Numerical Simulation of Impacts on Marine Environment by Sewage Discharge

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ABSTRACT: Numerical simulation on tidal field of sewage marine disposal engineering area was carried out by using the MIKE3 numerical model. The impact of volatile phenol of waste water, cyanide and COD on water environment was predicted. Results show that great changes of pollutant content have taken place in each water layer because of pollution discharge. The pollution discharge into deep water has the greatest effect on bottom water quality, and the impact decreases gradually from the bottom to the surface. It shows that pollution discharge into deep water is helpful to control the pollutant increment of surface water.

Keywords: MIKE3; 3D numerical simulation; sewage marine disposal engineering

1 INTRODUCTION

It is estimated that the development and construction of Caofeidian Industrial Zone will produce a large volume of industrial waste water. Considering the actual situations of Caofeidian, the sewage discharge into inland river will result in a pollution in a large area of local water system; therefore, we can take the unique geographical advantages in Caofeidian area and make full use of the capacity of marine environment and its capabilities of absorbing pollutants and self-cleaning, the sewage can be discharged via offshore diffusers installed on extended piping in deep sea to allow for sufficient dilution and diffusion of the sewage under the powerful hydrodynamic force in the deep sea as planned. Guo Feng et al. [1] analyzed impacts of 4 different discharge modes adopted in Jinshan District of Shanghai on water quality in sea areas where pollutants are absorbed. Song Qiang et al. [2] conducted an analysis of effects of municipal sewage discharge engineering in Shenzhen on marine environment. Zhao Junjie et al. [3] took the tail water in compliance with industrial standard discharge engineering in Nantong as an example to research the extent of influence of hydrodynamic force on diffusion of pollutants in various water depth conditions. Liu Cheng et al. [4] carried out simulation of the dilution and diffusion of sewage discharged into sea via existing and proposed outfalls in Shanghai. As the spreading pollutants are characterized by vertical and layered distribution, three-dimensional mathematical model is a preferred tool to reflect the differences in contents of pollutants in each layer as a result of deep-water discharge thus to demonstrate the performance of deep-water discharge [5].

2 NUMERICAL SIMULATION OF HYDRODYNAMIC FORCE

2.1 Model control equation

The three-dimensional hydrodynamic model was established with the commercial software MIKE3 which was developed by Danish Hydraulic Institute (DHI) [6].

The basic equation of motion is as follows:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial \sigma} = S \tag{1}$$

$$\frac{\partial u}{\partial t} + \frac{\partial (u^2)}{\partial x} + \frac{\partial (vu)}{\partial y} + \frac{\partial (wu)}{\partial \sigma} = fv - g\frac{\partial \eta}{\partial x} - \frac{1}{\rho_0}\frac{\partial p_a}{\partial x} \tag{2}$$
$$+ \frac{g}{\rho_0}\int_\sigma^0 \frac{\partial \rho}{\partial x}dz - \frac{1}{\rho_0 h}(\frac{\partial s_{xx}}{\partial x} + \frac{\partial s_{yy}}{\partial y}) + F_u + \frac{\partial}{\partial \sigma}(v_t\frac{\partial u}{\partial \sigma}) + u_s S$$

$$\frac{\partial v}{\partial t} + \frac{\partial (v^2)}{\partial x} + \frac{\partial (uv)}{\partial y} + \frac{\partial (wv)}{\partial \sigma} = -fu - g\frac{\partial \eta}{\partial y} - \frac{1}{\rho_0}\frac{\partial p_a}{\partial y} \tag{3}$$
$$+ \frac{g}{\rho_0}\int_\sigma^\eta \frac{\partial \rho}{\partial y}dz - \frac{1}{\rho_0 h}(\frac{\partial s_{yx}}{\partial x} + \frac{\partial s_{yy}}{\partial y}) + F_v + \frac{\partial}{\partial \sigma}(v_t\frac{\partial v}{\partial \sigma}) + v_s S$$

$$F_u = \frac{\partial}{\partial x}\left(2A\frac{\partial u}{\partial x}\right) + \frac{\partial}{\partial y}\left(A\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right) \tag{4}$$

$$F_v = \frac{\partial}{\partial y}\left(2A\frac{\partial v}{\partial y}\right) + \frac{\partial}{\partial x}\left(A\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right) \tag{5}$$

Where, $h=\eta+d$ is total depth of water; η is water level on surface; d is still water surface; u is the velocity in X direction (East); v is the velocity in Y direction (North); w is the velocity of σ coordinate system, sharing the same direction with the normal of iso-σ lines and its relationship with vertical flow velocity W under three-dimensional rectangular coordinate system is as follows:

$$w = W - u\left(\sigma\frac{\partial D}{\partial x} + \frac{\partial \eta}{\partial x}\right) - v\left(\sigma\frac{\partial D}{\partial y} + \frac{\partial \eta}{\partial y}\right) - \left(\sigma\frac{\partial D}{\partial t} + \frac{\partial \eta}{\partial t}\right) \quad (6)$$

Where, f is Coriolis force parameter; A is horizontal turbulent viscosity coefficient; ρ_0 is reference density; u_s, v_s are east and north components of the velocity at point source; S is the intensity at point source.

2.2 Boundary conditions

Lateral boundary conditions: at the fixed boundary, the normal component constant of flow is zero; $\vec{V}(x,y,z,t) = 0$ and there is no heat and salt exchange.

Open boundary conditions: the border of small zone was outlined by framing a large zone. The coordinates of simulated large zone ranged from 117°32′25″E to 122°17′3″E and from 37°6′1″N to 40°58′10″N; The open boundary in open sea of the large zone was determined with tidal level hydrograph Z=Z (T) which was provided in China Tide Table, and debugged on the basis of measured hydrological data. The boundary of small zone was determined by the calculation results of upper level model and the coordinates of simulated small zone ranged from 118°54′51″E to 118°56′30″E and from 38°7′0.35″N to 39°8′53″N.
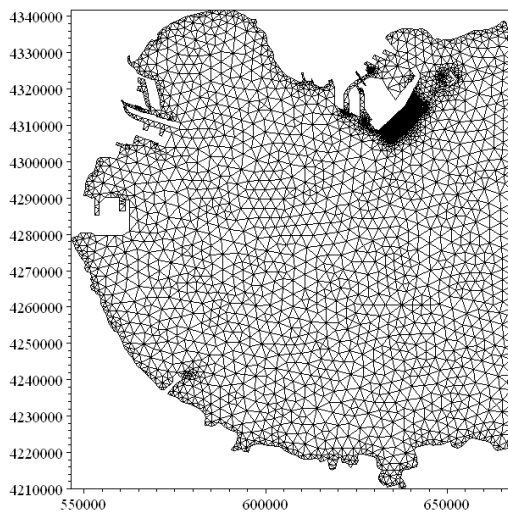
2.3 Scope of calculation and grid settings

Figure 1. Model range and computational grid

The outfall was located at 118°35′07.541″E, 38°57′03.058″N, 1.37 km away in a straight line from the shore and at a depth of 7m. For calculations, the eastern boundary of the model reaches 118°56′30″E, with a north-south span of approximate 113km. The model was based on nonstructural triangle grid system and divided into 6 σ layers vertically (surface layer, 0.2H, 0.4H, 0.6H, 0.8H and bottom layer); the grids at

outfall area was locally more intensive. In the aggregate, there were 8,853 triangle grid nodes and 16,669 triangular elements in the simulated area. Figure 1 shows the boundary of model and grids used for calculations.
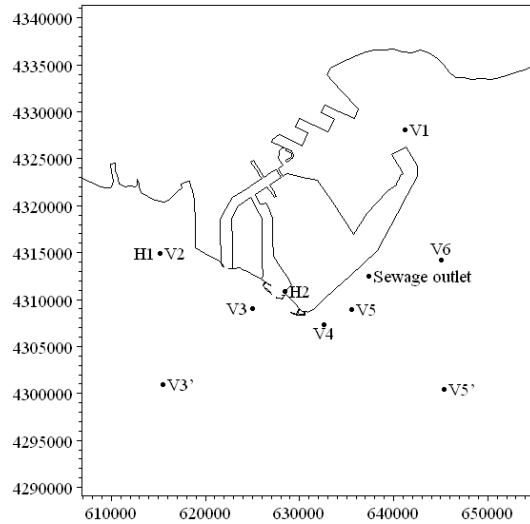

Figure 2. Verification point location

2.4 Verification and analysis of simulation results

The field data of violent, medium and weak tides measured in March to April of 2013 was used as input to verify tide level, velocity and flow direction. In total, 8 tide stations (V1~V6 and V3', V5') and two tidal level stations (H1, H2) were established. Figure 2 shows the positions of verification points. Figures 3-4 show verification curves of measured values and calculated values of tidal level, current velocity and direction (surface layer, 0.6H layer and bottom layer). It is indicated on the observation curves that there is only a slight difference between the measured values and calculations for each station in consideration of their overall trends. The calculated tidal level variation and the velocity and flow direction of each layer are basically identical to the experimental data, which indicates that the motion of tide simulated with the model can basically reflect the water flow conditions in Caofeidian sea area and thus can be used as the basis for further analysis and calculation.

As Caofeidian protrudes into the Gulf of Bohai in the form of a cape, the main directions at measurement stations are not identical due to the effects of their respective terrain, but the regularity is obviously the same, which lies in that the main flow direction is substantially parallel to the isobaths; at the nose of Caofeidian and in the sea areas being far from shoal, the tide flow is basically flowing in reciprocating motion in a east-west direction; in the sea areas near the shoal, the mainstream tends to flow along the coast or the direction of isobaths under the effects of changing terrain and water resistance of the shoal face. Conse-
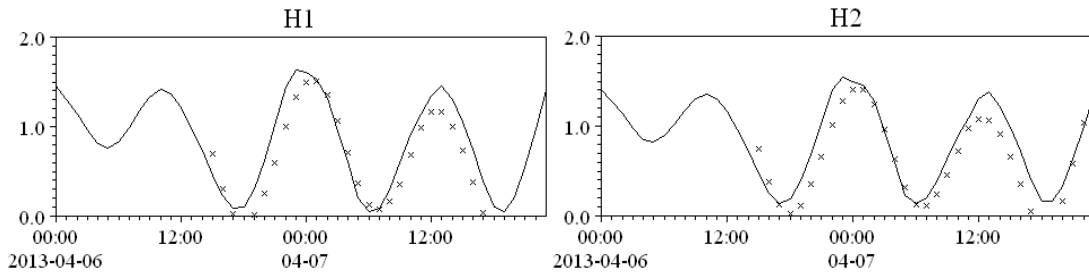
Figure 3. Comparison of predicted (—) and measured (×) tide level at H1, H2 tidal station
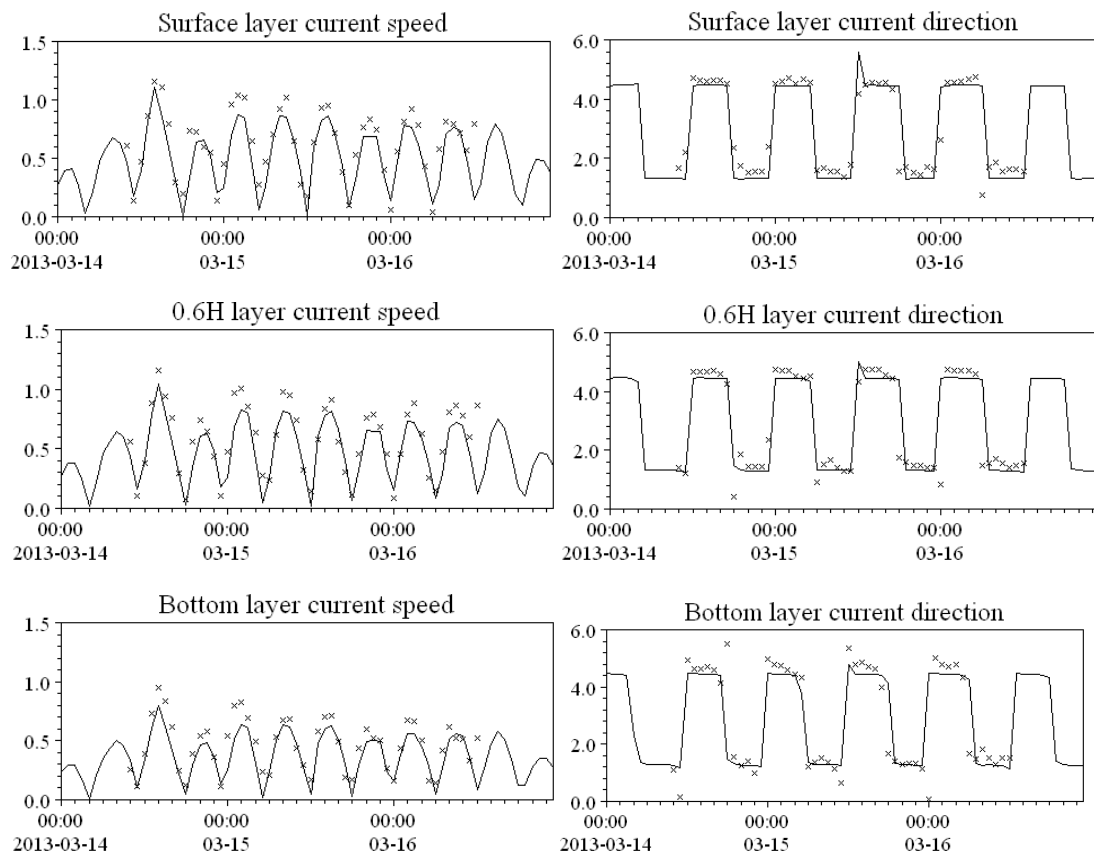

Figure 4. Comparison of predicted (—) and measured (×) current velocity at V4 station

quently, the tide in Caofeidian sea area basically flows in reciprocating motion, but obvious counterclockwise rotating flow is also noticed. In Caofeidian sea area, the velocity of flood tide is higher than that of ebb tide and the velocity at the bottom layer is less than that of surface layer and 0.6H layer. The maximum velocity in the surface layer, 0.6H layer and the bottom layer reaches 1.4m/s, 1.2m/s, 0.9m/s respectively in rapid flood tide cycle; the maximum velocity in the surface layer, 0.6H layer and the bottom layer drops down to 1.12m/s, 0.96m/s and 0.75m/s respectively in rapid ebb tide cycle.

3 PREDICTION ABOUT IMPACTS ON THE DIFFUSION OF POLLUTANTS

3.1 Model control equation

The convection diffusion mode (AD) contained in the mathematical model MIKE3 developed by Danish Hydraulic Institute (DHI) was adopted in this paper for numerical simulation of transport and diffusion of contaminants.

The diffusion equation is as follows:

$$\frac{\partial C}{\partial t} + \frac{\partial uC}{\partial x} + \frac{\partial vC}{\partial y} + \frac{\partial wC}{\partial \sigma} = F_C \tag{7}$$

$$+ \frac{\partial}{\partial \sigma}(D_v \frac{\partial C}{\partial \sigma}) - k_p C + C_s S$$

$$F_C = \left[\frac{\partial}{\partial x}\left(D_h \frac{\partial}{\partial x} \right) + \frac{\partial}{\partial y}\left(D_h \frac{\partial}{\partial y} \right) \right] C \tag{8}$$

Where, C is the concentration of pollutants; C_s is intensity at source point; D_v is the vertical diffusion coefficient; D_h is horizontal diffusion coefficient. The implication of other parameters is the same as that of hydrodynamic parameters.

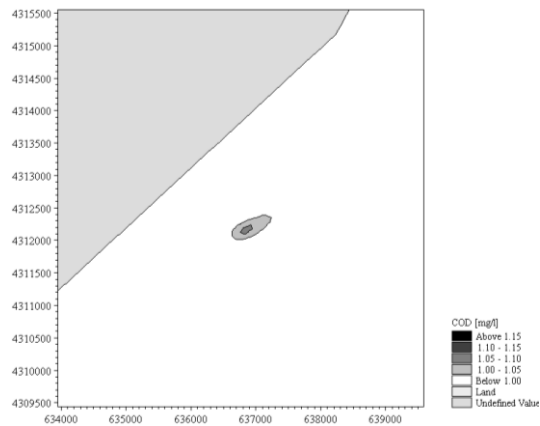### 3.2 Predicted scope of influence of pollutants
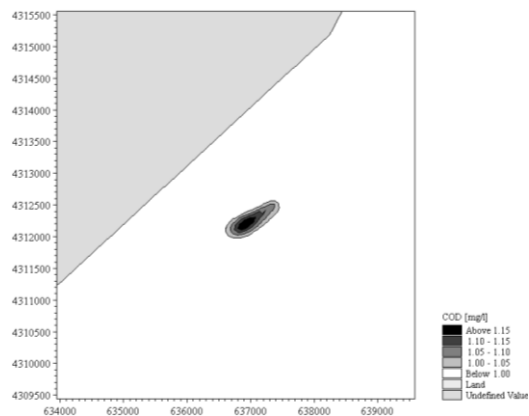

Figure 5. Surface layer concentration of COD

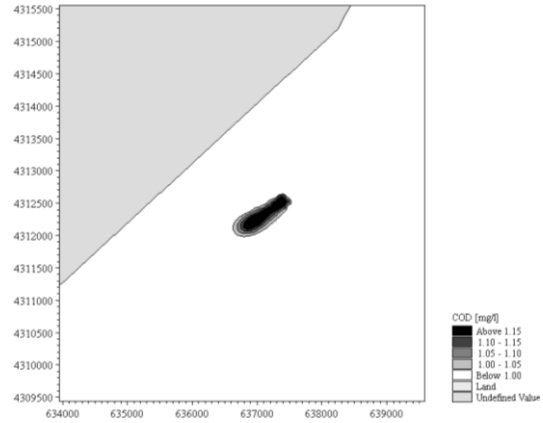Figure 6. 0.6H layer concentration of COD
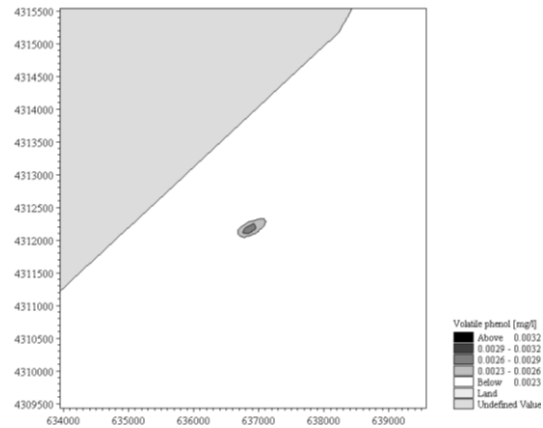

Figure 7. Bottom layer concentration of COD

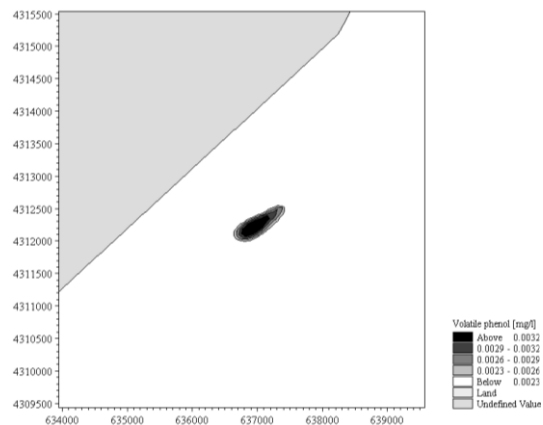Figure 8. Surface layer concentration of volatile phenols

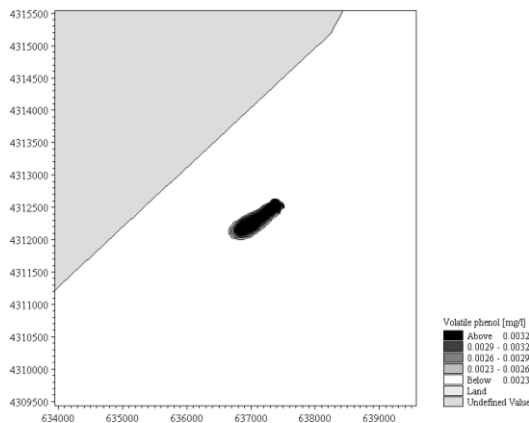Figure 9. 0.6H layer concentration of volatile phenols

Figure 10. Bottom layer concentration of volatile phenols

According to design, the sewage discharge engineering in Caofeidian may discharge sewage at a rate of 60,000m³/d and the concentration of volatile phenol in discharged waste water is 0.5mg/L, based on calculations which show the intensity at source point is 0.347g/s; the concentration of emitted COD is 50mg/L, the intensity at source point is 34.7g/s. 600h background flow is preset for simulation of dispersion conditions of pollutants, a concentration field is captured at an interval of 2min to make statistics of the maximum increment of concentration of pollutants at each calculated grid point during simulation and then such values are overlapped on the status quo concentration of each pollutant in the sea area to plot envelope lines of maximum concentration of pollutants in the surface layer, 0.6H layer and the bottom layer (refer to Figure 5-Figure 10).

The statistics based on the diffusion of various pollutants according to the simulation calculation showed that the maximum concentrations of COD in the surface layer, 0.6H layer and the bottom layer are 1.095mg/L, 1.48mg/L and 3mg/L respectively; while the maximum concentrations of volatile phenol in the surface layer, 0.6H layer and the bottom layer are 0.0032mg/L, 0.0068mg/L, 0.0225mg/L, all of which are less than the criteria established for quality of water under Grade 2 and thus sewage discharge has little impact on the marine environment. The envelope lines of simulated maximum concentration shows that: flood tide and ebb tide is accompanied by the maximum concentration in vicinity of outfall; as the pollutants diffuse by following the tide, the concentration reduces gradually as the pollutants flows apart from the outfall; in vertical direction, the sewage discharged into the water in bottom layer is mixed with the surrounding water on a continuous basis and subsequently the concentration of discharged sewage witnesses a gradual reduction with gradually reduced influence from the bottom layer to the surface layer, indicating that deep-sea discharge contributes to control over the increment of pollutant content in the surface layer of

water. Furthermore, the pollutants are also pushed by tide while they are flowing vertically upwards, which results in difference in trend of concentration between surface layer and bottom layer, namely the concentration in the main direction of tide firstly increases and then decreases in the surface layer while the concentration is experiencing a constant drop in the bottom layer.

4 CONCLUSION

There-dimensional numerical simulation was adopted to conduct simulation and analysis of transport and dispersion of volatile phenol, COD and some other pollutants for exploring the impacts of sewage discharge engineering in Caofeidian on the quality of sea area where pollutants are discharged. It can be known from the simulation results that: the maximum concentration of pollutants in each layer is less than that established for sea water under Grade 2 and sewage discharge has little impact on marine environment. The maximum concentration is noticed in the vicinity of the outfall and as the pollutants diffuse by following the tide, the concentration is reduced gradually as the pollutants flows apart from the outfall while the longer the distance is, the less the concentration will be. Deep-sea discharge results in difference in the concentration of pollutants in each layer of water. The water in the bottom layer suffers from the prevailing impacts from the discharge of sewage while such impacts will reduce gradually from the surface layer to the bottom layer. Deep-sea discharge contributes to controlling over the increment of pollutant content in the surface layer of water.

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