Study on Optimal Living Water Scheme for Typical Cut-off Surge in Plain River Network Area - Taking Wanlichangcheng River in Shishan Town as an Example

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Abstract. The dead-end creek, as a blind area for water exchange, has always posed a challenge in improving the water environment of the river network area. Based on an investigation and analysis of the current water quality and live water conditions of the Wanlichangcheng River, coupled with the overall water regulation strategy for the Jiefang River System, various live water schemes for the Wanlichangcheng River are proposed. Utilizing one-dimensional hydrodynamic and water quality mathematical models, a comparative analysis and evaluation of each scheme are conducted. Taking into account factors such as economic cost, technical feasibility, and the effectiveness of live water scheduling, the cascade gate and pump scheduling scheme is deemed as the optimal live water scheduling approach. This serves as a scientific foundation for the implementation of live water scheduling in typical dead-end tributaries within the river network area.

Keywords: Wanlichangcheng River; Water Scheduling for Live Water; Mathematical models of water quality; Water environment

1 Introduction

Live water scheduling is a way of water resource allocation, an important part of water governance, and an important means of transforming "water damage" into "water conservancy".[1] Through human intervention in the natural hydrodynamic processes of rivers, the introduction of transit fresh water enables the directional and orderly flow of water bodies within the main channels of the river network and promotes the rate of renewal of the water bodies as well as the virtuous cycle, thus improving the ecology of the water environment of the river, hydrodynamics, and the water landscape in order to increase the efficiency of the in situ restoration system[2].For example, South Korea has effectively improved the ecological environment of the water

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shed by pumping water from the Han River, collecting groundwater and rainwater, and recharging the Cheonggyecheon River with treated wastewater from sewage treatment plants.[3] In 2010, Wuxi, Changzhou and other riverine areas improved the water environment of the plains river network by using the tidal diversion of the Yangtze River on the basis of pump diversion, and the improvement effect was obvious[4].

The current living water scheduling project has been widely used. Currently, the living water scheduling project is widely employed in the water environment management projects in the plain river network area, and has greatly improved the water quality of the river. However, in engineering practice, it has been found that large-scale live water circulation cannot solve the hydrodynamic problems of cut-off gushing. The water exchange effect of cut-off gushing is not obvious and leads to the deterioration of the water quality of the river. This has become a black spot for river network area water quality improvement projects, seriously affecting the implementation of the water environment project in the area. As a blind area with weak water exchange, how to promote the activation of water bodies through certain engineering scheduling measures has always been a difficult point in the improvement of the water environment in the disconnected river.

This study aims to find the optimal living water scheme by conducting a study on the live water scheduling of the Wanlichangcheng River in the Jiefang River System. This will provide a reference for the improvement of the hydrodynamics of typical cut-off branch surges in the river network area.

2 Study Area

Jiefang water system is located in the eastern part of Shishan Town, with a catchment area of about 71.82km^2.The river systems in the basin present a "two vertical" (Jiefang River, Sanjiangkou River)) and "three horizontal" (Liu Bei River,Wanlichangcheng River, Hongqi River, Xinshaluodi River, Nantang River) pattern.The total length of rivers and streams in the basin is 56.82km, and they share the responsibility for the drainage, irrigation, ecology, and landscape of the Jiefang water system.

Wanlichangcheng River is located in the eastern part of the Jiefang River system, with a total length of 3.5km and a catchment area of about 19.97km^2. The basin includes 8 villages and industrial parks, and the current water quality of the river is mostly inferior to Class V.

The natural flow of the river runs from east to west, with water supplied from two upstream reservoirs. Due to the limited water supply from these two reservoirs and the need to maintain their own landscape water levels, they are generally in a non-draining state under normal conditions. The current situation of the Wanlichangcheng River reveals problems of low efficiency of water displacement and insufficient hydrodynamic force, with an average flow velocity of only 0.01m/s. The main reason is that the Wanlichangcheng River is situated higher in the east and lower in the west, and the river slope is steep, resulting in the current natural water flow direction being opposite to the direction of water replenishment. Furthermore, the river is long, and the water replenishment in the river mainly relies on the water level of the Jiefang River for supplementation, which is likely to cause reversed flow directions and lead to pollutant retention in the river.

The location of the Jiefang River System and the Wanlichangcheng River is shown in Figure 1.

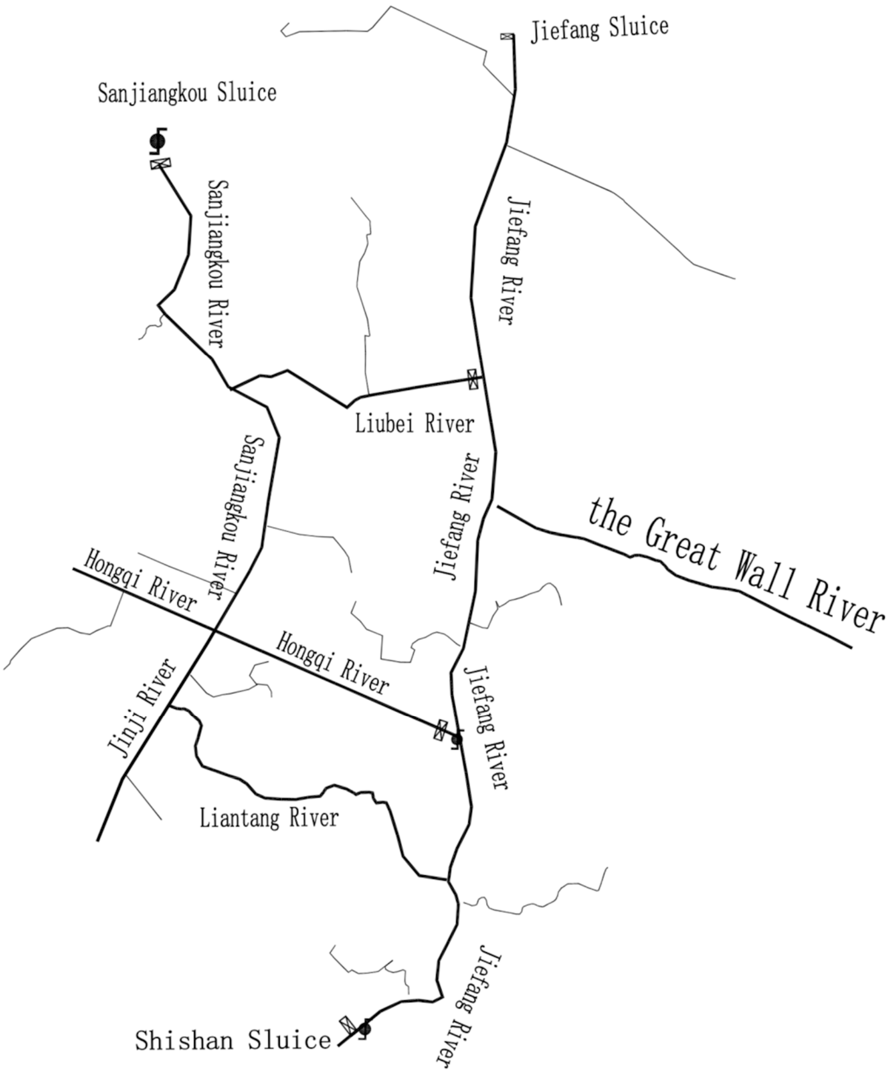


Fig. 1. Map showing the location of the Jiefang river system and the Wanlichangcheng river

3 Research Methodology

3.1 Feasibility Analysis of Live Water Scheduling

For the treatment of the water inflow environment of inland rivers, a water head difference is formed through the regulation of sluice pumps. This improves the hydrodynamic conditions of river inflow and enhances the water exchange capacity. Reference can be made to the experience of live water engineering in relevant rivers. For example, Kunshan City draws water from the Yangtze River to promote the smooth flow of fresh water in the polder area[5].The first Songhua River originally selected a minimum flow value based on an 80% guarantee rate for 7 consecutive days for its design flow. However, through calculations, it was found that if the flow rate doubled, various sources of pollution would not need to be cut to meet the water quality requirements[6].Initially, the first Songhua River was designed to have a minimum flow of 80% of the guaranteed continuous flow. Considering the water quality and pollution monitoring indicators of the Wanlichangcheng River, there is a need for comprehensive consideration of both water quality and hydrodynamic enhancement as management objectives[7]. When the water exchange rate reaches 70%, the water quality will improve. When the water exchange rate reaches 70% or above, it is considered that a better water circulation effect can be achieved.

3.2 Hydrodynamic and Water Quality Modelling

MIKE11 is a one-dimensional river and river network simulation software developed by DHI, a Danish water environment research institute, which is mainly used in flood control, water resource protection and water conservancy project research, planning and evaluation.MIKE11 can simulate various hydraulic structures such as sluices and pumping stations, and complete complex scheduling conditions simulations according to needs. Chinese scholars have conducted extensive research on the application of MIKE 11 in river water bodies, and it has been successfully applied in areas such as simulating hydrodynamic changes before and after engineering projects, simulating the transport and diffusion of pollutants in sudden water pollution accidents, and simulating and predicting water quantity and quality. In this analysis, the MIKE11 platform was used to establish a one-dimensional hydrodynamic water quality model to analyse the liberation water system.

4 Live Water Scheduling Programme Setup

4.1 Single Inland Waterway Gate and Pump Scheduling Programme Set Up

Considering the two scenarios that the control gates are constructed on the main stem of the river (Jiefang River) or on Wanlichangcheng River, the river network is shown in Figure 2.

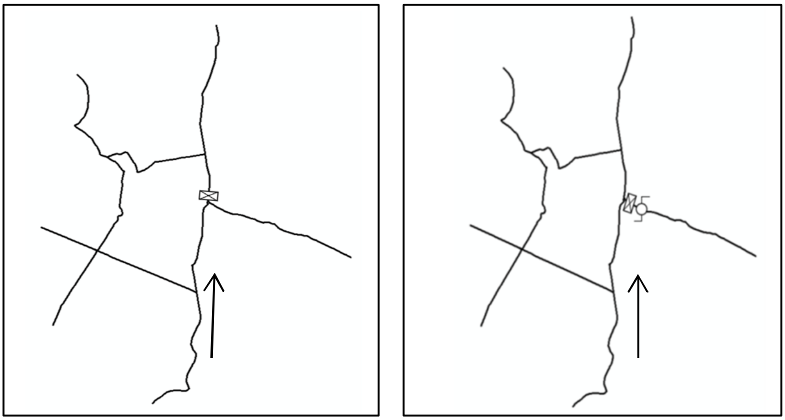
In the actual simulation process, in order to comprehensively reflect the efficiency of live water optimisation, three different working conditions were considered, with a view to selecting the relatively optimal live water scheme. A total of three "storage-discharge" processes (one per day) were simulated in this study.

(1) Diversion scheme 1

During this diversion process, the scheduling of other main streams and surges is not taken into account, and the gates of LiuBei River and Hongqi River are closed, so that the live water introduced from Shishan Pumping Station only passes through Jiefang River. At the same time, in order to reduce the scouring of the river, the gate opening is set to 0.1m uniformly, and the specific scheduling regulations are shown in the Table 1.

(2) Diversion scheme 2

Control gates and pumping stations will be built in the downstream section of Wanlichangcheng River, after the end of the liberation of the River to draw clear scheduling, from Jiefang River diversion of water into Wanlichangcheng River, the same set of three scheduling conditions, the specific scheduling protocols are shown in the Table 2.



(a) Sluice scheme 1 (b) Sluice scheme 2

Fig. 2. Schematic diagram of scheduling of control gates located in different river surges

Table 1. Gate and pump live water scheduling regulations

Serial number	Name of gate/pump (Mileage)	condition 1-1	Condition1-2	Condition1-3
1	Liubei Sluice (50)		cloture	
2	Sanjiangkou Sluice (50)		cloture	
3	Wanlichangcheng Sluice (3680)	Pre-gate level to 1.7m	Pre-gate level to 1.9m	Pre-gate level to 2.1m
			Opening 0.1m	
	Shizishan Pump / $10^4 m^3$	50.58	72	93.96
live-water route		The water flow is from south to north; $6m^3/s$ is introduced in Lion Rock Pumping Station, and the water discharge location is Liberation Station		

Table 2. Gate and pump live water scheduling regulations

Serial number	Name of gate/pump (Mileage)	condition 1-4	Condition1-5	Condition1-6
1-3	Liberation Gate (10200)	Diversion of water is fully open on the first day and closed from the second day onwards to start water storage		
1-4	Wanlichangcheng River Pumping Station (3680)	Build a new pumping station with a maximum flow rate of $1m^3$ /s, and stop diverting water when the water level in the surge reaches the corresponding level.		
1-5	Miles Surge Gate (3680)	Pre-gate level to 1.5m	Pre-gate level to 1.7m,Opening 0.1m	Pre-gate level to 1.9m
	Shizishan pump diversion volume / $10,000m^3$	17.28	21.6	25.92
	live-water route	The water flow is from south to north; $6m^3$ /s is introduced in Lion Rock Pumping Station, and the water discharge location is Liberation Station		

4.2 Scheduling Programme Setup For a Cluster of Ladder Gates and Pumps

Due to the overall length of Wanlichangcheng River, this study proposes to set up a stepped gate pumping station at river mileage 3700 and 1850 to simulate the effect of live water scheduling under various working conditions, and similarly carry out the process of "water storage - discharge" three times, the simulation schematic diagram is shown in Figure 3 and 4, the specific scheduling procedures are shown in Table 3.

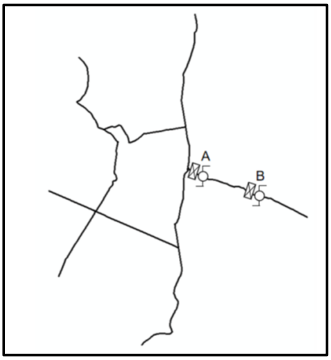


Fig. 3. Schematic diagram of gate and pump arrangement

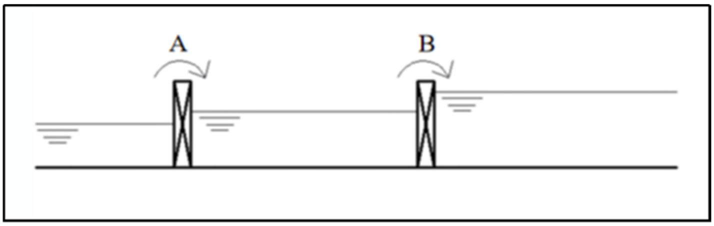


Fig. 4. Cross-section of the scheduling of Wanlichangcheng River ladder Sluice and pumps

Table 3. Locks and Pumps Live Water scheduling Regulations

Serial number	Name of gate/pump (Mileage)	condition 2-1	Condition 2-2	Condition 2-3
1	Wanlichangcheng Pump A (3700)	Divert water to 1.3m	Divert water to 1.5m	Divert water to 1.7m
	Actual pumping volume / 10,000m^3	4.32	6.48	8.64
	Wanlichangcheng Sluice A (3700)		Opening 0.1m	
2	Wanlichangcheng Pump B (1850)	Start-up water level 1.3m	Start-up water level 1.5m	Start-up water level 1.7m
			Shutdown water level 1m	
	Wanlichangcheng Sluice B (1850)		Opening 0.1m	
live-water route			Shishan pumping station to introduce 6m^3 /s, water discharge location for liberation station	

4.3 Topological Guide Wall Scheduling Scheme Setup

Topological deflector wall serves as a novel in-situ deflector technology for disconnected river surges[8]. Given that the river channel of the Wanlichangcheng River is vast, averaging a width of 20m, it is proposed to install a section of diversion wall in the centre of the riverbed. The wall is constructed from prefabricated reinforced concrete, and its height exceeds the average water level of the river's internal surges over many years. To minimize the impact on the flood carrying capacity of the Jiefang River, a combination of sectional gates and the diversion wall is employed. A sectional gate is erected at the confluence of the Jiefang River and the Wanlichangcheng River, and the operation of opening and closing the gates can be determined based on the objective of live water management. The structural schematic diagram is shown in Figure 5.

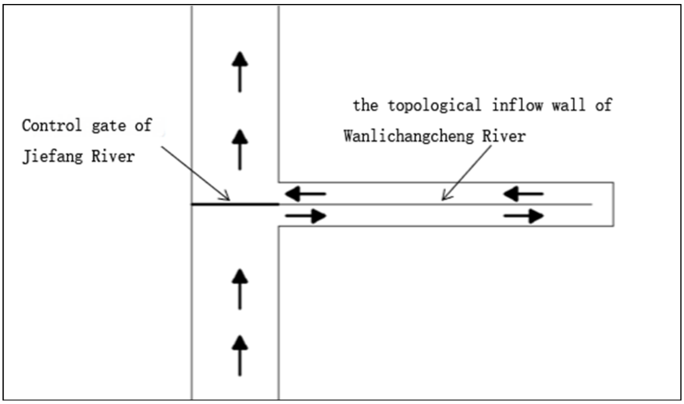


Fig. 5. Arrangement of Wanlichangcheng River topological deflector wall

In the model setting, the river network is generalized into Wanlichangcheng River1 and Wanlichangcheng River2. The simulation time is set to be consistent with the current scheduling, and 5 different diversion flows are simulated respectively. At the same time, the Liubei sluice gate and Hongqi sluice gate are closed. The typical sections of the downstream section of the Jiefang River and Wanlichangcheng River are taken as examples to reflect the active water effect of the topological diversion wall.The specific details are shown in Figure 6 and Table 4.

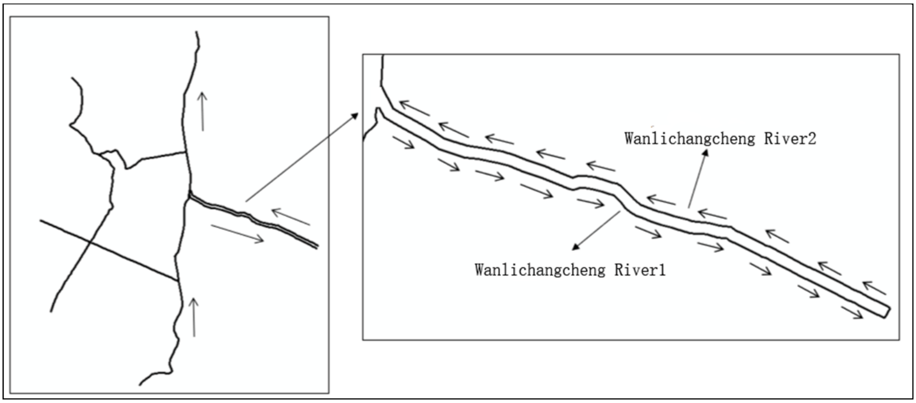


Fig. 6. The topological inflow wall river network in the one-dimensional model

Table 4. Model gate pump scheduling protocol settings

water-induction point		3-1	3-2	3-3	3-4	3-5
Shishan Pumping Station	Flow rate/m^3 /s	1	2	3	4	5
	Diversion time per day/h			8		
	Volume of water diverted/ 10,000m^3	14.4	28.8	43.2	57.6	72
live-water route		Water flow from south to north; along the course of Hongqi River, Liu Bei River gate are closed				

5 Analysis of the Effects of Live Water Scheduling

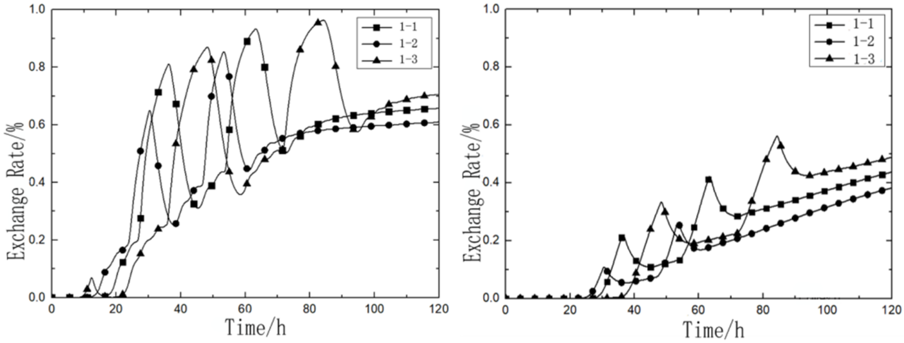
5.1 Analysis of the Results of the Simulation of a Single Inland River Lock and Pump Scheduling

The simulation results for the scheduling of a single inland river gate-pump system are shown in Figures 7 and 8, as well as Table 5.

(1) On the whole, the concentration of pollutants in the upwelling gradually decreased during the diversion period, and gradually increased during the drainage period. (2) Higher water exchange efficiency can be gradually achieved only after multiple drainage processes. (3) The higher the water level in front of the gate, the better the water change effect, and the main enhancement effect is reflected in the upper part

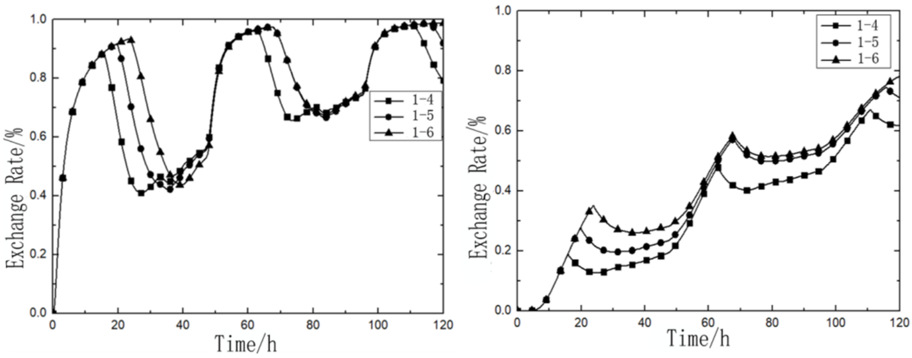
of the river swell. (4) Under the same conditions, the scheme of controlling the sluice at Wanlichangcheng River results in higher water exchange law, shorter time and less water requirement; taking the downstream section as an example, when the water head difference is consistent, the average increase rate of water exchange in the former water exchange process is 25%, while that in the latter is only 9%.

In summary, the live water scheme of building the control gates at Wanlichangcheng River is more preferable.



(a) Downstream section (b) Upstream section

Fig. 7. Results of scheduling water exchange rate with the control gate located on Jiefang River



(a) Downstream section (b) Upstream section

Fig. 8. Results of water exchange rate with the control gate located on Wanlichangcheng River

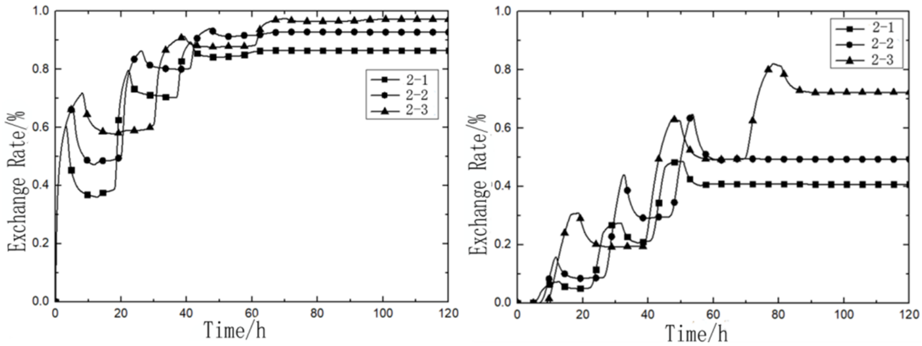
Table 5. Water body exchange rates under single instream gate and pump scheduling

Programme	Working condition	Location (mileage)	Point	Water exchange rate/h				Max velocity /m/s
				25 %	50%	75 %	Max/%	
The control gate is located at Jiefang River	1-1	Upstream section (1000)	1#	58.7	>120	>120	43.7	3.69
		Downstream segment (3350)	2#	27.3	72	>120	65.8	

The control gates are located in Wanlichangcheng River	1-2	Upstream section (1000)	3#	83	>120	>120	38.2	4.31
		Downstream segment (3350)	4#	24.5	64.4	>120	61	
	1-3	Upstream section (1000)	5#	45.4	>120	>120	48.7	4.96
		Downstream segment (3350)	6#	35.2	68.5	>120	70.6	
	1-4	Upstream section (1000)	7#	51.7	98.5	>120	61.7	3.57
		Downstream segment (3350)	8#	1.7	39.9	95.6	79.3	
	1-5	Upstream section (1000)	9#	49.2	80.9	>120	71.1	4.20
		Downstream segment (3350)	10#	1.7	41.5	95.5	91.9	
	1-6	Upstream section (1000)	11#	36	62.2	115.4	78	4.59
		Downstream segment (3350)	12#	1.7	45.5	95	98.6	

5.2 Analysis of the Results of the Simulation of the Scheduling of a Group of Ladder Gates and Pumps

As the first section of the step gate pump only needs to introduce live water from the Jiefang River, the maximum amount of clear water introduced is 86,400m^3, resulting in a relatively lower volume of live water.As shown in Figure 9 and Table 6,, the downstream section of the river, due to the scheduling of water from the Jiefang River, often ensures the effectiveness of the live water. Therefore, the efficiency of the live water remains relatively consistent under different conditions, with the maximum rates reaching 86.4% and 97.1% in conditions 2-1 and 2-3, respectively. The difference between the two is only 10.7%. On the other hand, as the upstream section introduces water with a certain concentration of pollutants into the downstream section, the efficiency of the live water is comparatively lower, necessitating the introduction of additional water. Consequently, Case 2-3 emerges as the optimal scheme, boasting a maximum water exchange rate of 72.2%. Calculations reveal that the average water exchange rate for a single diversion process in the downstream section stands at 30%, and the required head difference is smaller than that required in the case of utilizing a single gate-pump system.



(a) Lower section of Wanlichangcheng River (b) Upper section of Wanlichangcheng River

Fig. 9. Results of exchange rate under the scheduling of a group of stepped gates and pumps

Table 6. Water body exchange rates under scheduling for 6-step gate pump clusters

Working condition	Location (mileage)	sampling point	Water exchange rate/h 25% 50% 75 %Max/%	Maximum velocity /m/s
2-1	Upstream section (1000)	1#	46.8>120>120 40.7	1.45
	Downstream segment (3350)	2#	0.3 18.7 37.6 86.4	
2-2	Upstream section (1000)	3#	29.1 66.5>120 49.3	1.74
	Downstream segment (3350)	4#	0.3 20 21.8 92.7	
2-3	Upstream section (1000)	5#	39.9 69.9>120 72.2	1.96
	Downstream segment (3350)	6#	0.3 1.5 31.1 97.1	

5.3 Analysis of Topological Guide Wall Scheduling Results

As there is only one live water route, the downstream sections of some river sections of the live water channel, i.e. Jiefang River and the latter part of Wanlichangcheng River, were selected respectively to effectively reflect the effect of the live water in flushing out the pollutants, and the calculation results of the water exchange rate are shown in the following Figure 10 and Table 7.

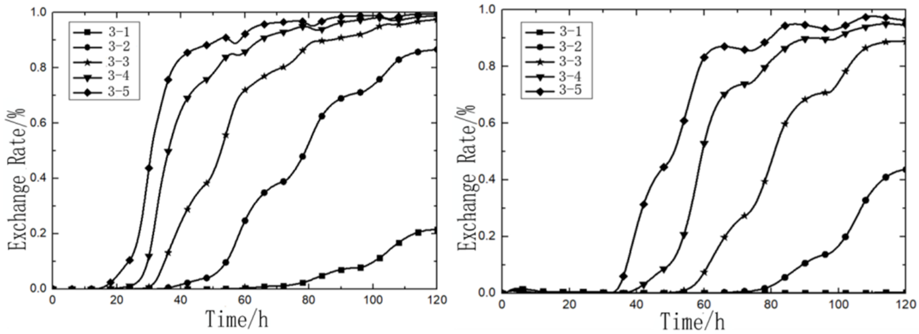
(1) After the installation of the topological diversion wall is carried out, due to the growth of the distance of the living water, new requirements on the size of the diversion flow should be considered to reduce the concentration of pollutants in order to reduce the impact on the capacity of the downstream river water environment.

(2) As can be seen from conditions 3-1 and 3-2, when the recharge flow is insufficient, the pollutants in the river move slower, and at the end of the recharge cycle, the water quality of the downstream section is still poor, and the exchange of the water body in the river is not good.

(3) From Case 3-3 to 3-5, it can be seen that with the increase of diversion flow rate, the water exchange lifting efficiency of the river water body gradually increases

and gradually decreases after reaching a certain peak, such as Case 3-3, the water exchange rate of the downstream section of Jiefang River is increased from 43.6% to 88.7% in Case 3-2, but the lifting efficiency gradually decreases after that. Therefore, the diversion flow rate of 3m3 /s can be considered as the optimal live water scheduling condition.

Overall, the control of flow velocity in the topology deflector wall scheme needs further study, and the effect of water exchange in the short-term ephemeral scheme is generally good, but it can be considered for the long-term construction of living water landscapes.



(a) Exchange rate of Wanlichangcheng River (b) Exchange rate of Jiefang River

Fig. 10. Topological guide wall scheduling results

Table 7. Water exchange rates under topological deflector wall scheduling

Location (mileage)	working condition	sampling point	Water exchange rate/h			
			25 per cent	50%	75 per cent	Maximum/%
Downstream section of Wanlichangcheng River 2 (1000)	3-1	1#	>120	>120	>120	21.5
	3-2	2#	60.1	78.9	101.3	86.6
	3-3	3#	40.4	52.8	63.6	97.4
	3-4	4#	32.1	36.1	46.9	98.8
	3-5	5#	27.2	30.8	35.9	99.5
Downstream section of Jiefang River (3000)	3-1	6#	>120	>120	>120	0.4
	3-2	7#	104.5	>120	>120	43.6
	3-3	8#	69.6	81	100.3	88.7
	3-4	9#	55	59.5	74.8	94.5
	3-5	10#	40.4	51.1	57.3	96.1

5.4 Summary

Taking the monitoring section of the downstream section of the Wanlichangcheng River (mileage: 3000) as an example, the comparison of the optimal working conditions among the various live water guide and control measures is shown in the Table 8.

Table 8. Comparison of optimal working conditions corresponding to different living water schemes

Serial number	Living Water Programme	optimal working condition	Water exchange rate /%	Volume of live water/ million m^3	Gate head difference /m	Velocity /m/s
1	The gate is located in Wanlichangcheng River	1-5	71.1	21.6	1.7	4.20
2	Stairway gate pump cluster	2-3	72.2	6.48	1.7	1.96
3	topological dividing wall	3-3	88.7	43.2	0	0.12

(1)Water exchange rate: The water exchange rate of the three programmes has reached 70%, which is in line with the water exchange requirements of the current status quo under Wanlichangcheng River, in which the topological inflow wall is the most effective.

(2)Maximum flow rate of the river: The three schemes meet the requirements, with the maximum water flow rate of the single gate and pump scheduling scheme being the highest and the maximum flow rate of the topological guide wall scheme being the smallest.

(3)Volume of live water: The volume of live water varies considerably between the different scheduling options, with the smallest volume of water stored in the terrace gate and pump cluster option and the largest volume in the topological guide wall option.

6 Conclusion

In this paper, through the use of a one-dimensional hydrodynamic and water quality mathematical model, different live water schemes for the Wanlichangcheng River are compared, analyzed, and evaluated. Furthermore, an optimal live water scheduling recommendation scheme is put forward. Additionally, the research explores the optimal live water scheme for a typical cut-off branch in the river network area, and the main conclusions and recommendations are summarized as follows:

(1) Disconnected surge water exchange is one of the most significant issues limiting the management of the water environment in the plains river network area.

(2) The living water scheme for the cut-off surge in the plain river network area needs to be considered in the context of the actual situation, encompassing geographical location, river network conditions, hydrodynamics, and pollution.

(3) When comparing the effect of water quality improvement, considering the economic cost, technical feasibility, and the impact of live water scheduling, the gradient gate and pump scheduling can be adopted as the optimal live water scheduling for the Wanlichangcheng River.

(4) The planning and design of water environment treatment in river network areas must follow the principle of "pollution control must precede water diversion". Single measures for improving water flow can only address the symptoms rather than the root cause. Long-term revitalization of the water system and maximum benefits of water scheduling can only be achieved on the basis of internal governance and realization of pollution interception and source control.

References

1. Xiaobing Cheng. Development History and Outlook of Water Resources Dispatch in China [J]. China Water Resources, 2023, (17): 1-5.
2. Yue Yang, Jie Chen. Application of water replenishment and water activation in urban black odour water body management[J]. China Water Transport (Next Half Month), 2018, 018(003): 137-138.
3. MC CALLUM, BRIAN. Areal Extent of Freshwater from an Experimental Release of Mississippi River Water into Lake Pontchartrain, Louisiana, May 1994[J]. new york united states, 1995:363-364.
4. Xiaobao PAN,Bin CAI,Yang LIU,et al. Progress of water transfer and diversion research in plains river network area[J]. Water Resources Planning and Design,2019(09):10-12+72.
5. Jingjing Huang. Research on the smooth flow of live water in the Yangtze River Delta's ultra-low-lying restricted drainage area - taking the typical polder area in Kunshan City as an example [J]. Green Technology, 2022, 24(12): 277-280.
6. Hongbin Xiong,Xue Chen. Research on the best solution for water quality improvement of polluted rivers based on MIKE11[J]. China Water Supply and Drainage,2019,35(03):61-65.
7. Yixin XU,Yiping LI, Yuchi LUO, et al. Assessment of the effect of water diversion to improve the water quality of tidal river network in the plains[J]. Water Resources Conservation, 2019, 35(06): 124-130.
8. Huajing Zhao, Jingjing Dai, Wei Jin. Strategies and innovations in the Wenfeng water system water environment governance project in Nantong urban area [J]. Water Resources and Hydropower Technology, 2019, 50(S2): 138-143.