ISSN 1001-0742
CN 11-2629/X

JES JOURNAL OF ENVIRONMENTAL SCIENCES

2013 Volume 25 Supplement
www.jesc.ac.cn

The 5th International Symposium on Environmental Economy and Technology

ELSEVIER
Science Press

Sponsored by
Research Center for Eco-Environmental Sciences
Chinese Academy of Sciences

ISSN 1001–0742 **Journal of Environmental Sciences** Supplement 2013

CONTENTS

Available online at www.sciencedirect.com
ScienceDirect
Journal of Environmental Sciences 2013, 25(Suppl.) S41–S44
JOURNAL OF ENVIRONMENTAL SCIENCES
ISSN 1001-0742
CN 11-2629/X
www.jesc.ac.cn

Numerical simulation of alga growth and control in Dalian Bay

Ying Li[1,*], Caisheng Huang[1], Jiti Zhou[2]

1. School of Environmental and Chemical Engineering, Dalian Jiaotong University, Dalian 116028, China
2. School of Environmental Sciences and Technology, Dalian University of Technology, Dalian 116024, China

Abstract

WAHMO model was used to simulate the distribution of pollutants in Dalian Bay, China as to predict well as the growth and control of alga. The observed and predicted values of main pollutants showed a good trend at all study locations and the different between them can be ignored. Simulation results illustrated that phosphate was one of limited factors to control algal growth at the location near the sewage outfall, meanwhile, away from the sewage outfall, the synergy of ammonium nitrogen and phosphate was the limited factor.

Key words: numerical simulation; alga growth control; ammonium nitrogen; phosphate; Dalian Bay

Introduction

In recent years, the pollution of the coastal waters was serious according to the China's Marine Environmental Quality Communique. The heavily polluted water is mainly distributed into estuary or seaport such as the Yalu River, the Liaodong Bay, the Bohai Bay, the Yangtze River, the Hanzhou Bay and the Pearl River as well as a number of coastal cities. Dalian Bay receives industrial wastewater and other kinds of wastewater in Dalian. The water quality is very poor and do not achieve the standard. The main pollutants in the seaport are inorganic ammonium nitrogen, active phosphate and lead. Results of the monitoring show a slow downward trend in general pollution while the content of ammonium nitrogen leads high marine red tides. The hydrodynamics and water quality are strongly affected by the seasonal variations of the gravitational circulation and the stratification in the bay. The three-dimensional hydrodynamics and water quality model (Shen et al., 2002) have been developed to simulate the long-term transport and the fate of pollutants.

Dalian Bay is divided into four regions according to the marine function zoning. The 1st region is the main place where receives the place receives all pollutant emissions in the Dalian Bay; the 2nd area is the place receives phosphorus emissions; in the 3rd region the emissions from farming class water; and in the 4th region the transportation diffusion from the main pollutants from other regions. For controlling the implementation of the plan based on the total quantity of pollutants in Dalian Bay, the 1st area is considered the main pollutant reduction region, and latest content of ammonium nitrogen and phosphorus need to be reduced 36% in short-term and 64% in long-term. In order to investigate the reduction of ammonium nitrogen and phosphorus on alga growth, the present study selected two monitoring stations (15 and H010) which located in 1st regional focus area near the entrance of ammonium nitrogen and phosphorus. The other monitoring station (17) is located far from the outfall at 2nd regional area and the exchange capacity of water is fairly weak in this area. Ammonium nitrogen and phosphorus in regions 3 and 4 are not considered in this article. The reason is that controlling ammonium nitrogen and phosphorus emissions of former two regions will be able to control their contents in the regions 3 and 4.

The model is calibrated against the data set of historical water quality observations (Paliwal et al., 2007). The calibration process is closely related to the estimation of parameter sensitivity and hence the corresponding model predictions (Rode and Suhr, 2007).

1 Numerical simulation

1.1 Site description

Dalian Bay is a typical semi-enclosed bay located at south of Liaotung Peninsula extending 11 km from north to south and 20 km from east to west. Waster streams from 81 drains released into the waters at different points along 80 km seafront. The salinity, temperature and density of ocean waters changes with season due to the response of tide move to gravity cycle.

* Corresponding author. E-mail: liying@djtu.edu.cn

1.2 Numerical computation

WAHMO model consists of two structure independent and content related sub-models (water movement sub-model and water quality sub-model). Velocity, temperature and salinity are calculated through water movement sub-model and then applied to water quality sub-model to calculate concentration of substance.

The governing differential equations are based on the three-dimensional Navier-Stokes equations, including the effects of earth's rotation, bottom friction, wind shear and turbulence, with hydrostatic pressure approximation and the Boussinesq approximation. The turbulence stress and turbulence mass flux are simulated by the concepts of turbulent viscosity and turbulent diffusion. The physical, biological and chemical processes are simulated and the interactions among the parameters related to pollution control are incorporated in the three-dimensional nonlinear system. The system integrates the refined models of hydrodynamics, biochemical reactions and ecosystem in coastal area. The model is calibrated according to the observation data and applied to the forecasting of water pollution.

Continuity equation:

$$\frac{\partial u}{\partial x}+\frac{\partial u}{\partial y}+\frac{\partial w}{\partial z}=0 \tag{1}$$

Momentum equations:

X direction:

$$\frac{\partial \rho u}{\partial t}+\frac{\partial \rho u^2}{\partial x}+\frac{\partial \rho uv}{\partial y}+\frac{\partial \rho uw}{\partial z}+\frac{\partial P}{\partial x}= \mu_{\mathrm{e}}(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2})+\Omega v \tag{2}$$

Y direction:

$$\frac{\partial \rho v}{\partial t}+\frac{\partial \rho uv}{\partial x}+\frac{\partial \rho v^2}{\partial y}+\frac{\partial \rho vw}{\partial z}+\frac{\partial P}{\partial y}= \mu_{\mathrm{e}}(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2})-\Omega u \tag{3}$$

Z direction :

$$\frac{\partial P}{\partial x}+\rho g=0 \tag{4}$$

Temperature equation:

$$\frac{\partial(\rho T C_{\mathrm{p}})}{\partial t}+\frac{\partial(\rho u T C_{\mathrm{p}})}{\partial x}+\frac{\partial(\rho v T C_{\mathrm{p}})}{\partial y}+\frac{\partial(\rho w T C_{\mathrm{p}})}{\partial z}= H+\frac{\partial}{\partial x}(D_x\frac{\partial(\rho T C_{\mathrm{p}})}{\partial x})+\frac{\partial}{\partial y}(D_y\frac{\partial(\rho T C_{\mathrm{p}})}{\partial y})+\frac{\partial}{\partial z}(D_z\frac{\partial(\rho T C_{\mathrm{p}})}{\partial z}) \tag{5}$$

Salinity equation:

$$\frac{\partial S}{\partial t}+\frac{\partial}{\partial x}(uS)+\frac{\partial}{\partial y}(vS)+\frac{\partial}{\partial z}(wS)= K_x\frac{\partial^2 S}{\partial x^2}+K_y\frac{\partial^2 S}{\partial y^2}+K_z\frac{\partial^2 S}{\partial z^2} \tag{6}$$

State equation:

$$\rho=1000+(0.797-0.001875T)S- 1000(0.562(T-4)/277)^{1.85} \tag{7}$$

Concentration equation:

$$\frac{\partial C_i}{\partial t}+\frac{\partial}{\partial x}(uC_i)+\frac{\partial}{\partial y}(vC_i)+\frac{\partial}{\partial z}(wC_i)= K_x\frac{\partial^2 C_i}{\partial x^2}+K_y\frac{\partial^2 C_i}{\partial y^2}+K_z\frac{\partial^2 C_i}{\partial z^2}+\omega C_i+\Sigma S_i \tag{8}$$

where, t is time; u, v, w is the longitudinal, lateral and vertical velocity components in the x, y and z directions respectively; P is the pressure; ρ is the density of water; μ_{e} is the viscosity of water; g is the gravitational acceleration; Ω is the Coriolis parameter; T is the temperature of water; C_{p} is the specific heat of water; H is heat exchange term; D_{x}, D_y, D_z is the turbulence coefficient; K_x, K_y, K_z is the turbulence diffusion coefficient; S is the salinity of water; N is the total number of substances incorporated in the model; C_i is the concentration of substance i; ω is the settling velocity for particulate substances; S_i is the net effect of all the source and sink terms simulated in the water quality and ecosystem interactions for substance i.

In order to establish the offshore water quality model to simulate the many interdependent processes between the variables, these processes can be simply divided into three groups: transport and mixing processes; chemical role of water quality variables; biological use and recycling of nutrients.

1.3 Model calibration and validation

The model was calibrated against the data set of historical water quality observations and demonstrates excellent agreement with available data in general. The calibration process is closely related to the estimation of parameter sensitivity and hence the corresponding model predictions. The calibrated parameters valued for the WAHMO are given in the order of decreasing sensitivity. The base values of the input parameters are as following KAM2, 0.07; KN20, 0.23; FARIC, 0.037; MP, 0.18; KON2 0.2.

Nitrate, ammonium nitrogen and dissolved oxygen are the "link substances" between the water quality and alga growth in water quality sub-model. And algal growth is related with the concentration of ammonium nitrogen and phosphate and the ratio N/P in coastal area. Ammonium nitrogen and phosphate are used for model calibration and validation as a result of the absence of monitoring data of alga growth.

WAHMO was calibrated for representing a high-flow period in July. The model was operated as three-dimensional dynamic state and completely mixed system. There were 15 monitoring stations distributed in costal area of Dalian Bay. Two sets of data were used for model calibration and validation as shown in **Fig. 1**. Errors

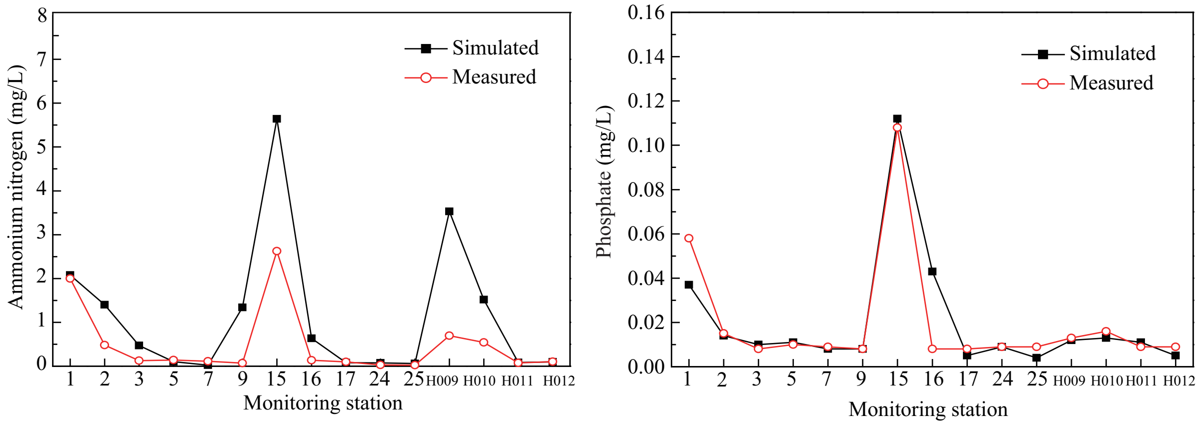

Fig. 1 Comparsion between simulated and measured values of ammonium nitrogen, and phosphate.

in simulations were estimated as the difference between model forecasted values and observed data. The highest relative error, for ammonium nitrogen, was 50% at the monitoring site 15 while it was within 20% at all other locations. Differences between the observed and predicted values of phosphate were insignificant and showed a good fit in all study locations.

2 Results and discussion

2.1 Alga growth and control

The impact of different reduction programs of ammonium nitrogen and phosphate on algal growth was discussed (**Fig. 2**). According to total pollutant control implementation plan of Dalian Bay, ammonium nitrogen and phosphate will be reduced 36% in recent years and 64% in forward years. Reduction plans were presented: 36% reduction of ammonium nitrogen (plan 2), 64% reduction of ammonium nitrogen (plan 3), 36% reduction of phosphate (plan 4), 64% reduction of phosphate (plan 5), 36% reduction of ammonium nitrogen and phosphate (plan 6), 64% reduction of ammonium nitrogen and phosphate (plan 7), 36% reduction of ammonium nitrogen and 64% reduction of phosphate (plan 8), 64% reduction of phosphate and 36% reduction of ammonium nitrogen (plan 9). The plan before reduction was set plan 1 to facilitate comparison.

2.2 Effect of N, P and N/P ratio on alga growth

As shown in **Fig. 3**, the concentration of ammonium nitrogen and phosphate was high at monitoring station 15, the increase of N/P ratio was less beneficial than alga growth at high concentration of phosphate (more than 0.1 mg/L). But at monitoring station 17, the concentration of ammonium nitrogen and phosphate was low. The concentration of phosphate was lower than the optimal vale of agla growth (0.07 mg/L). Alga growth was controled by the concentration of ammonium nitrogen.

Alga growth was controled at a certain range by the concentration of ammonium nitrogen and phosphate as well as the ratio of N/P. N/P atomic ratio in alga cells is 16. Phosphorus is considered to be the limiting factor if the N/P ratio is more than 16. On the contrary. When the N/P ratio is less than 10, ammonium nitrogen is generally considered as the limiting factor; when the N/P ratio is between 10 to 20, the limiting factor becomes uncertain. The ratio of N/P for alga growth is not reflected in a definite value, alga growth should be taken into account combination of the concentration of ammonium nitrogen and phosphorus as well as the ratio of N/P.

Figure 4 shows the change of N/P ratio and alga content in the alga growth peak of the curve at monitoring stations 15, H010 and 17. At monitoring stations 15 and H010 the ratio of N/P was greater than 20, phosphorus became

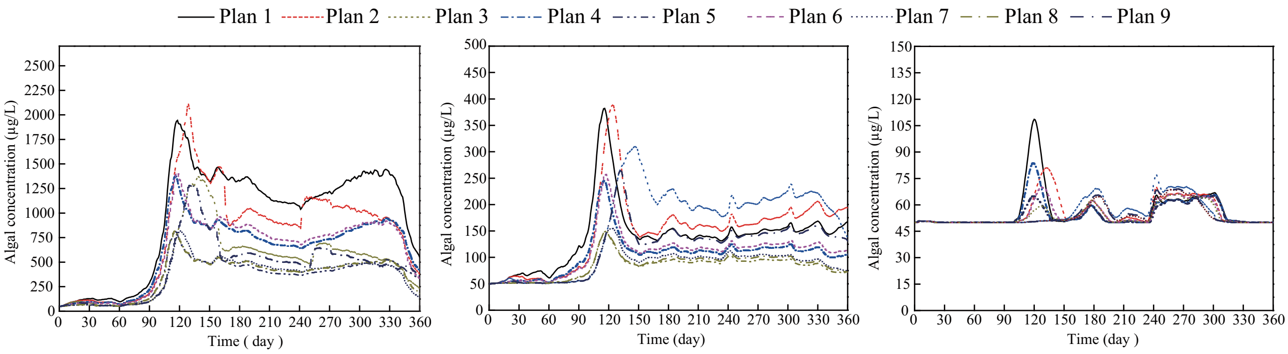

Fig. 2 Impact of ammonium nitrogen and phosphate reduction on algal growth. (a) Monitoring station 15 which near the sewage outfall; (b) monitoring station H010 which near the sewage outfall; (c) monitoring station 17 which away from the sewage outfall.

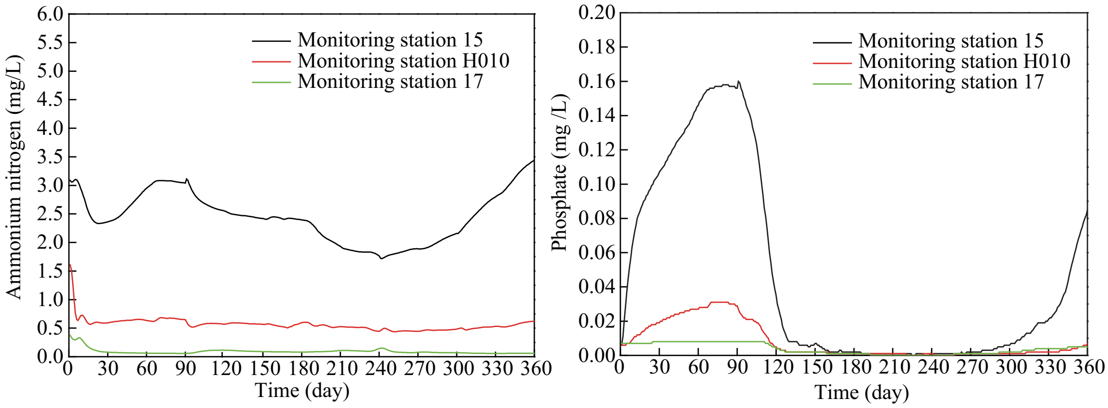

Fig. 3 Change of concentrations of ammonium nitrogen and phosphate in monitoring stations.

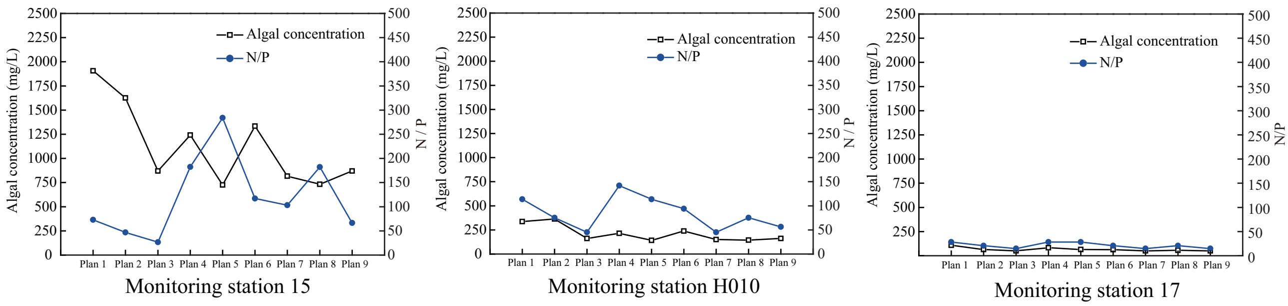

Fig. 4 Trend of N/P ratio and concentration of algal at the peak of algal growth.

the limiting factor for alga growth; at monitoring station 17, the ratio of N/P was between 10 and 20, ammonium nitrogen became the largest limiting factor in alga growth.

For plans 3, 7 and 9 alga growth inhibition was most obvious at ammonia nitrogen reduction of 64%, the decrease of alga growth compared to plan 8 at ammonium nitrogen reduction of 36% was not obvious, indicating that for plan 3, 7 and 9 the ratio of N/P suitable for alga growth (about 16); for the plan 2, 5 and 6 algae concentration was similar, indicating that the impact of phosphorus on algal growth can not be ignored. But compared to the role of ammonia nitrogen, the effect of phosphorus was weak, such as plan 2 on algal growth inhibition was more obvious than the plan 4; the same for plan 3 on algal growth inhibition was more obvious than plan 5. At monitoring station 17, algal growth was controlled by the concentration of ammonium nitrogen, phosphorus and the ratio of N/P.

3 Conclusions

Near the outfall, the concentrations of ammonia nitrogen and phosphorus were high (above 20). Recent phosphorus reduction rate on algal growth inhibitory effect was more obvious, making the phosphorus to become the limiting factor of controlling alga growth. But away from the outfall location, ammonia nitrogen and phosphorus concentrations were relatively low. The effect of ammonia nitrogen cut on alga growth had two aspects. On the one hand, it made the ratio of N/P closer to the best value (10–20) of alga growth; on the other hand, it reduced the alga nutrient supply required at this time. Ammonia nitrogen was the limiting factor to control alga growth, but the role of phosphorus on alga growth could not be ignored. Simulation results illustrated that phosphate was the limited factor to control algal growth at the location near the sewage outfall, meanwhile the synergy of ammonium nitrogen and phosphate was the limited factor at the location away from the sewage outfall. The results can provide scientific guidance for the control of algal growth and sewage program formulation.

Acknowledgments

This work was supported by the Opening Fund of Key Laboratory of Ministry of Education: Industrial Ecology and Environmental Engineering Grant (No. 0602) and the Key Laboratory of Office of Eduction of Liaoning Province: Environmental Science and Technology.

References

Paliwal R, Sharma P, Kansal A, 2007. Water quality modeling of the river Yamuna (India) using QUAL2E-UNCAS. *Journal of Environmental Management*, 83: 131–144.

Rode M, Suhr U, 2007. Gunter Wriedt. Multi-objective calibration of a river water quality model-Information content of calibration data. *Ecological Modelling*, 204: 129–142.

Shen Y M, Zheng Y H, Komatsu T, Kohashi N, 2002. A three-dimensional numerical model of hydrodynamics and water quality in Hakata Bay. *Ocean Engineering*, 29: 461–473.

JOURNAL OF ENVIRONMENTAL SCIENCES

环境科学学报(英文版)

(http://www.jesc.ac.cn)

Aims and scope

Journal of Environmental Sciences is an international academic journal supervised by Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences. The journal publishes original, peer-reviewed innovative research and valuable findings in environmental sciences. The types of articles published are research article, critical review, rapid communications, and special issues.

The scope of the journal embraces the treatment processes for natural groundwater, municipal, agricultural and industrial water and wastewaters; physical and chemical methods for limitation of pollutants emission into the atmospheric environment; chemical and biological and phytoremediation of contaminated soil; fate and transport of pollutants in environments; toxicological effects of terrorist chemical release on the natural environment and human health; development of environmental catalysts and materials.

For subscription to electronic edition

Elsevier is responsible for subscription of the journal. Please subscribe to the journal via http://www.elsevier.com/locate/jes.

For subscription to print edition

China: Please contact the customer service, Science Press, 16 Donghuangchenggen North Street, Beijing 100717, China. Tel: +86-10-64017032; E-mail: journal@mail.sciencep.com, or the local post office throughout China (domestic postcode: 2-580).

Outside China: Please order the journal from the Elsevier Customer Service Department at the Regional Sales Office nearest you.

Submission declaration

Submission of an article implies that the work described has not been published previously (except in the form of an abstract or as part of a published lecture or academic thesis), that it is not under consideration for publication elsewhere. The submission should be approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out. If the manuscript accepted, it will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright-holder.

Submission declaration

Submission of the work described has not been published previously (except in the form of an abstract or as part of a published lecture or academic thesis), that it is not under consideration for publication elsewhere. The publication should be approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out. If the manuscript accepted, it will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright-holder.

Editorial

Authors should submit manuscript online at http://www.jesc.ac.cn. In case of queries, please contact editorial office, Tel: +86-10-62920553, E-mail: jesc@263.net, jesc@rcees.ac.cn. Instruction to authors is available at http://www.jesc.ac.cn.

Journal of Environmental Sciences (Established in 1989)

Vol. 25 Supplement 2013

Supervised by	Chinese Academy of Sciences	**Published by**	Science Press, Beijing, China
Sponsored by	Research Center for Eco-Environmental		Elsevier Limited, The Netherlands
	Sciences, Chinese Academy of Sciences	**Distributed by**	
Edited by	Editorial Office of Journal of	Domestic	Science Press, 16 Donghuangchenggen
	Environmental Sciences		North Street, Beijing 100717, China
	P. O. Box 2871, Beijing 100085, China		Local Post Offices through China
	Tel: 86-10-62920553; http://www.jesc.ac.cn	Foreign	Elsevier Limited
	E-mail: jesc@263.net, jesc@rcees.ac.cn		http://www.elsevier.com/locate/jes
Editor-in-chief	Hongxiao Tang	**Printed by**	Beijing Beilin Printing House, 100083, China

CN 11-2629/X **Domestic postcode: 2-580** **Domestic price per issue RMB ¥ 110.00**

ISSN 1001-0742

9 771001 074130 99