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The Research on Water Quality of Water Area around Drain Outlets of Longwangzui Sewage Plant in China

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Abstract: This study is to investigate and monitor the pollution situation of water quality of water substance in South Lake, the draining situation of drain outlets around South Lake, the flow and water quality of sewage The quantity and pollutant burden of sewage that drained into South Lake by drain outlets can be got. After the quantitative analysis on the point source pollution in South Lake, the Priod study can be provided for the comprehensive treatment to stop pollution or after pollution. The self-purification rules of pollutants in the drain outlets are analyzed and water quality model is built to simulate and calculate the distribution of concentration field of pollutants in water area round the drain outlets. Those provide a theoretical foundation to analyze the rules of concentration changes of pollutants in the South Lake. The Longwangzui sewage plant outlet is a bigger sewage outlet of the South Lake, the amount of sewage is more than 150000 tons everyday. The water quality model of water body near the Longwangzui sewage plant is based on the sewage characteristic analysis. The sewage pollutant is divided into two parts: settled matter and unsettled matter. The self-purification of settled matter in the water body is sedimentation and the unsettled's is diffusion by laminar flow and dilution by turbulence flow. The two parts enter into lake and mix with the water in lake altogether. The comprehensive self-purification coefficient of TN and TP are deduced by the water quality monitor data near the outlet and the coefficient of TN and TP is 462.24, 172.8 day^{-1} each.

Key words: Sewage plant outlet, theory of surface jet flow, water quality model, self-purification

INTRODUCTION

In the past, the water quality of South Lake is all right. There are abundant baits in lake area and various aquatic lives in water, which provide a good ecological environment for the overall development of aquatic products in lake area. In the early period after China's liberation, a fishing ground was built on the South Lake. It become the production base of fishery after many years of development. However, with the neighboring population leaping and quick development of society and economy, a lot of untreated household sewage and industrial waste water have been dumped into South Lake. This makes the pollutions of lake water aggravates and water quality decreases. The worsen of water quality of South Lake is mainly because a large number of untreated sewage has been dumped into South Lake directly since many years ago. The destruction of neighboring part and ecological environment in lake intensifies the extent of pollution (Iwane, 2001; Baezaetal, 2001).

The established model is a one-dimensional water quality model (Deborah and Mossman,1996). In the calculation, the advection diffusion diluting function of the pollutants is analyzed combining with the jet theory. Combine the effusive theory to in the laminar flow of the pollutant spreads.

This study will build a water quality model based on the example of Longwangzui sewage plant outlet (Park and Lee, 1996) simulate the water quality of water area around the outlet and calculate the distribution of concentration field of pollutants (Al-Layla and Rizzo, 1989).

The main content:

- Investigate the outlets around South Lake
- Build water quality model of water substance round outlets (Whitehead *et al.*, 1981)

The Determination of Range of Pollution Zone around Outlets

According to the data of water flow and water quality of outlets, we will determine sewage discharge concentration of outlets and build the range of pollution zone around outlets combining jet flow theory

Building Water Quality Model of TN, TP in Water Area around Outlets

According to the feature analysis of water quality of sewage discharged from outlets, we will build water quality model of TN, TP in water area around outlets combining rules of self-purification of water substance (Goda and Nakanishi, 1991).

Simulating and Testing Model

For the water quality model of water substance which has already been built, we will determine the parameters in water quality model by using a group or several groups of observed data and correct parameters (Marcel and Marc, 1997).

Because the data of hydrology and water quality are limited, the water quality model of this study will be built on the monitored data of water quality of water area around outlets, draw the spatial changing rules of water quality of water area around outlets with component features of water quality and rules of self-purification of water substance and do a analog computation (Neely *et al.*, 1976).

MATERIALS AND METHODS

Longwangzui Sewage Plant (Geographic Location)

Wuhan Longwangzui sewage treatment plant locates at the Guanshancun of the South Lakes North bank in the Wuchang East Lake development area. The plant is about 13.3 ha (the first phrase is about 8.3 ha and the second phrase is about 5 ha) and the watercollecting area is 34 km^2. Its serving range takes Guandong industrial zone as the West, Luoshinanlu as the East, Changjiang wired power plant and South-Central University for Ethnic Communities as the North, Yujiashan and Mafangshan as the South. The serving population is 360,000.

The Project Situation

The designed treat scale of the plant is 150,000 m^3/d. And the whole project was divided into two phrases. The first project phrase was designed by Wuhan Municipal Design institute, using the general first grade treatment craft, starting in the April,1998, finishing in the end of 2002, starting to commission in June, 2003.

The second phrase project was designed by Wuhan Municipal Design institute and Zhongnan Design institute, using the second grade treatment to instead the first grade treatment, adopting the improved A^2/O craft. It started in April, 2004 and finished in the end of 2005. The total investment of the first and second phrase is about RMB160, 000,000.

The Physical Forms Analysis of the Pollutants in the Sewage

The Analysis Purpose of the Physical Forms Distribution Characteristics

The Longwangzui sewage plant source discharged from the pollutant discharging outlets decides that the pollutants types and components in the sewage are complicated. Each pollutant has its own physical, chemical and biochemical characteristics. According to the sizes of the pollutions, we can divide them into three types: the suspended state, the colloid state and the soluble state. Then we can determine their content proportions separately, which will set the foundation for the following water quality model establishment.

The pollutants in the water body spread in the aqueous medium by the forms of soluble, colloid and suspended particles. The particle diameter of the coarse dispersion system is bigger than 1 μm, that is, the suspended materials are easy to sink in the water body. The particle diameter of the colloid particle is between 1 nm to 1 μm and it is steady and not easy to sink. The colloid state pollutants discharged from the pollutant discharging outlet will mix with the water body under the dilution function. The pollutants which particle diameters are smaller than 1nm will form the true solution in the water body, mixing with the water under the dilution and dispersion function. This model is established on the basis of the pollutants forms analysis of the sewage discharged from the pollutant discharging outlets. To the different physical state pollutants, we study their movement transformation rules in the water body separately.

Measure Analysis Method

The physical forms characteristics analysis of the pollutants in the sewage includes the three states analysis of the water sample from the pollutants discharging outlet and the still sediment experiment. It can determine the three states component of TN, TP and the sediment rules of the sedimentable materials in the suspended materials. In the water quality analysis, the filter membrane which pore diameter is 0.45 μm is always used to separate the suspensions. And it intercepts the particles which particle diameter >0.45 μm and pass the colloid which particle diameter is 1 nm~0.45 μm, polymer substance and the solute which particle diameter <1 nm. Generally speaking, we can approximate take the materials which pass the 0.45 μm filter membrane as the soluble material.

The Analysis Testing Method of Water Sample Three States

The Measure of the Total Pollutants Concentration

Directly measure the TN and TP in the water sample of the original water, that is, the total concentration of each pollutant index.

The Measure of the Soluble TN and TP

Use the 0.45 μm filter membrane to filter 1000 mL water sample and measure the concentrations of TN and TP in the filter liquor, that is, the concentrations of each index soluble pollutants.

The Measure of Sedimentable TN and TP

Still sediment the 1000 mL water sample in Im hoff tube for 1 h. Then use the siphon tube get the supernatant fluid at the 1.5 m point below the water surface. Next measure the TN and

Table 1: The three states analysis table of TN and TP

		The suspended state		The colloid state		The soluble state	
Water sample	Total amount	Amount (mg L^{-1})	Proportion in the total amount (%)	Amount (mg L^{-1})	Proportion in the total amount (%)	Amount (mg L^{-1})	Proportion in the total amount (%)
TN	16.12	0.22	1.36	0.72	4.47	15.18	94.16
TP	1.02	0.20	19.61	0.23	22.55	0.59	57.84

Table 2: The soluble state and insoluble state composition of TN and TP

Water quality index	Composition soluble state (%)	Composition insoluble state (%)
TN	94.16	5.83
TP	57.84	42.16

TP in the supernatant fluid, that is, the concentration sum of colloid and soluble pollutants.The differences between the total concentrations and the measured values are the concentrations of sedimentable TN and TP.

Sediment Experiment Plan

Divide the pollutants into sedimentable and unsedimentable materials and do the still sediment experiment to the sewage from the pollutants discharging outlet. Then analyze the sediment rule of sedimentable pollutants and get the concentration changing by the time rules of sedimentable TN and TP.

Take the water sample of the pollutants discharging outlet to do the still sediment experiment. Evenly mix the original water and put 1000 mL into the graduated cylinder. Still wait for 0.5, 1.0, 2.0, 3.0 and 5.0 h, use the siphon tube to get the supernatant fluid at the 300 mL point and then measure the TN and TP in the supernatant fluid.

Analysis of the Three States Analysis

Research group took the samples from the pollutants concentration in the Longwangzui sewage plant pollutants discharging outlet in October of 2009. And analyze the three states of TN and TP. The results are shown in Table 1 and 2.

The major influence factors on the water body physical self-purification are different on different pollutants in the sewage. The soluble state pollutants in the sewage decrease the concentration by advection proliferation, turbulent diffusion and water body mix dilution. The sedimentable pollutants sediment into the lake bottom near the pollutants discharging outlet. The self-purification way of the colloid pollutants is the same as the soluble state pollutants.

The Result and Analysis of the Still Sediment Experiment

Take the original water from the Longwangzui sewage plant pollutant discharging outlet to do the still sediment experiment two times. The water sample is the instant sample of the pollutant discharging outlet. Measure the TN and TP of the supernatant fluid at different time, respectively and the experiment results can be found in Fig. 1, 2.

From the Fig. 1 and 2, we can know from the 0 to 0.5 h, the sediment speeds of TN and TP are relatively steady. From the 0.5 to 1.0 h, the sediment speeds of TN and TP are relatively quick. From the 1.0 to 2.0 h, the sediment speeds of TN and TP are relatively slow. From the 2.0 to 5.0 h, the sediment amounts are few and basically unchanged.

The Equation Analysis of the Still Sediment Experiment Curve of TN and TP

Combine the sediment experiment with the tristate analysis, analyze the sediment rule of the suspended pollutants at the pollutant discharging outlet. We can know the sediment

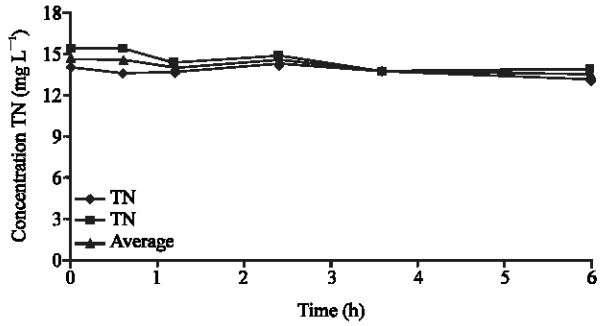

Fig. 1: The curve of TN change with the variation of still time in the supernatant fluid

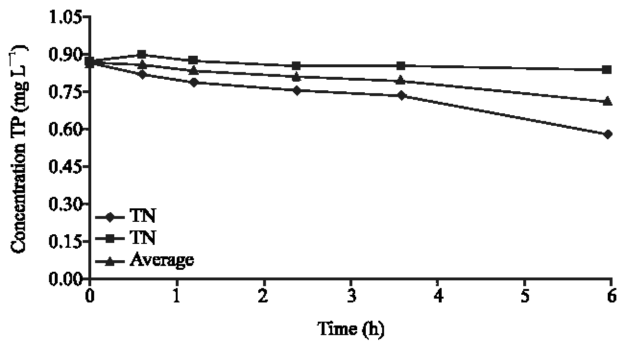

Fig. 2: The curve of TP change with the variation of still time in the supernatant fluid

speed of the suspended pollutants is relatively quick in 2.0 h. From 2.0 to 5.0 h, there is still some sediment and the sediment is basically steady. Take the concentrations of TN and TP at the still sediment 5.0 h as the pollutant amount which can't be removed by the sediment function any more.

From the experiment result, we can know the unsedimentable TN and TP are, respectively 92 and 91.5% of the TN and TP in the original sewage.

The Equation of the TN Sediment Curve

From the sediment experiment, we can measure the concentration change of the TN in the supernatant fluid, then we can get the TN sediment curve as Fig. 3.

From the Fig. 3, we can get the TN sediment equation:

$$(C_{TN} - 0.92C_{0TN})/C_{0TN} \times 100 = 12.669 \times e^{-1.2657t}$$

Where:

t = The sediment time (h)
C_{0TN} = The original TN concentration in the water sample (mg L^{-1})
C_{TN} = TN concentration in the supernatant fluid (mg L^{-1})

From the equation we can get the sedimentable TN sediment equation:

$$C_{STN} = C_{S0TN} \cdot e^{-k_s t} = 0.12669C_{oTN} \times e^{-1.2657t}$$

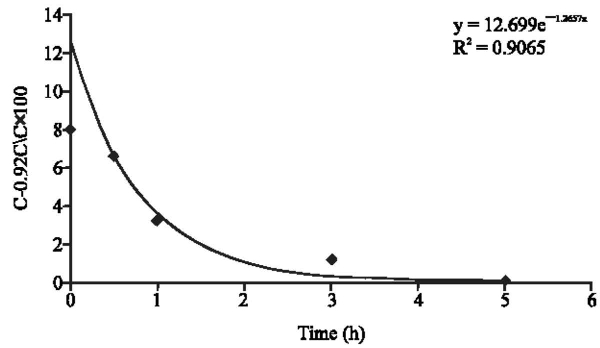

Fig. 3: The TN sediment curve

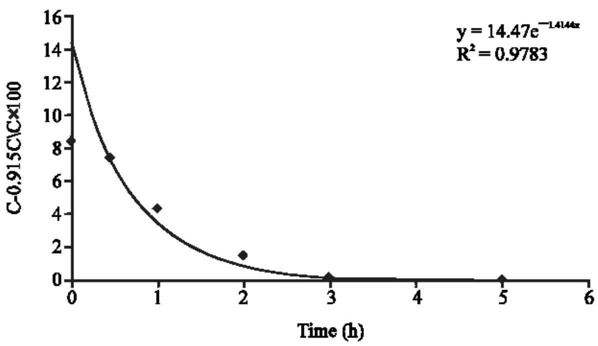

Fig. 4: The TP sediment curve

Where:

C_{SOTN} = Initial sedimentable TN concentration in the sewage of the pollutant discharging outlet (mg L^{-1})

C_{STN} = The sedimentable TN concentration at t time (mg L^{-1})

In the sewage of the pollutant discharging outlet, the initial sedimentable STN concentration is 0.08 C_{OTN} and the initial unsedimentable USTN concentration is 0.92 C_{OTN}.

The Equation of the TP Sediment Curve

From the sediment experiment, we can measure the concentration change of the TP in the supernatant fluid, then we can get the TP sediment curve as Fig. 4.

From the Fig. 4, we can get the TP sediment equation:

$$(C_{TP} - 0.915C_{0TP})/C_{0TP} \times 100 = 14.474 \times e^{-1.4144t}$$

Where:

t = The sediment time (h)

C_{0TP} = The original TPconcentration in the water sample (mg L^{-1})

C_{TP} = TP concentration in the supernatant fluid (mg L^{-1})

From the equation we can get the sedimentable TN sediment equation:

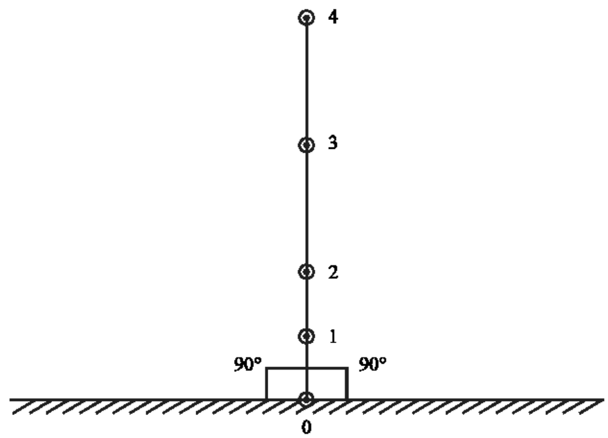

Fig. 5: Water monitoring points around drain outlets of Longwangzui sewage plant

$$C_{STP} = C_{S0TP} \cdot e^{-k_s t} = 0.14474 C_{oTP} \times e^{-1.4144t}$$

Where:

C_{0TP} = Initial sedimentable TP concentration in the sewage of the pollutant discharging outlet (mg L^{-1})

C_{STP} = The sedimentable TP concentration at t time (mg L^{-1})

In the sewage of the pollutant discharging outlet, the initial sedimentable STP concentration is 0.085 C_{0TP} and the initial unsedimentable USTP concentration is 0.915 C_{0TP}.

The Monitor of Water Quality of Neighboring Water Area

The Purpose of Monitor

We position the water area around drain outlets and take samples to learn the changing rules of pollutants in the water area around drain outlets of lake. This provides a foundation to analyze the changing rules of pollutants in pollution zone near drain outlets and factors of pollutants' self-purification. Practical monitor results can determine the coefficients and test the correctness of computer-simulating model.

The Monitor Items and Methods

The items that are needed to be monitored in the water area around drain outlets of Longwangzui sewage plant are TN and TP.

The Plan of Position

In the range from 0 to 300 m near drain outlets, we position on angular bisector which form an included angle along the bank side of drain outlets. Five sampling positions are 0, 50, 100, 200 and 300 m away from drain outlets. The laying of sampling positions are showed in Fig. 5.

We have done 2 times of sample and analysis. The samples are taken from the depth of 0.5m below the lake surface and glass samplers are used.

The Monitor Results and Analysis

The data and result analysis of TN and TP on the direction of mainstream of Longwangzui sewage plant outlets. Table 3 and 4 show, these results.

Table 3: The TN monitoring data analytical table about the water body near the pollutant discharging outlet of Longwangzui sewage plant

	TN (mg L^{-1})		
	Time		
Distance from outlets (m)	8-9-2009	30-10-2009	Mean
0	16.81	18.01	17.41
50	12.97	14.15	13.56
100	11.54	11.59	11.57
200	10.69	10.97	10.83
300	10.01	10.51	10.26

Table 4: The TP monitoring data analytical table about the water body near the pollutant discharging outlet of Longwangzui sewage plant

	TP (mg L^{-1})		
	Time		
Distance from outlets (m)	8-9-2009	30-10-2009	Mean
0	1.10	1.14	1.12
50	0.99	0.98	0.99
100	0.93	0.89	0.91
200	0.83	0.90	0.87
300	0.78	0.82	0.80

From the Table 3 and 4, we can see that the concentration of TN and TP clearly drop in the range of 0 to 50 m away from outlets, but they do not change much in the range of 50 to 100 m. The concentration of TN and TP are stable in the range of 100 to 300 m. From these we can infer that the length of pollution from outlets is approximately 100 m.

The Water Quality Model of Water Area near the Longwangzui Sewage Plant Outlets

The Assumed Conditions of Building Model

We make following hypothesis in the process of building water quality model of water area near the outlets.

- Water flow and water quality of water from outlets are assumed to be steady flow and don't change with time
- The changes of water quality with the depth are not taken into account
- The influence of wind to lake surface is not taken into account and we suppose that the water substance of lake is impound water
- The concentration changes of water quality of water substance near outlets are mainly caused by physical effects, so we ignore the biological effects in the process of building the water quality model of water substance near outlets. Only integrated influences of advective diffusion, turbulent diffusion of concentration and sedimentation are taken into account and the synthetic coefficient of self-purification of water substance is K
- In the process of building the water quality model of water substance, we ignore the influence of other pollution source on water quality of water substance, namely, the influence of endogenous source and surface source

The Determination of Parameters in the Range of Pollution Zone

To determine the parameters in the range of pollution zone around outlet is to calculate according to theory of surface jet flow. The formula is deduced from the comprehensive analysis of data from extensive experiments of Abramovich and it showed in Fig. 6.

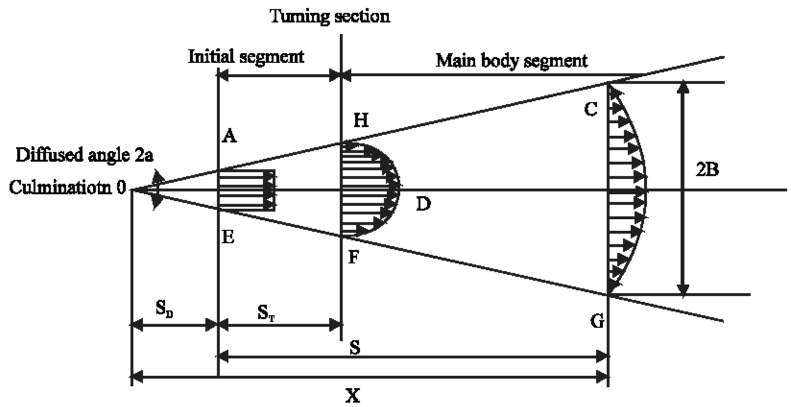

Fig. 6: Calculation diagram with water pollution mixed around drain outlets

The Calculation of Reynolds Number of Outlet at the Longwangzui Sewage Plant Outlet

u_0 is velocity of sewage of outlet, $u_0 \approx 0.6835$ m sec^{-1}, B_0 is halfwidth of water-carrying section of outlet, $B_0 \approx 0.9$ m, 2 $B_0 \approx 1.8$ m.

The calculation of Reynolds number of Longwangzui sewage plant outlet is the Eq. 1:

$$Re_0 = \frac{u_0(2B_0)}{v} = \frac{0.6835\times1.8}{1.007\times10^{-6}} = 12.22\times10^5 \quad (1)$$

v = Kinematic coefficient of viscosity, when the temperature is 20°C, $v = 1.007\times10^{-6}$ m^2 sec^{-1}

As showed by experiments: When $Re_0\geq30$, surface jet flow generally is turbulent jet flow. Because the Reynolds number of Longwangzui sewage plant that we calculated as 12.22×10^5 far more than 30, the theory to determine the flow filed of water area near Longwangzui sewage plant conform to the conditions of surface turbulent jet flow.

The Calculation of Velocity of Flow Field

A lot of experimental observations and analysis show that in any cross section of boundary layer of jet flow, the velocity in transverse direction is smaller than that in direction. It can be assumed that the velocity of jet flow equals to the longitudinal component velocity. The determination of velocity in the flow field is related to longitudinal direction, so it is one dimensional velocity field.

The distributions of velocity in the transverse direction of every cross section in jet flow filed are similar. According to the features of turbulent jet flow in main part of jet flow, when the axial velocity u_m gradually decrease with the increasing distance of x, the distributional curve of velocity of cross section is tend to be flat. If we adopt the dimensionless coordinates to show the distribution of velocity of cross section, the ordinate is u/u_m and the abscissa is $r/R_{0.5}$, the distribution of dimensionless velocity of every cross section is same. U is the velocity of r on radical coordinate, $R_{0.5}$ is the velocity of $u_m/2$ on radical coordinate, u_m is the axial velocity of centre of cross section and that is also the maximal velocity of this cross section.

- From formula: $$\frac{u_m}{u_0} = \frac{1.211}{k\cdot\chi}$$

- Can deduce that: $$u_m = \frac{1.211}{k \cdot \chi} u_0$$
- Calculate as: $$u_m = \frac{1.211}{k \cdot \chi} u_0 = \frac{1.211}{\frac{ks}{B_0} + 0.410} u_0 = \frac{0.8277}{0.1311s + 0.410} \quad (2)$$

- In the equation: k is the characterization coefficient of turbulent jet flow, which is related to the intensity of turbulent flow. If turbulent jet flow is jetted from slits of flat wall, the characterization coefficient k is 0.118. s is the longitudinal distance from precalculated point to outlet (m), χ is the dimensionless distance of flat jet flow:

$$\chi = \frac{s}{B_0} + \frac{0.410}{k}$$

(For the Longwangzui sewage plant outlet: B_0 = 0.9 m; u_0 = 0.6835 m sec^{-1}).

The Calculation of Mean Flow Velocity of Cross Section of Main Part

u_p is the mean flow velocity of cross section, then according to formula:

$$\frac{u_p}{u_0} = \frac{0.492}{k\chi} \text{Deduce that } u_0 \frac{0.492}{k\chi} = \frac{0.492u_0}{0.1311s + 0.410} = \frac{0.3363}{0.1311s + 0.41} \quad (3)$$

The Calculation of Water Flow in Main Part

The water flow of cross section of jet flow in main part is increasing in the flow direction because of jet entertainment and mixed-doped.

- According to formula: $\frac{q}{q_0} = 1.2k\chi$
- Deduce that:

$$q = q_0 1.2k\chi = (0.492 + 0.1573s)q_0 \quad (4)$$

where, q_0 is the discharge of sewage of outlet, (m^3 sec^{-1}); (q_0 = 150000 m^3/d = 1.736 m^3 sec^{-1}).

The Calculation of Angle of Flare and Half-width of Jet Flow in Main Part

The Determination of Angle of Flare in Main Part

- According to formula: $\tan\alpha = \lambda k = 2.44k = 0.28792$

where, λ-modulus of jet flow section, or spout shape factor, for surface jet flow, λ = 2.44; according to calculate we can get : $\alpha = 16.06° \approx 16°$. Angle of flare is $2\alpha \approx 32°$.

The Determination of Half-Midth of Jet Flow

- According to formula: $\frac{B}{B_0} = 2.44(k\chi)$
- Deduce that: $B = B_0.2.44(k\chi) = 0.9 \times 2.44 \times (0.118 \times \chi)$

$$B \approx 0.288s + 0.9 \quad (5)$$

The Calculation of Length of Initial Section

The distance S_T from spout to turning cross section is the length of core area, on the turning cross section, $u_0 = u_m$
The length of core area:

$$S_T = \frac{1.03B_0}{k} = 7.85 \approx 8\text{m} \tag{6}$$

The Calculation of Mean Velocity in Cross Section of Initial Section

- According to formula: $\frac{u_p}{u_0} = \frac{1+0.43\varphi}{1+2.44\varphi}$

Deduce that:

$$u_p = u_0 \frac{1+0.43\varphi}{1+2.44\varphi} \tag{7}$$

where, u_p is the mean velocity in cross section of initial section, m sec^{-1}; φ is the turbulent angle of flat jet flow:

$$\varphi = \frac{ks}{B_0} = \frac{0.118s}{B_0} = 0.1311s$$

Deduce that:

$$u_p = u_0 \frac{1+0.43\varphi}{1+2.44\varphi} = \frac{1+0.056373s}{1+0.319884s} u_0 \ (0 < s < 8) \tag{8}$$

The Calculation of Diffusing Time in Initial Section and Diffusing Time in Main Part
The Determination of Diffusing Time in Initial Section

- According to: $u_p = \frac{ds}{dt}$ and $\int dt = \int \frac{ds}{u_p}$ we get $\int u_p dt = \int ds$

Integral equation is

$$\int_0^t u_p dt = \int_0^8 ds \text{ we get } \int_0^t \frac{1+0.056373s}{1+0.319884s} u_0 = \int_0^8 ds \tag{9}$$

Integral is t = 71 sec ≈ 1.18 min ≈ 0.02 h.

The Determination of Diffusing Time in Main Part

The relationship between the diffusing time in pollution zone and distance is:

$$u_p = \frac{ds}{dt} \text{ and } \int dt = \int \frac{ds}{u_p} \tag{10}$$

And formula from Eq. 3:

$$u_p = u_0 \frac{0.492}{k\chi} = \frac{0.492u_0}{0.1311s + 0.410} = \frac{0.3363}{0.1311s + 0.410}$$

There:

$$\int dt = \int \frac{ds}{u_p}$$

$$\int_{71}^{t} dt = \int_{8}^{s} \frac{0.1311s + 0.410}{0.3363} ds$$

$$t = 0.19s^2 + 1.22s + 49 \approx 0.19s^2 + 1.22s \quad (11)$$

When, s = 50 m, t = 536 sec ≈ 8.93 min ≈ 0.14 h; Flow u_p = 0.0483 m sec^{-1};
The half-midth of jet flow: 15.3 m ≈ B = 15 m;
when, s = 100 m, t = 2022 sec ≈ 33.7 min ≈ 0.56 h; Flow u_p = 0.0249 m sec^{-1} ;
The half-midth of jet flow: 29.7 ≈ B = 30 m.

According to formula from Eq. 3, there is equation:

$$u_p = u_0 \frac{0.492}{k\chi} = \frac{0.492u_0}{0.1311s + 0.410} = \frac{0.3363}{0.1311s + 0.410}$$

When, u_p =0.04, the distance between pollution zone and outlet: s = 61 m
The diffusing time of pollution zone: t = 781.41 sec ≈ 13.02 min ≈ 0.22 h;
The diffusing width of pollution zone: $2B_0$ =18.5×2 = 37 m.

The Determination of Area of Pollution Zone

According to the above calculation, the diffusing range of pollutants in pollution zone around outlet is:

- The diffusing distance of pollution zone: s ≈ 100 m
- The diffusing width of pollution zone: 2B ≈ 60 m
- The diffusing area of pollution zone is calculated as: A ≈ 3094 m^2

The Equation Composition of Water Quality Model

This study will build self-purification equation according to physical self-purification which includes convective dilution, diffusing dilution, sedimentation and mixed action (Mahajan *et al*., 1999).

The Self-purification Model of the Non-sedimentable Materials

In the flowing water body, the non-sedimentable pollutants rely on the comprehensive function of the advection diffusion, the turbulent diffusion and the dispersion to dilute; in the still water body, the pollutants mainly rely on the molecular diffusion function to dilute.

The model uses the rectangular coordinate system, setting up the two-dimensional coordinate system, as shown in Fig. 7.

The diluted amounts of the advection diffusion and the turbulent diffusion in the infinitesimal patches are:

$$q\,(C + \frac{dC}{dx}\Delta x) - qC = -KC\Delta V \quad (12)$$

Where:

q	=	The flowing rate of Sewage ($m^3\ sec^{-1}$)
C	=	The concentration of the pollutant (mg L^{-1})
Δx	=	The Longitudinal infinitesimal distance (m)
$-KC\Delta V$	=	The self-purification amount of the non-sedimentable pollutants in the infinitesimal patches

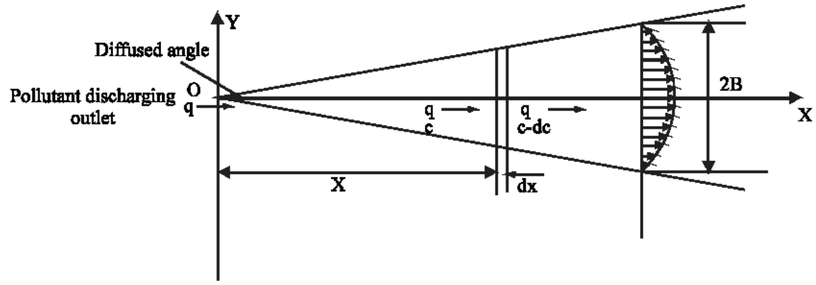

Fig. 7: The diagram of the water quality of the water body, which is near the pollutant discharging outlet

In the equation:

$$\Delta V = 2\tan\alpha \cdot x \cdot h \cdot \Delta x \quad (13)$$

According to the mass-balance principle, the model equation of the non-sedimentable materials in the infinitesimal patches:

$$q\frac{dC}{dx}\Delta x = -2\tan\alpha \cdot x \cdot h \cdot K \cdot C \cdot \Delta x \quad (14)$$

Solving the Eq. 14, you can get the model equation of the dilution and degradation of the non-sedimentable materials:

$$C = C_0 \exp\left(-\frac{K \cdot \tan\alpha \cdot h}{q} x^2\right) \quad (15)$$

Where:

C = The concentration of the non-sedimentable pollutants in the water body (mg L^{-1})
C_0 = The concentration of the non-sedimentable pollutants in the raw water of the pollutant discharging outlet (mg L^{-1})
K = The comprehensive self-purification coefficient of the non-sedimentable pollutants, (day^{-1})
2α = The spread angle of the pollutant discharging outlet, $2\alpha = 32°$, $\alpha = 16°$.

The Establishment of the Model Equation of Sediment

The sedimentable materials in the pollutants can be removed by the sediment, then decrease the concentration of the pollutants in the water body (Schladow and Hamilton, 1997). The size of the function of sediment can be expressed by this equation:

$$\frac{dC}{dt} = -k_s C$$

Where:

C = The concentration of the sedimentable pollutants in the water (mg L^{-1})
k_s = The constant of sediment speed (the sediment coefficient) (day^{-1})

Get the model equation of sediment

$$C = C_{S0}\exp(-k_s t) \quad (16)$$

Where:

C_{S0} = The concentration of the sedimentable pollutants in the raw water of the pollutant discharging outlet (mg L^{-1})
k_s = The sediment coefficient (day^{-1})
t = The sediment time (day)

The Establishment of the Mixed Model Equation

The pollutants which enter the lake water body through the pollutant discharging outlet mix with the lake water body completely (Grayand and Wang, 1999). That is, the pollutant concentration which is formed by the mix of the sedimentable pollutants and the non-sedimentable pollutants in the lake is the concentration of the pollutants in the lake water body. Establish the mixed model equation in the infinitesimal patches (Somlyody, 1978):

$$\overline{C} = \frac{C_W q + C_R \alpha Q}{\alpha Q + q}$$

Can inquire into the pollutant concentration equation of lake water body after the total mix:

$$\overline{C} = \frac{q\Delta t C(t) + \Delta V \times C_B}{q\Delta t + \Delta V} \quad (17)$$

Where:

$\overline{C}$ = The concentration of the polluted water after mix (mg L^{-1})
C_B = The background concentration of the pollutants in the lake water body (mg L^{-1})
C (t) = The pollutant concentration flowing into the lake at the time point t (mg L^{-1})
q = The flow rate which is flowing into the lake water body (m^3 sec^{-1})
Δt = Infinitesimal time (sec)
ΔV = Infinitesimal volume (m^3)

The Simulation of the Water Quality Model Equation

Diluted and Mixed Model Equation

After the polluted water mixing with the water of the water body, the concentration of the pollutants is reduced (Zhou *et al*., 1995). The average concentration of the totally mixed pollutants on the section is:

$$\overline{C} = \frac{C_W q + C_R \alpha Q}{\alpha Q + q}$$

$$\overline{C}(x) = \frac{q(x)\Delta t C(x) + \Delta V \times C_B}{q(x)\Delta t + \Delta V} = \frac{q(x)C(x) + \frac{\Delta V}{\Delta t} \times C_B}{q(x) + \frac{\Delta V}{\Delta t}}$$

In the equation: $C(x) = C_S(x) + C_{US}(x)$

$$C_{US}(x) = C_{US0}\exp(-\frac{K\cdot\tan\alpha\cdot h}{q}x^2)$$

$$C_S(x) = C_{S0}\cdot e^{-k_s t}$$

$$C(x) = C_{us0}\exp(-\frac{K\cdot\tan\alpha\cdot h}{q}x^2) + C_{s0}\cdot e^{-k_s t} \tag{18}$$

Where:

C_{US0} = The concentration of the initial non-sedimental pollutants in the polluted water of the pollutant discharging outlet (mg L^{-1})

C_{S0} = The concentration of the initial sedimental pollutants in the polluted water of the pollutant discharging outlet (mg L^{-1})

C_B = The background concentration of the pollutants in the lake water body (mg L^{-1}), respectively

K = The comprehensive self-purification coefficient of water body near the pollutant discharging outlet (day^{-1})

α = The spread angle of the pollutants of the pollutant discharging outlet (16°)

x = The longitudinal distance between the calculated point and the pollutant discharging outlet (m)

q (x) = Rate of flow (m^3 sec^{-1})

k_s = The sediment coefficient of the sedimentable pollutants (day^{-1})

t = The sediment time (day)

Get the diluted and mixed model equation:

$$\overline{C} = \frac{q(x)\cdot C(x) + 2\tan\alpha\cdot x\cdot h(x)\cdot u(x)\cdot C_B}{q(x) + 2\tan\alpha\cdot x\cdot h(x)\cdot u(x)} \tag{19}$$

Where:

C_B = The background concentration of the pollutants in the lake water body, according to the actual monitor the lake water body to confirming

h (x) = The changing law equation of the depth of water along x direction

h (x) = The velocity of flow at x point (m sec^{-1})

u (x) = The flow rate at x point (m^3 sec^{-1})

q (x) = The concentration of the pollutants at x point (mg L^{-1})

C (x) = The spread angle of the pollutants (16°)

The initial condition of the equation: when x = 0, C = C_0, u = u_0, B = B_0, q = q_0

The determination of the mixed polluted zone range and the equations of the flow velocity and the flow rate in the mixed polluted zone are:

Get:

$$t \approx 019x^2 + 1.22x$$

$$B(x) = B_0.2.44(k\chi) = 0.9\times 2.44\times(0.118\times\chi)$$

Get:

$$B \approx 0.288x + 0.9$$

$$q(x) = q_0\ 1.2\,k\chi = (0.492 + 0.1573x)\,q_0$$

$$u(x) = u_0\frac{0.492}{k\chi} = \frac{0.492u_0}{0.1311x + 0.410} = \frac{0.3363}{0.1311x + 0.410}$$

RESULTS

The Solution of the Diluted and Mixed Model Equation

Refer to a group of datas about TN and TP concentration, which are on the major direction of water body near the pollutant discharging outlet of Longwangzui sewage plant in the South Lake, simulating calculate the comprehensive self-purification coefficient K in the TN and TP diluted and mixed water quality model equation (Eq. 19). The mathematics solution use the dichotomy of the numerical calculation to calculate. And it use the Matlab to do the numerical simulation calculation.Take K into the Eq. 19 and do the check to another group of datas which are actually monitored.

The Simulation of TN Water Quality Model

The monitoring result and simulating calculation result of TN show as Table 5, 6 and Fig. 8, 9.

The Simulation of TP Water Quality Model

The monitoring result and simulating calculation result of TP show as Table 7, 8 and Fig. 10, 11.

Table 5: The determination of the monitoring result of TN in the water body near the pollutant discharging outlet and K-value

Distance (m)	TN (mg L^{-1})
0	16.81
50	12.97
100	11.54
200	10.69
300	10.01

The comprehensive self-purification coefficient $K_{TN} = 5.35\times10^{-3}$ $sec^{-1} \approx 462.24$ day^{-1}

Table 6: The monitoring simulation table of the TN (mg L^{-1}) concentration field

	Distance (m)				
Measures	0	50	100	200	300
Actual monitoring value	18.01	14.15	11.59	10.97	10.51
Model simulating value	17.98	13.09	8.40	2.50	0.55
Relative error (%)	0.17	7.49	-	-	-

Permissible error <20%

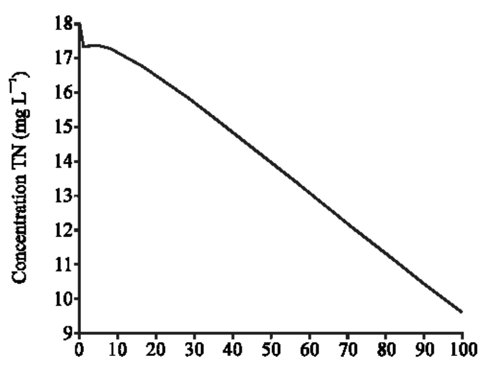

Fig. 8: The simulated curve graph of TN in the water body near the pollutant discharging outlet

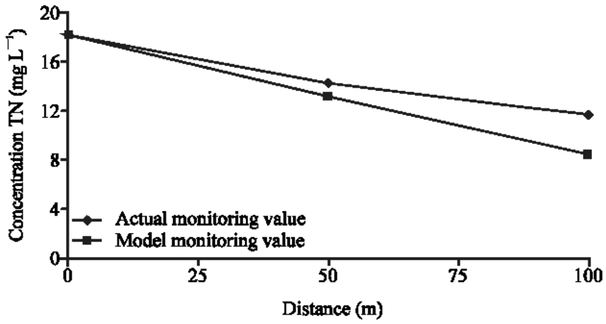

Fig. 9: The comparison diagram about the monitoring value and the simulating calculation value of TN

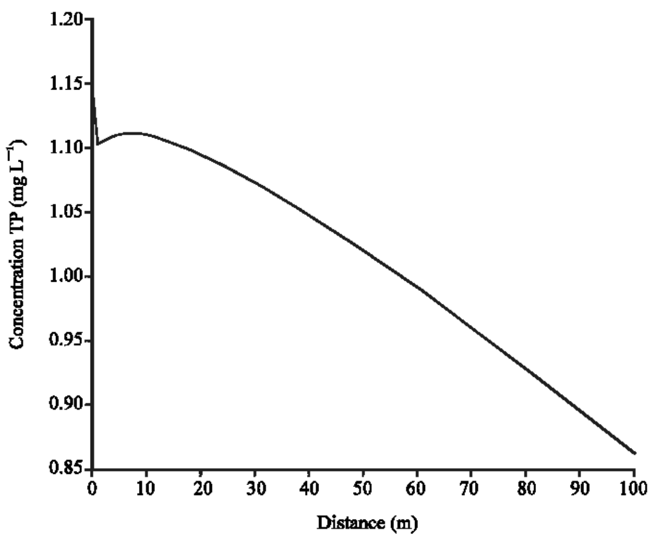

Fig. 10: The simulated curve graph of TP in the water body near the pollutant discharging outlet

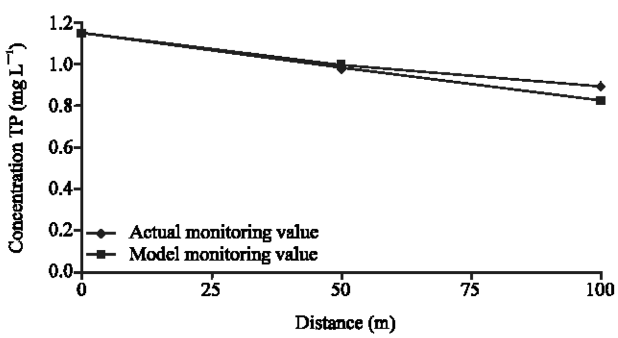

Fig. 11: The comparison diagram about the monitoring value and the simulating calculation value of TP

Table 7: The determination of the monitoring result of TP in the water body near the pollutant discharging outlet and K-value

Distance (m)	TP (mg L^{-1})
0	1.10
50	0.99
100	0.93
200	0.83
300	0.78

The comprehensive self-purification coefficient $K_{TP} = 2\times10^{-3}$ $sec^{-1} \approx 172.8$ day^{-1}

Table 8: The monitoring simulation table of the TP (mg L^{-1}) concentration field

	Distance (m)				
Measures	0	50	100	200	300
Actual monitoring value	1.14	0.98	0.89	0.90	0.82
Model simulating value	1.14	0.99	0.82	0.50	0.28
Relative error (%)	0.00	1.02	7.87	-	-

Permissible error <20%

DISCUSSION

When the sewage that contains pollutants discharge into river, lake and reservoir by outlets, generally it is turbulent jet flow. According to the differences of dynamic to go on moving after jet flow's outflow, it can be classified into momentum jet flow (jet flow for short), buoyant plume and buoyant jet flow.

In the range of jet flow, the advective diffusion and turbulent diffusion of pollutants in water substance dilute the discharged pollutants of high concentration with water substance in flow field and form a high concentration area of pollutants near the outlet, namely the mixed pollution zone. The concentration of pollutants in the mixed pollution zone is higher than of water substance in lake.

The determination of the range of mixed pollution zone with the changes of velocity, flow rate within the range of mixed pollution zone can be analyzed by the theory of jet flow. The sewage with certain velocity discharge from outlet into fresh water and this process of movement is sheer jet flow. When the fluid discharged from outlet has no concentration variation with receptive fluid, especially the receptive fluid is isotropic and still, the momentum of jet flow is in conservation. It means that the aggregated momentum of fluid that is jetted every cross section in unit time is invariable, the momentum flux is constant, it equals the initial momentum M_0 of jet flow.

The flow filed of jet flow includes core area and main part. The flow rate in core area is as the same as that in outlet, but gradually decrease in the main part with increasing water flow. Because the initial part is short, so it is ignored in building the water quality model. The fluid from outlet enters lake and then jets into static fluid in infinite space. It is assumed that the even distribution in depth direction of water flow has noting to do with the water depth because the water depth is low. This jet flow can be dealt with as two dimensional jet flow.

Surface jet flow is that fluid jet from a narrow and long orifice or an aperture and into the static fluid in infinite space. In the circumstance that the spout is not big, the velocity of fluid at the spout can be viewed as uniform. The jet velocity is u_0, the width of cross section of $2B_0$ and the Reynolds number is Re_0.

- From the calculation of the determination of parameters in the range of pollution zone around the Longwangzui sewage plant outlet, we know the flow velocity at the 50 m point is 0.0483 m sec^{-1}, the flow velocity at the 75 m point is 0.0328 m sec^{-1} the flow velocity at the 100 m point is 0.0249 m sec^{-1}. When the flow velocity is 0.04 m sec^{-1}, the distance is 61 m between it and the pollutant discharging outlet

Do the analysis of the model simulating calculation of water quality and the result of the actual monitor. We can know when the flow velocity is quicker than 0.04 m sec^{-1}, the pollutant concentration reduces relatively quickly because of the dilute of the advection diffusion and the turbulent diffusion and the sedimental purification function. But when the flow velocity is slower than 0.04 m sec^{-1}, the pollutant concentration mainly relies on biochemistry and other physical comprehensive functions to slowly reduce in the water body because most sedimentable materials have already sedimented and the flowing disperse and dilute function reduces.

From the simulation result of the water quality model, we know that the simulation result of the water quality model within the 50 m range of the pollutant discharging outlet is relatively accurate. At the moment, the flow velocity is slower than 0.04m sec^{-1}. But within the range from 50 to 100 m, the water quality model equation of TN is relatively inaccurate. Within the range from 50 to 100 m of the pollutant discharging outlet, the simulation results of the water quality model equation of TP are more accurate than TN. The analysis shows besides the physics purification function of TN in the water body, the biological chemistry function is relatively obvious outside the range of 50 m. But within the range of 100 m, the physics purification function of TP are the main functions.

When they enter the lake water body, the water body is basically still, the main purification factors of TN and TP are the biological chemistry function in the lake. And the concentrations change slowly in space and also slowly with the change of time. Within the range of 100 m of the pollutant discharging outlet, the sedimentable materials have already sedimented in the mixed polluted zone, which lead to the high concentration mud area and the high concentration polluted area.

- Do the water quality and the drainage discharge monitor to the polluted discharging outlet of Longwangzui sewage plant, we can get the scale of the drainage discharge, the law of the flow rate changing with time, the law of the pollutant concentration changing with time, the law of the pollutant load changing with time
- Combine the theory analyze and the experiments of the laboratory, we establish the water body mixed and diluted model near the polluted discharging outlet. Through the actual monitoring results of the water quality about the water area near the polluted discharging outlet, we can get the comprehensive self-purification coefficients of TN and TP, they are 462.24 and 172.8 day^{-1}. The test results show the models of TN and TP are relatively accurate within the range of 50 m

Because of the morphological difference in water substance (big, small inland rivers, reservoirs and so on), the hydrographic features of water substance are different. The specific ways to drain, the kinds of pollutants, the research purposes and technically processing methods differ, so there are different types and ways to the math modeling of water quality. The math modeling of water quality needs explicit model background and modeling purpose, in good command of various information on the object, getting clear of the features of pollutants after being drained into water substance in the physical, chemical and biochemical and other evolutions under the effect of comprehensive factors in water environment. Then it needs necessary simplification according to the features of real object and modeling purpose.

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