A Model on a Physico-Biological Engineering Experiment for Purifying Water by using *Trapa natans* var. *bispinosa* in Wulihu Bay of Taihu Lake, China*

HU Weiping, PU Peimin and LI Wanchun

Nanjing Institute of Geography & Limnology, CAS, Nanjing 210008, China

Abstract: A model on a physico-biological engineering experiment for purifying water in Wulihu Bay of Lake Taihu by using *Trapa natans* var. *bispinosa* was constructed. The state variables in water in the physico-biological engineering were ammonium nitrogen ($\text{NH}_4^+\text{-N}$); nitrate nitrogen ($\text{NO}_3^-\text{-N}$); nitrite nitrogen ($\text{NO}_2^-\text{-N}$); phosphate phosphorus ($\text{PO}_4^{3-}\text{-P}$); dissolved oxygen (DO); nitrogen (N) and phosphorus (P) in detritus; biomass density, N and P in phytoplankton and in *Trapa natans* var. *bispinosa*, N and P in the substance adsorbed by the membrane of the engineering and the rootstocks of *Trapa natans* var. *bispinosa*. The state variables in bottom mud layer were $\text{PO}_4^{3-}\text{-P}$ in the core water, exchangeable P and N. The external forcing functions were solar radiation, water temperature, $\text{NH}_4^+\text{-N}$; $\text{NO}_3^-\text{-N}$; $\text{NO}_2^-\text{-N}$; $\text{PO}_4^{3-}\text{-P}$; N and P in detritus; DO; phytoplankton concentrations in inflow water and the retention time of the water in physico-biological engineering channel. The main physical, chemical and biological processes considered in the model were: growth of *Trapa natans* var. *bispinosa* and phytoplankton; oxidation of $\text{NH}_4^+\text{-N}$ and $\text{NO}_2^-\text{-N}$, of detritus break down; N and P sorption by the enclosure cloth of the experimental engineering and by the rootstocks of *Trapa natans* var. *bispinosa* in water; reaeration of water; uptake of P, $\text{NH}_4^+\text{-N}$, $\text{NO}_3^-\text{-N}$ by phytoplankton and *Trapa natans* var. *bispinosa*; mortality of the phytoplankton and *Trapa natans* var. *bispinosa*; settling of detritus; and nutrient release from sediment. Comparison of calculated results and observed results showed that the model was constructed reasonably for the experiment. The mechanism of purifying lake water in the experiment engineering was discussed by the use of the model.

Keywords: Model, Physico-biological engineering, Water quality, *Trapa natans* var. *bispinosa*, Lake Taihu

1. Introduction

Wulihu bay lies in the northeast part of Taihu Lake, one of the five largest fresh water lakes in China. There was a dense submerged aquatic plant cover in the bay during 1950's. The water of high quality was used as the sources for drinking water plant. But the ecosystem structure has

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changed rapidly in the last 20 years. Submerged aquatic plants have disappeared. Water bloom often takes place in it (Li, W-CH, 1996). The water transparency was less than 50 cm in 1991~1994. The annual mean concentration of COD in the bay was $57.0 \text{ mg} \cdot \text{l}^{-1}$ in 1994. The annual mean concentration of ammonium nitrogen (NH_4^+-N) in the water was $0.53 \text{ mg} \cdot \text{l}^{-1}$ in 1991, $2.75 \text{ mg} \cdot \text{l}^{-1}$ in 1992, $1.99 \text{ mg} \cdot \text{l}^{-1}$ in 1993 and $4.12 \text{ mg} \cdot \text{l}^{-1}$ in 1994. The annual mean concentration of TN was 2.10, 4.69, 6.64, $10.92 \text{ mg} \cdot \text{l}^{-1}$ in 1991, 1992, 1993, 1994 respectively. The water in it is not the qualified sources of drinking water plant. Some effective measures must be taken to improve the water quality. So a series of physico-biological engineering experiments have been carried out since July 1994 on improving the water quality for the resource of a drinking water plant (Pu, P-M, *et al.*, 1995). A physico-biological engineering experiment for purifying water by using *Trapa natans* var. *bispinosa* is included in them.

The experimental physico-biological engineering included two parts: physical engineering and the artificial ecosystem. The physical part was soft enclosures, which were made of nontoxic chemical fibre cloth and were constructed in the intake area of the Old Zhongqiao Water Plant in Wulihu Bay. The structure of the physical engineering was shown in Fig.1. There were 10 water channels in it. Each is 5-metre wide and 40-metre long. Water in Wulihu Bay can only enter each channel at its south end. Different species of aquatic plants were cultured in different channel.

Fig. 1 Schematic drawing of the experimental engineering

Trapa natans var. *bispinosa* (TNVB) is a kind of leave-floating aquatic vascular plants, with its roots in both sediment and water. It can be easily planted in the shallow lakes. It can grow from April to Oct. in Taihu Lake. The leaf-form roots in water can directly uptake inorganic nutrients from water besides the long fibrous roots in sediment. The roots in water can also adsorb the suspended substance and improve water transparency. It was selected as the water plant to purify the bay water. It was planted in the 8th channel in July. As it grow, the transparency of the water in the channel increased from 60cm to 120cm and were planted in 8th channel (Fig. 1) from Mar. to Oct., 1996. The observed results of the experiment showed that it had a good effect on purifying the water.

This paper is aimed to use numeric simulation method to construct the nitrogen (N) and phosphorus (P) cycling model in the 8th channel in which TNVB was planted, to study the water-purifying processes of the plant. The model presented here is based upon previous modelling approaches by S.E. Jørgensen (1988), S.E. Jørgensen (1994), and Cai Q-H (1995). The model is different from the previous model by being more complex by including the dissolved oxygen (DO) and the process of absorption of suspended substance by the artificial membrane and the surface of the water plant to improve the accurate of the model.

2. Model of nitrogen and phosphorus cycling in the 8th channel

2.1 Conceptual model of the experiment of TNVB culturing

Because the nutrient conversions and physical, chemical and biological processes in the 8th channel were too complex, these must be simplified. According to the observed results of the experiment and previous results of L. K. Nielsen's study on mud-water exchange (L. K. Nielsen *et al.*, 1974), the conversions and physico-biological and chemical processes in the 8th channel can be summarized as Fig. 2. The biological processes in Fig. 2 are: (1) TNVB's and phytoplankton's growths and their uptakes for nutrient ammonium nitrogen ($\text{NH}_4^+\text{-N}$), nitrate nitrogen ($\text{NO}_3^-\text{-N}$) and phosphate phosphorus ($\text{PO}_4^{3-}\text{-P}$) from the channel water, (2) TNVB's and phytoplankton's mortalities and the nitrogen (N) and phosphorus (P) in them become suspended detritus N and P, (3) Biodegradation of suspended detritus N and P, N and P absorbed by the surface of the enclosure membrane and TNVB's roots, exchangeable P in the bottom and organic Nitrogen in bottom, (4) Oxygen production by phytoplankton photosynthesis. The physical processes in Fig. 2 are: (1) Input and output of $\text{NO}_3^-\text{-N}$, nitrite nitrogen ($\text{NO}_2^-\text{-N}$), $\text{NH}_4^+\text{-N}$, $\text{PO}_4^{3-}\text{-P}$, suspended detritus N and P, dissolved oxygen (DO) and phytoplankton, (2) Settling of detritus to the bottom; (3) absorption of the surface of the enclosure membrane and TNVB's roots, (4) Diffusions of nutrients from the bottom to the channel water; (5) The reaeration of water. The chemical processes in Fig. 2 are: (1) oxidation of $\text{NH}_4^+\text{-N}$ and $\text{NO}_2^-\text{-N}$; (2) the chemical processes involved in biological process. In Fig. 2, there were 18 state variables: 3 for the phytoplankton, 3 for TNVB, 6 for N, 5 for P, and 1 for DO. The forcing functions are: temperature, so-

lar radiation, the concentrations of $\text{NH}_4^+\text{-N}$; $\text{NO}_3^-\text{-N}$; $\text{NO}_2^-\text{-N}$; $\text{PO}_4^{3-}\text{-P}$; DO; N and P in detritus, and phytoplankton in inflow water.

Fig. 2 Conceptual diagram of the model

2.2 Mathematical equations of the model

On the assumption that the biochemical reactions and reaeration followed first-order kinetics and by the use of mass conservation law, the following differential equations (1-18) for state variables of the model can be set up:

$$\frac{dNH}{dt} = Q \cdot NH_i - Q \cdot NH + K \cdot V_{md} \cdot (N_d + N_{ab}) \cdot K_{mdt}^{T-20} + e^{0.151(T-20)} \cdot 10^{-5} (32 N_{se} + 8) - V_{nho} \cdot NH - NH_{pu} - NH_{tu} \quad (1)$$

$$\frac{dN3}{dt} = (1 - K) \cdot V_{md} \cdot (N_d + N_{ab}) \cdot K_{mdt}^{T-20} + Q \cdot N3_i - Q \cdot N3 + V_{n2o} \cdot N2 - N3_{pu} - N3_{tu} \quad (2)$$

$$\frac{dN2}{dt} = V_{nho} \cdot NH + Q \cdot N2_i - V_{n2o} \cdot N2 - N2 \cdot Q \quad (3)$$

$$\frac{dP}{dt} = Q \cdot P_i - Q \cdot P + V_{md} \cdot K_{mdt}^{T-20} \cdot (P_a + P_{ab}) + V_{mpp} (wei \cdot P_{cw} - P) \cdot \frac{(T + 273)}{280} - P_{pu} - P_{tu} \quad (4)$$

$$\frac{dDO}{dt} = \frac{2.26 \cdot v \cdot \exp(0.024(T-20))}{R^{2/3} \cdot 3600} \cdot (DO_s - DO) + O_p + Q \cdot DO_i - Q \cdot DO - O_m - O_{ox} \quad (5)$$

$$\frac{dN_d}{dt} = Q \cdot N_{di} - Q \cdot N_d + MR_p \cdot N_p + MR_t \cdot N_t - k \cdot N_d \cdot \frac{N_{a \max} - N_{ab}}{N_{a \max}} - Vmd \cdot K_{mdt}^{T-20} \cdot N_d - 0.065 N_d \quad (6)$$

$$\frac{dP_d}{dt} = Q \cdot P_{di} - Q \cdot P_d + MR_p \cdot P_p + MR_t \cdot P_t - k \cdot P_d \cdot \frac{P_{a \max} - P_{ab}}{P_{a \max}} - Vmd \cdot K_{mdt}^{T-20} \cdot P_d - 0.065 P_d \quad (7)$$

$$\frac{dP_{se}}{dt} = \max(0, P_{ab} - P_{a \max}) + 0.065 \cdot P_d - 1.4286 Pdmk \cdot P_{se} \cdot Kext^{T-20} \quad (8)$$

$$\frac{dP_{cw}}{dt} = 1.4286 Pdmk \cdot P_{se} \cdot Kext^{T-20} - V_{mpp} \cdot (P_{cw} \cdot wei - P) \cdot \frac{T+273}{280} \quad (9)$$

$$\frac{dN_{se}}{dt} = \max(0, N_{ab} - N_{a \max}) + 0.065 \cdot N_d - e^{0.151(T-20)} \cdot (32 N_{se} + 8) \cdot 10^{-5} - 10^{-5} \cdot 1.15^{T-20} \cdot N_{se} \quad (10)$$

$$\frac{dB_p}{dt} = GR_p \cdot B_p + Q \cdot B_{pi} - Q \cdot B_p - MR_p \cdot B_p \quad (11)$$

$$\frac{dN_p}{dt} = NH_{pu} + N3_{pu} + Q \cdot N_{pi} - Q \cdot N_p - MR_p \cdot N_p \quad (12)$$

$$\frac{dP_p}{dt} = Q \cdot P_{pi} - Q \cdot P_p + P_{pu} - MR_p \cdot P_p \quad (13)$$

$$\frac{dB_t}{dt} = GR_t \cdot B_t - MR_t \cdot B_t \quad (14)$$

$$\frac{dN_t}{dt} = N3_{tu} + NH_{tu} - MR_t \cdot N_t \quad (15)$$

$$\frac{dP_t}{dt} = P_{tu} - MR_t \cdot P_t \quad (16)$$

$$\frac{dN_{ab}}{dt} = k \cdot N_d \cdot \frac{N_{a \max} - N_{ab}}{N_{a \max}} - Vmd \cdot N_{ab} \cdot K_{mdt}^{T-20} - \max(0, N_{ab} - N_{a \max}) \quad (17)$$

$$\frac{dP_{ab}}{dt} = k \cdot P_d \cdot \frac{P_{a \max} - P_{ab}}{P_{a \max}} - Vmd \cdot P_{ab} \cdot K_{mdt}^{T-20} - \max(0, P_{ab} - P_{a \max}) \quad (18)$$

where:

$$\begin{aligned} NH_{pu} &= \frac{VNH_p \cdot NH_{pre} \cdot NH}{NH + KNH_p} \cdot B_p \cdot N_{ppro}; & N3_{pu} &= VN3_p \cdot N3 \cdot \frac{1.0 - NH_{pre}}{N3 + KN3_p} \cdot B_p \cdot N_{ppro}; \\ P_{pu} &= VP_p \cdot \frac{P_{ppro} \cdot P \cdot B_p}{P + KP_p}; & N_{ppro} &= \frac{N_{p \max} - N_p / B_p}{N_{p \max} - N_{p \min}}; & NH_{tu} &= \frac{VNH_t \cdot NH_{pre} \cdot NH}{NH + KNH_t} \cdot B_t \cdot N_{ipro}; \\ N3_{tu} &= VN3_t \cdot N3 \cdot \frac{1.0 - NH_{pre}}{N3 + KN3_t} \cdot B_t \cdot N_{ipro}; & P_{tu} &= VP_t \cdot \frac{P_{ipro} \cdot P \cdot B_t}{P + KP_t}; & N_{ipro} &= \frac{N_{t \max} - N_t / B_t}{N_{t \max} - N_{t \min}}; \\ P_{ppro} &= \frac{P_{p \max} - P_p / B_p}{P_{p \max} - P_{p \min}}; & P_{ipro} &= \frac{P_{t \max} - P_t / B_t}{P_{t \max} - P_{t \min}}; & NH_{pre} &= \frac{NH}{NH + N3}; \end{aligned}$$

$$GR_p = G_{\max p} \cdot \min(1 - N_{p \min} \cdot B_p / N_p, 1 - P_{p \min} \cdot B_p / P_p) \cdot e^{-0.007|T-25|} \cdot I_0 \cdot \frac{1 - \exp(-2(1.7/TSP + 0.014B_p))}{2(1.7/TSP + 0.014B_p)} \cdot IK;$$

$$GR_t = G_{\max t} \cdot \min(1 - N_{t \min} \cdot B_t / N_t, 1 - P_{t \min} \cdot B_t / P_t) \cdot 1.05^{-0.024|T-25.8|} \cdot I_0 / 1300 \cdot \pi;$$

$$MR_p = GR_p \cdot B_p / CA_p; \quad MR_t = GR_t \quad O_{ox} = 3.429V_{nho} \cdot NH + 1.143V_{n2o} \cdot N2;$$

$$O_m = 17.129(N_d + N_{ab}) \cdot V_{md} \cdot K_{mdt}^{T-20}; \quad O_p = 1.067GR_p \cdot B_p;$$

$$V_{nho} = K_{nho} \cdot DO / 5.0; \quad V_{n2o} = K_{n2o} \cdot N2 \cdot \max(0, (DO - 1.5) / 5.5).$$

Definitions of the symbols in above equations have been shown in table 1.

Tab. 1 List of symbols and definitions in above equations

Symbol	Definition	Symbol	Definition
NH	NH ₄ ⁺ -N concentration in the channel water	N3	NO ₃ ⁻ -N concentration in the channel water
N _{se}	nitrogen in bottom sediment	N2	NO ₂ ⁻ -N concentration in the channel water
B _p	biomass density of phytoplankton	P	PO ₄ ³⁻ -P concentration in the channel water
N _p	nitrogen in phytoplankton	DO	DO concentration in the channel water
P _p	phosphorus in phytoplankton	N _d	concentration of N in detritus in the channel
B _t	biomass density of TNVB	P _d	concentration of P in detritus in the channel
N _t	nitrogen in T. N. V. B.	P _{se}	exchangeable phosphorus in bottom sediment
P _t	phosphorus in TNVB	P _{cw}	phosphorus in core water
P _{ab}	P in the adsorbate on the membrane of engineering and the rootstock of TNVB	N _{ab}	N in the adsorbate on the membrane of engineering and the rootstock of TNVB
N _{di}	concentration of N in detritus in inflow water	P _{di}	concentration of P in detritus in inflow water
DO _i	DO concentration in inflow water	N3 _i	NO ₃ ⁻ -N concentration in inflow water
NH _i	NH ₄ ⁺ -N concentration in inflow water	N2 _i	NO ₂ ⁻ -N concentration in inflow water
P _i	PO ₄ ³⁻ -P concentration in inflow water	B _{pi}	biomass density of phytoplankton in inflow water
P _{pi}	concentration of P in phytoplankton in inflow water	N _{pi}	concentration of N in phytoplankton in inflow water
NH _{pu}	uptake of NH ₄ ⁺ -N by phytoplankton	N3 _{pu}	uptake of phytoplankton for NO ₃ ⁻ -N
NH _{tu}	uptake of NH ₄ ⁺ -N by TNVB	N3 _{tu}	uptake of TNVB for NO ₃ ⁻ -N
P _{tu}	uptake of PO ₄ ³⁻ -P by TNVB	P _{pu}	uptake of phytoplankton for NO ₃ ⁻ -N
Q	the volume of flow (m ³ ·s ⁻¹)	DO _s	oxygen concentration at saturation
O _{ox}	oxygen consumption of oxidation of NH ₄ ⁺ -N and NO ₂ ⁻ -N	K _{mdt}	influence constant of temperature on detritus mineralization
T	water temperature in the channel	K _{nho}	oxidation rate of NH ₄ ⁺ -N when DO=5 mg·l ⁻¹
K _{n2o}	oxidation rate of NO ₂ ⁻ -N when DO=7.0 mg·l ⁻¹	v	average flow (m·s ⁻¹)
R	water depth in the channel	O _p	oxygen production by phytoplankton growth
O _m	oxygen consumption of detritus and adsorbate	V _{md}	detritus mineralization velocity at 20 °C
MR _p	mortality rate of phytoplankton in the channel water	MR _t	mortality rate of TNVB in the channel water
GR _p	growth rate of phytoplankton in the channel water	GR _t	growth rate of TNVB in the channel water
P _{amaax}	maximum value of P _{ab}	Pdmk	P release velocity of anaerobic decomposition at 20 °C
k	adsorption rate of the membrane and the rootstock of TNVB	K	ratio of NH ₄ ⁺ -N to the sum of NH ₄ ⁺ -N and NO ₂ ⁻ -N produced by mineralization

N_{amax}	maximum value of N_{ab}	$VN3_p$	maximum uptake velocity of phytoplankton for NO_3^- -N
K_{ext}	influence constant of temperature on anaerobic decomposition	VNH_p	maximum uptake velocity of phytoplankton for NH_4^+ -N
VNH_t	maximum uptake velocity of TNVB for NH_4^+ -N	VP_p	maximum uptake velocity of phytoplankton for P
VP_t	maximum uptake velocity of TNVB for P	$VN3_t$	maximum uptake velocity of TNVB for NO_3^- -N
V_{mpp}	diffusion coefficient of core water phosphorus	KNH_p	half saturation constant of NH_4^+ -N for phytoplankton
$KN3_t$	half saturation constant of NO_3^- -N for TNVB	KP_p	half saturation constant of PO_4^{3-} -P for phytoplankton
KNH_t	half saturation constant of NH_4^+ -N for TNVB	$KN3_p$	half saturation constant of NO_3^- -N for phytoplankton
NH_{pre}	ratio of NH_4^+ -N to the sum of NH_4^+ -N and NO_3^- -N	KP_t	half saturation constant of PO_4^{3-} -P for T. N. V. B
N_{tpro}	normalized value for TNVB intracellular N	N_{ppro}	normalized value for phytoplankton intracellular N
P_{tpro}	normalized value for TNVB intracellular P	P_{ppro}	normalized value for phytoplankton intracellular P
N_{tmax}	Maximum quota of TNVB for N	N_{pmax}	Maximum quota of TNVB for phosphorus
N_{tmin}	Minimum quota of TNVB for N	N_{pmin}	Minimum quota of phytoplankton for P
P_{tmax}	Maximum quota of TNVB for P	P_{pmax}	Maximum quota of phytoplankton for P
CA_p	carrying capacity of phytoplankton	P_{pmin}	Minimum quota of phytoplankton for P
P_{tmin}	Minimum quota of TNVB for P	IK	saturation constant of phytoplankton for light
I_0	solar radiation	G_{maxp}	maximum growth rate of phytoplankton
TSP	water transparency in the channel	G_{maxt}	maximum growth rate of TNVB
KF	cover degree of water by TNVB		

The units of state variables are $mg \cdot l^{-1}$, and the others are $mg \cdot l^{-1} \cdot d^{-1}$ in table 1.

2.3 Parameters and state variable initial values

The model included more twenty parameters. Some important parameters were obtained from experimental observation, some from numerical simulation, the others from references. The values of the parameters are shown in table 2. The initial values are shown in table 4. For convenience, the state variable B_p , N_p , P_p , N_{se} , P_{se} , P_{cwi} , N_{ab} , P_{ab} were converted to the concentration in the whole water column. All the state variables were in unit of $mg \cdot l^{-1}$.

Tab. 2 Parameters in the model

Symbol	Unit	Value	Source	Symbol	Unit	Value	Source
N_{tmax}	g N/g d.w.	0.096	numerical simulation	KNH_o	mg/l	0.176	S. E. Jorgensen, <i>et al</i> , 1991
N_{tmin}	g N/g d.w.	0.0158	Wu, H-SH, <i>et al.</i> , 1995	KP_p	mg/l	0.010	S. E. Jorgensen, <i>et al</i> , 1991
P_{tmax}	g P/g d.w.	0.016	Wu, H-SH, <i>et al.</i> , 1995	$KN3_o$	mg/l	0.164	S. E. Jorgensen, <i>et al</i> , 1991
P_{tmin}	g P/g d.w.	0.00258	numerical simulation	KP_t	mg/l	0.010	numerical simulation
N_{omax}	g N/g d.w.	0.085	Endricchio, G. <i>et al.</i> , 1993, 1994	$KN3_t$	mg/l	0.150	numerical simulation
N_{omin}	g N/g d.w.	0.007	Endricchio, G. <i>et al.</i> , 1993, 1994	KNH_t	mg/l	0.300	Jin, S-D, 1994
P_{omax}	g P/g d.w.	0.015	Cai, Q-H, 1995	VNH_o	l/day	0.3840	S. E. Jorgensen, <i>et al</i> , 1991
P_{omin}	g P/g d.w.	0.001	Cai, Q-H, 1995	$VN3_o$	l/day	0.2400	S. E. Jorgensen, <i>et al</i> , 1991
G_{maxo}	1/day	0.11	S. E. Jorgensen, <i>et al</i> , 1991	VP_p	l/day	0.0025	S. E. Jorgensen, <i>et al</i> , 1991
G_{maxt}	1/day	0.11615	observed	VNH_t	l/day	0.0010	numerical simulation
V_{md}	1/day	0.022	Cai, Q-H, 1995	$VN3_t$	l/day	0.0010	numerical simulation
V_{mo}	1/day	0.005	numerical simulation	VP_t	l/day	0.0005	numerical simulation
P_{dmk}	1/day	0.013	Cai, Q-H, 1995	IK	$\mu E/M^2/s$	0.590	from observed results

K	0.55	numerical simulation	K _{mdt}	1.15	Cai, Q-H, 1995
N _{amax}	mg/l	[HU, W-P, <i>et al.</i> , 1995	K _{ext}	1.13	ai, Q-H, 1995
P _{amax}	mg/l	[HU, W-P, <i>et al.</i> , 1995	k	0.5	simulation
K _{nho}	1/day	numerical simulation	K _{n2o}	1/day 0.5	numerical simulation

Tab. 3 Initial value of state variables (mg·l⁻¹)

Variable	values	Variable	values	Variable	values
NH	0.32	P _{se}	3.96	N _{ab}	0.0
N3	0.52	P _{cw}	2.2704	P _{ab}	0.275184
N2	0.0022	N _{se}	159.75	P _d	0.05379
P	0.001	B _p	2.163	N _t	40.464
DO	0.47	N _p	0.2163	P _t	3.796
N _d	0.139	P _p	0.02163	B _t	900.0

3. Comparison of simulated results and measured results

Figures 3a, b, c, d, e and f showed the simulated results and measured results of concentration of NH₄⁺-N, NO₂⁻-N, NO₃⁻-N, DO, phytoplankton and PO₄³⁻-P in channel water and the inflow water. From Fig. 3, it can be found that simulated values of NH₄⁺-N, NO₂⁻-N, NO₃⁻-N, DO, phytoplankton and PO₄³⁻-P were coincided with measured curves in the channel water. This showed the model equations and its parameter values were reasonable. Figure 4 a, b showed values of concentration of TN and TP in the channel water. The tally of simulated results and measured results of TN and TP in Figure 4 further proved the model reasonable.

4. Discussion

Fig. 3 and 4 showed that the concentrations of NH₄⁺-N, NO₃⁻-N, phytoplankton, PO₄³⁻-P, TN and TP in channel water were lower than those in the inflow water. They suggested the physico-biological engineering could improve lake water quality and lower phytoplankton content. Fig. 3d showed that DO concentration in the channel water was lower than that in the inflow water. It implied that biochemical process in the channel was a consumed oxygen process. This could be seen from Fig. 5. In it the oxygen supply from water reaeration was insufficient to replenishing consumption by the oxidation of NH₄⁺-N, NO₂⁻-N and the mineralization of detritus and adsorbed N. NH₄⁺-N could not be oxidized to NO₃⁻-N completely. The concentration of NO₂⁻-N in the channel water increased, since oxygen was limiting in the channel. This was also showed by Fig. 3b. These results imply that other steps must be taken to increase the DO concentration and decrease NO₂⁻-N concentration in the channel water.

Fig. 3 Water parameter procedure curves during the experimental period. a- $\text{NH}_4^+\text{-N}$, b- $\text{NO}_2^-\text{-N}$, c- $\text{NO}_3^-\text{-N}$, d- DO, e- phytoplankton biomass density, f- $\text{PO}_4^{3-}\text{-P}$, +—calculated concentration in the channel water, —observed concentration in the channel water ◆—observed concentration in inflow water

Fig. 6 showed $\text{NH}_4^+\text{-N}$ flow during the experimental period. The uptake of $\text{NH}_4^+\text{-N}$ by *TNVB* was $0.113 - 0.402 \text{ mg} \cdot \text{l}^{-1} \cdot \text{d}^{-1}$, which was higher than the oxidation of $\text{NH}_4^+\text{-N}$ ($0.001 \sim 0.036 \text{ mg} \cdot \text{l}^{-1} \cdot \text{d}^{-1}$) and the release from bottom sediment ($0.016 \sim 0.019 \text{ mg} \cdot \text{l}^{-1} \cdot \text{d}^{-1}$), and about 20% of the amount of $\text{NH}_4^+\text{-N}$ outflow. Fig. 7 showed the N flow in channel water obtained from the model. The rate of N settling to the bottom sediment was higher than the rate of plant uptake by *TNVB*. However, this plant N uptake rate was greater than the physico-adsorption effect of N by the

membrane of the experimental engineering and rootstock of *TNVB*. It also showed that N-flow from the bottom to the channel water was smaller than the N-flow from the water to the bottom. This described that N-nutrient was deposited on the bottom surface. Fig. 8 was the detritus N source flow during the experimental period. It described that the detritus N mainly came from dead *TNVB*. As to P flow, the model described that the diffusion of P_{cw} was relatively stable, it was smaller than the uptake of P by *TNVB* and detritus P settling to bottom surface.

Fig. 4 TN, TP concentration curves from the model and measurement. a-TN, b-TP. +— observed concentration in the channel water ●— calculated concentration in the channel water, ◆— observed concentration in inflow water

Fig. 5 Oxygen input and output change curves in the channel water. 1-oxygen input due to the water inflow, 2-oxygen consumption due to the mineralization taken place in water, 3- oxygen output due to the water outflow, 4-oxygen consumption due to the oxidation of NH_4^+-N and $NO_2^- -N$, 5-oxygen input due to water surface reaeration

Fig. 6 The flow curves related to the NH_4^+-N concentration in the channel water. 1- NH_4^+-N input due to the water inflow, 2- NH_4^+-N output due to the water outflow, 3-due to the uptake of T. N. V. B. For NH_4^+-N , 4- NH_4^+-N output due to oxidation, 5- NH_4^+-N inflow due to the NH_4^+-N release from bottom.

The model also described that the uptake of P by *TNVB* was greater than the uptake of P by phytoplankton. Therefore, the model revealed that the main mechanisms of purifying water in the experimental engineering were that *TNVB* limited the growth of phytoplankton and its uptake for nutrient from channel water. Most of the NH_4^+-N and $NO_3^- -N$, $PO_4^{3-} -P$ in water was ta-

ken up by *TNVB* and assimilated into its biomass. As a result of *TNVB* mortality, detritus N and P settled to bottom and was deposited on the bottom.

Fig. 7 The N flow curves in the channel water. 1- N release from the bottom, 2- N flow from detritus to adsorption N, 3- N flow from water to T.N.V.B., 4- N flow from water to the bottom.

Fig. 8 The change curves of the source of detritus N in the channel water. 1-detritus N input from dead phytoplankton, 2-detritus N input from dead T. N. V. B., 3- detritus input due to the water inflow.

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