Field research of the impact of a hydropower station on the water temperature in the downstream river course

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Abstract: By online monitoring of the water temperature in the downstream river course of a power station, the author compared the temperature of water discharged from a hydropower station with the water temperature of the natural river course, and found that the temperature of water discharged from the power station was low in spring and summer, but high in autumn and winter; the maximum differences of temperature occur in April and December; the temperature of discharged water was 1.9 ℃ higher on average than that in the natural river course in April and was 4.9 ℃ lower on average than in the natural river course in December. Water samples were collected from similar water levels to compare the temperature of water discharged from the hydropower station and in the water inlet, and it was found that the temperature difference between the hydropower station and the inlet area was positively correlated to the water level of sampling. This study is expected to provide a technical basis for reservoir water temperature control and reservoir ecological regulation.

1. Introduction
When a reservoir is built, the hydrological and thermal conditions of the watercourse will witness tectonic changes and there will be a layered temperature structure in the water body of the reservoir. As the temperature of water in the reservoir is layered, the discharged water from the hydropower station will lead to delayed spawning of fish in the downstream river course and have detrimental impact on crops along the river [1-4]. As early as in the 1930s, America, the Soviet Union and Japan started prototype study on the water temperature of reservoirs, China started similar projects in the 1950s, but most were plumb-line observation of water [4]. After the 1990s, as many dams were built in China, water temperature observation and related studies gained increasing attention; preliminary water temperature observation was conducted via correction of the model parameters [5,6], but accurate, long-term and continuous observation of daily water temperature changes was absent [7,8]. The studied hydropower station was built and began to operate in December 2010. The dam had a maximum height of 173 m, and the power station water inlet had a fixed elevation. Once the reservoir was built, it would have some impacts on the spatial and temporal distribution of temperature in the original river course. Via prototype observation of the water temperature in the downstream river, the author studied the correlation between the temperature changes of water discharged from the reservoir and that in the natural river course, with a view to provide a technical basis for observation of the layered structure of reservoir water temperature, the water temperature recovery measures and reservoir ecological regulation.
2. Online observation of water temperature

2.1 Observation site
(1) The temperature of water discharged from the reservoir was observed at the tail of the hydropower station;
(2) The temperature of water in front of the reservoir was measured by setting a representative observation section within a range of 500 ~ 1000 m before the dam, with three vertical lines at the left, middle and right part of the section.

2.2 Observation instruments and methods
The automatic monitoring system for water temperature before and under the dam consists of a temperature monitoring station, a central control station and measuring instruments. The temperature monitoring station consists of temperature sensors, a remote monitoring device (RTU controller), a communication device, a power source and other units; the central control station consists of a receiving computer, a GSM communication module, an uninterrupted power source, an alternating current charger, an alternating power source arrester, an operating system, a database, and information receiving software.

This system was used to record the water temperature at the observation section once per hour, and the precision level of the water temperature detector was 0.1℃. The water temperature before the dam was observed by identifying the temperature measuring vertical lines by a float gauging boat; several deep-water temperature sensors and specific cables were hung under the boat for automatic monitoring of water. The temperature of water at the tail of the station showed no obvious layered structure; one water temperature sensor was installed 0.5 m under the surface of the water and the sensors were installed in a double pipe manner.

3. Result analysis

3.1 The measured monthly water temperature and comparison of water temperature between months
(1) As the average temperatures of 2013 and 2014 show, the discharge water temperature from March to May was lower than that in the natural water course, and April marked the largest difference, at -1.16 ℃, and May marked the smallest difference, at -0.59℃; the temperature between the discharged water and the natural water remained almost the same between June and August; from September to the following February, the discharge water temperature was higher than the natural water temperature, with December marking the largest difference of 5.44 ℃ in December and the smallest difference of 1.42 ℃ in February.
(2) The temperature of natural water at the dam ranges from 7.23℃ to 18.48 ℃ all year around, with an annual difference of 11.25 ℃. The average temperature difference in 2013 and 2014 was 9.19 ℃, and that between 2015 and 2017 was 7.94 ℃, which was 2.06 ℃ and 3.31 ℃ smaller than the temperature difference of natural water.
(3) The maximum temperature of water occurred in August. The maximum average temperature from 2013 to 2014 and that from 2015 to 2017 was 0.09 ℃ and 0.45 ℃ lower than that of the natural water. The average minimum temperature of discharge water occurred in February, and that of natural water occurred in January. The average minimum temperature from 2013 to 2014 and that from 2015 to 2017 of discharge water were 1.97 ℃ and 2.86 ℃ higher than the maximum temperatures of the natural water.

In summary, the discharged water from the reservoir from March to May and from July to August showed the low temperature effect, with April marking the most obvious effect. From January to February and from September to December, the discharged water had higher temperature than the natural water, with December marking the most obvious difference. The annual temperature changes of discharge water showed less changes than that of natural water, and the monthly changes also showed even distribution, and the annual temperature difference of discharge water was smaller than
that of natural water.

Table 1. Monthly average temperature of discharge water and natural water (℃)

| No. | species                        | Jan. | Feb. | Mar. | Apr. | May. | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
|-----|--------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|
| 1   | natural water                  | 7.23 | 8.67 | 11.56| 14.84| 15.89| 16.64| 17.95| 18.48| 16.38| 14.31| 10.68| 7.69 |
| 2   | measured temperature in 2013    | 9.50 | 9.00 | 10.9 | 14.15| 15.80| 17.54| 18.80| 19.10| 17.85| 16.14| 13.83| 12.93|
| 3   | measured temperature in 2014    | 10.20| 9.40 | 10.00| 13.20| 14.80| 16.12| 16.73| 17.68| 16.59| 16.14| 14.48| 12.40|
| 4   | measured temperature in 2015    | 11.14| 9.90 | 10.81| 14.00| 15.62| 17.26| 17.51| 18.07| 16.91| 16.17| 14.84| 13.34|
| 5   | measured temperature in 2016    | 11.29| 9.72 | 9.96 | 12.35| 15.33| 17.61| 17.54| 18.49| 18.22| 15.98| 14.62| 13.11|
| 6   | measured temperature in 2017    | 11.59| 10.56| 10.26| 12.29| 14.58| 15.19| 15.50| 17.52| 18.17| 16.82| 14.61| 12.95|

Figure 1. Comparison of measured monthly temperature of discharge water and natural water

3.2 Correlation between the temperature of discharged water and the water in front of the dam

The impact of the discharged water temperature on the temperature of water in front of the dam. The daily water temperature changes along the mid-perpendicular line of the dam from 1st January 2017 to 31st December 2017 was analysed, and the correlation between the temperature of water discharged from the dam and the temperature of water in front of the dam was analysed. The relative water sampling elevation was introduced to describe the relation between the temperature of water discharged from the power station and the temperature of water in front of the dam:

Relative water sampling elevation $=\Delta h_1/H_1$.

$\Delta h_1$ is the distance of the elevation of water temperature value corresponding to the discharge water temperature and the elevation of the baseboard of the water sampling site

$H_1$ is the distance between the elevation of the baseboard of the water inlet and the operating water level of the reservoir
The water sampling site was one single sampling site with an elevation of 765 m. According to the discharge water temperature measured from 1st April, 2017 to 30th November, 2017, the elevation for water temperature distribution in front of the dam and that of the corresponding discharge water was identified. As Figure 3 shows, the temperature of discharged water did not correspond to the temperature of the water sampling site, and the average water temperature was higher than that at the water inlet. In 1st May, 2017, the temperature of discharged water from the dam was higher than that at the water inlet, and the maximum annual water temperature difference reached 2.1 °C. The water level was 802.29 m, and the water temperature elevation corresponding to the discharge water temperature was about 788 m, and the relative water sampling elevation was 61.7%. In 1st November 2017, the average temperature of discharged water was higher than that at the water inlet, and the temperature difference reached a minimum of 0.9 °C, and the corresponding water level was 844.89 °C. The temperature of discharged water was the temperature of water in front of the dam at an elevation of 770.6 m, and the relative water sampling elevation was 7%.

Analyses above show that the temperature of discharged water higher than that at the water inlet is positively correlated to the relative water sampling elevation. Under the fixed elevation of the base board of the water sampling site of the power station, when the temperature of water in front of the dam showed a layered structure, the operating water level in front of the dam could be changed to influence the temperature of discharged water. For the studied reservoir, the temperature of discharged water is low from March to May and from July to August, the operation water level can be reduced to increase the temperature of the discharged water; when the temperature of discharge water is higher than the natural water from January to February and from September to December, the operation water level can be increased to reduce the temperature of discharged water.
4. Conclusion and suggestions

4.1 Conclusion
(1) The temperature of discharged water from the power station is low in spring and summer, while high in autumn and winter;
(2) The annual temperature of discharged water from the power station shows little changes around the year, and little difference from that of natural water; the impacts of the reservoir on the water temperature was larger from 2015 to 2017 than from 2013 to 2014;
(3) When the temperature of the discharged water is higher than that of water at the water inlet, the temperature difference is positively correlated to the relative water sampling elevation.

4.2. Suggestions
(1) It is necessary to continue online monitoring of water temperature in the water course, enrich the database of water temperature studies on power stations to make the original data more representative. The reasons why the impact of reservoir operation on the water temperature from 2015 to 2017 is larger than from 2013 to 2014 should be analysed, and the spatial and temporal law for water temperature changes caused by operation of the power station should be explored.
(2) Monitoring of the vertical water temperature should be strengthened, and the changes of water temperature structure in front of the dam with the changes in the water level of the reservoir should be analysed. Future studies should be made to accurately identify that in one water sampling site, how the temperature structure of water in the reservoir would influence the discharged water temperature; and studies should be made to explore how to regulate the water level in the reservoir to reduce the impact of discharged water from the reservoir.

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