Lake Water Environment Capacity Analysis Based on Steady-State Model

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Abstract: ***Estimating of the water environment capacity is an important content of the assessment of regional environmental impact. Water environment capacity is very important in the field of environmental science and it can provide reliable data environmental planning and management of water. In this paper, lake is the research object and one-dimensional model of water quality is built according to the conservation of mass of pollutants in the lake. Meanwhile, the method for confirming model parameters is put forward. The model is based on investigation in lake water environment and is applied to calculate water environment capacity of Xiaohu. Main pollutants of Xiaohu are COD, TN, fluoride, volatile phenol, BOD_5, whose water environment capacity are 581.008kg/d, 185kg/d, 61.553kg/d, 0.387kg/d, 25.098kg/d accordingly.***

Keywords: water environment capacity, one-dimensional model, lake, parameter, pollutant**.**

1. Introduction

Water environment capacity is the load quantity of certain pollutants during certain time, in a certain unit of water environment, under the condition that water can fulfill certain environmental object [1]. It is a measure of scale that can reflect the close relationship between aquatic environment and social economic activities [2]. From the perspective of environmental management, monitoring and oversight, water environment capacity refers to a maximum amount of pollutants that water body can accommodate [3]. If the amount of discharged pollutants exceeds the water environment capacity, some measures must be taken to protect the water from being polluted. Water environmental capacity is pollutant emission standard for region and an important basis of water environment management and planning. Lakes have characteristics of slow flow and long hydraulic cycle. Thus, once water environment is contaminated, it will be difficultly improved and restored in a short time. Research on water environment capacity of lake has a very important value and significance.

2. Research method

2.1 Statistical models.

Lakes are formed through tectonic activity, glaciations, river erosion and deposition and other geological or artificial excavation. Based on the above causes, lakes generally have characteristics of slow flow, long residence time of water, widely developed aquatic life, etc. Lake is a relatively closed ecosystem hydrology and pollutants can reach well mixed in the lake. Thus, basic equations of water mass balance can be used to calculate the capacity of organics [3],[4]. The change rate of nutrient substances such as nitrogen and phosphorus is the function of the input, output, and the amount of the deposition in the lake. Nutrient substances capacity can be calculated by Vollenwelder model, which can be expressed by the mass balance equation [5].

When pollutants in the lake only occur decay reaction and the reaction meets first-order kinetics, basic water mass balance equation can be expressed as:

$$V\frac{dc}{dt} = Q_n \cdot C_{in} - Q_{out} \cdot C_{out} - KVC - \frac{(C_s - C_0)V}{\Delta T} \quad (1)$$

Where,
V—designed water quantity of lakes, m^3
Q_{in}—inflow of water, m^3/d
Q_{out}—outflow of water, m^3/d
C_{in}—concentration of inflow pollutants, mg/L
C_{out}—concentration of outflow pollutants, mg/L
C—concentration of pollutants in lakes,mg/L
K—Synthetic Attenuation Coefficient, 1/d
Cs—control concentration of pollutants, mg/L
C_0—background concentration, mg/L
$\triangle T$—length of dry period, d.

When water quality in the lakes reaches stable, $V\frac{dc}{dt} = 0$, and the above equation becomes:

$$Q_{in} \cdot C_{in} = Q_{out} \cdot C_{out} + KVC + \frac{(C - C_0)V}{\Delta T} \quad (2)$$

Water environment capacity refers to a maximum amount of pollutants on the conditions of water quality reaching the control concentration [6]. If pollutant concentration is less than the control concentration, then $C_s = C_{out} = C$ and

$$W = Q_{in} \cdot C_{in} = Q_{out} \cdot C_s + KVC_s + \frac{(C_s - C_0)V}{\Delta T} \quad (3)$$

2.2 Determination of Model Parameter

(1) Determination of control concentration C_s

Water quality objectives are prerequisites for water environmental capacity. And water quality objectives are based on water function zoning of lakes. The water function zoning is not only the basis for water resources management but also a basic work of the exploitation and protection of water resources [7]. For small lakes with uniform distribution outfalls for pollutants, diffusion of pollutants in the water is uniform and water quality reaches steady state relatively short time. So, single water quality objective can be used to calculate water environmental capacity. But for large lakes, single water quality objective cannot be used. Water function should be zoned. Then, water quality objectives are selected for water function zoning.

(2)Determination of V

In order to make the results of the water environment capacity are reliable, water quantity in dry season is as security water quantity V for calculating water environment capacity. This can guarantee that water quality of the lake during normal impoundment period does not exceed water environmental capacity.

(3) Determination of Q_{out} and C_{out}

In the process of draining water, a part of the pollutants will be taken away. When calculating water environment capacity, outflow pollutants is also a part of water environment capacity. Because the outflow of lake is usually far from the estuary of pollutants and water has been thoroughly mixed before outflowing, regarding Cs as Q_{out} is reasonable when water quality is steady. In general, Q_{out} is determined according to monitoring data.

(4) Determination of Synthetic Attenuation Coefficient K

Determining synthetic attenuation coefficient has very important significance in calculation of water environment capacity. Because of being affected by water volume, temperature of water, flow rate, dissolved oxygen and external environment such as temperature and evaporation, data obtained by attenuation experiments in the field are volatile [6]. And it takes a long time and is not conducive to conduct a research. The results of indoor attenuation experiments are stable. However, due to environmental conditions, the results may be biased with the actual situation. Thus, synthetic attenuation coefficient K, obtained by combining previous experimental results, field measurements and results of experiments in laboratory, is relatively accurate.

(5) Determination of background concentration C_0

Background concentration C_0 of water quality is original initial concentration of pollutants under the premise of lakes unpolluted. In arid regions, if the lake is supplied by surrounding groundwater or spring water, local concentration of pollutants in groundwater is background concentration of lake. If the lake is supplied by rainfall, concentration of pollutants in rainfall is background concentration of lake.

(6) Determination of length of dry period ΔT

Length of dry period depends on changes of lake level during the year. For long dry period, water quality is at risk in the long time and water environment capacity value is small, correspondingly. If lake level is perennially stable, length of dry period is 90-150 d [8].

3. Empirical Analysis

3.1 Introduction of Xiaohu

Xiaohu is located in Shapotou Nature Reserve, in east longitude 105°7′26″ and latitude 37°35′25″. Elevation of Xiaohu is during 1251~1253 m and surface area is about $1.26km^2$. Average depth is 0.8 m and maximum depth is 2.5 m. Storage capacity is about 2,000,000 m^3. Xiaohu region has obvious characteristics of the desert climate, scarce rainfall, and strong evaporation. Average annual rainfall in Xiaohu is 188mm and rainfall is concentrated in 7-9 month, according to data from weather bureau of Zhongwei City. In addition to a small amount of rainfall, Xiaohu almost has no direct surface water recharge. And it is mainly recharged by groundwater and water drain to the paper mill. According to water quality monitoring data, the main pollutants of Xiaohu are COD, TN, fluoride, volatile phenol and BOD_5.

3.2 Determining the Target Value of Water Quality

Xiaohu has multiple functions, such as eco-tourism, farming, supplying water for industrial paper, supplying irrigation water for fast-growing forest. The standard value of water quality is referring to STANDARD OF SURFACE WATER ENVIRONMENT QUALITY (GB3838-83). Standard values of main pollutants, in Ⅲ class, are selected as control concentration of pollutants Cs. Meanwhile, concentrations of water quality, in Ⅰ class, are select as background concentration C_0.

Table 1: Standard Values of Pollutants（mg/L）

	Ⅰ	Ⅱ	Ⅲ	Ⅳ	Ⅴ
COD	15	15	20	30	40
TN	0.2	0.5	1	1.5	2
Fluoride	1	1	1	1.5	1.5
Volatile Phenols	0.002	0.002	0.005	0.01	0.1
BOD_5	3	3	4	6	10

3.3 Determining the Model Parameters

Design water level of Xiaohu is 1254 m and dead water level is 1252.5 m. Dead storage capacity is 891,560 m^3. Xiaohu has just a sluice gate, where the flow is 1.14 m^3/s. This is outflow of water Q_{out}. Water level of Xiaohu is relatively stable, according to monitoring data of water level over the years. Length of dry period is about 90 d. Background concentration of Xiaohu is quality standard of unpolluted groundwater. Background concentration and water quality testing data of Xiaohu are as follows:

Table 2: Water Quality Testing Data of Xiaohu (mg/L)

	Upstream	*Midstream*	*Downstream*	*Lake inlet*	*Xiaohu*
COD	84	38	49	42	15
TN	3.59	2.78	4.64	3.88	1.82
Fluoride	2.88	2.19	0.36	0.94	1.48
Volatile Phenol	0.014	0.003	0.002	0.002	0.04
BOD5	14.2	2.00	2.94	2.78	4.2

Synthetic attenuation coefficient *K* is an important parameter in the research of water environment capacity. Affected by many factors, such as water volume, flow rate, temperature, and wind speed, it is difficult to obtain a certain K by field test. In this paper, synthetic attenuation coefficients of pollutants are determined by indoor experiments and results are as follows:

Table 3: Synthetic Attenuation Coefficient *K*(1/d)

Pollutants	*K*
COD	0.001
BOD	0.021
TN	0.032
Volatile	0.052
Fluoride	0

3.4 Results

Water environment capacity can be calculated by the formulas and results are as follows:

Table 4: Water Environment Capacity of Xiaohu(m^3/d)

Pollutants	*K(d-1)*	*Cs(mg/L)*	*C0(mg/L)*	*V(m3)*
COD	0.001655	20	15	891560
BOD	0.021	4	3	891560
TN	0.032	1	0.2	891560
Volatile Phenol	0.052	0.005	0.002	891560
Fluoride	0	1	1	891560
Pollutants	ΔT (d)	Qout(m3/d)	W(kg/d)	
COD	90	25098.34	581.008	
BOD	90	25098.34	185.191	
TN	90	25098.34	61.553	
Volatile Phenol	90	25098.34	0.387	
Fluoride	90	25098.34	25.098	

In this paper, COD, TN, fluoride, volatile phenols and BOD5 are control factors. Water environment capacities are 581.008kg/d, 185kg/d, 61.553kg/d, 0.387kg/d, 25.098kg/d, according to the above model and parameters. The results show that Xiaohu still has some water environmental capacity in dry season. Among them, water environment capacity of COD is largest and Volatile Phenol is smallest.

4. Conclusion

Research on water environment capacity has an important role in development and management of water resource. It can provide reliable data environmental planning and management of water. In this paper, lake is the research object. And the paper is focused on one-dimensional steady model, as well as the determination of the parameters in the model. Because of its conditions, the parameters of the model used in lake water environment capacity calculation are established different way and different lake may have different method.

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