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Analysis on pollutant accidental discharge in Zhoushan Islands, China

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Abstract

The water quality diffusion and transport around archipelago have their own uniqueness and complexity. On the basis of multinest 2D mathematical model for currents around Zhoushan Islands, model for water quality prediction was built. The pollutants discharge of Xiaogan Island was taken into consideration and mathematical model for pollutant diffusion and transport in accident discharge was studied. The influence on water quality in different discharge intensity was calculated, which provided scientific basis for the control results. It was observed that the concentration contours of COD_{Mn} at 0.03 km^2 in three conditions corresponded to standard discharge at 0.90 mg l^{-1}, accidental discharge at 1.02 mg l^{-1} and extreme discharge at 1.42 mg l^{-1}, respectively. Although discharge point locates between the archipelago, diffusion of pollutants is rapid for the fast-flowing waters of Zhoushan Islands, that provides good diffusion conditions.

Key words

Accidental discharge, Archipelago, Contaminant transport, Modeling

Introduction

Emergency water discharge from sewage treatment plant damages the environment of water body, and affects water supply safety of water intaking in surrounding seawater desalination plant. As a result, significant economic losses occur. This has raised widespread concern in the community (Shou, 2009). In view of this, establishment of accidental pollutant emissions prediction model is of great significance. The value of water pollutant diffusion transport processes and the spatio-temporal concentration were simulated that enhance the sewage discharge in any emergency response capabilities. To enhance the emergency response capacity of sewage discharge accident, water pollutant diffusion transport processes and the spatio-temporal concentration were simulated.

For different types of water body, several researches have been carried out using different types of models to evaluate the extent and range of sudden pollutant dispersion process (Grifoll *et al*., 2010; Jing *et al*., 2006; Olita *et al*., 2012; Stelzenmüller *et al*., 2014; Cao, 2015). Simulation has been made on regularity of the diffusion of pollutants in different hydrodynamic conditions and the importance of binarization threshold has been demonstrated (Wang, 2014). Mao (1996) simulated the concentration field of offshore pollution in the Qian Tang River in China based on the model of turbulent flow, considering that the vertical concentration distribution of discharge port could reflect mixing and dilution process of the pollutants. Different treatment measures in the emergency water pollution have been introduced, however, Tao *et al.* (2013) concluded that the effect of poly aluminum chloride is better than other measures. Cai (2007) simulated the diffusion process of pollutants in the waters of Zhoushan and analyzed the influence of interface source on the distribution of pollutant concentration in the water body and opined considering that the concentration of the pollutant declined from northwest to southeast. Zhoushan Islands hydrodynamic model has been established to simulate the pollutants diffusion and

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transportation under different conditions.

Materials and Methods

Governing equation : The governing equation for 2D hydrodynamic and pollutant transport is :

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}-fv=\frac{\partial}{\partial x}\left(\varepsilon_{xx}\frac{\partial u}{\partial x}\right)+\frac{\partial}{\partial y}\left(\varepsilon_{xy}\frac{\partial u}{\partial y}\right)-g\frac{\partial \xi}{\partial x}-gu\frac{\sqrt{u^2+v^2}}{C^2h} \quad (1)$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial y}+v\frac{\partial v}{\partial x}+fu=\frac{\partial}{\partial x}\left(\varepsilon_{yx}\frac{\partial v}{\partial x}\right)+\frac{\partial}{\partial y}\left(\varepsilon_{yy}\frac{\partial v}{\partial y}\right)-g\frac{\partial \xi}{\partial y}-gv\frac{\sqrt{u^2+v^2}}{C^2h} \quad (2)$$

$$\frac{\partial(hc)}{\partial t}+\frac{\partial(uhc)}{\partial x}+\frac{\partial(vhc)}{\partial y}=\frac{\partial}{\partial x}\left(hE_x\frac{\partial c}{\partial x}\right)+\frac{\partial}{\partial y}\left(hE_y\frac{\partial c}{\partial y}\right)+s \quad (3)$$

where, t is the elapsed time (sec); h is the total water depth; ξ is the surface elevation; u and v are the horizontal velocity components of the cartesian coordinates x and y; $C(x,y)$ is Chezy number; $C = h^{1/6}/n$, n is manning number; g is acceleration of gravity; f is coriolis force ($f = 2\omega \sin\varphi$, ω is the angle of rotation of the earth; φ is local latitude), ε_{xx}, ε_{xy}, ε_{yx}, ε_{yy} are eddy viscosity coefficients; c is the concentration of pollutants; E_x, E_y are the summation of turbulent diffusion coefficients and dispersion coefficients in coordinates x and y; s is source and sink.

Model setup : The irregular semidiurnal tide influences significantly by the shallow water constituent. The studied area is located in Zhoushan Islands. In Zhujiajian Island, Dengbu Island, Taohua Island, Chuanshan Peninsula and Zhoushan Island of the study area offshore waves were less affected. The studied area is controlled by the East China Sea tidal system, that is spread by the waterway from the south-east of China. Residual current was approximately 0.02~0.06 m sec^{-1} around the Xiaogan Island (Fig. 2b) in Zhoushan Islands.

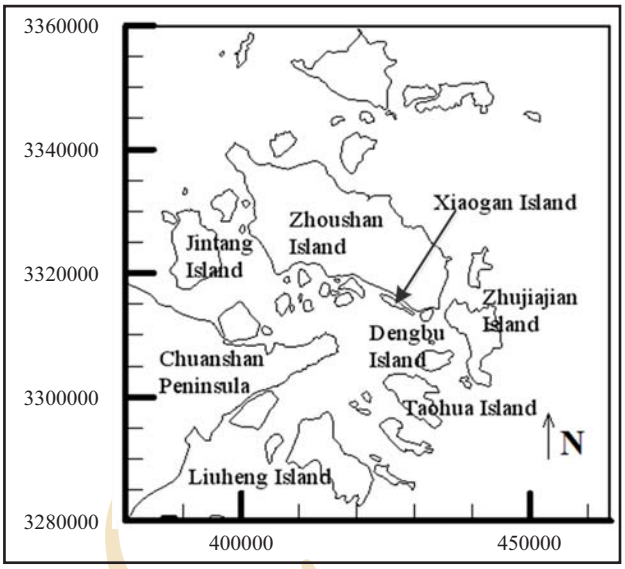

Fig. 1 : Large scale schematic

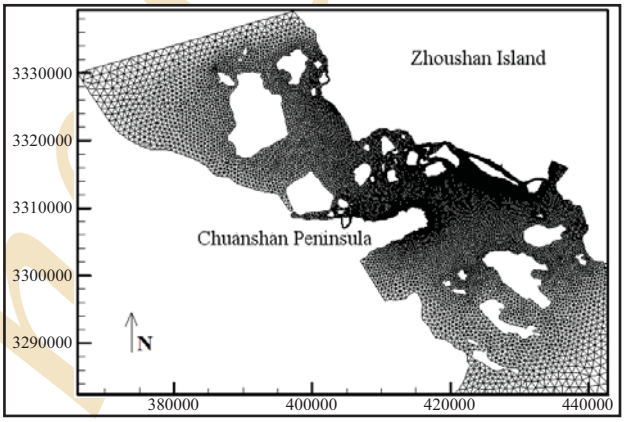

Fig. 2 (a) : Grid layout

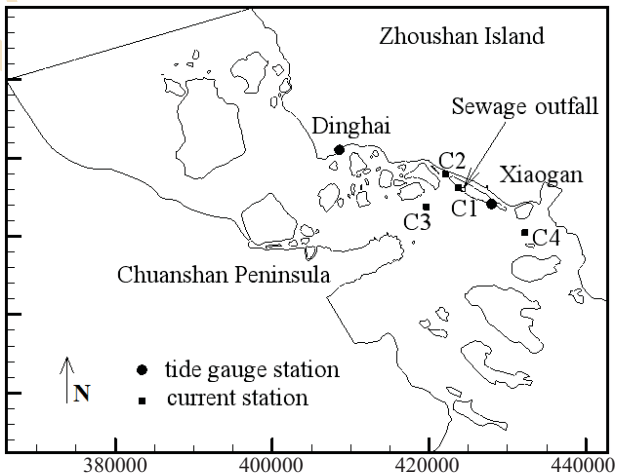

Fig. 2 (b) : Site map and sampling locations

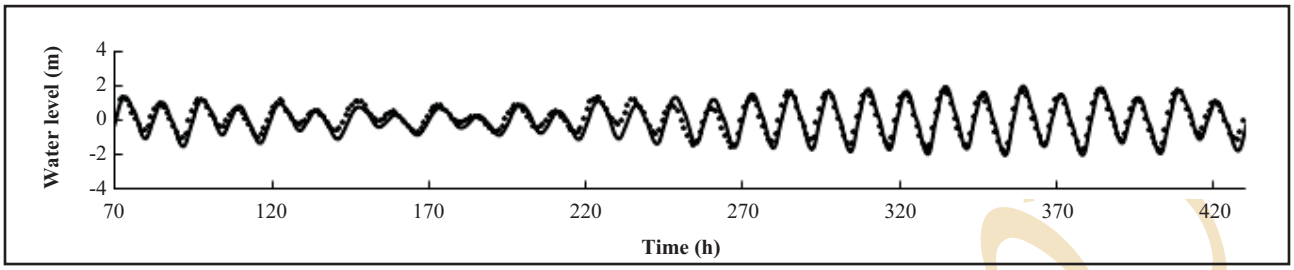

Fig. 3 : Comparison of simulated and measured tide elevation in Dinghai

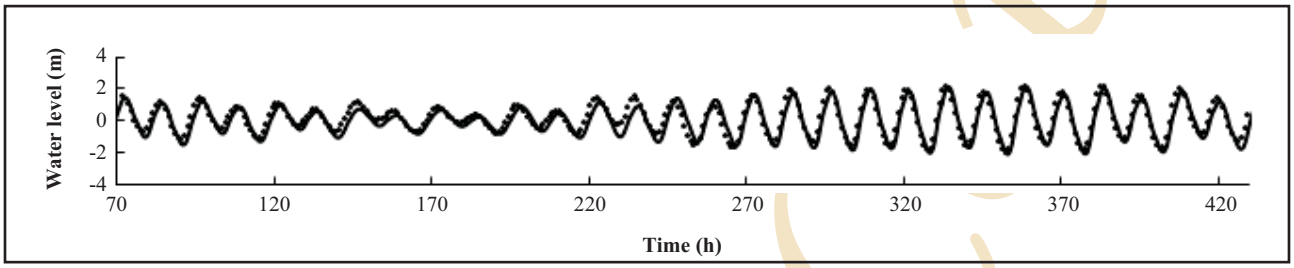

Fig. 4 : Comparison of simulated and measured tide elevation in Xiaogan Island

A wide range of hydrodynamic models have been processed for Hangzhou Bay and Zhoushan sea areas. The tide was validated by tide gauge stations of Dinghai, Xiaogan Island and the tidal currents were verified by four current stations of viz., C1, C2, C3 and C4. Based on the wide range of hydrodynamic model, small scale models have been established with open boundary of Jintang Island to the west, Pushen waterway to the north, Zhujiajian Island to the south, and Liuheng Island to the east respectively, in order to improve the accuracy of calculation and reliability of verification. Mesh was generated by unstructured triangular method in computing area, with local refinement in the project area and shoreline natural fitness, that includes 14334 nodes and 26510 elements. The computation duration ranged from 25th March to 12th April, 2012. The water level of open boundary in small scale model is given by data calculated by the wide range of hydrodynamic models. Large scale schematic, grid layout, site map and sampling locations are shown in Fig. 1, 2 (a & b).

Results and Discussion

Hydrodynamic model validation : The tide elevation verifying results are shown in Figs. 3-4. The velocity verification results are shown in Figs. 5-8, in which positive represents flood tide, otherwise negative represents ebb tide. The direction was measured in degrees counterclockwise from the north. In all the figures, the solid lines represent the simulated data and the points represent the observed values. The observed flow velocity and surface elevation of spring tide were used to calibrate this model. The tidal elevation was verified at Dinghai and Xiaogan. The tidal current was verified at station C1, C2, C3 and C4. The simulate time of spring tide was from 315 to 345, moderate tide was from 250 to 290, neap tide was from 150 to 185. Verification showed that the results of the model and measured data were in good agreement, while the change in tide range was basically same. The tidal change process is consistent, that indicates tidal level change could be simulated by established hydrodynamic model, i.e., POM, FVCOM, ECOM (Yang *et al*., 2012; Liang *et al*., 2002; Sun *et al*., 2002).

Figs. 3-8 reveal that there was a good agreement between the numeric solutions and observed data of tidal elevation, velocity amplitude and direction. These plots indicate that, under the influence of topography, the form of tidal wave would change when it entered Zhoushan Islands. Flood tide duration would be shortened and ebb tide duration may be prolonged. The pattern of the current in this area is characterized by irregular semidiurnal tide.

Fig. 9 reveals that the transformation law of tidal wave was complex for numerous criss-crossing waterways in Zhoushan Islands. The mean velocity magnitude of flood tide was larger than that of ebb tide in Shenjiamen harbor of Zhoushan Island. The flow in Pushen waterway between Zhujiajian Island and Zhoushan Island was almost reciprocating, and flood tide's velocity was greater than ebb tide. The flow in Zhoushan Islands showed swirling flow and the velocity of ebb tide was bigger than flood tide.

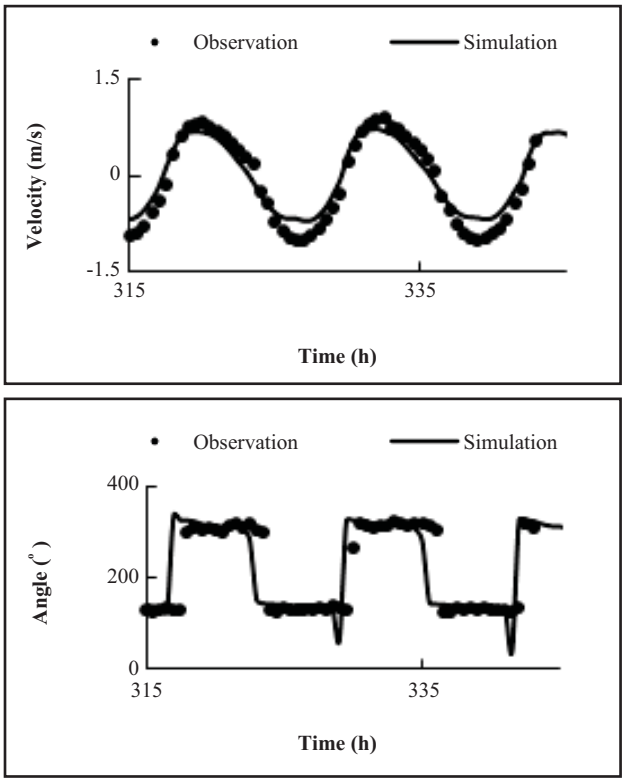

Fig. 5 : Verification of spring tidal current and velocity direction at C1

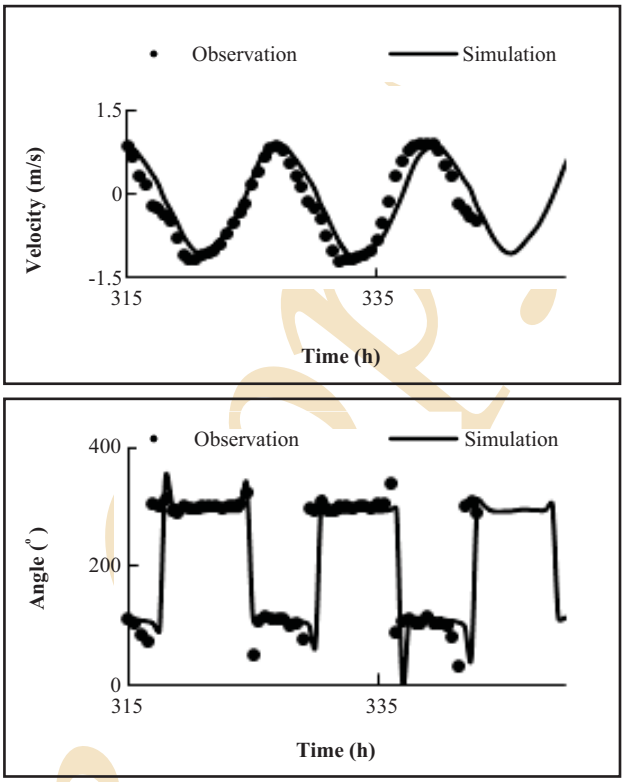

Fig. 7 : Verification of spring tidal current and velocity direction at C3

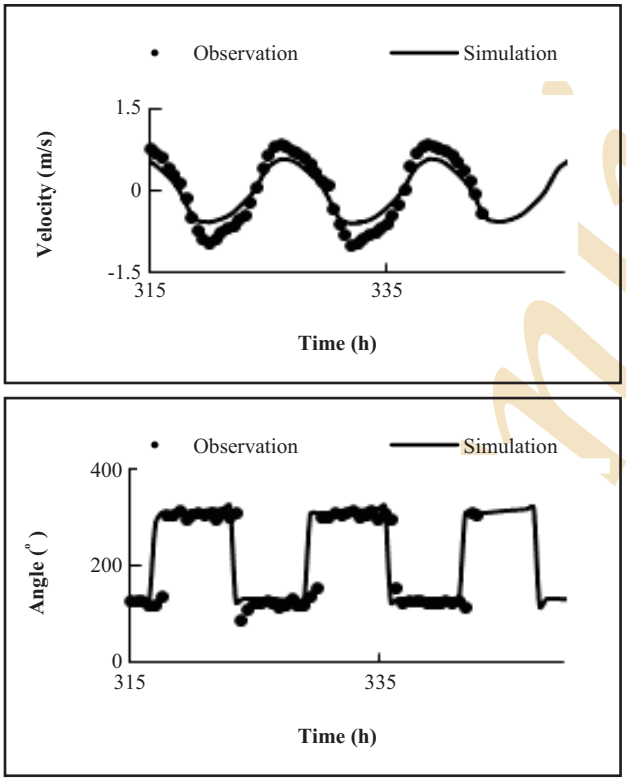

Fig.6 : Verification of spring tidal current and velocity direction at C2

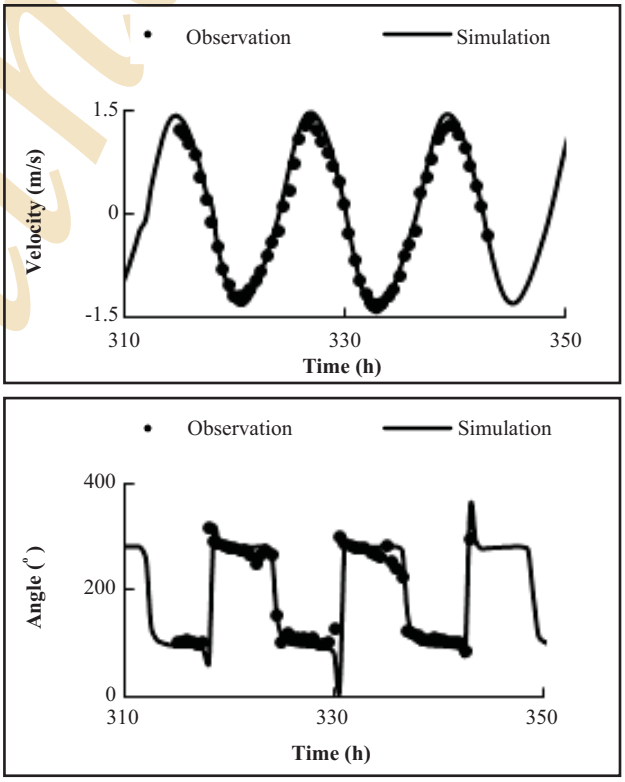

Fig. 8 : Verification of spring tidal current and velocity direction at C4

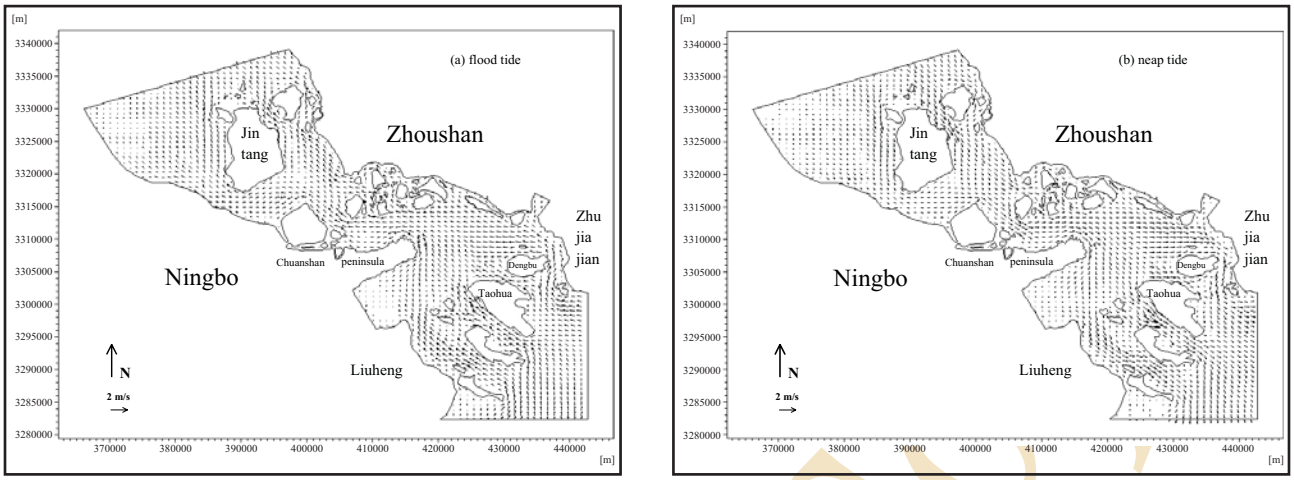

Fig. 9 : Schematic of spring flood and ebb tide

Table 1 : Emission conditions

Conditions	Contaminant species	Type of tide	Emission concentration (mg l^{-1})	Emission flux (m^3 h^{-1})
Standard discharge	COD_{Mn}	spring tide	14.3	2083
	NH_3-N		5	
Accidental discharge	COD_{Cr}		250	2083
	COD_{Mn}		71.4	
	NH_3-N		23	
Extreme discharge	COD_{Cr}		500	4166
	COD_{Mn}		142.9	
	NH_3-N		45	

Table 2 : The enveloping area of incremental maximum concentration of COD_{Mn} (km^2)

Conditions	Type of tide	>10 mg l^{-1}	>20 mg l^{-1}	>50 mg l^{-1}	>100 mg l^{-1}	>150 mg l^{-1}
Standard discharge	spring tide	0.00495	0.00039	0	0	0
Accidental discharge		0.00837	0.00070	0.00008	0	0
Extreme discharge		0.06783	0.01382	0.00214	0.00015	0

Table 3 : The enveloping area of incremental maximum concentration of NH_3-N (km^2)

Conditions	Type of tide	>10 mg l^{-1}	>20 mg l^{-1}	>50 mg l^{-1}	>100 mg l^{-1}	>150 mg l^{-1}
standard discharge	spring tide	0.00029	0	0	0	0
accidental discharge		0.00792	0.00086	0	0	0
extreme discharge		0.01552	0.00169	0	0	0

Table 4 : The enveloping area of incremental maximum concentration of CODCr (km^2)

Conditions	Type of tide	>10 mg l^{-1}	>20 mg l^{-1}	>50 mg l^{-1}	>100 mg l^{-1}	>150 mg l^{-1}
accidental discharge	spring tide	0.02930	0.00245	0.00039	0	0
extreme discharge		0.43741	0.05537	0.00752	0.00053	0

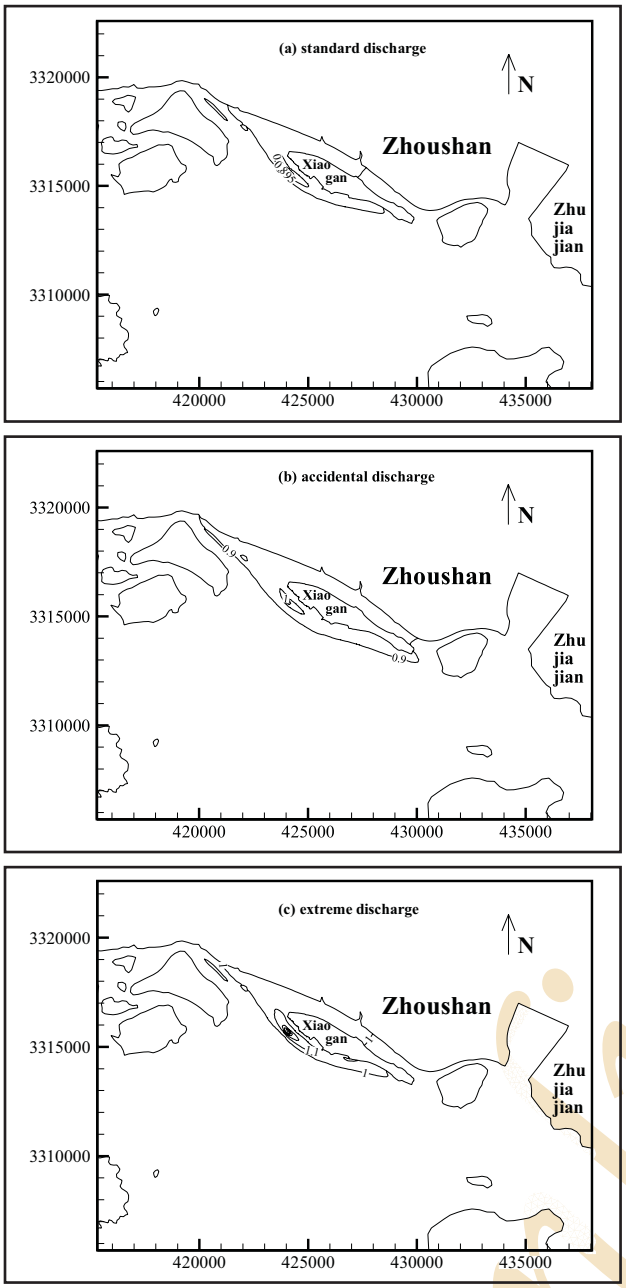

Fig. 10 : Distribution of the COD_{Mn} concentration with standard discharge, accidental discharge, extreme discharge respectively (mg/L)

The maximum velocity in Xiaogan Island was approximately 1.7 m sec^{-1}, velocity of sewage draining exit was 0.33 m sec^{-1} when the spring tide rose; the maximum velocity near Xiaogan Island was 1.8 m sec^{-1} and velocity in sewage discharge was 0.35 m sec^{-1} when the spring tide fall down. Flow rate near Xiaogan Island and outfall was 0.63 m sec^{-1}, 0.13 m s^{-1} and 0.64 m sec^{-1}, 0.15 m sec^{-1} when neap tide rose and fell down.

Water quality simulation and prediction : Considering the nearby sea conditions of Xiaogan Island, sewage treatment plant effluent would be discharged into the southern side of Island, which was about 200 m offshore, 5.80 m in depth, (424101, 3315689) of its coordinate. The form of sewage outfall pipe emission adopt low tide diffusion charge. In order to utilize the function of mixing and dilution of sea water effectively, and to make the sewage for getting more purified water, the sewage outfall was employed with duckbill valve. When the tide near to the outlet was over 2.5 m, the pump started and the wastewater was discharged with pressure. In order to predict quantitatively the influence of pollutant discharge water to the south sea area of Xiaogan Island, this mechanism simulates pollutant concentration field under three kind of conditions. It includes standard discharge, accidental discharge and extreme discharge. The background concentration of COD_{Mn} was 0.88 mg l^{-1} (Huiwen *et al*., 2007) and the water quality diffusion coefficient was 1.6 m^2 s^{-1} (Fang, 2012).

It was seen from the concentration of field in the average tide under three discharge conditions that the diffusion figure of COD_{Mn} of different emission intensity was basically same, with the characteristic of highest concentration at the pollution source and diffusion transport along the flow direction. The current at the point of emission is oscillating flow, and current flow to northwest along the narrow channel between Changzhi Island and Xiaogan Island is at flood tide. Flow to the southeast side along the south of Xiaogan Island was at ebb tide, so the diffusion of pollutants was essentially transported along the trend of the fluctuation in the direction of movement. Statistically, it was found that the concentration contours of COD_{Mn} at 0.03 km^2 in three conditions corresponded to the standard discharge at 0.90 mg l^{-1}, accidental discharge at 1.02 mg l^{-1} and extreme discharge at 1.42 mg l^{-1}. The concentration of extreme discharge was larger than the standard discharge and accidental discharge. So, not only the emission concentration was highest, but also the concentration and discharge flux was double of the accidental discharge.

Based on nested hydrodynamic model, this mechanism simulates the hydrodynamic of Zhoushan Islands. A 2D water quality prediction model of Zhoushan Islands has been established. Diffusion regularity at several emission intensity of standard discharge, accidental discharge and extreme discharge under the effect of tide current and the influence to water quality in Zhoushan Islands have been studied. It is found that the concentration contours

of COD_{Mn} is at 0.03 km^2 in three conditions. The incremental concentration of accidental discharge to standard discharge is 0.12 mg l^{-1}, incremental of extreme discharge to accidental discharge is 0.40 mg l^{-1}. The latter increment is 3.3 times of the former. Based on the model results, the impact of sewage discharge of various intensity to marine water quality was calculated. This study will provide a scientific basis for the control of emissions.

Acknowledgments

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