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Limit Level for Pollution Control of Sluices and Dams on Shaying River

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Abstract: Because of the serious pollution of Shaying River, the excessive water storage by sluices and dams on that river is one of the prime reasons for the pollution of trunk stream Huai River. To counter this problem, this paper tries to regulate the water storage by sluices and dams on Shaying River, this paper explores the limit level for pollution control to prevent water pollution incident caused by centralized discharge of polluted water by proposing and defining the concept of limit level for pollution control, and establishing a model of limit level for pollution control of sluices and dams for the purpose of reservoir profiting and pollution-control. Besides, this paper applies the above method to multiple sluices and dams on Shaying River in Huai River Basin, and solves the model by multi-objective genetic algorithm. The calculation results indicate that the established model is a practical, effective way to determine the limit level for pollution control of sluices and dams on Shaying River which provides important technical support for the development of pollution-control regulation among sluices and dams in Huai River Basin in China.

Keywords: *Shaying River; Sluices and dams, Limit level for pollution control, Multi-objective genetic algorithm, Pollution-control regulation*

1. Introduction

With the rapid socioeconomic development, more and more sluices and dams have been built on rivers to develop water sources and prevent and control flood. However, the excessive construction of sluices and dams also has some adverse impacts on the water environment of rivers, which require focused and sustained attention [1-3]. The adverse impacts are two-fold: First, the impact building of sluices and dams on the water environment of rivers; Second, the regulation of sluices and dams on the water environment of rivers [4]. Take Shaying River, a heavily polluted tributary to Huai River, for example. Since the sluices and dams on the river have store a huge number of industrial wastewater and domestic sewage, there will be a centralized discharge of polluted water when the sluices and dams release flood waters in rainy season, leading to sudden water pollution incidents downstream, such as the water pollution accidents in the trunk steam of Huai River [5].

In 1995, the State Council of the People's Republic of China issued the Interim Regulations on Prevention and Control of Water Pollution in the Huai River Basin. Article 25 stipulates that "In the premise of guaranteeing flood control and drought relief, and in consideration of upstream and downstream water quality, pollution-control regulation plans should be prepared for sluices in Huai River Basin to prevent the centralized discharge of polluted water stored in the rivers controlled by sluices." To reduce the polluted water stored in Shaying River, Huai River Water Resources Commission makes use of the environmental capacity of the trunk stream of Huai River by carrying out pollution-control regulation of the sluices and dams on the river in a reasonable manner so that the stored water can be discharged gradually to the trunk stream of Huai River. Nevertheless, when the total amount of polluted water stored by the sluices and dams on Shaying River exceeds the environmental capacity of the trunk stream of Huai River, even if the amount of polluted water has been reduced by pollution-control regulation of slucies and dams, the polluted water stored by sluices and dams on Shayibng River can still cause sudden water pollution incidents due to the need of flood control. (The sluices and dams are adjusted to the flood control level.) In this case, the effect of pollution-control regulation of sluices and dams is greatly reduced. Hence, the author believes that it is necessary to adjust the storage level of sluices and dams at a certain period of time (e.g. one month before the flood season) and design the limit level for pollution control for sluices and dams to cater for the demand of pollution-control regulation in order to prevent excessive water storage by sluices and dams, give full play to the pollution-control regulation of sluices and dams, and reduce the probability of water pollution incidents caused by the centralized discharge of polluted water. Based on the above analysis and viewpoints, and in light of the demand of pollution-control regulation for sluices and dams, this paper puts forward the concept of limit level for pollution control of sluices and dams, and defines it as: the upper limit of water stored by sluices and dams in a certain period of time for the purpose of maintaining a healthy water environment in the protected reach, reducing the probability of water pollution incident caused by centralized discharge of polluted water, and satisfying the needs of reservoir profiting and flood control.

Targeted at the sluices and dams on Shaying River and aimed at promoting reservoir profiting and flood control, this paper puts forward the limit level for pollution control to prevent excessive water storage by defining the concept of limit level for pollution control, and establishing a model of limit level for pollution control of sluices and dams on Shaying River. With this method, on the one hand, the sluices and dams have surplus storage capacity to store the polluted water from the upstream, thus preventing the centralized discharge of polluted water to the downstream and reducing the impact to the water environment in the downstream; on the other hand, the pollution-control regulation capacity of sluices and dams is fully displayed, which reduces the polluted water stored by sluices and dams on Shaying River, and lowers the probability of water pollution incident in Huai River caused by centralized discharge of polluted water.

2. Materials and Methods

2.1. Area and Timing

As Shaying River is the largest tributary of the Huai River. Originating in the Funiu Mountain, Henan Province, it flows 620km through 40 counties and cities in Henan and Anhui, such as Pingdingshan, Luohe, Xuchang, Zhoukou and Fuyang, covering a drainage area of nearly 40,000km2. Known as the most polluted river in the Huai River Basin, Shaying River accounts for 40% of the wastewater and pollutants in Huai River drainage. Most of the ammonia nitrogen in Huai River comes from Shaying River, and all sudden water pollution accidents in the trunk stream of Huai River are attributable to Shaying River. There are many sluices and dams on Shaying River [6]. Among them, Huaidian Sluice, Fuyang Sluice and Yingshang Sluice are key sluices and dams in the pollution-control regulation by Huai River Water Resources Commission in recent years. See Figure 1 for their locations.

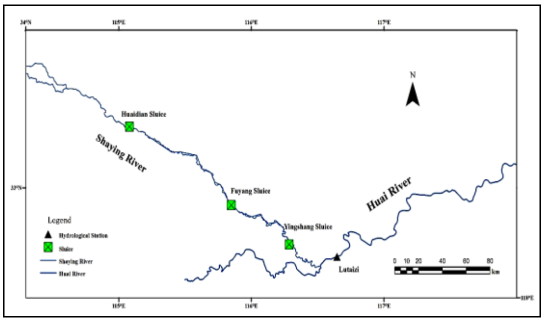

Figure 1: *Distribution map of sluices*

2.2. Model of Limit Level for Pollution Control

The purpose of studying the limit level for pollution control is to lower the probability of water pollution incident caused by centralized discharge of polluted water in the protected reach through the control of the total amount of polluted water stored by sluices and dams on Shaying River. In essence, the smaller the water storage volume of each sluice and dam, the smaller the probability of concentrated discharge of polluted water and the lower the probability of water pollution incident in the protected reach. However, if the water storage volume of the sluice and dam is too low, it will damage the local reservoir profiting. Therefore, it is necessary to strike a balance between “pollution-control” and “reservoir profiting” and obtain the optimal storage capacity of each sluice and dam. In view of this, the author constructs a model of limit level for pollution control in consideration of various factors like water volume and water quality.

2.2.1. Multi-objective Function

(1) Minimal Changes to Maximum Water Storage Volume of Sluices and Dams

The total water storage volume of sluices and dams on Shaying River should be adjusted according to the total pollutant bearing capacity of the protected reach. To reduce the impact of water storage adjustment to the local reservoir profiting, the water storage volume of sluices and dams should be maximized without affecting the “pollution-control”. That is to say, the total water storage volume of sluices and dams should be adjusted with minimal impact to the maximum water storage volume under normal conditions. The strategy is expressed as follows:

$$\operatorname{Min} E(\mathrm{v}) = \sum_{i=1}^{n} \left(\frac{V_{i,\max} - V_i}{V_{i,\max}}\right)^2 \qquad (1)$$

Where, V_i is the water storage volume of the i-th is sluice and dam; $V_{i,max}$ is the maximum water storage volume of the i-th sluice and dam under the normal conditions.

(2) Minimal Total Amount of Pollutants

The water storage volume of sluices and dams on Shaying River should be determined with full consideration of the water quality. If the water body has a good quality, the sluices and dams should store as much water as possible. If the water body is poor, they should store as less water as possible. Following the principle of “storing good quality water and discharging poor quality water”, the total amount of pollutants stored by each sluice and dam should be minimized. The strategy is expressed as follows:

$$\operatorname{Min} \mathrm{F}(\mathrm{v}) = \sum_{i=1}^{\mathrm{n}} (\mathrm{V}_i - \mathrm{V}_{i,\min})\ \mathrm{C}_i \qquad (2)$$

Where, $V_{i,min}$ is the minimum water storage volume of the i-th is sluice and dam; Ci is the concentration of a certain type of pollutant in the water stored by the i-th sluice and dam.

2.2.2. Constraints

(1) Water Storage Volume

It is high or too low. Hence, the water storage volume of each sluice and dam must meet the following conditions:

$$V_{i,\min} \le V_i \le V_{i,\max} \quad (3)$$

Where, the symbols have the same meanings as above.

(2) Total Pollution Bearing Amount in Protected Reach

The pollution-control regulation in Huai River mainly uses the environmental capacity of the protected reach to reasonably reduce the total amount of pollutants in rivers. Therefore, the total amount of pollutants stored by sluices and dams on Shaying River must not exceed the total pollution carrying amount of the protected reach in the same period of time. Hence, the total pollution carrying amount poses the following constraint:

$$\sum_{i=1}^{n}[(V_i - V_{i,\min})C_i] \le W \quad (4)$$

Where, W is the total pollution carrying amount in protected reach in the computation time.

(3) Non-negative Constraint

All variables should be positive.

2.2.3. Solution to the Model

(1)Generation of non-inferior solutions: This paper adopts Non-dominated Sorting Genetic Algorithms-II (NSGA-II). The algorithm makes the population evolve by genetic operators, carries out fast non-dominated sorting, and maintains the diversity of population by the crowding distance. Please refer to references [7] and [8] for the principles of the algorithm. According to the model constructed in this paper, the author seeks the set of non-inferior solutions by invoking the multi-objective optimization function gamultiobj improved based on NSGA-II during the programming in MATLAB R2009a.

(2) Optimization of non-inferior solutions: To optimize non-inferior solutions, different weights should be set for the objective function in consideration of the decision preference of the decision-maker. On this basis, the author adopts the fuzzy optimization of multi-objective system [9] to determine the plan with the highest relative superiority that is, to calculate the relative superiority of each plan by the relative superiority formula targeted at the minimum value, and discover the plan with the highest relative superiority. After that, the author obtains the limit level for pollution control of each sluice and dam by looking up the storage capacity curve of each sluice and dam corresponding to the plan. The relative superiority formula targeted at the minimum value goes as follows:

$$r_{i,j} = 1 - \frac{x_{i,j}}{\max(x_{i,j}) - \min(x_{i,j})} \quad (5)$$

Where, $r_{i,j}$ is the relative superiority of target i of decision j; $x_{i,j}$ is the i-th target value of decision j; $\max(x_{i,j})$ and $\min(x_{i,j})$ are respectively the maximum eigenvalue and the minimum eigenvalues of decision set j corresponding to target i.

3. Results and Discussion

3.1. Results

Shaying River is severely polluted. Ammonia nitrogen is deemed as the typical pollutant because excess ammonia nitrogen contributes heavily to the pollution of the river. Based on the water quality data from Huaidian Sluice, Fuyang Sluice and Yingshang Sluice, the mean concentration of ammonia nitrogen in April, 2000-2012 is taken as the calculation condition. The segment from Yinghekou to Lutaizi Profile is regarded as the protected reach. The mean flow and the mean concentration of ammonia nitrogen in April, 2000-2012 are regarded as the hydrological conditions. Table 1 shows the specific data.

Table 1: *Data of sluices*

Sluice	Range of water level (m)	Range of water storage capacity ($10^4 m^3$)	Average concentration of NH^3-N in April (mg/l)
Yingshang	20.5-25.5	4000-6800	11.2
Fuyang	27.8-29.1	5800-8700	9.3
Huaidian	35.6-39.3	800-2900	13.4

Calculation Steps as follows:

First, According to the Joint Prevention of Huai River Water Pollution (2001-2009), the mean ammonia nitrogen concentration should not exceed 1.5mg/L in the protected reach (Yinghekou-Lutaizi). Pursuant to the Code of Practice for Computation on Permissible Pollution Bearing Capacity of Water Bodies issued by the Ministry of Water Resources of the PRC and the hydrological conditions (Average flow is $406m^3$/average concentration of $NH3^3$-N is 0.8mg/) and the profile data of the protected reach, the author calculates that the total pollution bearing amount in April of the protected reach stands at 767,587 kg.

Second, the program is written in the MATLAB R2009a environment. $V_{i,max}$ stands for the normal water storage amount of each sluice, and $V_{i,min}$ stands for the water storage amount of each sluice at the flood control level. Invoking the gamultiobj function, the author sets ParetoFraction at 0.1, PopulationSize at 100, Generations at 200, StallGenLimit at 200, and Tolfun at 1e-4. See Table 2 for the results. Then, Attaching equal importance to reservoir profiting and flood control, this author give equal weight, 0.5, to objective functions E(v) and F(v). Plan 3, the plan with the highest relative membership is obtained by calculating the relative membership of each sluice.

Last, Appropriate limit levels for pollution control are obtained from the storage capacity curve of each sluice corresponding to the plan with the highest relative membership. It is calculated that the limit levels for pollution control of Yingshang Sluice, Fuyang Sluice and Huaidian Sluice are respectively 23.9m, 28.2m, and 38.6m.

Table 2: *Pareto set of sluice's water storage*

Result	E(v)	F(v)	Water storage of Yingshang（10^4m^3）	Water storage of Fuyang（10^4m^3）	Water storage of Huaidian（10^4m^3）	Total water storage (10^4m^3)	Relative membership degree
1	0.12	559245	5886	7741	2050	15677	0.506
2	0.36	367538	5122	7604	1353	14079	0.431
3	0.02	762126	6351	8632	2557	17540	0.552
4	0.14	448686	5285	6910	2304	14499	0.432
5	0.16	514282	5489	7946	1904	15339	0.501
6	0.03	708281	6032	8515	2503	17050	0.532
7	0.38	329440	4439	7880	1448	13767	0.392

3.2. Discussion

(1) After analyzing and comparing the different plans, the author finds that every plan satisfies the constraint posed by the total pollution bearing amount of the protected reach. Plan 3 has the largest total water storage amount and the highest total pollution bearing amount, while Plan 7 has the lowest total water storage amount and the lowest total pollution bearing amount. The two plans differ by 3773×10^4 m^3 in total water storage amount and by 459,105kg by total pollution bearing amount. In Plan 3, the water storage amount of Yingshan Sluice, Fuyang Sluice and Huaidian Sluice are lower than the normal maximum water storage amount by 15.4%, 11% and 10%. In general, the average water storage amount of the group of sluices and dams is lowered by 18.4%. In Plan 7, the water storage amount of Yingshan Sluice, Fuyang Sluice and Huaidian Sluice are lower than the normal maximum water storage amount by 39.1%, 15.2% and 50.9%. In general, the average water storage amount of the group of sluices and dams is lowered by 41.9%. Correspondingly, the total pollution bearing amount of the group of sluices and dams drops 41.9% on average. Hence, Plan 3 favors reservoir profiting, Plan 7 favors pollution-control, and other plans fall between the two.

(2) In this paper, the weight of the two targets is the same, and the relative superiority is the third one. The corresponding water levels of Yingshang Gate, Fuyang Gate and Huodian Gate in Scheme 3 are 23.9m, 28.2m and 38.6m respectively. According to the data of Huai River Water Pollution Prevention and Control from 2001 to 2009, it is proved that the weight of the objective function is reasonable in this paper, and the method of calculating the relative superiority is reliable, furthermore, it is proved that the model and the solution method are practicable and reliable.

(3) This author sets different weights for each objective function to calculate the relative superiority of each plan generated in this paper, and to analyze the influence of target weight on the sensitivity of the model. It is found that when the weight coefficient of the objective function 1 is greater than or equal to 0.5 (that is, the weight of the objective function 2 is less than or equal to 0.5), Plan 3 has the highest relative superiority, indicating that the subjective weight has less influence on the optimization of the plan; when the weight coefficient of the objective function 1 is less than 0.5 (that is, the weight of the objective function 2 is greater than 0.5), the subjective weight has a great influence on the optimization of the plan, indicating that the optimization is highly dependent on the value of subjective weight. In essence, the objective function 1 of this paper pursues the maximum amount of water, and the objective function 2 pursues optimal water quality. In view of the results of this paper, the author holds that both water volume and water quality are important issues in the study of water amount and quality in heavily polluted rivers. Thus, their weight coefficient should not deviate significantly from the equal weight value of 0.5.

4. Conclusions

In response to the demand of pollution-control in Huai River Basin and on the basis of the understanding that water pollution incidents are caused by centralized discharge of polluted water, this paper puts forward the concept of limit level for pollution control, discusses about the necessity of setting up the limit level for pollution control, and suggests implementing the limit level for pollution control in a certain period of time so as to constrain the total water storage amount of sluices and dams on Shaying River and to lower the probability of sudden water pollution incident in the protected reach caused by centralized discharge of polluted water. On this basis, this paper establishes a model of limit level for pollution control targeted at “reservoir profiting” and “pollution-control”, and solves the model by multi-objective genetic algorithm. The calculation results indicate that the established model can coordinate the contradiction between “reservoir profiting” and “pollution-control” on Shaying River, and provides practical, theoretical basis and technical support for administration departments of heavily polluted rivers to set up the limit level for pollution control of sluices and dams.

It is worth mentioning that setting up the limit level for pollution control of sluices and dams on heavily polluted rivers provides a necessary precondition for pollution-control regulation of groups of sluices and dams. Under the precondition, reasonable pollution-control regulation of sluices and dams will have a better effect in reducing the total amount of wastewater stored by sluices and dams on heavily polluted rivers and in reducing the probability of sudden water pollution incidents in the protected reach; Otherwise, even if the limit level for pollution control is in place, sudden water pollution incidents may still occur in the protected reach if the sluices and dams regulation is inappropriate. To further deepen the research on limit level for pollution control, the author will focus on further strengthening the joint regulation of groups of sluices and dams in future, aiming at fully integrating the limit level for pollution control with the regulation of sluices and dams so as to maximize the pollution-control regulation of groups of sluices and dams, and eventually reduce the probability of sudden water pollution incidents caused by centralized discharge of polluted water.

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