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Original Research Paper

Impact of Control Section and Pollution Source Generalization on Calculation of Water Environment Capacity

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ABSTRACT

Based on the one-dimensional water quality modelling theory, this paper discusses the impact of different calculation methods on water environment capacity in different water functional areas. Through a case study of the Yinma River in Jilin province, in the same condition, the influence of four calculation methods (1. section-beginning control and no pollution sources generalization; 2. section-beginning control and uniform pollution sources generalization; 3. section-end control and no pollution sources generalization; 4. section-end control and uniform pollution sources generalization) on the calculated results of water environment capacity were analysed. The calculation results of four calculation methods from big to small are: 4,3,2,1. In the case of considering only one of the model parameters, control section or pollution source generalization, the percentage improvements of water environment capacity are the same.

INTRODUCTION

Water function area is divided into two levels, it is the functional area that defined and performed corresponding water environment quality standards to meet the reasonable development, utilization, conservation and protection of water resource demand (Hou & Li 2008). According to the situation of the natural condition, the development and utilization of water resources, the basin comprehensive planning, water resources protection planning, economic and social development requirements, these water environment quality standards are formulated in accordance with the dominant function of water area. The water environmental carrying capacity is the maximum number of pollutants that water can hold in certain conditions and satisfy the requirement of the water quality goals (GB25173-2010). Water environment capacity is decided by the characteristics of the water, the quality target of water, the characteristics of pollutant and so on. Li & Li (2006) studied the main influence factors of water environmental carrying capacity, and enumerated several river pollutant carrying capacity calculation models. Zhou et al. (1999) suggested three kinds of methods for calculating water environmental capacity in the case of different section-ending control method (section-beginning control, section-end control and function section-end control), and compared the advantages and disadvantages of the methods. Han et al. (2002) proposed the pollutant carrying capacity calculation method based on the different combinations of water functional areas. Lao Guo-ming (2009) analysed the impact of pollution source generalization on the computation of pollution carrying capacity. Zhang Xiu-ju et al. (2012) discussed the impact of uncertain parameters on water environment capacity, and analysed the influence mechanism of assimilative capacity theoretically. Lu & Su (2011) analysed the influence of the different calculation methods for the river pollutant carrying capacity calculation results and discussed the applicability of different methods. Fang et al. (2007) used QUAL2K model to calculate the assimilative capacity in Qiantang River, and compared its applicability with the 1-D model. Liu et al. (2009) analysed the applicability of MIKE11 model based on the water quality mathematical model of the Songhua River. Xu et al. (2011) used two methods based on WASP 7.3 model to study assimilative capacity of Lan River, the first is empirical formula method and the second is the trial-and-error method. Zhou et al. (2014) proposed a water environmental capacity calculation method based on two dimensional water environment simulation code (WESC2D) and repulsive particle swarm method (RPSM).

Yinma River is a first grade tributary of Songhua River as well as the main water source of Changchun city. With the continuous development of economy, Yinma River has been exploited and utilized in a high degree, and has been polluted heavily (Liu et al. 2013). Although in recent years, the pollution situation of Yinma River has relieved, but the water quality there is no obvious change. The water quality of Yinma River mostly is still below class V. In order to improve the water environment quality of Yinma River, it is necessary to calculate the water environmental carrying capacity, and formulate the corresponding measures to limit pollution emissions. Based on the data of Yinma River, this paper analysed the impact of different selections of control cross-section and pollution source generalization on calculation of water environment capacity in different water functional areas.

DATA AND METHODS

Situation of Yinma River: Yinma River, an upstream tributary of Songhua River, is located in the middle of Jilin province, originated in the Hulan ridge, flows through Panshi, Younji, Shuangyang, Jiutai, Dehui, converges the Yitong River in the 21 km north of Nongan county, and then joins the second Songhua River. Yinma River is 389.8 km long with a basin of 18,247 km², the total runoff of Yinma River basin is between 0.7 and 1.6 billion cubic meters. Yinma River basin is the most developed economic region in the Jilin province, and the extent of exploitation and utilization of water resources is at a high level. Besides, the Shitoumen reservoir on the Yinma River is the main water source of Changchun city. In this paper, with the major pollution COD and NH_3-N calculating as an example, analyses the impact of different calculating methods on the results of water environment capacity.

Design conditions: The design flow is calculated according to 11 year series, from 2000 to 2010, and the design flow velocity is calculated according to the Q~V curve and the design flow. Comprehensive pollutant attenuation coefficients taken are K_{COD}=0.15/d, K_{NH3-N}=0.20/d (Table 1).

National Surface Water Environmental Standards (GB3838-2002) classifies water into five grades, from class I (the best) to class V (the worst). The upper reaches of Yinma River are protected area, which has higher requirements of water quality, the water quality shall not be lower than class II. The water quality shall not below class IV in development and utilization area, and not below class III in buffer area.

The one-dimensional water quality model: For the river whose width-depth ratio is not big, and the pollutants on the river section have mixed evenly, the one-dimensional water quality model can be used to calculate the water environmental carrying capacity. In the case of steady state or quasi steady state, a one-dimensional mathematical model for water quality is:

$$C_x = C_0 \bullet \exp\left(-K \cdot \frac{x}{u}\right) \quad ...(1)$$

Where, C_x is the pollutant concentration through x distance, mg/L; C_0 is the pollutant concentration of the initial section, mg/L; K is the pollutant comprehensive damping coefficient, 1/s; x is the longitudinal distance along the river, m; u is the design flow velocity, m/s.

Section-beginning control method: The section-beginning control method, which controls the section located in the upstream sewage outlet cross section, requires that the water quality of upstream control section must reach the goal of the stream segment. Due to the degradation of pollutants, the water quality within the segment is at or above the water quality requirement. Section-beginning control method controls that the river water quality meet the requirement strictly, its schematic diagram is shown in Fig. 1.

The water environment capacity of the stream segment i is

$$M_i = \left[C_{s,i-1} - C_{i,0}\exp\left(-K_i \cdot \frac{x_i}{u_i}\right)\right]Q_i \quad ...(2)$$

Where, M_i is the environmental carrying capacity of the segment i, g/s; $C_{s,i}$ is the quality requirement of the segment i, mg/L; $C_{i,0}$ is the upstream pollutant concentration of the segment i, mg/L; K_i is the comprehensive pollutant attenuation coefficient of the segment i, 1/s; x_i is the longitudinal distance of the segment i, m; u_i is the design flow velocity of the segment i, m/s; Q_i is the design flow of the segment i, m³/s.

Section-end control method: The section-end control method, in which the control section is located in the downstream sewage outlet cross section, requires that the water

Table 1: The basic information on water functional area in Yinma River.

First-order water functional area	Second-order water functional area	No.	Length (km)	Water quality target	Corresponding standard (mg/L) COD	NH_3-N
Protected area		1	21.30	II	15.00	0.50
Development and utilization area	Agriculture and fishing area	2	118.00	III	18.00	0.70
	Drinking and fishing area	3	36.00	II-III	15.00	0.50
	Agriculture area	4	90.00	III	20.00	1.00
	Agriculture area	5	72.00	IV	30.00	1.50
Buffer area		6	26.90	III	20.00	1.00

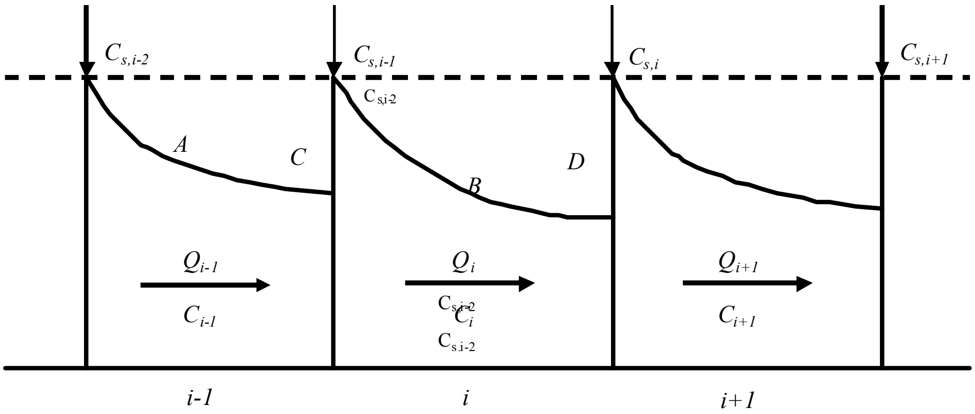

Fig. 1: Schematic diagram of section-beginning control method.

(*A*-the pollutant concentration attenuation curve of segment *i-1*; *B*-the pollutant concentration attenuation curve of segment *i*; *C*-the pollutant concentration difference of segment *i-1*, mg/L; *D*-the pollutant concentration difference of segment *i*, mg/L; C_i-the pollutant concentration of section *i*, mg/L; Q_i-the stream flow, m³/s.)

Table 2: Water environment capacity in Yinma River t/a.

No.	Section-beginning control				Section-end control			
	No pollution sources generalization		Uniform pollution sources generalization		No pollution sources generalization		Uniform pollution sources generalization	
	COD	NH_3-N	COD	NH_3-N	COD	NH_3-N	COD	NH_3-N
1	3.88	0.20	4.31	0.23	4.82	0.27	5.36	0.31
2	42.35	1.95	65.09	3.40	107.48	6.74	165.17	11.76
3	41.62	1.52	55.98	2.24	77.76	3.49	104.58	5.15
4	120.10	8.41	148.04	11.07	185.37	15.00	228.50	19.75
5	463.31	25.59	614.80	37.07	840.19	56.59	1114.91	81.98
6	5.31	2.08	6.51	2.73	8.12	3.67	9.96	4.80
Total	676.57	39.74	894.74	56.74	1223.73	85.75	1628.48	123.76

quality of downstream control section must reach the goal of the downstream segment. The water quality within the segment is 100% under the water quality requirement. The water quality will not meet the requirement by using this method. The schematic diagram is as shown in Fig. 2.

The water environment capacity of the stream segment *i* is

$$M_i = \left[C_{s,i} \exp\left(K_i \cdot \frac{x_i}{u_i}\right) - C_{i,0}\right] Q_i \quad ...(3)$$

Uniform pollution source generalization method: Normally, sewage outlets are distributed irregularly in different sections of the water function areas, the pollutant concentration of downstream section is the superposition of all pollutants discharged from the sewage outlets. Considering the complexity of calculation and the requirements of general planning, the distribution of pollution sources in water function area can be generalized. The uniform pollution source generalization method is a uniform calculation method that considers the pollution sources to be uniformly-distributed along the river, and the schematic diagram is as shown in Fig. 3.

Take a micro section *dx* of the river, the distance from the micro section to the upstream section is *x*, then after the pollutant transported to the section *x=L*, the pollutant's weight is

$$dm = \frac{M}{L} \exp\left(-K\frac{L-x}{u}\right) dx \quad ...(4)$$

Where: *L* is the length of river, m.

The total weight of pollutants in the section *x=L* is

$$m = \int_0^L dm = M\frac{u}{KL}\left[1 - \exp\left(-K\frac{L}{u}\right)\right] \quad ...(5)$$

The corresponding water environment capacity is:

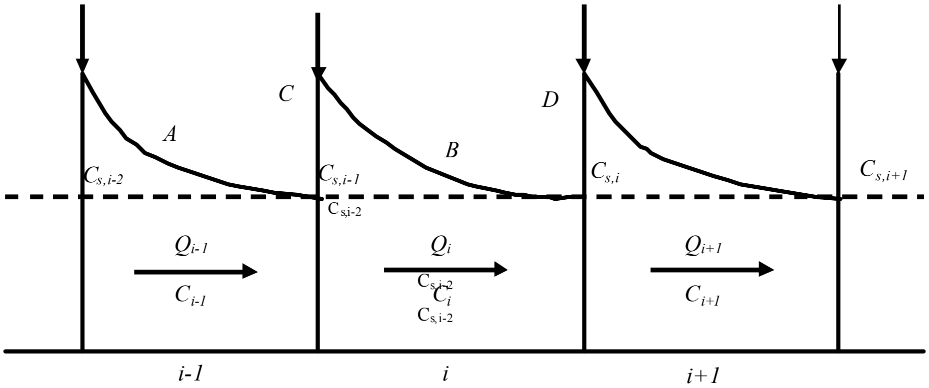

Fig. 2: Schematic diagram of section-end control method.

Table 3: The percentage improvements of water environment capacity by using section-end control method comparing to section-beginning control method %.

No.	No pollution sources generalization		Uniform pollution sources generalization	
	COD	NH_3-N	COD	NH_3-N
1	24.30	33.65	24.30	33.65
2	153.75	246.11	153.75	246.11
3	86.82	130.10	86.82	130.10
4	54.35	78.37	54.35	78.37
5	81.35	121.15	81.35	121.15
6	52.89	76.13	52.89	76.13
Total	80.87	115.76	82.01	118.12

Table 4: The percentage improvements of water environment capacity by using uniform pollution source generalization method comparing to no pollution sources generalization method %.

No.	Section-beginning control		Section-end control	
	COD	NH_3-N	COD	NH_3-N
1	11.27	15.20	11.27	15.20
2	53.68	74.61	53.68	74.61
3	34.48	47.39	34.48	47.39
4	23.27	31.71	23.27	31.71
5	32.70	44.88	32.70	44.88
6	22.73	30.96	22.73	30.96
Total	32.25	42.77	33.07	44.33

$$M = \frac{QKL}{u} \frac{C_s - C_0 \exp\left(-K\frac{L}{u}\right)}{1 - \exp\left(-K\frac{L}{u}\right)} \quad ...(6)$$

THE ANALYSIS AND RESULTS

Under the condition of same hydrological design, four calculation methods (1. section-beginning control and no pollution sources generalization; 2. section-beginning control and uniform pollution sources generalization; 3. section-end control and no pollution source generalization; 4. section-end control and uniform pollution source generalization) are used to calculate the water environment capacity of COD and NH_3-N in Yinma River. The results are given in Tables 2-4.

As shown in the Table 2, the results of section-end control method are more than the results of section-beginning control method in the water environment capacity calculation both of COD and NH_3-N. Compared with section-beginning control method, the results of section-end control method are raised slightly in protected area, and highly in development and utilization area and buffer area. The results of uniform pollution source generalization method are

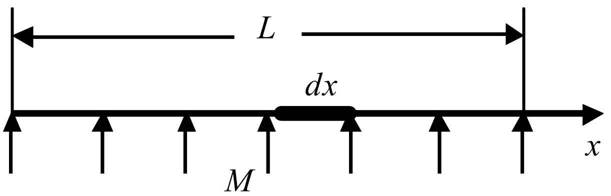

Fig. 3: Schematic diagram of uniform pollution source generalization method.

more than the results of no generalization, the results are raised slightly in the protected area, and highly in development and utilization area and buffer area as well.

From Table 3, when only comparing the results of section-beginning control method and section-end control method, the percentage improvements of water environment capacity are the same, whether have pollution sources generalization or not. At the same time, from Table 4, the percentage improvements of water environment capacity are the same when only considering the generalization of pollution sources.

CONCLUSION

The calculated results show that, in the same design conditions, the calculation results of four calculation methods from big to small are: 4. section-end control and uniform pollution sources generalization; 3. section-end control and no pollution sources generalization; 2. section-beginning control and uniform pollution sources generalization; 1. section-beginning control and no pollution sources generalization.

In the region with high water quality requirement and low level of pollution, the section-beginning control method is more conducive to improve river water quality, while in the case of a polluted river, using the section-end control method cannot improve the water quality but is easy to control pollution. The uniform pollution source generalization method is suitable for the situation where sewage outlets are distributed dispersedly. If sewage outlets are concentrated in upstream area, it is better to use no pollution sources generalization method. In practical applications, the water environment capacity calculation method must be selected based on the specific circumstance of the river.

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