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 82Br 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. 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. 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. 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.

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. The longitudinal and transverse dispersion coefficients are determined by moment method 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.

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 82Br which is a gamma emitter with half-life of 35.5 h was used as the trace element. The radioactive 82Br 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 82Br 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](image)

**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
river7). 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.

\[
\frac{\partial c}{\partial t} + \frac{\partial (uc)}{\partial x} + \frac{\partial (vc)}{\partial y} = D_x \frac{\partial^2 c}{\partial x^2} + D_y \frac{\partial^2 c}{\partial y^2} + \sigma c + \frac{R(c)}{h} \]

(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, \( \sigma \) 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
equation5).

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

(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.

\[
X(t_i) = X(t_0) + \frac{1}{2} (\Delta t) [V(t_0) + V(t_i)]
\]

(3)

If the trajectory is calculated at time \( t_f \), 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 \( V(t_i) \) is not a priori known.

\[
\begin{align*}
X^{0}(t_f) &= X(t_0) + (\Delta t) V(t_0) \\
X^{1}(t_f) &= X(t_0) + \frac{1}{2} (\Delta t) [V(t_0) + V^{1}(t_f)] \\
X^{2}(t_f) &= X(t_0) + \frac{1}{2} (\Delta t) [V(t_0) + V^{1}(t_f)] \\
&\vdots \\
X^{i+1}(t_f) &= X(t_0) + \frac{1}{2} (\Delta t) [V(t_0) + V^{i}(t_f)]
\end{align*}
\]

(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 Yougdam of the upper area and
water surface elevations at Sutong of the lower area. The
moment method8) 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.

\[
D = \frac{1}{2} \dot{\sigma}^2
\]

(5)

Where \( \dot{\sigma}^2 \) is the variance of the temporal concentration
profile at each distance and \( \dot{v}^2 \) 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 m²/sec and
0.011 m²/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.
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.

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.

\[
\text{Error} = \sqrt{(X_r - X_c)^2 + (Y_r - Y_c)^2}
\]

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.

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References