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Modeling approach in mapping groundwater vulnerability

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요약문

A numerical modelling method using a backward-in-time advection dispersion equation is introduced in assessing the vulnerability of groundwater to contaminants as an alternative to classical vulnerability mapping methods. The flux and resident concentration measurements are normalized by the total contaminants mass released to the system to provide the travel time probability density function and the location probability function. With the results one can predict the expected travel time of a contaminant from up stream location to a well and also the relative concentration of the contaminant at a well. More specific groundwater vulnerability can be mapped by these predicted measurements.

Keywordsgroundwater vulnerability, backward advection dispersion equation

INTRODUCTION

Researches have been carried out to assess the intrinsic vulnerability of groundwater (Aller *et al.*, 1987; Palmer and Lewis, 1998; Madl-Szonyi and Fule, 1998). Most of them were based on overlay and index mapping methods. These methods are widely used but have some defects. The physical process of flow and transport in aquifer system cannot be described properly with these methods. Also it is impossible to validate the result of these methods. The purpose of this study is to propose a physically based method of mapping groundwater vulnerability, overcoming the defects of the former layout and index approaches. As an alternative to the classical methods, numerical modelling methods will be used to assess the vulnerability of groundwater. With backward-in-time advection dispersion equation the prior location of contaminant and its concentration at a well are evaluated in the form of probability.

THEORETICALBACKGROUND

The equivalent backward probability model can be obtained by reversing the sign on the advection term to consider for the reversed flow of information and by modifying the boundary conditions and initial condition. However, no sign reversal is performed on the dispersion term. Reversing the direction of velocity does not affect the sign on the dispersion coefficient because the dispersion is proportional to the magnitude of velocity. The simple form of the backward advection dispersion equation(ADE) can be written as follows

$$\frac{\partial \phi C}{\partial t} = \nabla \cdot \mathbf{q} C + \nabla \cdot \phi \mathbf{D} \cdot \nabla C \tag{1}$$

where C is the resident concentration [ML^{-3}], t is time [T], ϕ is porosity or mobile water content [-], $\mathbf{q}$ is the water flux vector [LT^{-1}], and $\mathbf{D}$ is the dispersion coefficient tensor [L^{2}T^{-1}] (Cornaton, 2003).

If we conceptualize the water particles or contaminant particles following the streamlines from a target zone in toward the upstream direction, then the expected travel time expectancy at a given point , which corresponds to the time required to travel from that point to the target, can be considered ais equivalent towill be the time counted backwards from the initial time at the target zone to the given upstream point. To evaluate such a probability a backward equation is required. Therefore tThe backward equation will be used to estimate the travel time and location probability of water particles from the target well to the any region of concern.

METHODOLOGY

Typical criteria defining the intrinsic vulnerability are often related to the acceptable maximum concentration at the concerned outlet and the time to reach this maximum concentration. If the concentration measurements are normalized by the total contaminant mass released to the system, the resulting distribution can be considered as the probability density function of concentration. When flux concentration C^f, a measure of the mass of solute passing through a fixed location per unit water flux at a given time, is normalized, the result will be the travel time probability density function g_t for the transport from the source to the well (Neupauer & Wilson, 1999).

$$g_t(\mathrm{x},t) = \frac{F(\mathrm{x})C^f(\mathrm{x},t)}{m} = \frac{C^f(\mathrm{x},t)}{\int_0^\infty C^f(\mathrm{x},t)dt} \tag{2}$$

where x is location, m is the released mass and $F(\mathrm{x})$ is the flow rate passing through the section area.

The resident concentration C^r, a measure of the mass of solute per unit volume of water at a given location, represents the location probability density function g_x when it is normalized (Neupauer and Wilson, 1999).

$$g_x(x,t) = \frac{C^r(x,t)}{\int_\Omega \phi(x)C^r(x,t)d\Omega} \tag{3}$$

One of the another advantages of using the backward ADE is that it can simulate with a single run the travel time distribution of the particles to at the target well, as a result of any upstream release of these particles within the domain. The same information could be obtained by solving the forward ADE, but only after an enormous computing effort since one would need to perform as many forward runs as possible upstream input locations, in order to cover and describe the effect on the target of any contamination event (Figure 1).

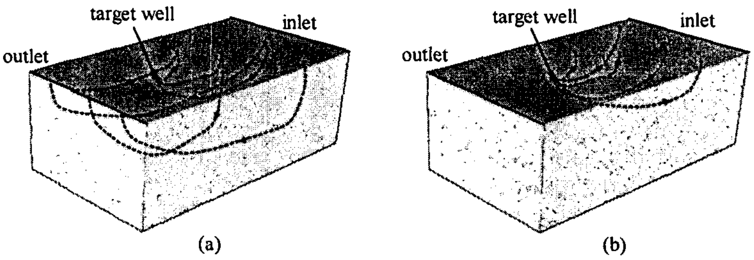

Figure 1. Schematic illustration showing the processes of simulating well capture zone by using the forward ADE modeling (a) and by the backward ADE modeling (b).

Groundwater protection maps, which account for the groundwater vulnerability to source contamination can be established by post-processing the expected travel time probability density function curves. The times to reach a given threshold concentration at the well, and the contaminant concentration at the well from a source located upstream of the well can be evaluated and mapped. Figure 2(a) is a schematic illustration of a map of expected relative concentration at the well and Figure 2(b) is a map of travel time expectancy to reach the relative concentration of a specific criterion at the well, from the result of the simulation of the backward ADE. If the contamination source is, for example, located within, for example, the line of relative concentration level of 0.001, and injected into the aquifer domain, then the detected relative concentration at the well would be more than 0.001. In this way, if the source is located within the line of expected travel time of 100 days, then the contaminant of the specific concentration would be detected at the well within 100 days.

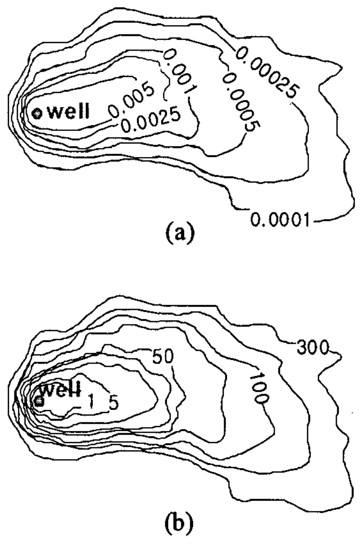

Figure 2. Schematic illustration of a map of expected relative concentration at the well (a) and a map of travel time expectancy to reach the specific concentration at the well (b).

SUMMARY

Assessing the vulnerability of groundwater to contaminants by using numerical modeling is proposed. Backward advection dispersion equation is introduced to describe the physical process of flow and transport. The information about the times to reach a given threshold concentration at the well and the contaminant concentration at the well from a source located upstream of the well can be provided. With this, more specific vulnerability map can be made.

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