IOP Conf. Series: Materials Science and Engineering **392** (2018) 042013 doi:10.1088/1757-899X/392/4/042013

Study On Water Transfer During Ice Period Using The Deep Waters Temperature Of Shuangwangcheng Reservoir

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Abstract. Since the water transfer in the winter from the Project of Diversion from Yellow River to Qingdao is affected by the cold air flow in the north, the surface of the channel water body is prone to icing. In the process of water conveyance, ice accidents such as ice icicles, ice jams and ice dams often occur, causing serious damage to hydraulic structures such as pumping stations, gates, and channel side slopes along the line, it not only affects the safety of water delivery, but also affects the efficiency of water delivery. In view of the local meteorological conditions and the characteristics of the channels in the Shouguang water conveyance section, this paper proposes the method for water conveyance by using the deep water temperature of the Shouguang Shuanghuangcheng Reservoir for ice-free water conveyance, calculating the change of water temperature and channel non-freezing length during water conveyance based on water body heat balance theory, providing the new ideas and theoretical basis for solving water transport problems in the winter.

1. Introduction

The Project of Diversion of Yellow River to Qingdao was completed in 1989. Due to the constraints on economic and technological conditions at that time, the automation controlled equipment for the channel lags behind. Recently, with the rapid development of the economy in the area along the line, the demand for water consumption has gradually increased. The methods which convey water under the ice sheet cannot solve the current problems. Currently, researchers have done a lot of research on taking water from different layers based on water temperature in reservoirs of water quality, water ecology, etc[1]. Some reservoirs often use the curtain method to increase the temperature of water discharged from the reservoir and achieved significant results[2].Numerical simulation has also achieved certain research results in this respect [3]. Gao Xueping used a three-dimensional k-ε turbulence model to provide an effective method of predicting water temperature in reservoirs[4]. The main factors affecting the reservoir bottom waters temperature include the incoming water temperature , ground temperature , and density current , etc . Hu Ping [5] used NAPRWT numerical analysis software to analyze the condition that when the reservoir is in the absence of density current and other special circumstances, the temperature of the reservoir of the bottom of the warm water layer in cold regions up to 4 ~ 6 °C due to the maximum density of water at 4 °C.Over the years , surface water source heats pump technology has become increasingly sophisticated , and the water intake program has also shown diversified developments [6] . The main methods adopted are floating pontoon water intake , artificial lake water intake and water infiltration , and so on . These lay the technical foundation for transferring the warm water of the bottom layer of the reservoir of the winter .

The most common method of water transport without ice caps included heat insulation method and the method of warming [7].The thermal insulation method establishes insulation boards on the channels to make the open channel darken. This method is mainly applicable to short-distance small-sized water conveyance channels. The warming method generally chooses areas where groundwater resources and geothermal resources are abundant, and extracts underground hot water for melting ice water conveyance [8].Based on the Shouguang hydrogeological report and the shallow geothermal energy surveyed report, this paper analyzes the conditions of the groundwater resources along the Shouguang section of the Project of Diversion of Yellow River to Qingdao. The geothermal energy in this area is relatively abundant, but it is located in the middle of Shouguang micro-slope plain area, adjacent to Laizhou Bay. The groundwater resources are relatively scarce, and over-exploitation is serious, and the degree of groundwater mineralization is generally high. Meanwhile, the hydrological and meteorological conditions in the area and the characteristics of water transfer of the Yellow River to the Qingdao are analyzed. The abundant shallow geothermal energy resources in this area have a good heat preservation effect on winter reservoirs, which ensures that the Double King City Reservoir has ample heat storage capacity. Therefore, this paper proposes the method of using the water temperature at the deep of the Shuangwangcheng Reservoir, and adopts the method of diversion water to melt the ice to realize the water conveyance without ice sheet. Overview of the study area as shown in Figure 1.

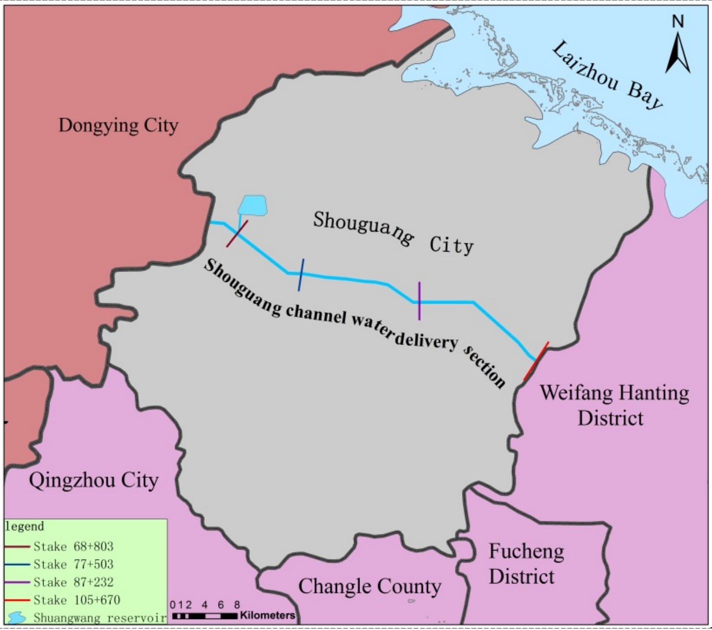

Figure 1. Research area overview.

2. Not freeze the length calculation theory

This article is based on Soviet scholars' research achievement on the thermal balance of water body [9]. It uses the thermal balance method to calculate the length of unfreezing. The Water body heat income is equal to expenditure and can be expressed as

$$E_w + E_l + E_k + E_s = E_c + E_e \quad (1)$$

In the formula, E_w is the total heat storage of water at the channel entrance; E_l is the heat which the ground bed supply to the water body; E_k is the heat converted from the channel water body energy loss; E_s is the heat of the channel surface to absorb solar radiation; E_c is be the loss of heat of the channel water surface and atmospheric convection ; E_e is the heat loss due to evaporation of the channel water.

According to Eq. (1), when the sum of the heat storage and the income heat of the channel water in winter is greater than the sum of the total calories consumed during the water conveyance, the channel water will not be frozen (means the water temperature is greater than 0°C) [10]. The length of the water body is called the length of non-freezing. That is, the theoretical non-freezing length L_t can be expressed as

$$L_t = E_w / (E_c + E_e - E_l - E_k - E_s) \qquad (2)$$

3. Calculation of each thermal equilibrium component

In formula (1) each thermal equilibrium component is calculated as follows:

（1）Total heat reserve E_w

Set a time period for 24 hours, the total heat storage capacity E_w according to the heat capacity of water is expressed as

$$\begin{aligned} E_W &= 86400 Q_m T_m \rho c \\ &= 3.6174 \times 10^5\, Q_m T_m \times 1000\ kJ/d \end{aligned} \qquad (3)$$

Wherein, Q_m is the sum of reservoir diversion flow Q_r and channel incoming water flow Q_c, m^3/s; ρ is the density of water, $1000 kg/m^3$; **c** is the heat capacity of water, $1 kcal/(kg \bullet ^\circ C)$; 86400 is a constant that converts time of one day into seconds, s/d; T_m is the temperature of the water after mixing the reservoir diversion and the channel water, $^\circ C$; T_r is temperature of reservoir diversion water, $^\circ C$; T_c is temperature of channel water, $^\circ C$; T_m can be expressed as

$$T_m = (Q_r T_r + Q_c T_c) / (Q_r + Q_c) \qquad (4)$$

(2) The heat of the Geothermal of per meter channels bed supplied to the body of water E_l

The heat of the Geothermal of channel bed supplied to the body of water includes the heat which the per meter channel bottom transfer to water body E_{gr} and the heat transferred to the water body through the slope E_{sl} ; If the water body temperature is greater than the channel bed temperature, it is considered as a heat expenditure item.

The heat which the per meter channels bottom transferred to the water body E_{gr}

$$\begin{aligned} E_{gr} &= 24 \lambda A_1 (T_{gr} - 0.5 T_m)\ kcal/(m \bullet d) \\ &= 100.48 \lambda\, A_1 (T_{gr} - 0.5 T_m)\ kJ/(m \bullet d) \end{aligned} \qquad (5)$$

Wherein, A_1 is the area of the bottom of the water per meter of channels length, m^2/m; T_{gr} is the average ground temperature of the channels bottom, $^\circ C$; λ is the heat transfer coefficient of channel concrete lining, $kcal/(m^2 \bullet h \bullet ^\circ C)$;24 is the number of hours in a day.

The heat which the per meter canal slope transferred to the water body E_{sl}

$$\begin{aligned} E_{sl} &= 24 \lambda A_2 (T_{sl} - 0.5 T_m)\ kcal/(m \bullet d) \\ &= 100.48 \lambda\, A_1 (T_{sl} - 0.5 T_m)\ kJ/(m \bullet d) \end{aligned} \qquad (6)$$

Wherein, A_2 is the area of the slope under the water per meter of channel length, m^2/m; T_{sl} is the average ground temperature of the slope of the channel, $^\circ C$.

（3）The heat converted from the loss of kinetic energy per meter of channel body water. E_k

$$E_k = 8.64 \times 10^5\, hVIA\ kJ/(m \bullet d) \qquad (7)$$

Wherein, h is water depth, m; V is flow rate, m/s; I is channel longitudinal slope; A is the water surface area per meter channel, m^2/m.

（4）The heat loss caused by water convection per meter channel. E_c

$$E_c = 50(T_t + T_m)V_w / (0.5 + 0.1V_w)\ kcal/(m^2 \bullet d) = 209.34A(T_t + T_m)V_w / (0.5 + 0.1V_w)\ kJ/(m \bullet d) \quad (8)$$

Wherein, T_t is negative temperature absolute value, $^\circ C$; V_w is the wind speed, *m/s.*

（5）The loss of heat generated by evaporation of water surface per meter channel. E_e

$$E_e = 130(E - e)V_w / (0.6 + 0.1V_w)\ kcal/(m^2 \bullet d) = 544.28A(E - e)V_w / (0.6 + 0.1V_w)\ kJ/(m \bullet d) \quad (9)$$

Wherein, *(E-e)* is the difference in atmospheric saturation, *pa*.

（6）The solar radiant heat absorbed by the water surface per meter channel. E_s

$$E_s = PAS_n\ kcal/(m^2 \bullet d) = 4.186PAS_n\ kJ(m \bullet d) \quad (10)$$

Wherein, P is the absorption coefficient of water surface to the solar radiation; S_n is solar radiation, $kcal/(m^2 \bullet d)$.

4. Utilize the bottom water temperature of Shuangwangcheng Reservoir to carry out the glacial water delivery

The Shuangwangcheng Reservoir is located in the north of Yanjiawu Village, Shouguang City, Shandong Province, geographical coordinates is 118.7N, 37.1E, covering an area of 7.79km2. The basic parameters of the reservoir are as follows: the dead water level is 3.9m, the designed impoundment water level is 12.5m, and the designed storage flow is 8.6 m3/s, the outbound flow rate is 28m3/s. The research area is located in the middle latitude zone and belongs to the continental climate in the warm temperate monsoon region. The annual average sunshine duration is 2548.8 hours, and solar radiation is the lowest in December.The average temperature for many years are 12.7°C. The average minimum temperature for January is -3.1°C. The annual average relative humidity is 66%. The average annual evaporation is 2029.5mm, the maximum is 2531.8mm, and the minimum is 1620.2mm. The dominant wind direction for the whole year is south east by south wind, northerly wind prevails in winter, and the average annual wind speed is 3.1m/s. The largest wind speed is in April, with an average of 3.9 m/s. According to the actual situation of snowfall in Shouguang City, the snowfall in this area has little impact on the water supply during the glacial period, so it is neglected. According to the material, the characteristics of the channel section of the Shouguang section of the Project of Diversion of Yellow River to Qingdao were analyzed, and the Shouguang section was roughly divided into three sections for calculation of the non-freezing length. The three sections include the Shuangwangcheng reservoir entrance section to the Songzhuang pump station section (stake 68+803-77+503), Songzhuang Pump Station Section to Mihe Section (stake 77+503-87+232) and Nihe Section to Shouguang Boundary Section (stake 87+232-105+670), The basic parameters are shown in Table 1.

Tab.1 The basic parameters of each channel section

	Channel segment (Stake 68 + 803-77 + 503)	Channel section (stake 77+503-87+232)	Channel section (stake 87+232-105+670)
Slope factor	2.5	2	2
Ground temperature at the bottom of the channel, ℃		0.5	
Ground temperature on the slope of the channel, ℃		0.1	
Area of the water bottom of the channel length per meter, m^2	15.5	5.8	8.4
Area of the underwater slope the channel length per meter, m^2	13.5	13.4	15.65

Heat transfer coefficient of channel concrete lining, $kcal/(m^2 \bullet h \bullet ℃)$		24.7	
Absorption coefficient of water facing the solar radiation		0.93	
Water surface area per meter of channel , m^2	28	17.8	22.4
Solar radiation , $kcal / (m^2 \bullet d)$		114	
Negative temperature absolute value, ℃		3.1	
Wind speed ,*m/s*		3.1	
Difference in atmospheric saturation ,*pa*		1.665	
Depth of water ,*m*	2.5	3.0	3.5
Flow rate ,*m/s*	0.653	0.975	0.603
Channel longitudinal slope	1/13500	1/9000	1/20000
Design flow , m^3/s	35.5	34.5	32.5

5. Segment calculation

Conveying water from the Shuangwangcheng Reservoir to the border of Shouguang City , the total length of the channel are 36867m ; Actually , it is the non-freezing length that needs to be calculated in this paper . Using the theory of heat balance to analyse the effect of water diversion of the ice-free covers when the Shouguang sections channel under the condition of different water temperature and water intake . Because there is a difference in the geometry section in the whole channel of the Shouguang section of the Project of Diversion of Yellow River to Qingdao , the calculation of the non-freezing length needs to be calculated in sections . According to the existing channel data , it is roughly divided into three sections . The water in the cited reservoir passes through Songzhuang and then flows through the Mihe section . Finally , it exits the border of Shouguang City . The lengths of the three channels are known to be 8700m , 9729m , and 18438m , respectively . Thus , the non-freezing total length of the channel can also be theoretically expressed as

$$L_t = L_1 + L_2 + \cdots + L_{n-1} + L_{t,n} \cdots\cdots (L_{t,n} \le L_n) \tag{11}$$

Wherein, L_n (n=1、2、⋯、n) denotes Nth channel actual length; $L_{t,n}$ (n=1、2、⋯、n) denotes the non-freezing length of the section which is calculated under the thermal reserves owned by the water in the nth channel.

The total heat reserve remained in the channel water from the previous channel to the subsequent stage can be expressed as

$$E_{w,n+1} = \frac{L_{t,n} - L_n}{L_{t,n}} E_{w,n} \cdots\cdots (n \ge 1 \bigcup L_{t,n} \ge L_n) \tag{12}$$

Wherein, $E_{w,n}$(n=1、2、…、n) denotes the total heat reserve of the nth channel canal water.

Eq.(13) can be obtained from Eq. (3). The channel water temperature at the end of segment Nth is

$$T_{e,n} = E_{w,n+1} / (3.6174 \times 10^8 Q_{Df,n+1}) \cdots\cdots (n \ge 1) \tag{13}$$

Wherein, $T_{e,n}$ (n=1、2、⋯、n) denotes the channel water temperature at the end of the segment Nth; $Q_{Df,n}$ (n=1、2、⋯、n) denotes the Nth channel design flow.

According to Eqs. (1)-(13), 9 different conditions were analyzed and calculated to obtain the channel water temperature at the end of segment Nth and the non-freezing length of the last channel under the remaining total heat reserves the water temperature .The results are shown in Table 2.

Tab.2 the Project of Diversion of Yellow River to Qingdao (Stake 68+803-105+670) segment calculation results

category	The water outlet temperature of the reservoir.℃	Mixing ratio (Q_r : Q_c)	Combined water temperature℃	(Stake 68+803-77+503) Water temperature at the end of the segment,℃	(Stake 77+503-87+232) Water temperature at the end of the segment,℃	(Stake 87+232-105+670) Water temperature at the end of the segment,℃	（Stake 87+232-105+670） $L_{总3}$（m）
Condition 1		1: 1	0.25	0.165	0.107	/	12165.96
Condition 2	0.5	1: 2	0.167	0.082	0.022	/	2650.51
Condition 3		2: 1	0.33	0.247	0.191	0.103	20937.12
Condition 4		1: 1	0.5	0.411	0.361	0.265	36558.29
Condition 5	1	1: 2	0.333	0.247	0.192	0.102	20922.88
Condition 6		2: 1	0.667	0.576	0.530	0.427	50078.50
Condition 7		1: 1	1	0.905	0.869	0.752	72269.09
Condition 8	2	1: 2	0.666	0.576	0.530	0.427	50057.20
Condition 9		2: 1	1.334	1.234	1.207	1.076	89750.55

Analysis of results: It can be seen from the calculation results that, under the assumed 9 kinds of working conditions, the water temperature of the channel water at the end of the first two sections is greater than zero degrees Celsius, that is, the water transport under the ice-free cover in winter has realized. When the channel water continues to flow into the third channel, the non-freezing length of the canal section in working condition 1 and working condition 2 is less than the actual length of the section which is 18438 m. Therefore, water conveyance under the ice-free cover for Shouguang section of the Project of Diversion of Yellow River to Qingdao cannot be fully realized in the case. The water temperature of working conditions 3 to working conditions 9 is greater than 0 °C when channel water flow out of Shouguang City, ensuring that water conveyance under ice-free covers in the entire section completely realized.

6. Conclusion

According to the theory of heat balance, the water temperature of the deep of Shuangwangcheng reservoir is used for the water conveyance in the glacial period by analyzing the geometric section of the water conveyance canal from the Shouguang section of the Project of Diversion of Yellow River to Qingdao, and calculating the conditions for ice-free water transport in winter under different operating conditions .It can be seen from the calculation results that the non-freezing length is directly proportional to the reservoir diversion volume and the reservoir diversion temperature. Therefore , when the theoretical non-freezing length of the channel and the actual non-freezing length are calculated , if there are deviations , the mixing ratio of water diversion from the channel can be appropriately adjusted . In order to increase the non-freezing length of water transport during the glacial period in the project, the proportion of reservoir water diversion can be increased. At the same time, certain engineering measures can also be adopted during the water transport process to optimize the influencing factors of the heat expenditure item and reduce the heat loss of the water body. It is feasible to use the water temperature of the reservoir deep for the water transfer of ice period . The combination of the reservoir and the channel during the water transfers process of ice period will greatly improve the efficiency of the water transfer of the Project of Diversion of Yellow River to Qingdao and ensure the safety of water delivery of the channel . Meanwhile , it provided new ideas of the water transfer projects during ice period in other cold regions .

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