NUMERICAL MODELING FOR CONTAMINANT PATHWAY ANALYSIS IN GROUNDWATER UNDER RIVER AND PUMPING EFFECTS

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1. Introduction

The objective of this study is development of groundwater flow and solute transport modeling for assessment of spatial and temporal contaminant distribution in the groundwater system polluted by chlorinated hydrocarbon underneath O river, O City. The paper encompasses the integration of assumed contamination conceptual model, selected simulation scenarios and applied a variety of numerical method which are proposed to estimate the history and future development of plume concentration, particularly under condition in which the availability of important data is very limited. In this paper the role of the river on the transport of the contaminants is described. Similarly, the effect of installed pumping wells on the development of concentration plume is discussed. Moreover, the capability of implemented pumping work to clean up the site is evaluated

2. Modeling methodology

The fundamental equation for the horizontal confined aquifer is presented as:

$$S_0 \times B\frac{\partial h}{\partial t} = \frac{\partial}{\partial x}\left(Bk\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(Bk\frac{\partial h}{\partial y}\right) - \sum Q_m \delta(x - x_m)\delta(y - y_m) + q_w(x,y,t) - q_r(x,y,t) \quad (1)$$

where S_0 is the storage coefficient, B is aquifer thickness (L), k is the hydraulic conductivity(LT^{-1}), h is the pressure head (L). The term $Q_m(x,y)$ (L^3T^{-1}) is the water extraction rate by pumping at location (x_m, y_m) at time t. The delta functions $\delta(x - x_m)$ and $\delta(y - y_m)$ represent the location of the pumping well, the term $q_w(x,y,t)$ (L^3T^{-1}) reflects the groundwater recharge and the term $q_r(x,y,t)$ (L^3T^{-1}) expresses groundwater discharge to river.

The governing mass transport equation in the two-dimensional coordinate system can be expressed as follows:

$$\frac{\partial C}{\partial t} + \frac{U'}{R_d}\frac{\partial (C)}{\partial X} + \frac{V'}{R_d}\frac{\partial (C)}{\partial Y} = \frac{1}{R_d}\frac{\partial}{\partial X}\left(D_{XX}\frac{\partial C}{\partial X} + D_{XY}\frac{\partial C}{\partial Y}\right) + \frac{1}{R_d}\frac{\partial}{\partial Y}\left(D_{YX}\frac{\partial C}{\partial X} + D_{YY}\frac{\partial C}{\partial Y}\right) - \frac{\lambda}{R_d}(C) \quad (2)$$

where C is concentration of the pollutant (ML^{-3}), D is the hydrodynamic dispersion coefficient (L^2T^{-1}), U' is the pore velocity (LT^{-1}) in the X coordinate direction, V' is the pore velocity (LT^{-1}) in the Y coordinate direction, λ is first-order decay rate (T^{-1}) and R_d denotes retardation factor.

An area of 1300 x 800 m of sandy confined aquifer was discretized by 5 x 4 m cells which accounts for 260x200 grids. The fixed boundary conditions of the piezometric potential on the west and east sides were maintained, whereas no flow boundary condition was assumed to all other sides. The porosity was assumed to be uniform within the model area. The interaction between the river and groundwater was considered as well by incorporating the seepage term from groundwater into river.

At the first simulation scenario, the steady state of horizontal flow and transport simulation in a confined aquifer was performed presuming the river was absence in the model domain. In the mean time, the second simulation scenario was conducted reflecting the natural condition. It was aimed to analyze the river role on affecting the contaminant distributions. Accordingly, the third simulation scenario was also carried out by operating several pumping stations to take into account the effect of pumping. The comparison of the second simulation result and the third one was eventually exercised to evaluate the consequent of pumping.

In the present study, the 2-dimensional horizontal transport simulation was executed by inputting CB concentration resulting from 1-dimensional simulation as soon as the assumed significant amount of CB concentration arrived at the bottom of second layer. The concentration gained from the 1-dimensional simulation was exerted as fixed – time dependent boundary condition for 2-dimensional contaminant transport simulation. Meanwhile, the grid mesh at (140,100) in the 2-dimensional simulation was assumed as the suspected contaminant point source in reference to the analysis of the local government reports signifying that the highest concentrations of all pollutants were detected at that point.

3. Result and discussion

The maximum period of horizontal transport simulation in this study was 50 years from 1960 to 2010 which is aimed not only to trace back the history of pollutant distribution but also to estimate the future plume development throughout the model domain. The uncertainty in the biodegradation process was approximated by using the CB half life of 45 years regarded as the conservative degradation rate taking into consideration the limited availability of dissolved oxygen in the site.

The development of plume after 43 years from 1960 to 2003 as the result of transport simulation of first scenario where the river is absence in the model domain is depicted in **Fig.** 1 . In the meantime, **Fig.2** shows the second scenario result of transport which was also performed for 43 years. It is important to note that the measured data utilized for calibration in this study is collected in 2003. The comparison of those figures implies that the plume with the direction of pure groundwater flow without river interference is substantially more distributed than that when the river is present. It would seem that some amount of pollutant

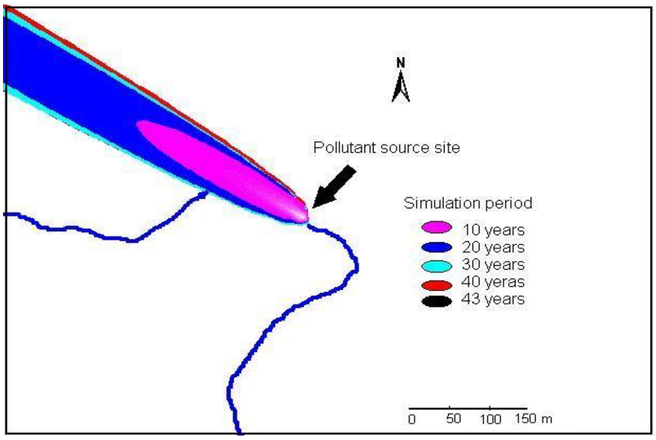

Fig.1. Development of CB plume in the absence of river.

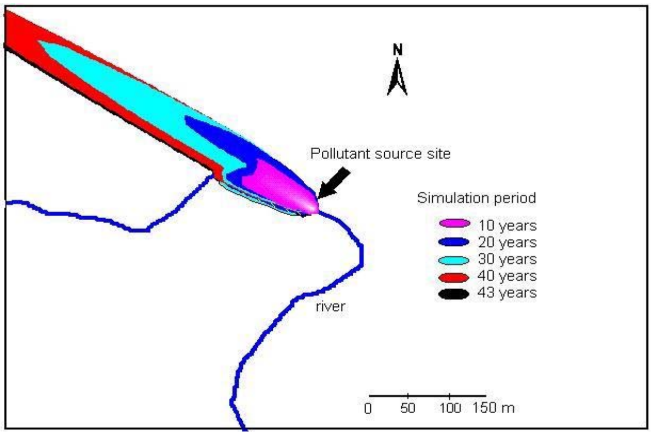

Fig.2. Development of CB plume in the presence of river.

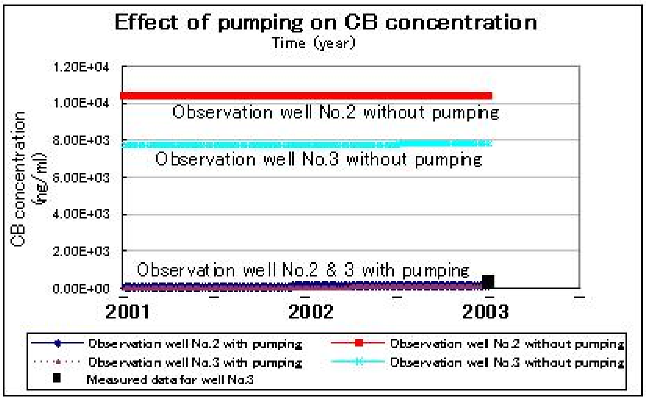

Fig. 3 . Effect of pumping on CB concentration.

concentration is discharged to the river. Due to the fact that river flow is much faster in several orders of magnitude than groundwater flow, the pollutant spreading to greater distance is notably enhanced in the presence of river.

The simulation at which pumping wells operated was carried out as the third scenario. In this simulation we assume that this pumping was undertaken in 2001 which was two years earlier than that of the sampling (2003). A combination of trials and analytical solution were computed to examine the most reasonable magnitude of pumping rate. It resulted in the 3 years operation of four pumping wells from 2001 until 2003 with the rate of 7 m^3/day each. Those pumping wells are situated parallel with the flow of the river central portion. Meanwhile, the

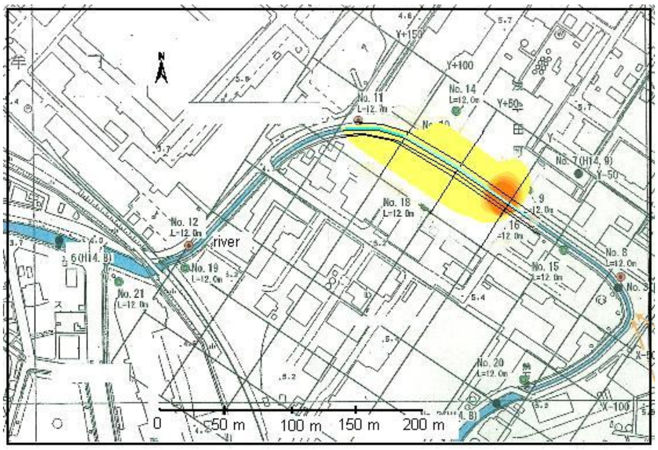

Fig.4. Prediction of CB plume extent in 2010.

different concentration between the second simulation and third simulation result as given in **Fig.3** may reflect the effect of pumping on CB concentration.

It can be also evaluated that the predicted pumping rate, duration and the well position to some extent has well functioned on extracting 90 % of CB concentration (3800 mg/l in total). This amount is obtained by comparing the concentration in 3 observation wells with and without pumping operation.

It may be then realistic to use that best scenario to predict the extent of plume in 2010 as shown in **Fig.4**. It can be seen that the estimated pumping rate, position and duration is capable of holding up the further plume expand in the future.

4. Conclusion

The two-dimensional flow and transport model is designed in the present study to support the pathway analysis of chlorinated hydrocarbons waste. The transport of CB carrying dioxins with it coupled the processes of advection, dispersion, adsorption and degradation. The proposed modeling approach employing various hypothetical scenarios demonstrated the capability of reconstructing the history of release and future plume development of the pollutants.

The hypothetical well pumping rate and duration were also estimated by comparing the numerical solution with the observed piezometric head of groundwater. More than 90 % of the contaminant concentration observed in three wells was reduced after 3 year operation at the four pumping wells since 2001 until 2003, suggesting that high efficiency of multiple pumping techniques is expected to prevent more migration of contaminants. On the other hand, it was demonstrated that the plume already extended further than 130 m downstream of the source can not be captured by the current pumping work since the predicted transport path is out of well capturing zones.

References

1. Kurniawan, B., and Jinno, K. 2006. *Numerical Transport Model of Chlorinated Organic Compounds in Multy-layer Saturated Porous Media*. Memoirs of the Faculty of Engineering, Kyushu University, Vol.66, pp 84-97.