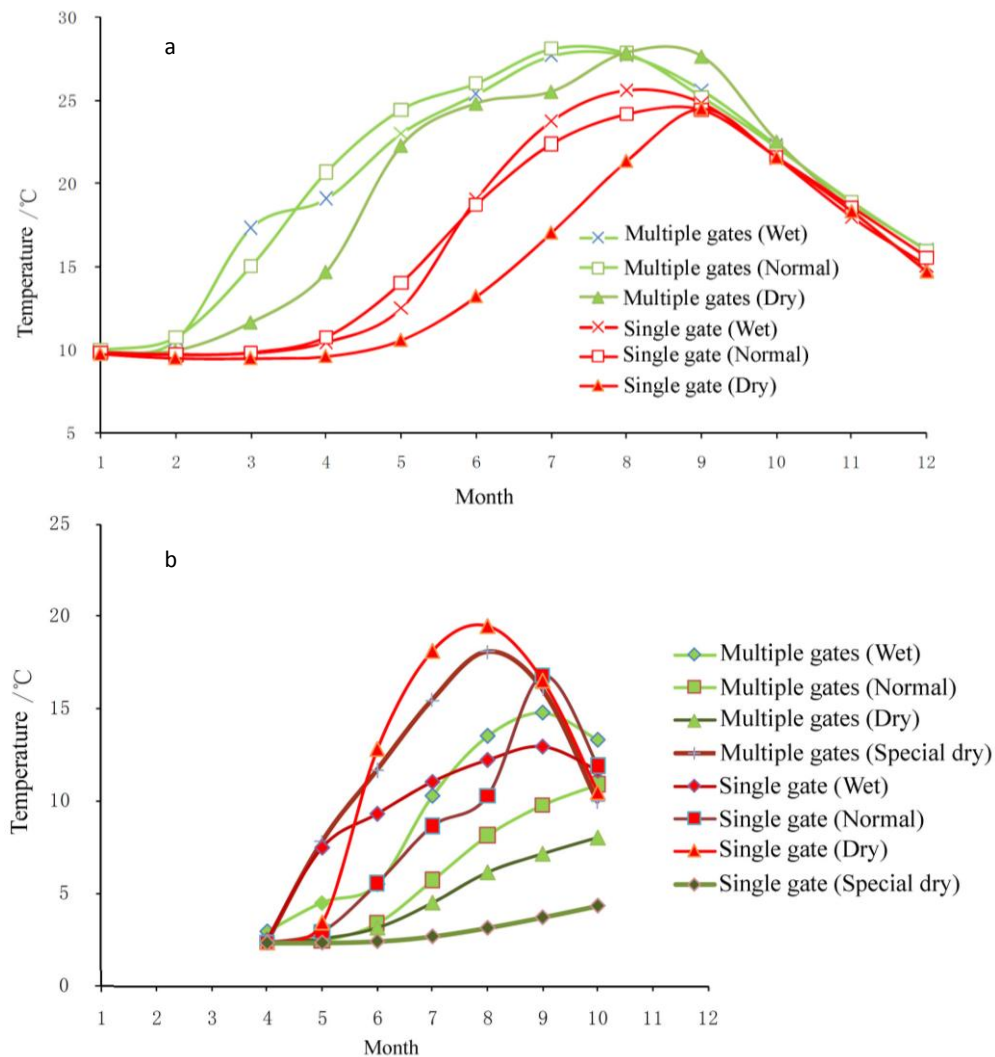


Figure 3. The comparison of simulated water temperature released from single gate and multiple gates from Guanjingkou reservoir (a) and Fengdou reservoir (b).

4. Conclusion

The numerical solution with Delft3d package can be the optimum or advanced method for reservoir water temperature prediction for the capability in simulating reservoir operation. Compared to those statistical experimental formula and the 2 dimensional simulations, one of the most suitable reasons for three dimensional simulations is that the variation of water levels can be included. The other advantage is that the horizontal convection can be simulated, which is crucial for the calculation of water temperature for the reservoir operation.

The downstream water temperature would be significantly decreased by the construction of the reservoir especially in the single gate scheme at the two reservoirs. The downstream aquatic ecosystem would eventually be affected by the original design of the two reservoirs. The revised solution of stoplogs gates and multiple gates at two reservoirs can improve the water temperature

released from the two reservoirs. Thus, the negative effects of the water with lower temperature on the downstream aquatic ecosystem can be alleviated.

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