Total Quantity Control Research of NPS Pollution of Suzhou Creek Based on Gis

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Abstract: With the link of NPS models, GIS technology and total amount control measure, water environmental capacity was discussed to determine amount of permitted pollution discharge or cut-down of NPS in Suzhou creek watershed in this paper. It was found that loads from NPS pollution were larger than that from point sources in the study area. To meet the objectives of total quantity control of Suzhou creek in 2010, various NPS pollution should be reduced more or less. The largest cut-down amount of CODcr was from livestock and poultry, reaching 1,627 t/a; the second was from villages, reaching 1,130 t/a; while 939 t/a came from rice fields. For pollution cut-down amount of CODcr for unit grid, villages ranked first, towns and ponds were also larger relatively. Finally some countermeasures of NPS pollution for total quantity control were presented to integrate total amount target and the environmental capacity.

Keywords: nonpoint source pollution, total quantity control, GIS, Suzhou creek

Total amount control (TAC) is to determine pollutant amount of maximum discharge or minimum cut-down beginning with water environmental objectives and capacity. Generally, TAC includes capacity, objective, and occupational total amount control (Xu Gui *et al.*). Due to comprehensive consideration of environmental protective objectives, characteristic of pollution sources and water environmental capacity, Implement of TAC can improve effectively water environmental quality, and reduce pollution load in scheme in all. At present, the measure had made some good progresses on the cure of point sources pollution in China.

Non-point source (NPS) pollution originates from diffuse land areas that intermittently contribute pollutants to surface and ground water (Daniel E.Line *et al.*), and was recognized to be a major source of water environmental problem. With the perfect of TAC system in China, how to introduce it into the research of NPS pollution prevention will have great significance to water environmental protection. This paper focused on total amount control of NPS pollution in Suzhou creek through pollution models, GIS and modeling experiments.

1 Measures

We classified land pattern in the study area into five land uses about paddy field (PF), dry land (DL), nursery (NL), village (VL) and town land use (TL). And pollution load of ponds was estimated alone. A year was divided into four rainy seasons consisting of spring (from Mar to May), summer (Jun to Jul), autumn (Aug to Oct) and winter (Nov to Feb). The SCS model was calibrated through measured surface runoff data. The study area was grid and Suzhou creek was generalized to build answer-response relationship of grid-section with GIS. NPS pollution loads and water environmental capacity of each controlled section were estimated according to the objectives of water environmental planning for each grid viewed as a NPS source and CODcr as a control factor. Pollutant cut-down amount for different types NPS, as to an individual grid was allocated in terms of a certain criteria.

2 Estimation of NPS pollution loads

2.1 Study area

Suzhou creek, which suffered from serious pollution, is the water body with some important functions in Shanghai. Terrain in Suzhou creek watershed is plain and seasons are distinctive due to the impact of southeast monsoon. Mean annual precipitation is about 1,152mm. The study river section was form Zhaotun to Huacao in Suzhou creek with a watershed area of about 427 km^2 including 17 towns (Figure 1).

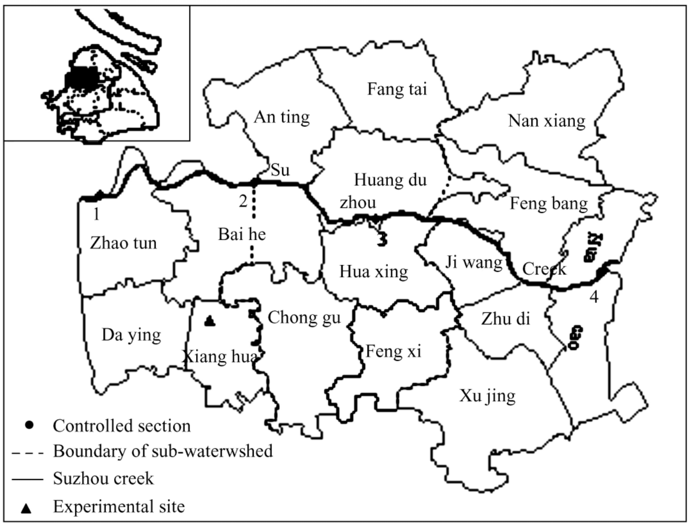

Fig. 1 Study area, its site in Shanghai and controlled section of Suzhou creek

2.2 Sampling and analysis

The field experiment was arranged in Xianghua town in Qingpu district. Three plots, including nursery, paddy field and vegetable plot (blue purple soil) about 5 ha, 2 ha and 2 ha, respectively, with a meteorological observation station nearby, were chosen for the study to determine surface runoff and nutrient load. In each plot, surface runoff volume was measured using precalibrated flumes equipped with water-lever recorders. During the experiment, surface samples were taken at the entrance to water body of runoff avoid the start-end of runoff after each rainfall when runoff existed with 5—10 samples being collected from Dec 1999 to Nov 2000. Furthermore, previous measured materials of rainfall-runoff were collected in the same region. Concentration of COD in water samples was determined by potassium dichromate method.

2.3 Rainfall-runoff coefficient

(1) SCS model

The SCS model considered sufficiently the impacts of a watershed factors including soil, vegetable, antecedent moisture conditions (AMC) and their temporal-spatial change, human activities to surface runoff. So the model was popularized extensively in the world. Its basic form is as follow:

$$Q = \begin{cases} (P - 0.2S')^2 / (P + 0.8S') & (P \geq 0.2S') \\ 0 & (P < 0.2S') \end{cases}$$

and $$S' = (25400/CN) - 254$$

where, Q = daily runoff depth (mm); P = daily precipitation (mm); S' = soil retention coefficient; CN, non-dimension parameter.

(2) *CN* calibration

Estimated runoff volume directly using SCS comparing with measured runoff data had relative errors range from –74.2% to 8.9 % and average errors about –30%. So the SCS model should be calibrated in this Study. Surface runoff relates to coefficient of permeability especially in plowpan of soil. Moreover, antecedent five-day precipitation is ease to get. So *CN* numbers of the SCS were calibrated from above two aspects in this paper.

AMC ranks were determined according to its definition and synthesized analysis to antecedent five-day precipitation of 70 measured surface runoff data in blue purple soil. Using above AMC classifications and the SCS model, We deduced in reverse *CN* numbers of different land uses in blue purple soil in different rainy seasons. The mean *CN* number result of synthesized analysis was shown in Table 1.

Table 1 AMC ranks of different rainy season and *CN* of different runoff types in purple soil

Season	Antecedent five-day precipitation (mm)	AMC	PF	DL	NL	VL & TL
Spring	<15	I	84	82	70	8 0
	15—30	II	90	89	82	9 2
	>30	III	95	94	91	9 6
Summer	<20	I	\	87	75	8 7
	21—50	II	\	94	88	9 4
	>50	III	\	98	93	9 8
Autumn	<15	I	\	84	70	8 0
	15—30	II	\	91	83	9 3
	>30	III	\	94	91	9 7
Winter	<13	I	60	58	55	72
	13—28	II	72	70	71	86
	>28	III	87	86	86	94

Note: PF-paddy fields, DL-dry lands, NL-nursery lands, VL-village lands, and TL-town lands

Being impossible of measuring runoff volume from village and town land, we looked their *CN* up in the manual based on investigation of the non-penetrated area proportion in some villages and towns (Novotny, G *et al*.). Because discharged water of paddy fields is effected by rainfall and irrigation volume in summer and autumn, the SCS model is not fit for paddy fields (Zhang Dadi *et al*.). So we got their runoff coefficients directly from measured data.

(3) Runoff coefficient

We recognized that an individual rainfall could not generally produce surface runoff when precipitation was less than 10 mm, 5 mm, 10 mm or 20 mm in spring, summer, autumn or winter rainy season respectively through above *CN* calibration. The following showed a case study of surface runoff coefficient in dry lands in purple soil in spring rainy season.

Runoff volume of each rainfall more than 10mm was estimated with the SCS model through the selection of *CN* number from Table 1 in spring from 1987 to 2000, and then accumulated by day for each spring in different years. Furthermore precipitation more than 10mm was also accumulated by day for each spring from 1987 to 2000. So runoff coefficient in spring rainy period of different years could be calculated through total precipitation divided by total runoff volume. And rainfall-runoff relationship was built through regressive statistics analysis（Y=0.0545P+12.274, R=0.976, Y, runoff coefficient, P, precipitation）. Other runoff coefficient of different land uses in different rainy seasons could be determined by this measure.

Because leakage coefficients of 9 types soil in study area were different with each other (Hou Chuanqing), runoff coefficient in other soil should be modified. The revised numbers of runoff coefficient in different type soil were shown in Table 2 with above-mentioned measure for runoff coefficient in purple clay viewed as 1.

Table 2 Leakage coefficient of different soil and corrected runoff coefficient

Soil type	Leakage coefficient	Revised value
Blue purple clay	7.06	1.00
Blue purple soil	3.96	1.16
Blue purple tou	4.58	1.11
Blue yellow clay	20.02	0.95
Blue yellow soil	8.22	0.99
Yellow tidal clay	3.03	1.20
Ditch dry tidal clay	41.4	0.92
Yellow clay tou	51.00	0.89
Tidal sand clay	54.00	0.85

2.4 Pollutant concentration

Measured pollutant concentration effected by many factors had great varaliablity, which brought great difficulty in loading estimation. For example, CODcr concentration ranged from 20mg/L to 151mg/L in villages in spring rainy period. However, Average concentration of CODcr was adopted to evaluate NPS loads in this paper.

2.5 Pollution load estimation

Pollution load estimation model was as following:

$$W = \Sigma\ (A \times P \times r_t \times C_t) + \Sigma\ (A \times P \times r_j \times C_j \times R_j) + \Sigma\ (A \times S)$$

where: W = pollutant load; A = area of unit grid (200×200) m^2; P = precipitation; r = runoff coefficient; C = pollutant concentration; R = revised value of runoff coefficient; S = pollutant discharge coefficient of pond; subscript t, town lands; j, paddy fields, dry lands, villages and nursery lands.

2.5.1 Gridding

The following principals were adopted in gridding.

(1) Space resolution of grid cell should be in agreement with actual conditions. Density of stream network in study area is about 6 km/km^2-7km/km^2. If rivers distribute equally, distance of field plot to river is less than 200m. So space resolution of grid cell should be less than 200 m×200m。(2) Mapping area of different land use types in grid layer is equal to actual area approximately. (3) Balance of disposal velocity of computer with displaying precision should be taken into account when the parameters of grid were set. Space resolution should be upgraded in utmost within displaying time of grid not over five seconds. So four approaches of gridding were chosen to compare with each other (Fig 2).

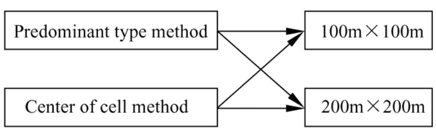

Fig. 2 Approaches of gridding

After many trials, center of cell method with cell of 200m×200m which could meet above principals was chosen in this research. So the study area was divided into 10,675 cells with paddy field of 6,062 cells, dry lands 1,422, nurseries 262, villages 2,148, towns 37 and ponds 407, respectively.

2.5.2 Pollution of ponds

Generally, pond exchanged water with ambient water body for two times per year, and we changed two times per year into four in this paper. Exchanged water volume was about 15,000 m^3/(ha • a) and annual exchange load of CODcr could be found in Table 3.

Furthermore, we did not consider the weight of runoff coefficient in town lands in this paper.

Table3 Pollutant discharge coefficient of pond

Project	CODcr
Concentration margin (mg/L)	18.29
Annual exchange load (kg/(ha • a))	274.35

3 Water environmental capacity

3.1 Model

The following nonlinear attenuation model was used to estimate water environmental capacity:

$$W=C_N(Q+q)-C_0Q_1-C_N(Q+q)[1-\exp(-kx/U)]$$

where, W = water environmental capacity, g/s; CN = designed standard of water quality, mg/L; Q = designed flow, m^3/s; q = discharge amount of point sources when NPS occurred, m^3/s; C_0 = pollutant concentration from the upper region, mg/L; Q_1 = flow from the upper region, m^3/s; K = self-cleaning coefficient; x = river length, m; U = designed velocity of flow, m/s.

3.2 Assumptions

(1) Although Suzhou creek is a middle tidal river with bi-direction flow, we did not consider reverse direction flow in estimation of water environmental capacity.

(2) Because water quality in the tributaries of Suzhou creek was worse, water environmental capacity of the tributaries was not taken into account.

(3) According to the minimum precipitation that could produce runoff in different rainy seasons, time of non-point sources was about 45 d/yr. If each runoff lasted two hours, total time of non-point sources was 90 h/yr.

(4) Livestock and poultry included intensive and scattered measure, of which CODcr emission coefficient could be found in reference 5. Discharge rate of CODcr from villager and urban resident's living pollution was 5.84 kg/person and 7.30 kg/person. yr ,respectively.

(5) Suzhou creek was generalized into upper (Zhaotun-Baihe), middle (Baihe-Huangdu), and backward section (Huangdu-Huacao).

(6) Self-cleaning coefficient of CODcr was 0.15/d and point sources flow was 0.5 m^3/s, 1.5 m^3/s, 1 m^3/s in the upper, middle and backward section respectively. Estimation of water environmental capacity referred to water quality planning objectives of Suzhou creek in 2001 and national surface water environmental quality standards（GHZB1-1999）。

3.3 Water environmental capacity

(1) Answer-response relationship of section-grid was built up with GIRD according to the collective sub-watershed of each controlled section (Table 4).

(2) Point-NPS pollution loads in each controlled section were estimated according to above assumptions (Table 5). It was found that CODcr amount from living pollutant, surface runoff, livestock, industry point source reached 8,913t/a, 6,742t/a, 4,228t/a, 4,197t/a respectively. So *NPS* pollution should be controlled efficiently.

Table 4 Grid number in each section

Section	PF	DL	NL	VL	TL	Pond
Upper	1,051	162	48	277	45	46
Middle	2,828	804	151	883	122	177
Backward	2,183	456	63	989	206	184

(3) Length, control objectives, CODcr loading of point-*NPS* pollution and water environmental capacity of different river sections could be found in Table 6.

Table 5 Loads of point-*NPS* in each section (t/a)

Section	Industry point	Living pollution	Runoff	Livestock	Total
Upper	323.53	965.95	1025.8	731.97	3,047.25
Middle	2,131.49	4,352.53	3,058.91	1,560.5	11,103.4
Backward	1,742.1	3,595.25	2,658.17	1,935.5	9,931.02
Total	4,197.12	8,913.73	6,742.88	4,227.9	24,482.7

Table 6 Pollution condition and water environment capacity in each section in Suzhou creek

Section	Length (km)	*NPS* (t/a)	Point source (t/a)	Point source (t/n*)	Designed flow (m^3/s)	Designed flow velocity(m/s)	Environmental capacity(t/n*)
Upper	10.5	1,804.77	1,289	14.7	41.5	0.25	189.8
Middle	10.5	4,812.4	6,484	74	61.2	0.30	180.6
Backward	8.3	4,754.64	5,337	60.9	71.4	0.34	52.97

Note: n* , Time of producing runoff within a year.

4 Total amount control

An equitable and reasonable criterion was adopted to determine allocated amount of pollution load in the research of total amount control. The formula is as follow:

$$X_i = W_{in}\left(\frac{W_i - W_{it}}{W_{it}}\right) \times R$$

where, X = permitted or cut-down amount; W_{in} = *NPS* pollution load; W_i = water environmental capacity, W_{it} = total loads of point-NPS; R, difficulty coefficient of *NPS* control comparing with point sources, 0.4; subscript i, the controlled section.

We programmed the model in AML macro language of GIRD software to estimate pollutant amount permitted emission or cut-down for each grid, different land uses and regions, respectively (Table 7). (Due to no permitted amount, cut-down amount was taken as positive number).

Table 7 Cut-down amount of *NPS* pollutants and that for unit grid

section	annual pollutant cut-down amount (t/a)							
	PF	DL	NL	VL	TL	Livestock	Pond	Total
Upper	159.4	22.4	3.4	146.6	16.27	261.4	18.07	627.45
Middle	447.2	113.5	11.4	484.6	44.67	600.25	74.69	1,776.26
Backward	332.7	62.3	4.75	498.8	72.64	765.36	79.94	1,816.36
Total	939.3	198.2	19.5	1,130	133.58	1,627	172.7	4,220.07

section	cut-down amount for each grid (kg/a)					
	PF	DL	NL	VL	TL	Pond
Upper	151.67	138.02	68.79	529.24	361.56	392.82
Middle	157.13	141.17	75.43	548.76	366.15	421.97
Backward	152.39	136.64	75.39	504.34	352.62	433.46
Total	—	—	—	—	—	—

Above results demonstrated that CODcr cut-down amount of *NPS* reached 4,220t/a, and main region where *NPS* pollution should be greatly reduced was from the middle and backward sub-watershed in Suzhou creek. The difference of annual CODcr cut-down amount from different *NPS* types was great. The largest cut-down amount of CODcr was from livestock, which accounted for one-third of total cut-down amount and reached 8 times more than that from nursery lands. The difference of annual CODcr cut-down amount from villages and paddy fields, which both came next to that from livestock, was not significant. But cut-down of unit grid from villages was 3 times more than that from rice fields; The larger cut-down amount for each grid was from town and pond lands, however, Annual total cut-down of CODcr from which was not too large. Moreover, the cut-down of the same *NPS* in different regions had great difference.

5 Countermeasures

The results demonstrated the largest cut-down amount of CODcr was from livestock. It was very happy to us that Shanghai municipal government began to gradually rebuild, close or move 44 large and medium livestock pastures along Suzhou creek beginning with 2000. So the objective of “zero emission from livestock ” would come true in 2010.

Paddy fields and dry lands cover a large portion of the study area. Labor structure change in study area made residents who ever managed land not the direct planter instead of the farmers from outside whose objectives were higher production. And chemical fertilizers continued to be increasingly used in recent years. So limits to chemical fertilizers use would be very important in *NPS* pollution prevention.

Villages and towns should be major land uses for pollution reduction. Generally, the cost of engineering prevention measures is higher and the benefit is relatively lower, which are not fit to be adopted at present. So rubbish of villages should be treated collectively. Improving cleaning ways and increasing cleaning frequency and efficiency in town lands will be primary measures to reduce surface accumulation. Construction of green and decrease of non-infiltration area will help to reduce greatly surface wash-off erosion in town lands.

Accumulated silt in ponds became a major threaten to water environment of ambient water body especially at high temperature in summer. So sediment in ponds should be excavated each year by the collectivities. Furthermore, reduction of the exchange water amount of pond with ambient water body, and improvement of the fodder structure will help to attain the objective of total quality control.

If above countermeasures can be taken in simultaneity, the objectives of total amount control of Suzhou creek would be attained.

6 Conclusions

(1) To meet water quality objectives of Suzhou creek in 2001, various *NPS* pollution should be reduced more or less, especially from livestock with cut-down amount of CODcr reaching 1,627t/a. Villages and towns were also major reductive sources. For pollution cut-down amount of CODcr for unit grid, villages ranked first, reaching over 500 kg/a, and towns and ponds were also larger relatively.

(2) It will be very important to prevent *NPS* pollution with TAC measure, but fulfillment of TAC system depends on healthy development of environmental management institution in China.

(3) GIS, models and TAC will play an important role in the research of *NPS* pollution.

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