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ARTICLE

Numerical Simulations for Pollutant Transport using Radioisotope Data in River System

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A tracer experiment using radioisotope was carried out to investigate the characteristics of a pollutant transport and to estimate the dispersion coefficients in a river system. A well-known radioisotope tracer technique was applied to measure the dispersion coefficients. The radioisotope ^{82}Br in the form of aqueous ammonium bromide was used to estimate the flow patterns and dispersion phenomena in river. The radioisotope was instantaneously injected into a flow as a point source by an underwater glass-vial crusher. The dispersion coefficients are determined by moment method based on the measured radioisotope data. Two-dimensional numerical models were used to simulate the flow fields and the concentration distributions of the radioisotope injected into the river. The calculated results were compared with the measured ones. Trajectory model have been developed to estimate the unknown source position and the calculated results showed reasonable values within error range.

KEYWORDS: radioisotope, field tracer experiment, trajectory model

I. Introduction

It is very important to predict the damage from an accident and understand the movement of pollutants in a river. A considerable research for dispersion of pollutants in a river has been applied to its conceptual and analytical modeling[1,2]. Hydrodynamic dispersion, commonly known as the dispersion coefficients, indirectly includes the combined effects of molecular diffusion, turbulent mixing, and mixing due to transverse and vertical shear[3]. Determination of the longitudinal and transverse dispersion coefficients is one of the important factors to evaluate the characteristics of a pollutant's behavior in a natural river. If the pollutants from the any accident are released in river, it needs to find out the unknown source location in aspects of the water resource management. The methodology for estimating the location of the pollutant sources is based on the solution of the trajectory equation[4]. Various methods to compute trajectory based on the different assumptions have been developed and the accuracy of calculated trajectory has gradually improved in environmental sciences[5].

In this study, a field tracer experiment using radioisotope were performed to understand the process of the pollutant transport and to determine the dispersion coefficients in river. Radiotracer method is an useful tool for investigating the pollutant dispersion and description of mixing process taking place in natural streams. The main advantage is that tracer detection remains unaffected by such factors as variations in chemical composition of labeled medium and the presence of deposits[6]. The longitudinal and transverse dispersion coefficients are determined by moment method[3] using the measured radioisotope data. Two-dimensional numerical models were used to simulate the flow patterns and the concentration distributions of the radioisotope injected into the river. The calculated results using the dispersion coefficients obtained from the radioisotope data were compared with measured concentrations. Also, the trajectory models are developed to estimate the unknown source location and applied to compare the measured one in river.

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II. Field Experiment

A field tracer experiment using a radioisotope was carried out on June 25, 2007 near the upper area of the Keum river for the purpose of investigating the characteristics of a pollutant transport and a determination of the dispersion coefficients in a river system. Measurements of the velocity and bathymetry before a tracer experiment were performed to select the sampling lines for a detection of the radioisotope. The release point and detection lines of the tracer were determined by GPS system (Fig. 1). The radioisotope ^{82}Br which is a gamma emitter with half-life of 35.5 h was used as the trace element. The radioactive ^{82}Br in the form of aqueous ammonium bromide solution was used to estimate the characteristics of a pollutant transport and a determination of the dispersion coefficients. The radioisotope was instantaneously injected into a flow as a point source by an underwater glass-vial crusher. The detection was made with 2 x 2 inch NaI(Tl) scintillation detectors at 3 transverse lines at a downstream position. Multi-channel data acquisition systems were used to collect and process the signals transmitted from the detectors. The release amount of the ^{82}Br was about 40 mCi. The velocity was measured at about 0.8 ~ 1.0 m/s at the centre point of the detection line and at about 0.3 ~ 0.5 m/sec at the edge of the river. It was inferred that the radioisotope dispersed rapidly near the centre area of the river due to the relatively large velocity profiles. Also, the radioisotope moved from the centre area to the left side of the river due to the transverse velocity of the left direction based on the measured velocity profiles. The longitudinal distance of the experimental range was about 1 km from the release point. So, the radioisotope passed through line 3 after 1 hour from an injection at the release point. The measured concentration of the radioisotope decreased at line 3 in the downstream direction due to the dilution effects.

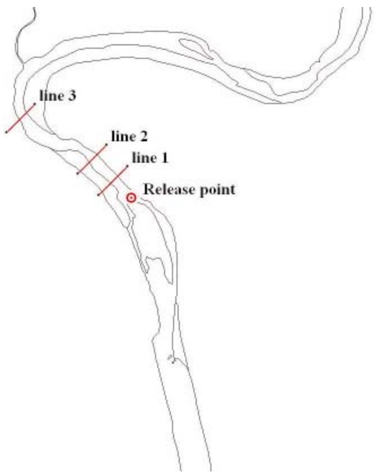

Fig. 1 Location of the release point and the detection lines

III. Dispersion and Trajectory Models

Two-dimensional numerical models were used to simulate the hydrodynamics(RMA2) and the concentration distributions(RMA4) of the radioisotope injected into the river[7]. RMA2 is a two-dimensional depth averaged finite element hydrodynamic model. RMA4 is designed to simulate the depth-averaged advection-diffusion process in an aquatic environment. The depth-averaged form of two-dimensional advection-dispersion equation for a non-conservative material can be written as follows.

$$h\left(\frac{\partial c}{\partial t}+u\frac{\partial c}{\partial x}+v\frac{\partial c}{\partial y}-\frac{\partial}{\partial x}D_x\frac{\partial c}{\partial x}-\frac{\partial}{\partial y}D_y\frac{\partial c}{\partial y}-\sigma+kc+\frac{R(c)}{h}\right)=0 \qquad (1)$$

Where c is concentration, h is depth, u,v are velocities, D_x,D_y are dispersion coefficients in x and y direction, k is first order decay of pollutant, σ is source or sink term and $R(c)$ is rainfall or evaporation rate. The velocity fields are calculated in hydrodynamic model and they can be supplied with the basic input in dispersion model.

Trajectory model is defined by the differential trajectory equation[5].

$$\frac{dX}{dt}=V[X(t)] \qquad (2)$$

Where X is the position vector and V is the velocity vector. Equation (2) is solved by finite difference approximation using constant acceleration scheme.

$$X(t_1)\approx X(t_0)+\frac{1}{2}(\Delta t)[V(t_0)+V(t_1)] \qquad (3)$$

If the trajectory is calculated at time t_1, it is a forward trajectory scheme. If the trajectory is calculated at time t_0, it is a backward trajectory scheme. Equation (3) has to be solved by iteration because $V(t_1)$ is not a priori known.

$$\begin{aligned}
X^1(t_1) &\approx X(t_0)+(\Delta t)V(t_0)\\
X^2(t_1) &\approx X(t_0)+\frac{1}{2}(\Delta t)[V(t_0)+V^1(t_1)]\\
&.\\
X^i(t_1) &\approx X(t_0)+\frac{1}{2}(\Delta t)[V(t_0)+V^{i-1}(t_1)]
\end{aligned} \qquad (4)$$

The superscripts indicate the number of iteration.

IV. Numerical Simulations

The hydrodynamic and dispersion models are applied to calculate the flow fields and concentration distributions in the experimental site. The computational domain for the hydrodynamic and dispersion simulations is composed of 1077 elements and 3540 nodes. It has two open boundaries. Boundary conditions for the simulation were established by measured discharge at Youngdam of the upper area and water surface elevations at Sutong of the lower area. The moment method[8] is used to determine the dispersion coefficients by using the measured concentrations of the radioisotope. This method for determining the dispersion coefficient is based on the moments of concentration profiles.

$$D=\frac{1}{2}\overline{v^2}\frac{d\sigma_t^2}{dt} \qquad (5)$$

Where σ_t^2 is the variance of the temporal concentration profile at each distance and $\overline{v^2}$ is mean velocity. The values of D_x and D_y using equation (5) based on the measured concentration data of the radioisotope were 0.32 m^2/sec and 0.011 m^2/sec, respectively. Fig. 2 and Fig. 3 presented the concentration distributions obtained by both the measured and the simulated. The calculated concentrations agreed well with the measured ones at each detection line.

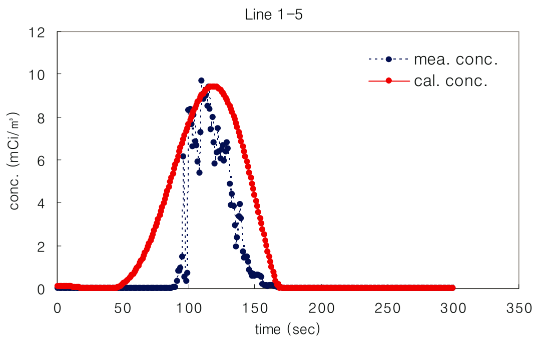

Fig. 2 Comparison of the calculated and measured concentrations at the center point of detection line 1

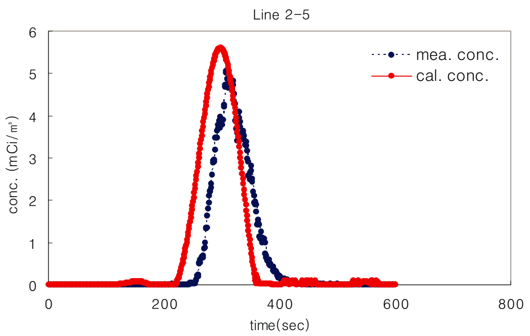

Fig. 3 Comparison of the calculated and measured concentrations at the center point of detection line 2

The back trajectory model is applied to estimate the unknown position of the pollutant source. We know the position of the release point and the center points at each transverse line at experimental site. The velocity fields from hydrodynamic model are supplied to estimate the location of the release point in trajectory model. The back trajectories were computed from two different starting locations at the center points at 2 transverse lines. The calculated trajectory showed in Fig. 4-5 and the computed coordinates of release point presented in Table 1. The computed results agreed with the real position of the release point.

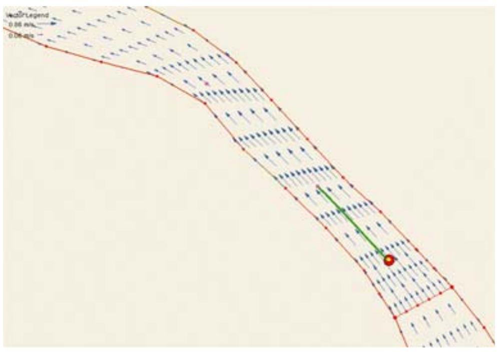

Fig. 4 The calculated source point from starting location of the center point at line 1

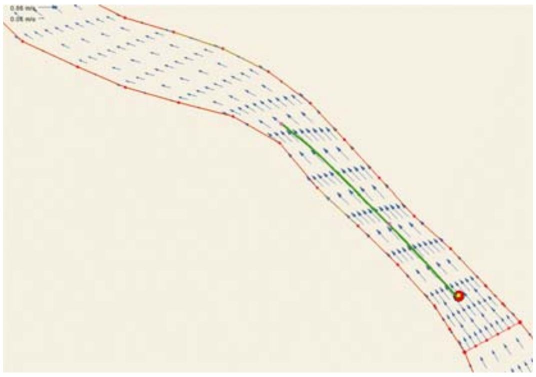

Fig. 5 The calculated source point from starting location of the center point at line 2

Table 1 The real and calculated coordinates of release point

Real coordinates of release point (unit : meter)	Calculated coordinates (unit : meter)[1]	Calculated coordinates (unit : meter)[2]
255456.67(X_r) 280430.05(Y_r)	255455.72(X_c) 280429.19(Y_c)	255454.75(X_c) 280428.97(Y_c)

[1] Coordinates of calculated release point from starting location of the center point at line 1
[2] Coordinates of calculated release point from starting location of the center point at line 2

The coordinate systems in Table 1 are based on the Korean TM(Transverse Mercator). Error to check the accuracy of trajectory model is defined as follows.

$$Error = \sqrt{(X_c - X_r)^2 + (Y_c - Y_r)^2} \quad (6)$$

Where X_r, Y_r are real coordinates of release point and X_c, Y_c are calculated coordinates of release point. The error is about 1.25 m in the case of estimation the release point from starting location of the center point at line 1. Also, the error is about 2.18 m in the case of estimation the release point from starting location of the center point at line 2. The calculated results to estimate the unknown source position showed reasonable values.

V. Conclusions

A tracer experiment using radioisotope was carried out to investigate the characteristics of a pollutant transport and a determination of the diffusion coefficients in a river system. A well-known radioisotope tracer technique was applied to measure the dispersion coefficients. The dispersion coefficients were obtained from an in-situ measurement with a radiotracer data. Two-dimensional numerical models were used to simulate the hydraulic parameters and the concentration distributions of the radioisotope injected into the river. Especially, a numerical model for dispersion using obtained data from a tracer experiment was applied to evaluate the characteristics of a pollutant's behavior. The calculated concentrations were compared with the measured ones. Also, a back trajectory model was used to estimate the unknown location of source point of pollutant and the calculated results agreed with the real location of release point. The tracer method by using radioisotope appears to be a convenient tool to investigate a pollutant transport and dispersion processes in surface water. The data obtained by the tracer experiment will be used as a basis for an assessment of an actual state of the pollution in a river system.

Acknowledgement

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