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The nutrient budget of Chaohu Lake

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Abstract — The nutrient budget was measured during 1987.5-1988.4 and calculation was made according to the formula: $M = Q \cdot C$. Chaohu Lake has a heavy allochthonous nutrient load: 23.36 g N/m^2 per year and 1.43 g P/m^2 per year. The Nanfei River receives wastewater from the capital city — Hefei of Anhui Province and agricultural runoff from its suburbs, and those 38.5% TN load and 37.6% TP load of the total nutrient input. The nutrient load from all point sources contributes 40.1% for TN and 36.8% for TP of the total input. The control of eutrophication of Chaohu Lake should reduce nutrient load from both point sources and nonpoint sources.

keywords: nutrient budget; point source; nonpoint source; eutrophication.

INTRODUCTION

The Chaohu Lake located in Anhui Province, is one of the five largest lakes in China. In recent decades, great eco-environment changes have taken place on the Chaohu Lake basin as the result of agricultural and industrial development. Human activities have seriously influenced the lake to cause eutrophication. The seriousness of eutrophication has done great damage to its water use and reduced the water quality. The lake has been heavily polluted and its eco-environment must be improved. Thus it is important and urgent to calculate the nutrient budget of the lake in order to provide the scientific basis for control the pollution sources and prevent further eutrophication.

The nutrient budget measurement was carried out during 1987-1988. The calculation of the nutrient balance is described in the following paragraphs.

ANNUAL HYDROLOGICAL BUDGET OF CHAOHU LAKE

1. A survey of the hydrographic net of Chaohu Lake

Chaohu Lake has 32 tributaries. The major rivers flowing into the lake are the Hangfu River (including its major tributary Fengle River), Nanfei River (including Dianfu River), Paihe River, Baishishang River, Zhigao River and Zhaohe River which contribute 84.5% of the total water input (Table 1).

Table 1 The drainage areas of main tributaries and annual water input

River name	Area. km^2	Percentage of total area, %	Runoff volume, 10^6 m^3	Percentage of total runoff volume, %
Hangfu River	4214	39.6	2066	37.1
Baishishan River	792	7.4	482	8.7
Paihe River	602	5.7	424	7.6
Nanfei River	1699	16.0	768	13.6
Zhigao River	547	5.1	462	8.3
Zhaohe River	1390	13.1	493	8.8
Direct diffuse	1404	13.2	881	15.8
Total	10648	100.0	5575	100.0

In the whole watershed, there are minor runoff sources designed in the name of "direct diffuse". Its drainage area and runoff volume are shown in Table 1. The division of the total catchment area into subcatchments of the major rivers and direct diffuse areas are shown in Fig. 1. Among the rivers, Fengle River and Hangfu River have one river mouth into the lake and they are combined and are indicated as Hangfu River. Dianfu River and Nanfei River are the same case and are indicated as Nanfei River.

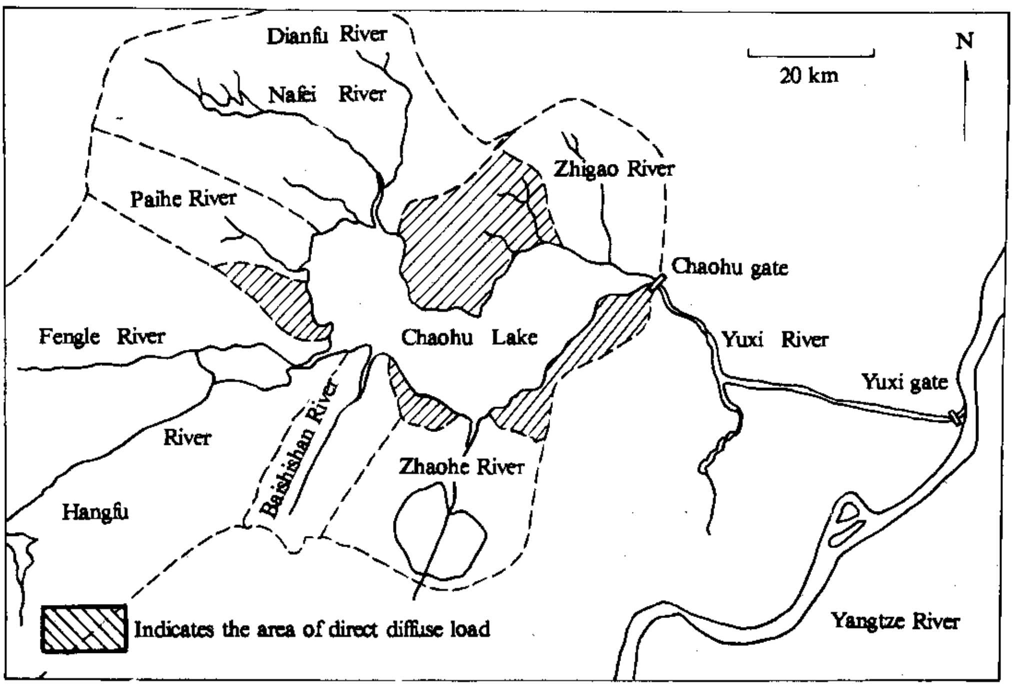

Fig. 1 Subwatershed of Chaohu Lake indicates the area direct diffuse load

2. The calculation of annual flow volume

The control points for tributary input are located at sections, which are preventative for water and nutrient loads from the catchment. They are mostly near the months of the rivers and at a few kilometer upstream in order to avoid or reduce the backflow influence of the lake. The amounts of runoff volume of the major rivers into the lake are listed in Table 2.

Table 2 The runoff volume of the river flowing into the lake (unit: 10^6 m^3)

	Hangfu River	Nanfei River	Paihe River	Zhigao River	Baishi River	Zhaohe River	Direct diffuse	Total
1987								
5	301.4	89.9	82.1	52.5	96.9	121.6	130.1	875.1
6	193.8	39.7	25.6	18.9	30.5	21.4	64.4	394.4
7	569.2	279.2	113.4	187.3	129.8	158.5	268.2	1705.6
8	371.9	150.8	115.6	124.6	113.3	116.2	184.4	1180.8
9	60.6	2.1	1.1	1.2	4.5	12.0	14.6	72.1
10	139.9	79.8	34.1	30.9	55.6	13.0	71.2	398.6
11	130.6	40.3	18.2	13.1	7.9	7.8	43.9	261.8
12	18.8	0.3	0	0	0	3.3	3.9	26.1
1988								
1	10.5	4.5	2.1	2.0	4.0	3.2	4.9	24.6
2	86.1	37.3	17.45	16.3	19.8	13.6	37.1	227.6
3	123.3	26.0	9.0	9.9	13.9	69.8	38.0	289.9
4	59.9	14.1	5.4	4.9	6.3	8.7	19.5	118.8
Total amounts	2066.0	764.0	424.1	461.5	482.4	492.7	880.8	5575.2

The flow across the sections are calculated from precipitation using a runoff coefficient, which was kindly supplied by Anhui Hydrology Bureau.

The calculation is only for the period from May, 1987 to April 1988.

3. The calculation of precipitation input to Chaohu Lake

The average measured precipitation by the four stations, i.e., Chaohu Gate, Zhongmiao, Kuiling, Tianxi is multiplied by the area of the lake and the precipitation input is obtained (Table 3).

Table 3 The precipitation input volume on Chaohu Lake (unit: 10^6m^3)

	1987							
Name of input	5	6	7	8	9	10	11	12
Precipitation input	105	55	256	133	10	90	46	0
	1988							
Name of input	1	2	3	4		Total amounts		
Precipitation input	14	71	56	24		860		

4. The calculation of the water discharge from industry and agriculture

The calculation is based on the water consumption of the regions. It is typical in this area that agricultural discharge is about 20% of the agricultural irrigation water and the industrial discharge is about 70% of industrial water consumption.

5. The groundwater input into the lake

The amount is calculated by the potential difference between the ground water level and average water-level of the lake surface and the filtration coefficient and permeation speed of typical soil types.

The amount of groundwater flowing into Chaohu Lake is 446.28×10^6 m^3.

6. The output water volume

It is calculated by the output flow rate through Chaohu Gate and the flow time.

7. Evaporation on the lake

It is calculated with factors of humidity, temperature and wind speed by the Anhui Meteorological Bureau.

8. Agricultural and industrial water consumption

According to the data provided by the water plants along the lake. Agricultural Department and Water Resource Management Department, the total amount of agricultural and industrial water consumption is $1099.1 \times 10^3 m^3$ in 1987–1988 (Table 4).

Table 4 The lake output water volume (Unit: $10^3 m^3$)

Time / Name of items	1987: 5	6	7	8	9	10	11	12
Output water to Yuxi River	23.7	519.0	142.8	476.1	981.2	785.1	762.8	682.3
Industrial water intake	38.3	39.0	35.1	36.3	41.6	43.3	44.5	47.3
Agricultural irrigation intake	32.5	175.5	130.0	19.5	149.5	130.0		
Vaporization	80.9	81.5	64.2	89.2	76.4	53.8	34.2	28.5
Total amounts	175.4	814.9	372.1	621.1	1248.6	1012.2	841.5	758.1

Time / Name of items	1988: 1	2	3	4	Total amounts
Output water to Yuxi River	12.9	0	460.7	210.0	5656.6
Industrial water intake	36.8	26.9	39.7	33.3	462.1
Agricultural irrigation intake					637.0
Vaporization	25.5	32.0	36.0	62.0	661.2
Total amounts	75.1	58.9	536.4	305.2	7417.5

Table 5 lists the water budget of Chaohu Lake. With an error of water balance 5.2%.

Table 5 Water budget of the lake of 1987－1988 (Unit: $10^6 m^3$)

Input items		Output items	
River input	4691	River output	5657
Direct diffuse	881	Industrial and agricultural intake	1112
Precipitation	861	Evaporation	661
Industrial and agricultural discharge	451		
Groundwater input	466		
Total	7350	Total	7430

THE CALCULATION OF NUTRIENTS BUDGET

The following equation was used to calculate the nutrient budget of the lake:

I-river + I-indirect + I-rainfall + I-discharge + I-groundwater = O-outflow + O-industry use + O-irrigation (I = Input, O = output).

The calculation equation of nutrients:

$$M = Q \times C, \tag{1}$$

Where: M is the input or output of nutrients, tons; Q is the input or output water amount, tons; C is the concentration of nutrients, mg/L.

Measurements and calculations of total nitrogen and total phosphorus concentrations in water samples were accomplished by our field laboratory, the Hefei Environmental Monitor Station, Nanjing Institute of Geography and Limnology and Anhui Institute of Environmental Sciences. All samples were taken once a month, with additional samples in rain events.

The calculation is based on the concentration and water input-output amount of each month.

The amounts of nutrient input from major rivers and nutrients input from precipitation, direct runoff, the groundwater and industrial and agricultural discharge water, and their contribution percentage are shown in Table 6.

Table 6 The input ways of nutrients and their percentage

Way	Input amount, ton/a		Percentage	
	TN	TP	TN, %	TP, %
Hangfu R.	4254	239.4	21.2	25.5
Paihe R.	1494	65.6	7.5	7.0
Zhaohe R.	1451	34.2	7.2	3.6
Baishishan R.	946	36.2	4.7	3.9
Zhigao R.	911	53.5	4.5	5.7

Table 6 (continued)

Way	Input amount, ton/a		Percentage	
	TN	TP	TN, %	TP, %
Nanfei R.	7701	353.7	38.5	37.6
Shiwule R.	321	2.6	1.6	0.3
Sum	17079	785	85.3	83.5
Direct diffuse	803	103.4	4.0	11.0
Precipitation	674	17.2	3.4	1.8
Ground water	1119	23.3	5.6	2.5
Agricultural discharged water	348	11.5	1.7	1.2
Sum	2752	155.4	14.7	16.5
Total	19831	940	100	100

Calculation of nutrient output is made up of three parts: output water through the Yuxi River (Table 7), industrial and agricultural water and water for fishery. The fishery output is calculated by the annual fish production and their average nutrient content. The total budget is shown in Table 8.

Holding coefficient of N and P =(input − output)/input × 100%, TN = 27.2%; TP = 24.4%.

Table 7 Calculation of river nutrient output from the lake

Time	1987					
Name of items	5	6	7	8	9	10
Chaohu Gate runoff volume, $10^6 m^3$	624	519	143	476	981	785
TN concentration, mg/L	1.24	1.65	2.38	1.88	1.10	0.96
TP concentration, mg/L	0.095	0.105	0.093	0.066	0.088	0.063
The nutrients of TN, ton	773	856	339	895	1079	754
The nutrients of TP, ton	59.3	54.5	13.3	31.4	86.3	49.5

	1987		1988				Total
	11	12	1	2	3	4	amounts
	763	682	13	0	461	210	5657
Ibid	1.51	1.17	1.56	2.18	3.07	0.93	
	0.074	0.094	0.113	0.278	0.143	0.101	
	1152	789	20	0	1414	195	8277
	56.5	64.1	1.5	0	65.9	21.2	503.5

Table 8 The nutrient budget of Chaohu Lake of 1987--1988 (unit: ton/a)

Input item, ton			Output item, ton		
Names	TN	TP	Names	TN	TP
River & industral discharge water	17079	785.0	Rivers	933	509.1
Precipatation of lake	671	19.2	Industrial water consumption	3232	134.1
Direct runoff	803	103.4	Agricultural water consumpt.	1768	58.5
Ground water input	1119	23.3	Fishery output	105	9.5
Irrigation discharge	348	11.5			
Total	19831	940	Total	14439	711

The difference between the input and output of nutrient is: TN = 5392 tons; TP = 229 tons. The result indicates that the 27.2% of the nitrogen and 24.4% of phosphorus are kept in the lake system.

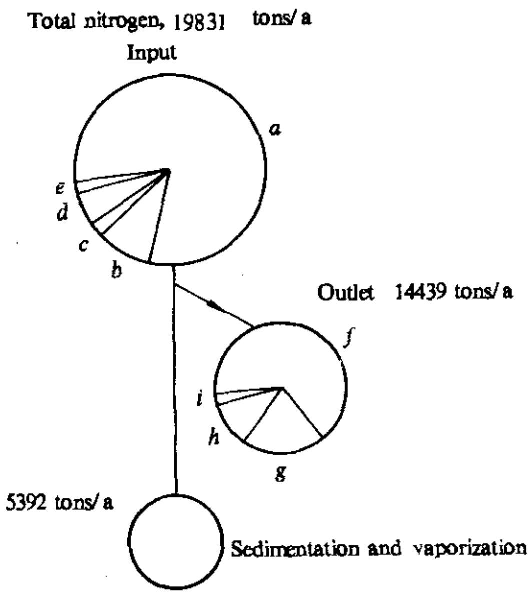

Fig. 2 The difference of TN nutrients between input and outlet lake
a. River input and wastewater discharge; b. Precipitation input;
c. Direct runoff input; d. Groundwater input; e. Irrigation discharge water;
f. Lake outlet water; g. Water taken for industry;
h. Water taken for agriculture; i. Output by fishery products

Evaluation of the nutrient inputs into the lake

In Table 6 we can compare the contribution of nutrients from different sources to Chaohu Lake.

The rivers are the major pathways which load the nutrients into the lake with 83.5% total phosphorus and 85.3% total nitrogen. Second is the direct runoff which brings the 11% TP and 4% TN to the lake. The other inputs are rather small. Among these rivers, the percentage inputs of Hangfu and Nanfei Rivers are comparatively higher which bring 21.2% TN, 25.5% TP and 38.5% TN, 37.6% TP to the lake separately (Fig. 2 and Fig. 3).

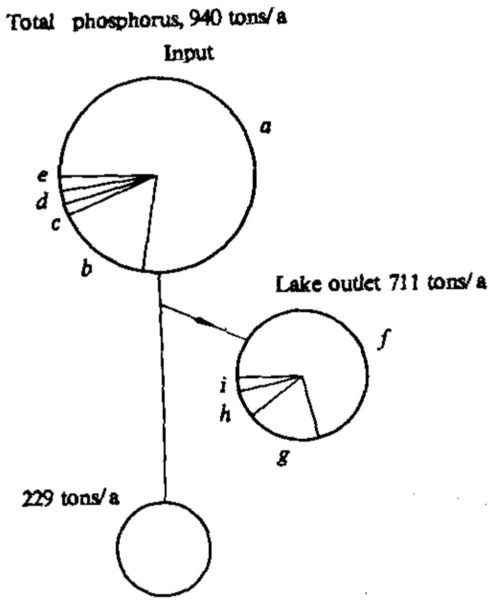

Fig. 3 The difference of TP nutrients between input and outlet lake
a –i are the same as to Fig. 2

According to the water and nutrient budget of the lake during 1987-1988. The loading of TP and TN were 1.43 g/m^2 per year and 26.36 g/m^2 per year which is about 10 times as much as the OECD permissible phosphorus loading. Obviously, Chaohu Lake should belong to among the eutrophic lakes in the light of nutrient loading.

RELATION BETWEEN NUTRIENT INPUT AND ECONOMIC

Nutrients come into the lake through two ways: point sources and nonpoint sources.

The industrial wastewater and domestic sewage from cities of Hefei, Feixi, Shuchen, Chaohu and Lujiang in the Chaohu Basin are point sources of pollution. The development of industry in

Chaohu Basin is rapid. There are about 2500 industrial and mineral enterprises. And Hefei is a new industrial city which has metallurgical, mechanic, electronic industries and so on.

The amount of wastewater discharged is 0.19 billion tons per year into Chaohu Lake Basin, 75% of which is from Hefei City, i. e., 0.111 billion tons per year. The wastewater directly discharges into the tributaries to the lake or directly into the lake with little treatment. This makes Chaohu Lake receive the largest amount of wastewater per unit lake volume comparison with the other four large lakes in China.

The wastewater discharge made a total nitrogen load of 7960 tons and a total phosphorus load of 353 tons. Thus the contribution from point sources is 40.1% for total nitrogen and 36.8% for the total phosphorus. Control of point source nutrient discharge, which is relative easier and less expensive than control of nonpoint sources, will reduce a large portion for the nutrient load.

An important point source is the domestic sewage from city residents. According to the survey on the residents discharge of a small district of Hefei City in December 1987, 1.0g of P and 12g of N was discharged by each resident per day. there are 970000 residents in towns along the lake. It is estimated that 354 tons P (Wang, 1989) and 4380 tons N are discharged per year. Among the point sources pollution, the proportion of TN and TP of domestic wastewater are 55% and 80% of point source pollution of the lake which exceeded the proportion of industrial wastewater.

The number of rural enterprises have been increasing fast in recent years. It is very serious that these enterprises discharged pollutants arbitrarily because of poor management, low environmental consciousness and backward technology. Especially, there are more than ten enterprises which are doing P mining in the catchment of Chaohu Lake. These rural enterprises are now still in small scale and they do not use the city water supply or sewage system. So in this budget they are mostly considered as nonpoint sources.

The important nonpoint sources pollution are domestic waste from villages, agricultural runoff and soil erosion. There are 4.5 million people living in the countryside of the lake basin, and 985.5 tons of phosphorous and 16425 tons of nitrogen are discharged each year based on the calculation of 0.6 g of phosphorus and 10 g of nitrogen discharged by each person per day. Most of it will be taken to the field and retarded in the agro-ecosystem. But the discharge by village along the riverside will mostly enter the water.

CONCLUSIONS

The Chaohu Lake has a heavy nutrient load in the measured year (1987-1988) and TN and TP loading are 23.36 g/m^2 per year and 1.43 g/m^2 per year, which exceeds the permission loading and is the main cause of eutrophication.

Among all the nutrient routes, the Nanfei River makes the largest load into Chaohu Lake.

Its TN load was 38.5% and TP was 37.6% of the total nutrient input in the year of 1987-1988. The next is Hangfu River with the TN portion of 21.2% and TP of 25.5% . The majority of nutrients input is from tributaries.

The nutrient load in the measured year was 19831 tons TN and 940 tons TP. The nutrient output in the measured year was 14439 tons TN and 711 tons TP. The holding efficiency was 27.2% for TN and 24.4% for TP.

The amount of wastewater discharge is 190 million tons in Chaohu Lake watershed. 139 million tons is from Hefei City, 111 million tons is from industries of Hefei City and 29 million tons is the domestic sewage.

The nutrient load from the point sources of industries and domestic sewage contributes 40.1% for nitrogen and 36.8% for phosphorus of the total inputs. The proportion from domestic wastewater is 55% for TN and 80% for TP of the point source inputs. The nutrient concentration of Nanfei River, Shiwuli River and Paihe River are very high which exceed the value from different lake experiment. To control the concentration of these rivers is an effective way and must be done first to decrease eutrophication in the lake.

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