The influence mechanism research of inflow temperature in different time scale on the water temperature structure

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Abstract. A 3D hydraulic-thermodynamic mathematical model is established to predict the temporal and spatial distribution of temperature in a large reservoir in different time scale inflow temperature condition, and a further research on the influence mechanism of inflow temperature on the water temperature structure is made. It is found that the convection current between the upper and the lower of the reservoir always appear when the storage heat in a reservoir decreases; the stratification phenomenon appears in most time of a year in a large reservoir which is controlled by the climate, and there is a close relationship between the water temperature distribution and the inflow temperature. Different inflow temperature has different affected area where the density current propagates, in the affected area, the difference of water temperature distribution occurs by the cumulative effect of the previous months, for the other area, the more detailed the inflow temperature is, the more accurate the simulation results are.

1. Introduction
Water resource is clean and renewable; it is a common measure to exploit the water resources by building a dam on a river [1]. There are both advantages and disadvantages, on the one hand, the construction of a reservoir can bring a lot of benefit in flood control, power generation, irrigation, navigation and aquaculture; on the other hand, it makes impacts in quality environment and ecological environment, and the water temperature is one of the important basic indictors [2]. It will change the original temporal and spatial distribution of the natural river water temperature after the reservoir’s building, especially for the hydrological parameters, flow state and the heat transport process after its water storage, and the stratification phenomenon appears in a large reservoir, which can create an environmental problem that cannot be ignored—the lower temperature water released...
from the reservoir which has a significant impact on the downstream ecological environment [3]. In order to give full play to the comprehensive benefits of water conservancy project and reduce the adverse effect to the minimum, it needs to do a lot of research and study the influence factors which have effect on the water temperature and the temporal and spatial rules of the water temperature distribution in a reservoir.

The main factors that influence the water temperature in a reservoir include the inflow, the solar radiation, the air temperature, the water intake position, reservoir scale, terrain condition and operation mode [4]. In some specific region, the inflow and the reservoir scale have a great influence on the water temperature distribution, and when the scale and the shape of the reservoir are certain, the influence of the inflow cannot be ignored. When doing a research on the water temperature distribution in a reservoir, the accurate and detailed inflow data is the basic for accurately predicting the spatial and temporal distribution of water temperature in a reservoir. However, in actual engineering, especially for the reservoir planned to build, the inflow data which can be obtained is often not detailed enough, and to obtain the detailed inflow data usually cost a lot, which cause the incompatible problems with the economy of the original data collection for the accuracy of the water temperature prediction [5], so a balance between the two needs to be seek. So the 3-dimensional hydraulic-thermodynamic numerical model is established to predict the temporal and spatial distribution of the temperature in a large reservoir in this paper, and a further research on the influence mechanism of inflow temperature on the water temperature structure of a large reservoir is made according to the research, the affected area by inflow temperature is indicated which can be used to be the basis for judging reliability of the inflow temperature.

2. Establishment and validation of the mathematical model

2.1. Selection and assumption of mathematical model

The research object is a large reservoir, the stratification phenomenon appears in most time of a year, and the current has a three dimensional character in the inlet and the outlet, so a 3D hydraulics-thermodynamic mathematics model is established in this paper. The model is based on the three assumptions: incompressible assumption, shallow water assumption and Boussinesq assumption. The body-fitted orthogonal curvilinear coordinate system is used in the horizontal direction, and a Cartesian coordinate system is used in the vertical direction.

Control equations:

(1) Continuity equation:

$$\frac{\partial \xi}{\partial t} + \frac{1}{\sqrt{G_{\xi\xi} G_{\eta\eta}}} \frac{\partial}{\partial \xi} \left[ (d + \xi) U \sqrt{G_{\eta\eta}} \right] + \frac{1}{\sqrt{G_{\xi\xi} G_{\eta\eta}}} \frac{\partial}{\partial \eta} \left[ (d + \xi) V \sqrt{G_{\xi\xi}} \right] = 0$$  \hspace{1cm} (1)

(2) Momentum equation:

- $\xi$ direction:

$$\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial \xi} + v \frac{\partial u}{\partial \eta} + w \frac{\partial u}{\partial z} - \frac{g}{\rho g} \frac{\partial G_{\eta\eta}}{\partial \eta} \frac{\partial u}{\partial \eta} - f v = - \frac{1}{\rho_g \sqrt{G_{\xi\xi}}} P_{\xi} + F_{\xi} + \frac{\partial}{\partial \zeta} \left( \nu_v \frac{\partial u}{\partial \zeta} \right) + M_{\xi}$$  \hspace{1cm} (2)

- $\eta$ direction:

$$\frac{\partial v}{\partial t} + u \frac{\partial v}{\partial \xi} + v \frac{\partial v}{\partial \eta} + w \frac{\partial v}{\partial z} + \frac{g}{\rho g} \frac{\partial G_{\xi\xi}}{\partial \xi} \frac{\partial v}{\partial \xi} - \frac{g}{\rho g} \frac{\partial G_{\eta\eta}}{\partial \eta} \frac{\partial v}{\partial \eta} = - \frac{1}{\rho_g \sqrt{G_{\eta\eta}}} P_{\eta} + F_{\eta} + \frac{\partial}{\partial \zeta} \left( \nu_v \frac{\partial v}{\partial \zeta} \right) + M_{\eta}$$  \hspace{1cm} (3)

$Z$ direction:
\[
\frac{1}{\rho} \frac{\partial P}{\partial z} = -g
\]  

(4)

(3) Heat transport equation:

\[
\frac{1}{\sqrt{G_{\xi\xi}} \sqrt{G_{\eta\eta}}} \left\{ \frac{\partial}{\partial \xi} \left[ \sqrt{G_{\eta\eta}} (d + \zeta) u T \right] + \frac{\partial}{\partial \eta} \left[ \sqrt{G_{\xi\xi}} (d + \zeta) v T \right] \right\} + \frac{\partial}{\partial t} \left( d + \zeta \right) T + (d + \zeta) \frac{\partial w T}{\partial z} = \left( d + \zeta \right) \frac{\partial T}{\partial z} + S + \frac{d + \zeta}{\sqrt{G_{\xi\xi}} \sqrt{G_{\eta\eta}}} \left\{ \frac{\partial}{\partial \xi} \left[ D_u \sqrt{G_{\eta\eta}} \frac{\partial T}{\partial \eta} \right] + \frac{\partial}{\partial \eta} \left[ D_v \sqrt{G_{\xi\xi}} \frac{\partial T}{\partial \xi} \right] \right\}
\]  

(5)

(4) Turbulent model equations:

\[
\frac{\partial k}{\partial t} + u \frac{\partial k}{\partial \xi} + v \frac{\partial k}{\partial \eta} + w \frac{\partial k}{\partial z} = \frac{\partial}{\partial \xi} \left[ \left( \nu_m + \frac{\nu_D}{\sigma_1} \right) \frac{\partial k}{\partial \xi} \right] + P_k + B_k - \varepsilon
\]  

(6)

\[
\frac{\partial \varepsilon}{\partial t} + \frac{u}{\sqrt{G_{\xi\xi}}} \frac{\partial \varepsilon}{\partial \xi} + \frac{v}{\sqrt{G_{\eta\eta}}} \frac{\partial \varepsilon}{\partial \eta} + \frac{w}{\sqrt{G_{\xi\xi}}} \frac{\partial \varepsilon}{\partial z} = \frac{\partial}{\partial \xi} \left[ \left( \nu_m + \frac{\nu_D}{\sigma_2} \right) \frac{\partial \varepsilon}{\partial \xi} \right] + P_\varepsilon + B_\varepsilon - c_\varepsilon \frac{\varepsilon^2}{k}
\]  

(7)

(5) State equation:

\[
\rho = 999.842594 + 6.793952 \times 10^{-3} t - 9.095290 \times 10^{-3} t^2 + 1.001685 \times 10^{-4} t^3 - 1.120083 \times 10^{-8} t^4 + 6.536332 \times 10^{-9} t^5
\]  

(8)

Where, \( u, v \) are the average velocity in the \( \xi \) and \( \eta \) directions; \( G_{\xi\xi} \) and \( G_{\eta\eta} \) are the conversion coefficient between a body-fitted orthogonal curvilinear coordinate system and Cartesian right-angle coordinate system; \( P_k \) and \( P_\varepsilon \) are the hydrostatic pressure gradient in the \( \xi \) and \( \eta \) directions; \( F_z \) and \( F_\eta \) are the turbulent momentum flux in the \( \xi \) and \( \eta \) directions; \( M_z \) and \( M_\eta \) are the source or sink of momentum in the \( \xi \) and \( \eta \) directions; \( \nu_m \) is the vertical eddy viscosity coefficient; \( D_u \) and \( D_v \) are the horizontal and vertical eddy diffusion coefficient; \( \sigma_1 \) is the Prandtl-Schmidt number, and \( \sigma_1 = 0.7 \); and \( S \) is the source or sink caused by the heat exchange on the free surface per unit area.

2.2. Solution conditions and solving method

(1) Solution conditions

The inlet and outlet use the mass flow rate boundary and inflow flux is equal to the released flow flux, the flux loss is ignored in the free surface and at the bed of the reservoir, the shear stress in the bed and the wind on the surface are taken into account, and the vertical thermal diffusion flux of the water surface and the bed are ignored.

(2) Solving method

For the three-dimensional shallow water mathematical model constructed above, the Alternating Direction Implicit Method (ADI method) is used to solve the continuous equation and the U and V direct momentum equations. Since the vertical velocity is related with the horizontal direction velocity by the convection term and the viscous term, the complete implicit time integration method is used to solve the z-direction momentum equation. The staggered grids are arranged in the calculation area, that is, the flow velocity components are arranged at the center of the grid walls, the water level and the temperature are arranged at the grid center points, and the water depths are arranged at the grid nodes. Therefore, the computing for the velocity is staggered with other variables (such as pressure, water level, etc.) when the calculation unit data is stored, which can avoid the production of the wave velocity field and wave pressure field. The essence of ADI is the time distribution method, which divides a calculation periodic into two parts. It implicitly solves the U-parameter in the first one-half step first and the V-direction parameter is explicitly processed. It
solves V direction parameter implicit in the later 1/2 step first, the U direction of the parameters for explicit treatment. The details can be seen in Leendertse’s study [6].

2.3. Model verification
The model is verified by the test conducting by Johnson [7-8] from the Army Corps of Engineers in 1980-1981 in order to study hydrodynamic character in a reservoir, the length of the reservoir is 24.39 m, the depth varies from 0.30 m in the entrance to 0.91 m in the dam site, the width varies linearly from 0.3m in the entrance to 0.91m in the point where there is 6.1m far from the entrance, and then it keeps the same width until the dam site. The details are shown in fig.1.

The reservoir is filled with 21.44 °C of water at the initial time, there is a baffle from 0m to 0.15m in water depth in the entrance, and the inflow flow rate is 0.00063 m$^3$/s with 16.67 °Cof the temperature, the released flow rate is equal to the inflow flow rate.

3D mathematical models were established above, according to the simulation results, we could obtain the hydrodynamic character and the water temperature distribution character in the reservoir. Fig.2 was a comparison diagram of the calculation values calculated by the model above and the observation values measured in the test 11 min later after the start of the experiment, from the changing curve of the velocity, we could find that there was backflow on the upper level of the reservoir, which was consistent with the experimental conclusion. Fig.3 indicated the rules of the released water temperature changed with time, it showed that the released water temperature decreased with time, and the variation rules of the calculated values and experimental values were the same. Therefore, the above mathematical model could be used to study the hydrodynamic character and water temperature distribution character of a reservoir.
Figure 3. Released water temperature changes with time

3. Design of inflow temperature in different time scales
There were two important factors for the inflow: the flow rate and the water temperature, according to the research of predecessors, the correlation between inflow temperature and reservoir water temperature distribution was much closer than that between the inflow flow rate and the reservoir water temperature in the reservoir studied in this paper, and it had the same simulation results with the daily average inflow temperature and the monthly average inflow temperature in the same other boundary conditions, so this article focused on the analysis of the influence of the inflow temperature on the reservoir water temperature distribution in the detailed inflow flow rate conditions.

3.1. The model reservoir
The selected model reservoir is located at the southwest plateau climate zone, the mean annual runoff at the site of the dam is 0.542 billion m³, the capacity is 0.153 billion m³, and other main parameters are as follows: the reservoir is approximately 10 km long, 500 m wide, the dam elevation is 3522 m, the maximum dam height is 124.4 m, and the water intake elevation is at 3471 m.

3.2. Meteorological data
The detailed meteorological data is shown in figure 4.

Figure 4. Meteorological data for the area of the reservoir
3.3 Design for the inflow temperature
We had the detailed data of inflow temperature, and the four different time scales of the inflow temperature were designed according to the details of inflow data---T1, T2, T3 and T4. Where, T1 was the monthly average inflow temperature, T2 was the seasonal average inflow temperature which was averaged in the months corresponding to the seasons, T3 was the periodic average inflow temperature and T4 was the yearly average inflow temperature, and the details were shown in table 1.

| Month | Monthly average | Season | Month | Seasonal average | Period | Month | Periodic average | Yearly average |
|-------|-----------------|--------|-------|-----------------|--------|-------|-----------------|----------------|
| 1     | 0               |        | 6     | 5.92            |        | 6     |                 |                |
| 2     | 0               | Summer | 7     | 7               |        | 7     |                 |                |
| 3     | 2.14            |        | 8     | Wet season      | 9      | 8     | 9.92            |                |
| 4     | 5.86            | Autumn | 9     |                 | 10.96  | 10    |                 |                |
| 5     | 9.76            |        | 10    |                 |        | 10    |                 |                |
| 6     | 9.76            |        | 11    |                 |        | 11    | 5.76            |                |
| 7     | 10.96           |        | 12    |                 |        | 12    |                 |                |
| 8     | 12.17           | Winter | 1     | 6.16            |        | 1     |                 |                |
| 9     | 10.16           |        | 2     | Dry season      | 3      | 2     | 2.79            |                |
| 10    | 6.57            |        | 3     |                 |        | 3     |                 |                |
| 11    | 1.76            | Spring | 4     | 0               |        | 4     |                 |                |
| 12    | 0               |        | 5     |                 |        | 5     |                 |                |

4. The reservoir water temperature distribution different inflow temperature time scale conditions
The four different time scales of inflow temperature were used to be the inflow boundary condition respectively in numerical simulation, and the four different temperature distributions could be calculated, the water temperature distributions of every month before the dam in different inflow temperature time scale condition were shown in Figure 5, Figure 6, Figure 7 and Figure 8 were shown respectively which indicated that there were three different distributions of the water temperature in a whole year: the water temperature presented inversion distribution vertically (the lower water temperature in the upper and the higher water temperature in the lower), the water temperature presented normal distribution vertically, and the water temperature presented isothermal distribution vertically, it declared that the vertical temperature distribution characteristics was more determined by the climatic than the inflow. There also existed difference among the figures, the main difference was in value in the same position of different time scale condition, but the vertical water temperature in T1 condition changed accordantly with that in T2, T3 and T4 condition.
**Figure 5.** Vertical temperature distribution before the dam in T1 condition

**Figure 6.** Vertical temperature distribution before the dam in T2 condition

**Figure 7.** Vertical temperature distribution before the dam in T3 condition
As shown in figure 5, the stratification phenomenon would occur from January to October in T1 condition, it reflected the changing rules of vertical water temperature in value clearly. The water temperature in the upper was higher than that in the lower from May to October, the annual maximum water temperature appeared in the surface in August; it was transitional periodic in November and December, and the vertical water temperature before the dam was almost isothermal distribution at the time; the temperature inversion distribution phenomenon before the dam appeared from January to April, duo to the lower air temperature and the weaker radiation in winter, the water temperature in the upper was lower than that in the lower and with the water temperature in a reservoir below 4℃ whose density was maximum, and the surface water temperature could reach 0 ℃ minimum (freezing phenomenon may occur), the bottom water temperature was about 4 ℃, the difference may be up to 4 ℃ between the surface and the bottom.

Although the rules of the vertical water temperature distribution in T2, T3 and T4 condition changed accordantly with that in T1 condition, the difference in values still existed. Comparing the figure 6, figure 7 and figure 8 with the figure 5, we could find that the values of maximum water temperature difference in the surface in the whole year were different, with 13.3 ℃ in T1 condition, 12.9 ℃ in T2 condition, 12.5 ℃ in T3 condition and 10.3 ℃ in T4 condition; The relative elevation was 18.7m below the water surface where the water temperature was up to 4 ℃ in January in T3 condition, which was higher than that in other conditions; the water temperature of T3 condition in November and December had the maximum value in the four conditions; the maximum water temperature of four conditions in the whole year was also different in value. According to the disorderly rules just shown in the four figures above, we would like to do a research on the formation mechanism of the vertical water temperature distribution below.

5. The inflow mechanism research of inflow temperature on the water temperature structure in a large reservoir

Due to the different time scale inflow temperature used as inlet boundary, it had different influence on the reservoir water temperature distribution. That is, the different inflow temperature affected the water temperature distribution of different regions. The formation process of the reservoir water temperature distribution in every month was studied in this section, and the mechanism of the difference of reservoir water temperature distribution in different time scales were analyzed in depth in order to get more useful conclusions and to deepen understanding on the propagation rules of the inflow in a stratified reservoir.

5.1. The influence mechanism research of the radiation and the air temperature on water temperature distribution

According to the maximum density with the temperature 4 ℃ and the different changing rules with the water temperature greater and less than 4 ℃(as shown in figure 9), the water temperature
stratification phenomenon may occurred only when the solar radiation was getting stronger and weaker throughout a year in a large reservoir. When the solar radiation was stronger (from March to August), and the air temperature was getting increased at that time, it could not make a balance between the absorbed heat and the released heat of the water in the reservoir, the imbalance of the heat also occurred when the solar radiation was getting weaker (from September to October), and it roughly get balance in November and December and it showed a uniform distribution in a reservoir because of the convection current between the upper and the lower. As the solar getting weaker and the temperature decreased, the mass of absorbed heat was less than that of released heat, then the water temperature in the upper (in the surface accurately where the conduction happened between the water in a reservoir and the air) further decreased. In the changing process of the water temperature in a reservoir, the conduction and the convection among the layers in a reservoir were the main heat transfer ways that made the different water temperature distribution in a reservoir. And we would analyze deeply the influence mechanism of the radiation and the air temperature on water temperature distribution.

As shown in figure 5, figure 6, figure 7 and figure 8, it displayed the similar changing rules of the water temperature in different month, which indicated the main factor that affect the water temperature distribution in a cold plateau region in winter. The water temperature was more than 4 ℃ in November in the whole vertical section, due to the weaker solar radiation and the lower air temperature, there existed the heat exchange between the external and the water in a reservoir, and the mass of absorbed heat was less than the released heat, which cause the water temperature decrease in the surface, the density got increased with the water temperature getting decreased when water temperature was above 4 ℃, then the water started to plunge and the water below rise accordingly, and the heat convection phenomenon occurred, due to the small difference in water temperature, the affected region may be limited in the local region in the upper and transferred step by step, such heat exchange appeared until the water temperature below the upper of the reservoir reached about 4 ℃, and at that time, the density in the bottom reached the maximum value, and the reservoir water temperature in the surface still continued to decrease because of the decreased air temperature, the density got increased with water temperature increased when water temperature was below 4 ℃, the heat convection phenomenon disappeared, such as in January and February, the reservoir water temperature distribution with the water temperature lower in the upper and the water temperature higher in the lower would be formed in the reservoir, namely, the inversion temperature distribution formed. In this process, the heat conduction was the main way to transfer heat between the layers. Since March, the solar radiation and the air temperature had increased, the water temperature in the upper started to increase from the minimum temperature 0 ℃, because of the
maximum density in the lower, the heat convection between the different layers could not happened, and the heat conduction was the transfer heat way, such as in March and April. As the water temperature increasing, not only the water temperature in the upper increased, but also the water temperature in the lower, and the water temperature in the whole vertical section was above 4℃, according to the different influences, the change in the upper in the upper was bigger than that in the lower, and it has the maximum change in the surface, such as in May, June, July and August. In September and October, the solar radiation got weak and the air temperature got low generally, the mass of entering heat in the surface was less than that of exiting heat, the water temperature in the surface decreased, and it plunged when it was denser than that in the layers below, but due to the temperature difference between the upper and the lower and the small coefficient of the heat conduction, the water temperature in the lower still increased until the water temperature was equal to the water temperature in the lower, in the process, the heat conduction was the main heat transfer way in the lower and the heat convection was the main heat transfer way in the surface. As the solar radiation and the air temperature decreasing, the water temperature in the surface decreased which caused the water plunged, and at the same time, the heat convection occurred and the convection current made water temperature uniform in the whole vertical section in a short time if the temperature difference existed. However the water temperature in the reservoir was still greater than 4℃, so the phenomenon would occur until the temperature reduced to 4 ℃ when the lower water temperature reached the maximum, as the surface water temperature got decreased at that time, the density would get decreased.

5.2 The influence mechanism research of the inflow temperature on water temperature distribution

The changing rules of the water temperature distribution were different throughout the year because of the different climate in different months. Due to the different inflow temperature, the inflow had different influence on the water temperature distribution in a reservoir in different time. According to the difference between the inflow temperature and the ambient water temperature, different flow forms were formed at the entrance of the reservoir, commonly referred to as the density current. If the inflow density was less than the surface water density in a reservoir, the surface density current may be formed [9]; if the inflow density was larger than the surface water density in a reservoir, sometimes, the plunging density current formed [10], if the density of the density current still was larger after its plunging, the density current would propagated along the bottom of the reservoir, and the heat exchange happened between the density current and the ambient water in the reservoir then and it would affect the water temperature along the way.

If the reservoir was stratified, according to the inflow density and the distribution of water temperature in a reservoir, three kinds of flow forms would be formed. Considering the different conditions of water temperature distribution and inflow water temperature, the influence of inflow temperature on the reservoir was also different and it affected the water thickness where it intruded if it existed.

(1) Monthly average inflow temperature (T1 condition)

Due to the strong turbulence vertically, the river vertical water temperature was uniform, if it could not keep the balance between the absorbed heat and the released heat, the heat exchange would be continuous through the surface throughout a year, even at one time of a day the heat exchange existed if the imbalance existed, comparing with the reservoir, it need less heat to get the balance because of the less mass of the water in a river, so the value of the inflow temperature could reflect the intensity of the solar radiation and the air temperature directly. According to the different ability of the absorbed heat and released heat, the inflow temperature was different with the reservoir water temperature (the water temperature in the surface accurately), then the different of the flow forms may occurred.

The simulation results in T1 condition could be more accurate relatively to reflect the changing rules of water temperature distribution in the reservoir throughout the year in nature, the more
detailed the inflow data was, the more accurate the simulation results were, so the simulation results in T1 condition was more accurate than that in other conditions. According to different reservoir water temperature distribution structure in different inflow temperature time scales, the influence of inflow temperature after its plunging into the reservoir on the reservoir water temperature distribution was also different. The water temperature above 4 °C in the reservoir showed a uniform distribution in November and December in T1 condition. The water temperature in November was 1.76 °C whose density was approximately equal to the reservoir ambient water density at that time in spite of the different water temperature, the inflow propagated in the surface and formed new mixed water whose temperature was between the inflow temperature and the ambient water temperature in the surface of the reservoir. And the density of the new mixed water was greater than that of the reservoir ambient water, so the plunging phenomenon may occur, and then the density current would propagated along the reservoir bottom until its density was close to the ambient water temperature where it intruded into the reservoir, in the propagation process, the heat exchange between the density current and the ambient water took place through K-H wave breaking [11-12], which made the water temperature along the way decreased, and the local convection current occurred. The solar radiation and the air temperature decreased gradually as December coming, affected by which, the storage heat of the reservoir reduced, and not only the water temperature in the upper and in the propagation path decreased further, but also the thickness of the water where it intruded into the reservoir if the intrusion existed. Due to the smaller inflow temperature, the density current still occurred, and the similar phenomenon still happened until the reservoir water temperature reduced to 4 °C in the whole vertical section. If small temperature difference existed, the convection current occurred, and by the local convection the influence of the different water temperature was transferred from the surface to the bottom, which caused the water temperature the same, and the reservoir water temperature vertically in the reservoir presented a uniform distribution.

During November and December, the storage heat in the reservoir continued to decrease as the solar radiation and air temperature decreased. The density of the water body reached a maximum value when the water temperature in the reservoir decreased to 4 °C, that is, the inflow density was relatively smaller, and the inflow propagated in the surface, which showed that the main influence area by the inflow was limited to the surface layer of the reservoir at that time, the main heat transfer way was heat conduction between the upper and the lower of the reservoir in a distance away from the entrance, which had little effect on the water temperature in the lower because of the small heat conduction coefficient. In January and February, the inflow temperature reduced to 0 °C, whose density was the minimum comparing with the reservoir water density, the phenomenon above happened, it had occurred until the March coming, the solar radiation and the air temperature increased clearly, which made the inflow temperature increased quickly. Due to the smaller changing of the water temperature in the surface, the plunging phenomenon occurred and the affected area was not only the surface of the reservoir, but also the area where it intruded into and the area between the two. In April, the inflow temperature was 5.86 °C with the smaller density comparing with the reservoir water temperature, it propagated along the surface again and affected the water temperature in the surface, and it transferred heat between the layers by the heat conduction in the main reservoir, although the storage heat increased, it presented temperature inversion distribution in the reservoir because of the local climate, water temperature in the upper was less than that in the lower and the largest density was in the lower of the reservoir with the temperature 4 °C. As the solar radiation and the air temperature increasing, the reservoir was continuous to storage heat and not only the water temperature in surface but also the temperature of water below the surface increased, and the temperature was more than 4 °C, the inflow temperature was still larger than the water temperature in the surface of the reservoir, the surface density current had occurred until September coming, during the period, the heat conduction was the main heat transfer way. The solar radiation and air temperature decreased gradually from September, the changing of inflow temperature was larger than that in the surface, the plunging density current
occurred which enlarged the affected area, and the heat convection in the interface between the density current and the ambient water was the main heat transfer way which reduced the water temperature below, but due to the water temperature difference between the lower and the upper, the heat conduction still made the water temperature in the lower increase which could be seen through the vertical water temperature distribution in September and October in figure 5, the convection current in the vertical section could not occur because of the stably stratified phenomenon in the reservoir, and the storage heat reduced, the normal water temperature distribution had been continuous until the water temperature in the surface was lesser than that in the lower, the heat transfer way was in the same way. The convection current occurred when the water temperature in the surface was lesser than that in the lower at one time, which would make the vertical water temperature uniform, so the water temperature was equal in the whole section in November and December, and the reservoir water temperature in November was smaller than that in December because of the weaker solar radiation and lower air temperature, duo to the lower inflow temperature comparing with the reservoir water temperature, the plunging density current would occurred, the affected area may enlarge to the whole vertical section.

(2) Other average inflow temperature (T2, T3 and T4 condition)
Comparing with the inflow temperature in different time scales in table 1, the inflow temperature in other time scales was the average of different inflow temperature in corresponding months, for example, the seasonal average inflow temperature in winter was the average of the inflow temperature in December, January and February, and it could be seen that the inflow temperature became more and more flat from the T1 condition to T4 condition. According to the analysis on the affected area of the density current above, there must be a difference of the vertical water temperature distribution in value, but it could not change the structure of the water temperature distribution. Because of the more detailed inflow data, the simulation results in T1 condition were more accurate in comparison with other conditions, so the assumption that the simulation results were the actual water temperature distribution was feasible, and based on which, the minimum point that the density current may intrude into the reservoir (the area above the intrusion point may be the affected area) in different inflow temperature time scales were indicated in figure 10, figure 11, figure 12 and figure 13. From the figures, duo to the inflow temperature and the water temperature distribution, we could find that the affect area was the same in some months, but it was different in most of the months, and it indicated clearly the difference of the affect area.

Figure 10. The minimum point that the inflow of the next month could affect in T1 condition
For example, according to the water temperature distribution in August, the possible intrusion points for the inflow temperature in September were 30.2m below the water surface in T1 condition, 44.7m in T2 condition, 56.4m in T3 condition and the bottom of the reservoir in T4 condition, above which place were the affect area by the inflow, the difference of the affect area was one factor that made the difference of the water temperature distribution in September in different inflow time scales conditions, and the climate was another factor. The inflow temperature were 10.16℃ in T1 condition, 6.16℃ in T2 condition, 9.92℃ in T3 condition and 5.76℃ in T4 condition, comparing with the inflow temperature in T1 condition, the inflow temperature in T3 condition was the nearest inflow temperature in other conditions, so the water temperature
distribution difference between the T1 condition and the T3 condition was minimum, and mainly embodied in the area above about 50m below the water surface where the density current may intrude into the reservoir, the density current would affect the ambient water along the way by the mixing through the interface which occurred because of K-H wave breaking. The inflow temperature in T2 condition was less than that in T2 condition, so it had greater influence on the water temperature distribution, but there was little difference of the water temperature below its intrusion point. The inflow temperature was the minimum in the four inflow temperature and also less than the reservoir water temperature in August, so it may affect the temperature distribution in the whole section, and there was relatively large difference in the lower of the reservoir (as shown in figure 14). But the difference among the water temperature distribution did not only occur by the inflow temperature in last month, but also occur by the cumulative effect of the previous months.

![Figure 14. The water temperature distribution in September in different conditions](image)

According to the analysis above, we could give rise to the difference of water temperature distribution in different inflow temperature conditions, without regard to the effect by the climate, the inflow temperature was the main affected factor on the water temperature distribution, and according to the affected area, we could indicate the area where there was the similar water temperature distribution that didn’t affected by the inflow temperature, so for such area, every time scale inflow temperature was the suitable for the simulation of the water temperature distribution in a reservoir; but for the other area, the more detailed the inflow temperature was, the more accurate the simulation results were.

6. Conclusions
Based on the analysis above, we can conclude that in the cold plateau, the convection (water mass exchange) between the upper and the lower in large reservoirs often appear when the reservoir storage heat reduces. When the storage heat in the reservoir increases, the local convection will occur in the upper layer of the reservoir and the temperature of the upper water is between 0 and 4 ℃ at the time; when the whole water temperature in the reservoir is more than 4 ℃, the heat conduction is mainly the heat transfer way between the different layers in the reservoir.

Besides, the stratification phenomenon appears in most time of a year in a large reservoir, and there is a close relationship between the water temperature distribution and the climate, sometimes, the climate can decide if the water temperature distribution is stratified, and the inflow temperature decides the forms of water temperature distribution;

In addition, in a stratified reservoir, different inflow temperature has different affected area in the reservoir, the affected area is concerned with the inflow and the water temperature distribution,
and we can indicate it simply by the intrusion point where the density current intrudes into the reservoir if the phenomenon exists. Without regard to the effect by the climate, the inflow temperature is the main affected factor on the water temperature distribution. And in the affected area, the difference of water temperature distribution occurs by the cumulative effect of the previous months, so for such area, every time scale inflow temperature is the suitable for the simulation of the water temperature distribution in a reservoir; but for the other area, the more detailed the inflow temperature is, the more accurate the simulation results are.

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