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Effect of low temperature water discharged from large reservoir on aquatic ecosystem and agricultural production

Effect of low temperature water discharged from large reservoir on aquatic ecosystem and agricultural production

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Abstract. Low temperature water discharged from large reservoirs caused a lot of environmental problems, which consist of the impairment of downstream aquatic ecosystem and agricultural production. In order to quantify the impact of low temperature water discharged from large reservoir, an ecological survey and water temperature measurements were carried out on Gangkouwan Reservoir in Anhui province China. The Environmental Fluid Dynamics Code (EFDC) was employed to study the vertical water temperature profile and estimate the temperature of water released from Gangkouwan Reservoir in different hydrological year. And a measure was proposed for alleviation of the negative effects of the low temperature water.

1. Introduction

In 20th century, many large reservoirs were built without mitigation measures of low temperature water, such as Xinanjiang reservoir, Foziling reservoir, Chencun reservoir, Gangkouwan reservoir in China. While supporting the economic and social benefits by means of flood control, water supply, and electricity generation, it has not been in line with the increasing requirements of the construction for ecological civilization in the new era. The impact of low temperature discharges is mainly manifested by less dissolved oxygen in deep water, slowing inhibited growth of aquatic organisms, delaying propagation or even no breeding, and reduction of crop yield in downstream irrigation area [1]. At present, the mitigation measures of low temperature water released from reservoirs include multi-layer (vertical well) intake, floating intake, overflow multi-layer intake etc [2,3]. However, these stratified water intake facilities need to be built with cut-off flow, which are suitable for proposed or under construction reservoirs rather than existing reservoirs [4]. Based on the investigation and analysis of the effects of low temperature water on downstream aquatic ecosystem and agricultural production at Gangkouwan reservoir, it is suggested that the construction of water-proof curtain wall should be built as a "replace the old by the new" measure to solve the environmental problems caused by the low temperature water discharged from the reservoir.

The Gangkouwan reservoir is located on the Xi-Jin river (115°53′04″E, 30°35′04″N), Ningguo city, Anhui province China (figure 1). The reservoir has a catchment area of 1120km^2 with 941 million m^3 of total capacity and 133 m of normal storage water level [5]. As a large water conservancy and hydropower project, Gangkouwan reservoir has great benefit of flood control, power generation, and irrigation. The Gangkouwan reservoir is a carry-over storage reservoir, which started construction in 1998, finished river closure in October 1999, completed the dam panel in December 2000, impounded in March 2001, and passed the check and acceptance procedure in January 2002 [5,6].

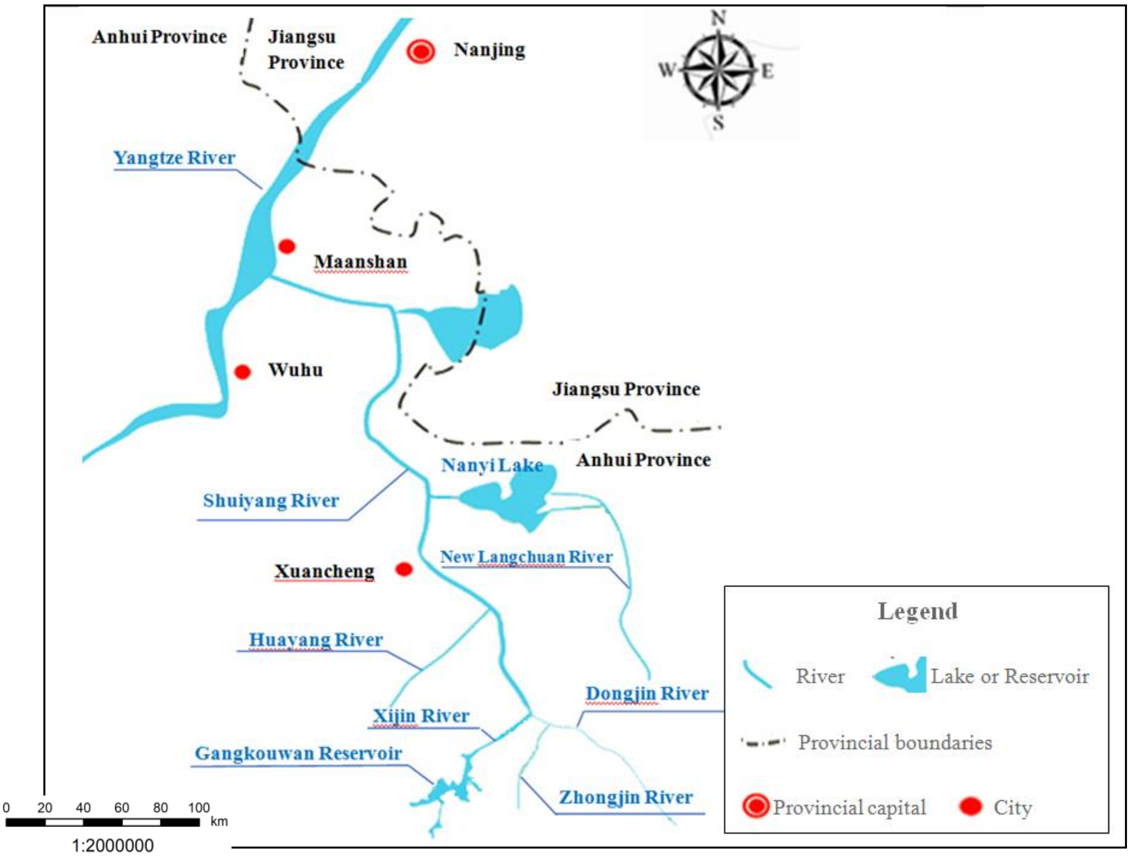


Figure 1. Location map of Gangkouwan reservoir.

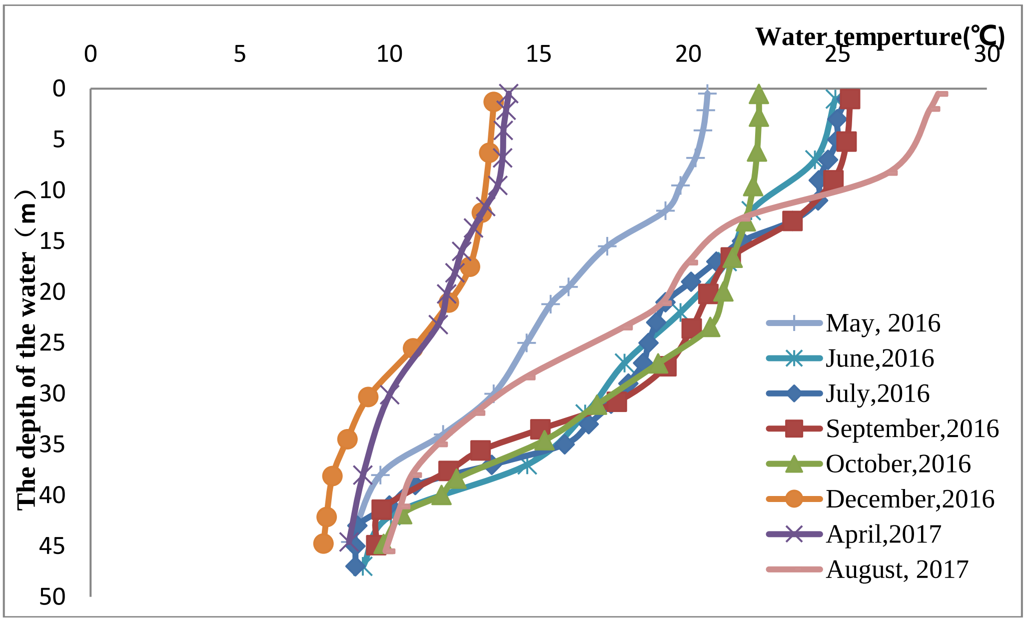


Figure 2. The water temperature structure of Gangkouwan reservoir.

2. Investigation and study on water temperature structure of reservoir

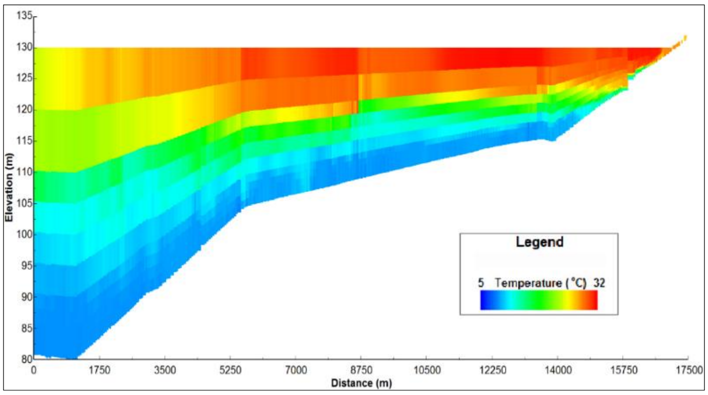
From May to December in 2016, April and August in 2017, the vertical temperature profile, temperature of the water discharged from reservoir, and downstream water temperature of Xijin river were measured respectively with water depth and temperature gauge. The survey results showed that the epilimnion, thermocline, and hysteresis layer are located at the depth of 0~10m, 10~40 m, and more than 40 m. The temperature of deep water varies from 8.5 to 10℃ in a year. The water temperature structure of Gangkouwan reservoir is shown in figure 2. The difference of the measurements between the discharged water and river water temperature is shown in table 1.

Table 1. Water temperature measurements.

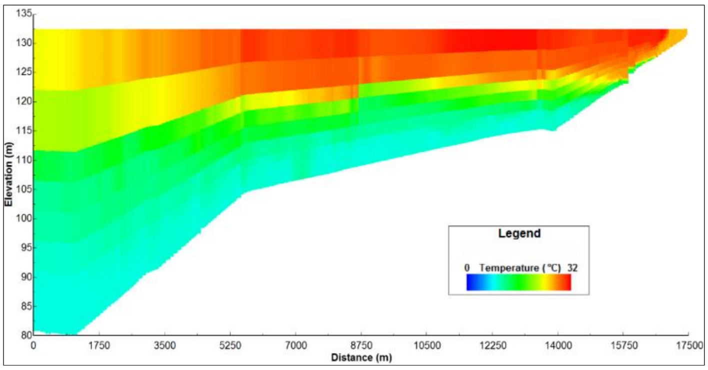
Time	Reservoir water level (m)	The temperature of Reservoir discharged water (℃)	River water temperature (℃)	Difference (℃)
May 14, 2016	128.77	18.2	20.8	-2.6
June 17, 2016	132.74	19.5	27.0	-7.5
July 1, 2016	132.95	20.3	28.0	-7.7
September 21, 2016	131.29	22.6	27.9	-5.3
October 22, 2016	133.82	20.7	22.9	-2.2
December 1, 2016	134.08	12.8	9.1	3.7
April 12, 2017	133.74	11.4	16.8	-5.4
August 20, 2017	133.20	19.8	28.1	-8.3

According to the measurements of water temperature, the maximum temperature difference is -8.3℃ between water discharged from reservoir and river water.

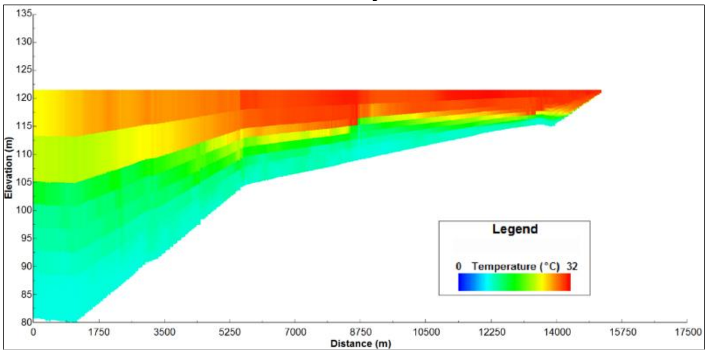
The water temperature measurements in 2 years were used for Environmental Fluid Dynamics Code (EFDC, USA Environmental Agency) model calibration, which was constructed to predict the water temperature structure of Gangkouwan reservoir and the temperature of discharged water in wet, normal, and dry years. The computation grid of the model and simulation results of vertical temperature profile of Gangkouwan reservoir in typical years are shown in figure 3. It is shown that the water temperature structure of Gangkouwan reservoir is stable and stratified in different hydrological years. According to the predictions of EFDC model, the stratification of the reservoir water temperature is evident from April to October with maximum temperature difference of -8.4℃ in June during the wet year.



wet year



normal year



dry year

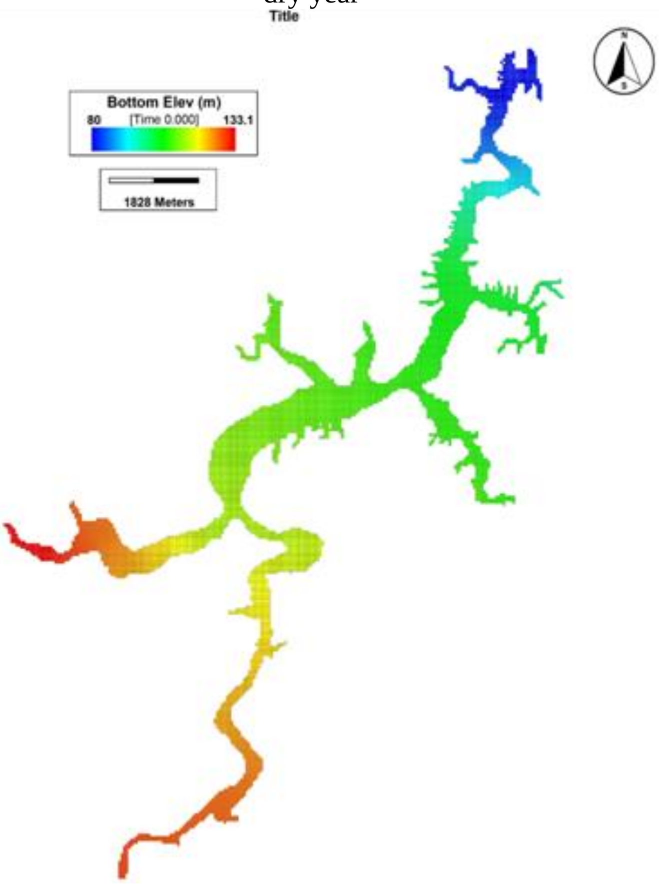


Figure 3. Computation grid for the model and Vertical temperature profile of Gangkouwan reservoir.

3. Effect of low temperature discharged water

3.1. Impact on downstream fish and fishery production

Based on the historical data surveyed by Anhui Survey and Design Instiute of Water Conservancy and Hydropower 25 years ago, there were nearly 40 species of fish had been spotted in Xijin River before the completion of the Gangkouwan Reservoir. In 2015, two aquatic ecological surveys were carried out by means of catch on Shuiyang River, Xijin River, Zhongjin River and Dongjin River. According to the findings, a total of 890 fish were captured, but only 8 species of fish had been caught in Xijin River. In contrast, 33 species of fish were found in Shuiyang River Basin, coupled with 16 species of fish were found in DongjinRiver and Zhongjin River.

According to the ecological investigation, there are warm fishes distributed in local river system, such as *Spinibarbus hollandi*, *Erythroculter ilishaeformis*, *Xenocypris microlepis Bleeker*, *Acrossocheilus fasciatus*. They are adapted to be growing with the water temperature range of 20 ~ 26℃. The metabolism and growth of fish will be slowed down with lower water temperature. Moreover, the required water temperature for these species reproduction (spawning and hatching) is also between 22 and 26℃. It is not suitable for spawing with water temperature below 20℃ [6].

Gangkouwan reservoir is located in the Shuiyang river basin where fish spawning is mainly concentrated from April to July. However, the significant low-temperature water is released from the reservoir in this period. According to the water temperature survey results, the discharged water temperature is below 20℃, which will apparently delay or even stop the fish spawning at downstream.

Compared to the other studies of ecological investigation in the same region, the fish weight is rather big in general at downstream of Xijin River, but the abundance of fish is low. Compared to brood amount in *Siniperca chuatsi* parent fish catched in Shuiyang and Xijin River, 44,000 spawn were found in one fish at Shuiyang River while only 26,000 spawn were distinguished in one fish at Xijin River. According to previous researches on the brood amount of two winter age sexual maturity *Siniperca chuatsi*, the number of spawn normally ranges from 40,000 to 90,000. Therefore, it is obviously that the brood amount of the parent fish in downstream river of the reservoir is subnormal with significant reducing by 14,000. Low temperature water discharged from the reservoir decreased the richness of fish species. In addition, brood amount of the parent fish is lower than the normal range in the downstream Xijin River. Therefore, it is indicated that the low temperature water discharged from reservoir has negative effects on the spawn and growth of fish. The species of the parent fish and brood amount during ecological survey were shown in table 2.

Table 2. The species of the parent fish & brood amount in the ecological survey point.

River name	The species of parent fish	Quantity of catch (tail)	brood amount (thousand grain)
Shuiyang river	*Carassius auratus*	16	1.3~1.4
	Ctenopharyngodon idellus	2	13.9~19.5
	Megalobrama amblycephala	2	44.0~58.2
	Paramisgurnus dabryanus	3	0.9~1.0
	Siniperca chuatsi	**1**	**4.4**
	Hypophthalmichthys molitrix	1	1.55
Dongjin river	*Carassius auratus*	3	1.3~1.4
Xijin river	*Carassius auratus*	4	1.0~1.2
	Siniperca chuatsi	**1**	**2.6**

3.2. Impact on agricultural production

It is 20 kilometers from the dam of Gangkouwan reservoir to the junction of Xinjin River and Dongjin River. There are no other irrigated areas on both sides of the 20 kilometers river except for the Liucun dam irrigation area. Therefore, the Liucun dam irrigation area is the only research site affected by low temperature water in this area. The cultivated land is distributed along the two sides at downstream of Xijin River with an elevation of 62~42 m, and the original irrigation area is 10,000 mu, which is irrigated with water released from Gangkouwan reservoir.

The agricultural production area of Zhufeng community is located in the Tanshu dam irrigation area (8 kilometers away from Liucun dam irrigation area), which is used for agricultural production comparison. Tanshu dam irrigation area is distributed along the two sides of Zhongjin river downstream with a height of 70~55 m (refer to figure 4). The design area is 10,000 mu with irrigated water from Zhongjin River. In addition to water temperature of irrigation, the technology of agricultural production, crop variety, air temperature and climate are basically similar in the Liucun dam and Tanshu dam area. Therefore, the cultivated rice yield can well reflect the level of grain supply and production in the two irrigation areas.

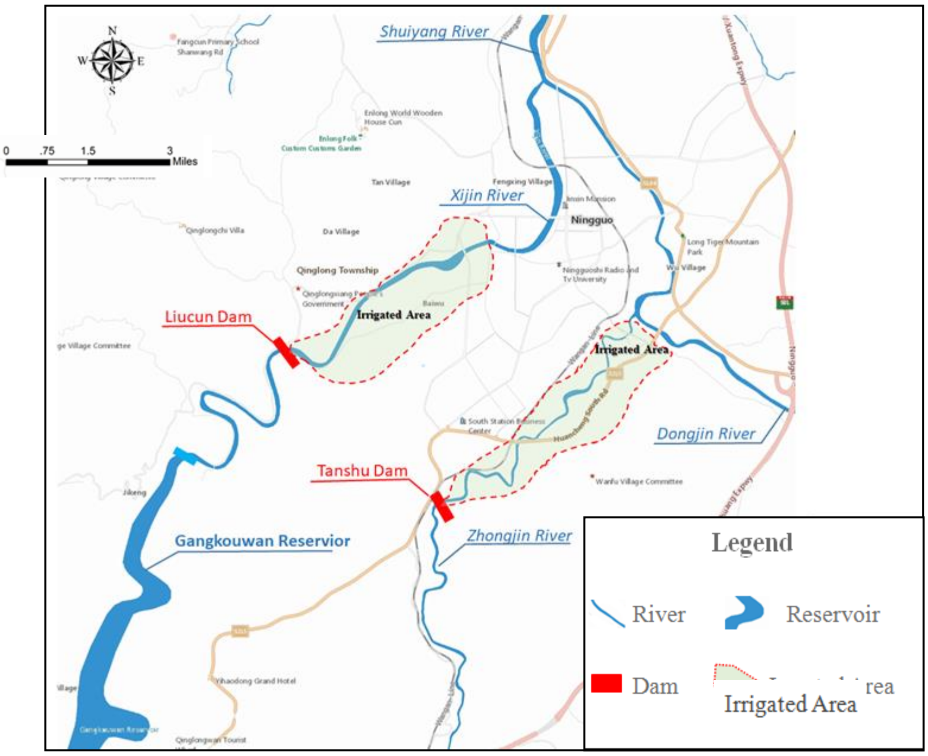


Figure 4. Geographic location of Liucun dam and Tanshu dam irrigation area.

According to the statistical yearbook of NingGuo city from 2002 to 2015, the output of cultivated rice in Xijin community and Zhufeng community are shown in table 3 [7].

Based on the analysis of grain output between two irrigation areas, the difference value between Liucun dam and Tanshu dam irrigation area is similar in the period from 2002 to 2003, and the difference is range from 1.33 to 6.52 kg/mu. But in the period from 2004 to 2015, the output of the Liucun dam irrigation area was significantly lower than that of the Tanshu dam with the difference ranged from 14.65 to 77.20 kg/ mu (except for the outputs in 2009 and 2010). In total, the annual output of Liucun dam irrigation area was lower than that of the Tanshu dam.

The Liucun and Tanshu irrigation area are located in same region with the same cultivation technology, crop variety and meteorological conditions, which imply that the lower agricultural output in Liucun irrigation area is ascribe to the low temperature water released from Gangkouwan reservoir.

Table 3. Comparison of output per mu in two irrigated areas.

Statistical year	Liucun dam irrigation area			Tanshu dam irrigation area			Difference of per mu yield (kg/mu)
	Sown area (mu)	Output (t)	Output per mu (kg/mu)	Sown area (mu)	Output (t)	Output per mu (kg/mu)	
2002	7725	2815	364.40	6465	2398	370.92	6.52
2003	6615	2434	367.95	6510	2404	369.28	1.33
2004	6090	2332	382.92	6930	2801	404.19	21.26
2005	7050	2761	391.63	6615	2716	410.58	18.95
2006	7095	2709	381.82	4110	1680	408.76	26.94
2007	6375	2446	383.69	4080	1719	421.33	37.64
2008	6375	2196	344.47	4650	1844	396.56	52.09
2009	7560	2675	353.84	3870	2154	556.59	202.75
2010	6750	2113	313.04	3810	2126	558.01	244.97
2011	8205	2461	299.94	4020	1498	372.64	72.70
2012	6645	1921	289.09	4860	1694	348.56	59.47
2013	5670	2161	381.13	4260	1686	395.78	14.65
2014	3360	1175	349.70	4590	1890	411.77	62.06
2015	2790	1058	379.21	4530	1945	429.36	50.15
Average	5965.50	2122.0	358.36	4864.	1947.30	399.95	41.59

Gangkouwan reservoir started impounding in 2001~2002, the water level was raised to the normal water level in October 2002. The stable stratified water temperature structure was gradually formed at the initial the operation of reservoir. Thus, the grain production of Liucun dam irrigation area have been affected since 2003(the corresponding statistical year was 2004), while the Tanshu dam irrigation area was not affected by low temperature water all the time.

Before the reservoir discharged low temperature water, the agricultural outputs of two irrigation areas are basically the same. After the low temperature water released from the reservoir from 2003(the corresponding statistical year was 2004), the agricultural outputs of Liucun dam irrigation area have been significantly lower than that of Tanshu dam. In summary, the low temperature water released from Gangkouwan reservoir has a certain degree of influence on outputs in Liucun dam irrigation area, which is the average reduction of 41.6kg/mu in ten years with an average reduction ratio of 10%.

4. Discussion and conclusion

It is found that the vertical water temperature structure in Gangkouwan reservoir is stable stratified type. Based on the investigation during the reservoir operation period, low temperature water discharged from large reservoir could make a great difference on aquatic ecosystem and agricultural production.

Thus, it is needed to take some measures to slow down the adverse effects of low temperature water. Considering Gangkouwan reservoir had been built and operated for nearly 20 years, it is suggested to use the “water curtain wall” to alleviate the negative effects of low temperature water on the ecosystem and agriculture. The principle of "water curtain wall" is to arrange a water temperature control curtain in front of the water intake port in the reservoir. The deeper water with the lower temperature is blocked by the curtain wall. The result of outflow temperature with "water curtain wall" simulated by EFDC model is shown in figure 5. The maximum temperature difference between water discharged from Gangkouwan reservoir and natural river is merely 1.8℃ from May to October.

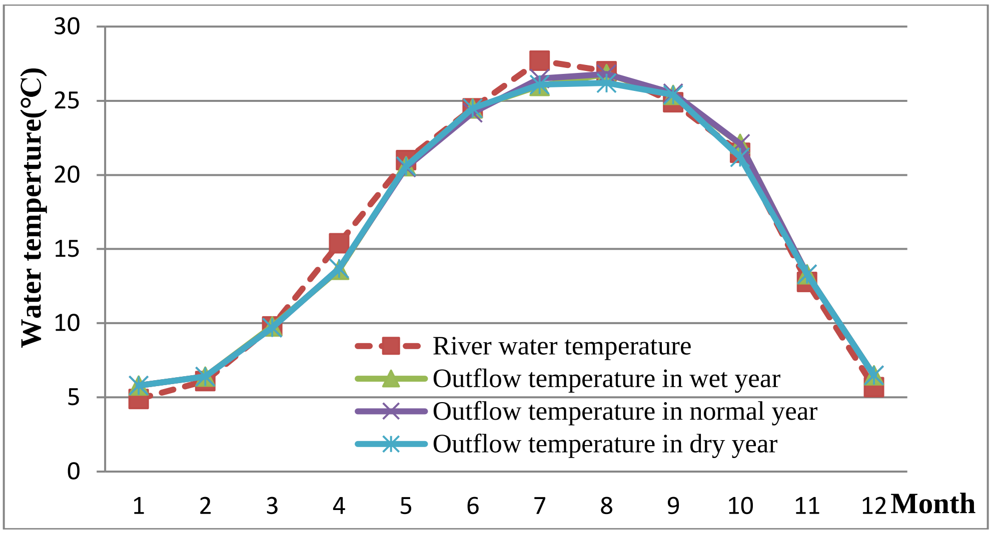


Figure 5. The results of outflow temperature prediction with "water curtain wall".

The difference of water temperature released from the reservoir with and without "water curtain wall" can be theoretically reduced to 6.6℃ [8,9]. The design and installation of water temperature control curtain wall is relatively simple with low cost of construction and maintenance. In addition, the water curtain wall does not affect the power generation processes [9,10]. Because there are many large reservoirs which were built in 20th century without measures designed to alleviate the negative effect of low temperature water, so "water curtain wall" has a good prospect of application.

Acknowledgments

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