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Simulation of Groundwater Pollution in a Factory Based on Visual Modflow

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ABSTRACT: The groundwater pollution situation of an industrial park in Mengzhou City, Henan province was simulated to provide reference for groundwater pollution migration and prevention. Through various experiments and hydrogeological surveys to obtain basic parameters for simulation work, this paper uses Visual Modflow software to establish groundwater numerical model in the study area, and on this basis, MT3DMS module is used to simulate solute transport of leaked pollutants COD and NH3-N. In this paper, solute transport is simulated under two working conditions: under abnormal working conditions, the influence range and maximum transport distance of pollutants in sewage transport pipeline leakage without seepage prevention measures; Sewage transport pipeline leakage but seepage prevention measures in the case of pollutant diffusion.

KEYWORDS: Groundwater pollution, Visual Modflow, Numerical model, Solute transport

I. RESEARCH BACKGROUND

Water is the source of life. With the rapid development of current society and industrialization, the pollution of water resources is also increasing year by year. In recent years, with the emphasis on water pollution in China and the strengthening of prevention and remediation work, the quality of surface water has been significantly improved. However, the most harmful pollution in water resources is the pollution of groundwater. Because of its strong concealment and slow update speed, it is difficult to recover once the groundwater is polluted, which has a serious impact on the ecological environment. At present, about 2 / 3 of the urban water consumption in China comes from groundwater, and about 90 % of the urban groundwater is polluted by organic and inorganic harmful toxic pollutants to varying degrees. It is urgent to improve the water quality of the sewage[1,2]. The theme of the thirtieth "World Water Day " held on March 22,2022 is " cherish groundwater and cherish hidden resources. " It can be seen that the problem of groundwater has attracted global attention. Groundwater resources should be valued and prevented so as to avoid greater damage to the safety of human life and property. This paper mainly studies the pollution discharge of a new factory in an industrial park in Mengzhou City, Henan Province. The production sewage and domestic sewage produced by the plant are transported to the sewage treatment plant for treatment through the water pipeline. Under normal operating conditions, the leakage of the water pipeline is very small, and there are anti-seepage measures, even if the leakage will not penetrate into the groundwater. This paper mainly considers the situation when the sewage tank leaks and the anti-seepage measures fail. This situation will lead to the infiltration of sewage through the vadose zone, thus causing groundwater pollution. In this paper, Visual Modflow is used to simulate the infiltration of pollutants, the influence range, the exceeding range and the maximum migration distance of pollutants when the leakage occurs in the sewage tank. The simulation results are used for the auxiliary prediction of local groundwater and provide reference for groundwater pollution control.

II. OVERVIEW OF THE STUDY AREA

The study area is located between the Jiyuan Basin and the Luoyang Basin. The faults related to the study area are all unbroken Quaternary bedrock faults, which have limited impact on the site, and do not pose a potential danger to the activity of the broken surface. Therefore, the impact of the fault on the site can be ignored. The evaluation area is located on the second terrace of the alluvial plain of the Yellow River. The lithology of the stratum is dominated by Quaternary alluvial and slope deposits such as silt, silty clay and sandy pebble. According to the previous data, within the exploration range of 60 m, it is divided into four layers from top to bottom according to the stratigraphic age, genesis and burial law. The details are as follows : Layer 1 silt (Q3a1 + p1) : brown-yellowish brown, loose structure, containing white mycelium and black spots, pore development, wormholes, newly accumulated loess of gully alluvial, most of the upper part is cultivated soil, and miscellaneous fills such as waste bricks and garbage can be seen locally. The layer is distributed in the site, the depth of the bottom layer is 6.2-10.5 m, and the thickness is 6.2-10.5 m. Layer 2 silty clay (Qa1 + p1) : reddish brown, with white filamentous stripes and black stripes, slightly glossy section, cracks and pores are slightly developed. In the upper part of the layer, small pieces of ginger stone are occasionally seen, and silt and silt are partially sandwiched. The layer is generally distributed in the site, the depth of the bottom layer is 16.7-28.6 m, and the thickness of the layer is 8.6-14.5 m. Layer 3 pebbles (Q2a1 + p1) : gray white, mixed color, the parent rock is mainly quartz sandstone, the diameter is generally 3.0-8.0cm, the maximum is more than 20cm, the roundness is good, the filling is mainly sand, local boulders, the layer is generally distributed in the site, the thickness is stable, generally greater than 10m. The depth of the bottom layer is 57.0-65.3 m, and the thickness of the layer is 26.8-47.2 m. Layer 3 mudstone and siltstone (N) : The mudstone and sandstone of this layer are interbedded or staggered, and the mudstone fissures are not developed, showing a thick layered structure, which is a good aquiclude between the Quaternary aquifer and the Neogene aquifer. According to the previous drilling hole (HK6) in the area, the maximum thickness of the exposed layer is 48.6 m.

III. ESTABLISHMENT AND CORRECTION OF NUMERICAL MODEL

In this paper, Visual Modflow groundwater simulation software is used for simulation. It is a three-dimensional visualization professional software developed by Waterloo Hydrogeological Company of Canada, which is mainly used to simulate the flow state of groundwater (Modflow), solute transport (MT3DMS), given particle trajectory (MODPATH), specific water volume change (ZONE BUDGET).

A. Hydrogeological model

The aquifers in the study area can be divided into Quaternary pore aquifer group and Neogene pore fissure water aquifer group according to the formation age and burial conditions. The strata in the evaluation area are mainly composed of layer 1 silt (Q3a1 + p1), layer 2 silty clay (Q2a1 + p1), layer 3 pebble (Q2a1 + p1) and layer 4 mudstone and siltstone (N). Among them, layer 1 silt (Q3a1 + p1) and layer 2 silty clay (Q2a1 + p1) are vadose zones. The lower layer 4 mixed rock is the water-proof floor of the pore water of the loose rock. Layer 3 pebble color is more complex, the parent rock is mainly quartz sandstone, the diameter is 30-80cm, the maximum is more than 20cm, the roundness is good, the filling is mainly sand, local boulder. The depth of the bottom layer is 57.0-65.3 m, and the thickness of the layer is 26.8-47.2 m. The thickness gradually becomes thicker from north to south and from west to east. According to the hydrogeological conditions, the groundwater flow in the study area is mainly horizontal flow from northwest to southeast.

Boundary conditions : if there is a reservoir in the east of the simulation area, the east can be generalized as the first type of boundary (constant head boundary) ; the northern, southern and western parts of the simulation area are all watersheds in each region, and they are generalized into the second type of boundary (zero flow boundary). The vertical boundary : between the vertical distribution of the Quaternary pore aquifer group and the underlying Neogene pore aquifer group, there is a layer of clay rock with a thickness of about 40 m continuously and stably distributed, so the bottom of the simulation area is generalized as a water-proof floor ; the top is generalized as a free boundary.

Groundwater recharge, runoff and discharge : The main recharge in the simulation area comes from atmospheric precipitation infiltration, lateral infiltration of the eastern reservoir and groundwater runoff recharge in the adjacent area. The groundwater flow is mainly in the horizontal direction from northwest to southeast. Because of the loose texture and large porosity of the unsaturated zone, the buried depth of the front water level is less than the limit evaporation depth in this area, so evaporation and excretion is one of the main excretion ways in the simulation area. The industrial and agricultural water in the simulation area is mainly exploited in the phreatic aquifer, and the exploitation of industrial and agricultural water and domestic water is also the main discharge route in the simulation area. Based on the above observation data and the change of water level in the study area, the dynamic characteristics of groundwater in the simulation area are as follows : the annual water level variation is small and the amplitude is close, and the annual amplitude is generally about 1-2m, that is, the groundwater level changes with time or space. The influence is small, so the groundwater in the simulation area can be approximated as a steady flow[3].

B. Water flow model

The groundwater flow model in the simulation area is based on the hydrogeological conceptual model, according to the actual hydrogeological boundary conditions, groundwater flow characteristics and the changes of various seepage conditions in the hydrogeological environment [4]. The groundwater in the simulation area is heterogeneous and isotropic, and the three-dimensional groundwater flow partial differential equation follows Darcy 's law. The mathematical model is expressed as follows [5] :

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial H}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial H}{\partial y}\right)+\frac{\partial}{\partial x}\left(K_{zz}\frac{\partial H}{\partial z}\right)+\omega=\mu_s\frac{\partial H}{\partial t}$$

$$H(x,y,t)|_{t=t_0}=H_0(x,y,t_0)$$

$$H(x,y,t)|_{\Gamma_1}=H_0(x,y,t_0) \qquad t\geq 0$$

$$T\frac{\partial H}{\partial n}|_{\Gamma_2}=-q(x,y,t) \qquad t\geq 0,(x,y)\in\Gamma_2$$

where H is the water head ; w is the source sink term ; us is the amount of water released from the unit volume pore when the water head drops by one unit (volume unit, dimension L-1) ; kxx, Kyy and Kzz represent the main permeability coefficients in the x, y and z directions, respectively. H0 (x, y, t0) is the initial head value ; h1 (x, y, t) is the boundary head value ; n is the outer normal direction of the boundary Γ2 ; q is the unit width flow on the boundary ; t is the transmissibility coefficient of the aquifer at the boundary ; γ1 and Γ2 are the water head and flow boundary of the study area, respectively.

On the plane, the simulation area is generalized into a 2km × 2km area, which is divided into 100 rows × 100 columns of 20m equidistant orthogonal grids. In this case, the simulation area is divided into 10,000 units, of which 7880 are active units. The specific simulation range is as follows :

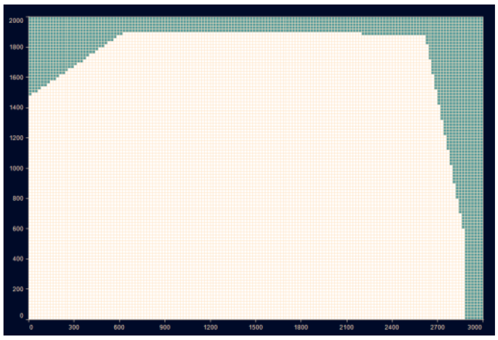


Fig.1 Study area division

C. Model identification

Using the measured hydrogeological parameter values, the model is identified to verify whether the established flow model can accurately and objectively predict the change of groundwater flow field [6].

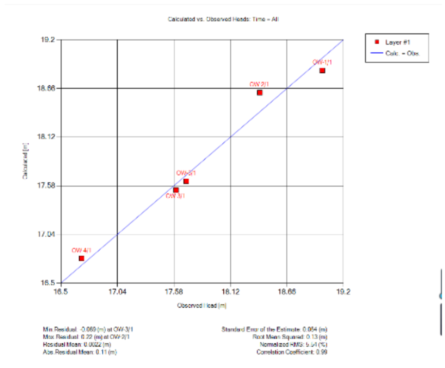


Fig. 2 Model identification diagram

D. Solute transport model

The solute transport model is based on the water flow model. The solute transport model established in this paper based on the actual situation in the simulation area is a convection-dispersion equation that does not consider the adsorption of pollutants in groundwater and biochemical reactions. The mathematical model is as follows [7] :

$$R\ \frac{\partial(\theta C)}{\partial t}=\frac{\partial}{\partial x_i}\left(\theta D_{ij}\frac{\partial C}{\partial x_j}\right)-\frac{\partial}{\partial x_i}(\theta v_i C)-WC_s-WC-\lambda_1\theta C-\lambda_2\rho_b\bar{c}$$

$$C(x,y,z,t)=C_0(x,y,z) \qquad [(x,y,z)\in\Omega_1\ ,\ t=0]$$

$$C(x,y,z,t)\Gamma_2=c(x,y,z,t) \qquad [(x,y,z)\in\Gamma_1\ ,\ t\geq 0]$$

Where: D_{ij} —hydrodynamic dispersion coefficient(m2/d), $D_{ij} = \alpha_{ijmn} v_m v_n / |v|$; α_{ijmn} —aquifer dispersion; the velocity components in v_m and v_n— m and n directions; $|v|$—velocity module; R—hysteresis coefficient, dimensionless;t — simulation time (d);c — the mass concentration of simulated pollutants (mg/L); θ—effective porosity; C_s—source and sink mass concentration of simulated pollutants(mg/L); W—source-sink flux per unit area; v_i—groundwater seepage velocity (m / d); ρ_b— medium density.

For the prediction of pollutant transport in this area, it was detected that the main pollutants in the sewage discharge of the factory were COD and NH3-N, so COD and NH3-N were selected for solute transport simulation. The leakage of pollutants is shown in the following table 1:

Table 1. Initial concentration of pollutants

contaminant	Leakage situation	Sewage leakage /(m3/d)	longitudinal dispersion coefficient /(m2/d)	initial concentration /(mg/L)
COD	series	0.08	0.2	300
NH3-N	series	0.08	0.2	30

IV. POLLUTION SIMULATION PREDICTION

Under normal working conditions, industrial wastewater discharge treatment devices are treated with anti-seepage and anti-corrosion treatment. According to the operation and management experience of similar projects for many years, there should be no leakage to groundwater due to the exposure of wastewater treatment plant or other materials under normal conditions. In this paper, it is set that under abnormal conditions, the sewage pool is damaged and leaks into the groundwater, and the maximum distance and influence range of pollutant concentration in the aquifer are predicted.

A. Pollution source setting under abnormal conditions

According to the characteristics of the project, combined with the relevant data of engineering analysis, the source strength is determined after full demonstration. The bottom of the sewage tank is damaged, and the characteristic pollutants are CODcr (concentration 300mg / L) and ammonia (concentration 30mg / L). The cracking length of the bottom of the pool is set to be 5 m, and the width of the crack is set to be 2.0 cm.

According to the characteristics of the proposed project and the accident scenario, the distribution position of the main pollution sources is set, and the priority control pollutants are selected. The one-dimensional stable flow two-dimensional hydrodynamic dispersion model is used to predict the migration process of each characteristic pollutant under the accident scenario, and the influence range, exceeding range and concentration change after moving out of the plant area are further analyzed.

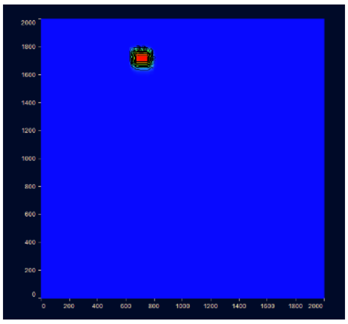
Among them, the range of COD exceeding the standard refers to the Class III standard in the ' Surface Water Environmental Quality Standard ' (GB3838-2002), and the range of ammonia exceeding the standard refers to the ' Groundwater Quality Standard ' (GB / T14848-2017). The detection limits of various pollutants refer to the detection limits of conventional instruments. The lower limit of pollutant detection and its water quality standard limit are shown in the table.

Table 2. Pollutant concentration reference standard

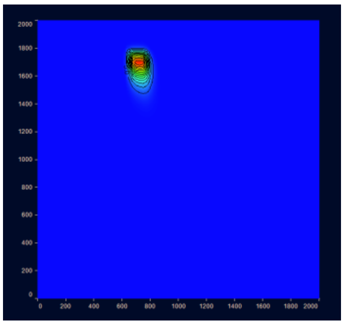
contaminant	Detection of lower limit (mg/L)	standards restriction (mg/L)	criterion-referenced
COD	10	20	《 water environment quality standard》(GB3838-2002)IIIstandard
NH3-N	0.03	0.2	《quality standard for groundwater》(GB/T14848-2017)

B. Pollution source prediction

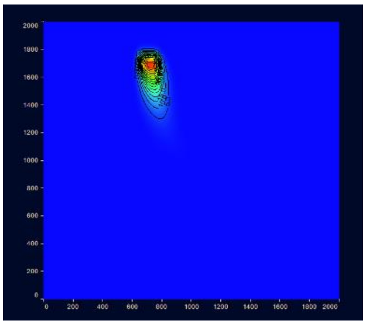
By predicting the above set conditions, the maximum influence range, exceeding range and maximum migration distance of pollutants over time are obtained [8].



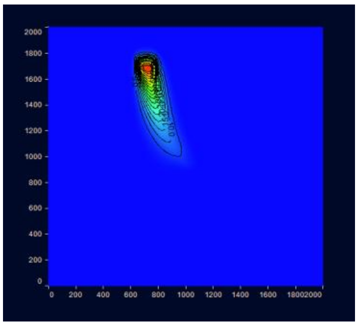
（1） 100d



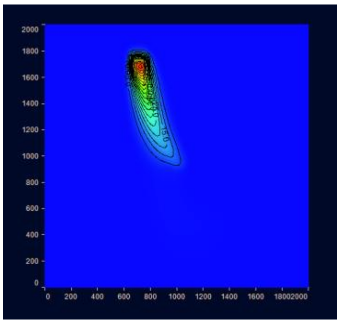
（2） 1000d



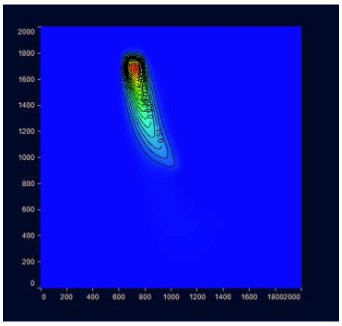
（3） 5a



（4） 10a

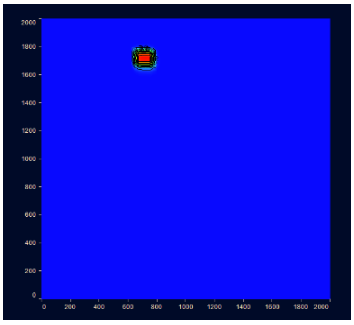


（5） 20a

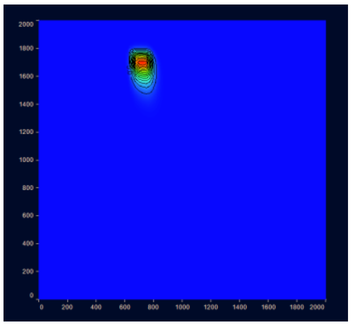


（6） 30a

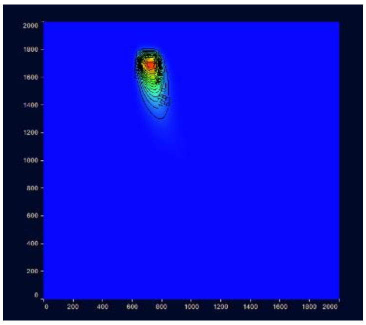
Fig. 3 COD transport distance



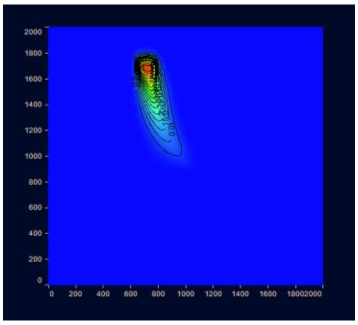
（1）100d



（2）1000d



（3）5a



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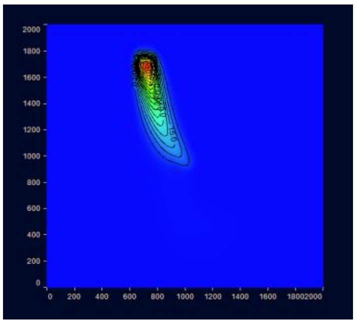
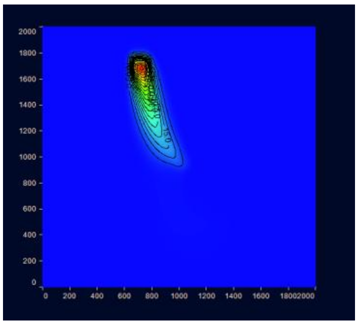


（5）20a



（6）30a

Fig.4 NH3-N transport distance

In the case of damage and leakage of the bottom of the septic tank, the prediction results show that after 100 days of leakage, the influence range of CODcr pollutants in the aquifer is 2237m2, the exceeding range is 2111m2, and the maximum migration distance is 39m ; after 1000 days, the influence range of CODcr pollutants in the aquifer is 15750m2, the exceeding standard range is 14279m2, and the maximum migration distance is 164m ; after 5 years, the influence range of pollutants in the aquifer is 27394m2, the exceeding standard range is 25517m2, and the maximum migration distance is 249m ; after 10 years, the influence range of pollutants in the aquifer is S7232m2, the exceeding standard range is 54052m2, and the maximum migration distance is 411m ; after 20 years, the influence range of pollutants in the aquifer is 125512m2, the exceeding standard range is 193121m2, and the maximum migration distance is 707m ; after 30 years, the influence range of pollutants in the aquifer is 201206m2, exceeding the standard range of 191417m2, and the maximum migration distance is 981m .

Pollution years	incidence /(m2)	overproof range /(m2)	maximum movement distance /(m)
100d	2237	2111	39
1000d	15750	14279	164
5a	27379	25517	249
10a	57322	54052	411
20a	125512	119331	707
30a	201206	191417	981

5. CONCLUSION

It can be seen from the prediction results that the pollutants migrate downstream along the direction of groundwater flow, and as time increases and the migration distance becomes longer, the maximum migration distance of pollutant COD is 981 m, and the maximum exceeding range is 191417m2.COD has a greater impact on the water environment.

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