Calculation of Water Environmental Capacity in the Lower Reaches of the Lancang River Basin

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Abstract: The deterioration of water quality in the lower reaches of the Lancang River basin has attracted worldwide attention. Reasonable estimation of water environmental capacity (WEC) can effective implement the prevention and control of water pollution in the lower reaches of Lancang River basin. However, research on WEC was scarce in the Lancang River basin. In this study, a two-dimensional water quality model was established to calculate the WEC in the Jinghong-Guanlei segment located at the downstream of the Lancang River basin. The WEC of CODCr in the Jinghong-Guanlei segment with different design flow rates (90%, 75% and 50% hydrological guarantee flow rate) are 2.83, 3.05 and 3.32 million tons/year, respectively. Design flow rate plays an important role in the calculating the WEC in the lower reaches of the Lancang River basin. Influence of cascade dams operation on flow rate is minor. Therefore, cascade dams operation will not have a greater impact on the WEC of CODCr in the lower reaches of the Lancang River basin. The current water quality in the segment is fairly good. However, under the couple effects of climate change and cascade dams operations, there is an increasing trend of CODCr concentrations in the lower reaches of the Lancang River basin. Therefore, water quality monitoring and water pollution controlling should be strengthened in the long run. Research results will provide scientific basis for decision-making and implementation of regional water pollution control measures.

1. Introduction

Water environmental capacity (WEC) has the same concept as total maximum daily load (TMDL). It refers to the maximum number of pollutants discharged into a water environment element under the specified environment objectives, and denotes that the allowable discharge of pollutions should not wreck the functions of environmental element [1, 2]. With the development of society and economy, water pollution problems are becoming one of the most important restricting factors for the world sustainable development. Therefore, the simulation and research of regional WEC are vital to the water quality simulation, water pollution prevention plan and control, and have become one of the hot and frontier research areas in water management science [3-6].

The Lancang-Mekong River is an important international river in Southeast Asia. As the upstream of the international river, water environmental issues in the Lancang River basin have attracted worldwide attention [7, 8]. Because of the operation of cascade reservoirs in the Lancang River basin, research mainly focuses on flow regime, soil erosion and fish resources [9-11]. However, research on water environment capacity was scarce in the Lancang River basin. Under the influencing of human activities and climate change, the deterioration of water quality in the lower reaches of the Lancang River basin has become increasingly serious [12]. If the estimation and allocation of WEC are unreasonable, the prevention and control of water pollution may not be able to effectively carry out in

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the Lancang River basin. The consequent water environmental issues will not only hinder the regional economic and social sustainable development, but also affect the related interests of countries along the international river. Therefore, it is urgent to calculate the WEC in the lower reaches of the Lancang River basin. Research results will provide scientific basis for decision-making and implementation of regional water pollution control measures.

Jinghong-Guanlei segment locates at the downstream of the Lancang River basin. This study takes the segment as the research object, constructs a two-dimensional water quality model to calculate the WEC in the segment, and then analyses the effects of flow rates and cascade dams operation on the WEC

2. Study Area

The Lancang River, located at the upstream of the Lancang-Mekong River, which is an important international river in Asia that runs through 6 countries: China, Burma, Laos, Thailand, Cambodia, and Vietnam. The Lancang River runs south until it leaves China, then changes name from the Lancang River to the Mekong River. This region is rich in water resources and hydropower. Against the background of rapid economic and population growth, the "two dam and eight cascades" program has been planned in the mainstream of the Lancang River in Yunnan Province to meet the increasing demand for hydropower.

The water quality in the segment is fairly good; however, there is an increasing trend of COD_{Cr} and NH_4^+–N concentrations (Zhang et al., 2005). Considering the data availability, this study focuses on WEC of COD_{Cr} in the Jinghong-Guanlei segment (Figure 1).

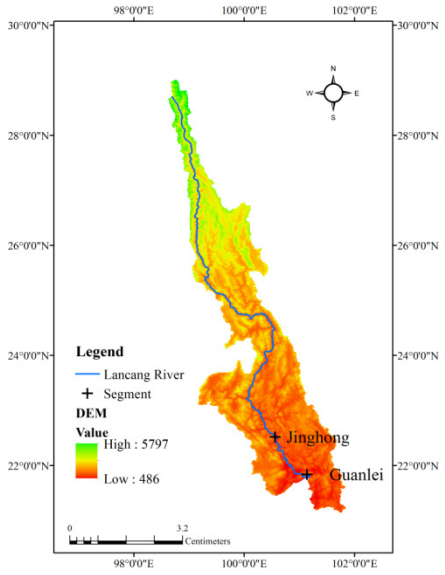


Figure 1 Sketch map of the study area

3. Data and Methods

3.1 Water Environmental Capacity Calculation Model

According to the hydrological conditions and the water purification mechanism, calculation of WEC need to select an appropriate model to simulate the dilution, diffusion, migration of pollutants in water, and then estimate the maximum number of pollutants discharged into a water environment element under the specified environment objectives. WEC calculation models have zero-dimensional, one-dimensional and two-dimensional models. These models have corresponding application range. The average annual flow of Jinghong-Guanlei segment is larger than 150 m^3/s. The segment belongs to

large river reach. A two-dimensional water quality models was therefore developed to calculate the WEC in the Jinghong-Guanlei segment. The model is described by the following equation:

$$M = [(C_s - (C_0 + \frac{m}{h\sqrt{\pi E_y x v}}) \exp(-K \, x/v)]Q \quad (1)$$

Where, M (g/sec) is the water environmental capacity of the segment for a certain pollutant. C_s (mg/L) is the according concentration of the pollutant at the end of the segment based on the specified environment objectives. C_0 (mg/L) is the water quality at the beginning of segment. m (g/sec) is the pollution load of the segment. h (m) is the average water depth of the segment. E_y (m^2/sec) is the transverse diffusion coefficient. x (m) is the length of the segment. v (m/sec) is the average flow velocity of the segment. K (sec^{-1}) is the comprehensive degradation coefficient of the pollutant. Q (m^3/s) is the design flow rate.

3.2 Pollution Load Calculation

According to the data of Yunnan Statistical Yearbook-2015, the pollution load of COD_{Cr} in the Jinghong-Guanlei segment was calculated.

(1) Industrial pollution load of COD_{Cr}, which is calculated by the following equation: Industrial pollution load of COD_{Cr} = the gross value of industrial output× COD_{Cr} emission per output value.

The gross value of industrial output in Yunnan Province is 392.5 billion Yuan (Chinese currency). COD_{Cr} emission per output value is 4.17 kg. Industrial pollution load of COD_{Cr} in Yunnan Province is therefore 5.19 kg/sec. Yunnan province has a drainage basin area of 390,000 km^2. The Jinghong-Guanlei segment is 12900 km^2. Based on the proportion of the segment area to Yunnan province area, Industrial pollution load of COD_{Cr} in the segment is 171.7 g/sec.

(2) Agricultural pollution load of COD_{Cr}, which is calculated by the following equation: Agricultural pollution load of COD_{Cr} = Agricultural land area×water consumption per unit of area× COD_{Cr} in agricultural water withdrawals.

Agricultural land area in Yunnan province is 43.1 million mu. Water consumption per unit of area is 398 m^3. COD_{Cr} in agricultural water withdrawals is 46.52 mg/L. Agricultural pollution load of COD_{Cr} in Yunnan Province is therefore 25.3 kg/sec. Based on the proportion of the segment area to Yunnan province area, Agricultural pollution load of COD_{Cr} in the segment is 836.3 g/sec.

(3) Pollution load of COD_{Cr} from domestic sewage is about 2.9 million tons in Yunnan province. Based on the proportion of the segment area to Yunnan province area, Pollution load of COD_{Cr} from domestic sewage in the segment is 300.9 g/sec.

To sum up, the pollution load of COD_{Cr} in the Jinghong-Guanlei segment is 1308.9 g/sec.

3.3 Model Parameters Setting

The depth and flow velocity of the segment under design flow are calculated by uniform-flow equation. According to water function zoning, C_s in the segment is set to 20 mg/L. Based on mean value of COD_{Cr} for the Yongjinghong station during the past 10 years, C_0 is set to 2.2 mg/L. Based on National Water Environment Capacity Verification Manual, transverse diffusion coefficient (K) and comprehensive degradation coefficient (E_y) are calculated by the following equations:

$$K = 10.3Q^{-0.49} \quad (2)$$

$$E_y = (0.1 \sim 0.2) H\sqrt{gHJ} \quad (3)$$

Where, g is the gravity. J is the hydraulic slope.

4. Results and Discussion

4.1 Influence of Design Flow Rate on the WEC of COD_{Cr} in the Lower Reaches of the Lancang River Basin

Based on the long-term hydrological data during 1967-2013, 90%, 75% and 50% hydrological

guarantee flow rate are calculated and set to be the design flow rate. The WEC of COD_{Cr} is calculated with different design flow rates and the results are shown in Table 1. The WEC of COD_{Cr} in the Jinghong-Guanlei segment with different design flow rates (90%, 75% and 50% hydrological guarantee flow rate) are 2.83, 3.05 and 3.32 million tons/year, respectively. Comparing to the WEC of COD_{Cr} calculated with 90% hydrological guarantee flow rate, the WEC of COD_{Cr} with 75% and 50% hydrological guarantee flow rates are larger.

Table 1 WEC of COD_{Cr} with Different Design Flow Rates

Length (km)	Environment Objectives	WEC (ton/year)		
		90% hydrological guarantee flow rate	75% hydrological guarantee flow rate	50% hydrological guarantee flow rate
86	III	283130	305142	332642

Design flow rate plays an important role in the calculating WEC in the lower reaches of the Lancang River basin. The amount, dilution and self-purification of the pollutants in the water will be different with different flow rates, which will result in the differences in WEC of the water. Based on the monthly average flow in the segment during 1967~2013, the relationship between flow and WEC of COD_{Cr} in the segment was established (Figure 2). As can be seen from Fig. 2, the WEC of COD_{Cr} in the Jinghong-Guanlei segment is positively related to the flow rate. $1m^3$/sec increase in flow rate can result in a 630 tons increase in the WEC of COD_{Cr} in the segment.

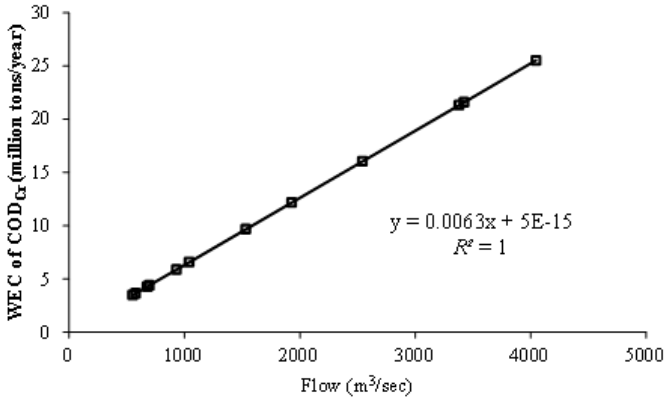


Figure 2 Regression Relation between Flow Rates and the WEC of COD_{Cr} in Jinghong-Guanlei Segment

4.2 Influence of Cascade Dams Operation on the WEC of COD_{Cr} in the Lower Reaches of the Lancang River Basin

Dam construction and operation are the dominant human activities resulting in flow rates changes in the Lancang River basin. The Manwan dam, which began operation in 1993, is the first dam on the Lancang River. In this study, therefore, 1993 is adopted as the segment point of the flow series. During the period 1967~1992, there were no impacts of dam on natural flow. This period was used as the reference period. From 1994 to 2013, dam construction and operation exert influences on flow. This period was regarded as the changed period.

Under the effects of cascade dams operation, flow changes have taken place in the segment. Table 2 shows the flow changes in Jinghong hydrologic station in the Lancang River basin. Compared to the flow rate during reference period, 90%, 75% and 50% hydrological guarantee flow rate during changed period have a decrease of 1.5%, 4.1% and 7.2%, respectively.

Table 2 Flow Changes in Jinghong Hydrologic Station in the Lower Reaches of the Lancang River Basin

Period	Design Flow Rate (m^3/sec)			Change (%)		
	50% hydrological guarantee	75% hydrological guarantee	90% hydrological guarantee	50% hydrological guarantee	75% hydrological guarantee	90% hydrological guarantee
Reference Period (1967~1993)	528.40	490.10	461.79	1.5	4.1	7.2
Changed Period (1994~2013)	520.52	470.10	428.67			

During the reference and changed periods, the WEC of COD_{Cr} in the segment is calculated with different design flow rates and the results are shown in Table 3. Compared to the WEC of COD_{Cr} during reference period, the WEC of COD_{Cr} with 90%, 75% and 50% hydrological guarantee flow rate during changed period have a decrease of 1.2%, 4.2% and 7.1%, respectively. Because of the relationship between flow and WEC of COD_{Cr} in the segment, Influence of cascade dams operation on flow is minor (Table 3). Therefore, cascade dams operation will not have a greater impact on the WEC of COD_{Cr} in the lower reaches of the Lancang River basin.

Table 3 Influence of Cascade Dams Operation on the WEC of COD_{Cr} in the Jinghong-Guanlei Segmnt

Period	WEC (ton/year)			Change (%)		
	50% hydrological guarantee	75% hydrological guarantee	90% hydrological guarantee	50% hydrological guarantee	75% hydrological guarantee	90% hydrological guarantee
Reference Period (1967~1993)	333272	309116	291260	1.2	4.4	7.1
Changed Period (1994~2013)	329273	295515	270581			

5. Conclusion

The WEC of COD_{Cr} in the Jinghong-Guanlei segment with different design flow rates (90%, 75% and 50% hydrological guarantee flow rate) are 2.83, 3.05 and 3.32 million tons/year, respectively. Design flow rate plays an important role in the calculating the WEC in the lower reaches of the Lancang River basin. 1 m^3/sec increase in flow rate can result in a 630 tons increase in the WEC of COD_{Cr} in the segment. Influence of cascade dams operation on flow rate is minor. Therefore, cascade dams operation will not have a greater impact on the WEC of COD_{Cr} in the lower reaches of the Lancang River basin. The current water quality in the segment is fairly good. However, under the couple effects of climate change and cascade dams operations, there is an increasing trend of COD_{Cr} concentrations in the lower reaches of the Lancang River basin. Therefore, water quality monitoring and water pollution controlling should be strengthened in the long run.

Acknowledgements

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