Impact of Instream Installation on the Pollutant Mixing in a River: A 2D Numerical Study

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Introduction

Pollutant transport in rivers exerts a significant impact on water resources management and safe water supply. The mixing of pollutants in rivers is influenced by various factors, but the impacts of hydraulic structures on pollutant mixing have rarely been studied. Especially in Korea, over 33,000 weirs have been installed in rivers for agricultural purposes (Ministry of Oceans and Fisheries, 2020). To improve the connectivity between upstream and downstream of the weir, most weirs have more than one notch at the crest. This notch form causes flow deflection at the upstream of the weir, and generates storage zones, particularly at the side of the banks and between the notches. In this study, the effect of the notch on the storage zone is quantitatively investigated by the 2D numerical model.

Methods

When stagnation of pollutants occurs due to the storage zone, the pollutant cloud is trapped in the storage zone, and therefore concentration shows a skewed distribution. To interpret these non-Fickian mixing problems, the following storage zone model was proposed by many researchers (Bencala and Walters, 1983; Seo and Cheong, 2001):

$$\frac{\partial \overline{C}_f}{\partial t} + U_f \frac{\partial \overline{C}_f}{\partial x} - K_f \frac{\partial^2 \overline{C}_f}{\partial x^2} = \varepsilon_s T^{-1}\left(\overline{C}_s - \overline{C}_f\right) \quad (1)$$

$$\frac{\partial \overline{C}_s}{\partial t} = T^{-1}\left(\overline{C}_f - \overline{C}_s\right) \quad (2)$$

where $\overline{C_f}$ is the spatially averaged concentration of the main flow zone; U_f is the spatially averaged velocity of the flow zone; K_f is the one-dimensional longitudinal dispersion coefficient of the main flow zone; ε_s is the ratio of storage zone area to the main flow zone area; $\overline{C}_s$ is the spatially averaged concentration of the storage zone; T is the residence time of the cross-sectional area of the storage zone.

To investigate the influence of weir notch geometries and flow characteristics on the storage

Table 1. Numerical simulation cases for research.

Case	*Discharge (m^3/s)*	*Upstream water depth (m)*	$B_{notch}/\triangle d_{notch}$
DN1			0.182
DN2			0.145
DN3	0.053	0.29	0.123
DN4			0.105
DN5			0.093

mechanism, a 2D numerical simulation using EFDC (Hamrick, 1992) was conducted. The hydrodynamic model was validated with the experimental results from the laboratory flume. The numerical model was simulated by changing the distance between notches ($B_{notch}/\triangle d_{notch}$) from 0.093 to 0.182 as shown in Table 1.

Results

The flow simulation results show that the notched weir exhibits the horizontal storage zones between the notches and near the wall downstream of the weir, and the area of the storage zones increases with increasing distance between notches. The concentration-time curve shown in Figure 1 reveals a strong storage effect of the weir structure with the long tail of the BTC (Breakthrough curve) at Section.2 (downstream section).

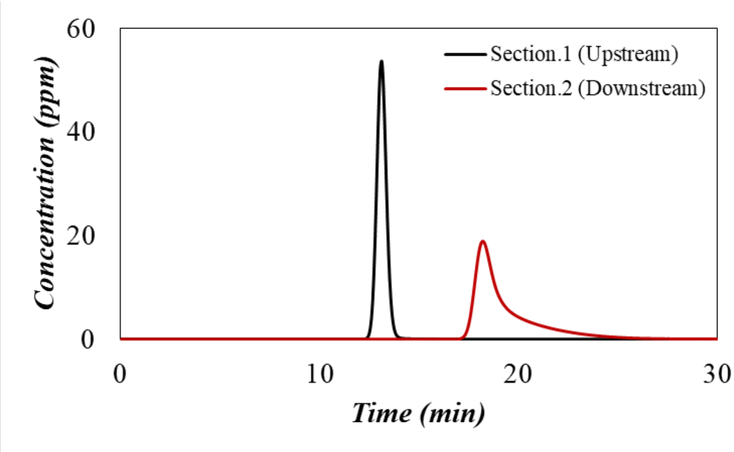

Fig. 1. Breakthrough curves of the numerical simulation (Case DN5)

Conclusions

The results from this study show that the storage effect of the notched weir in the open channel is driving the non-Fickian transport. The combined storage effects upstream and downstream of the notched weir trigger the non-Fickian transport with the tailing effect of BTC of the solute tracer. The change in distance between notches may significantly affect both the area of the storage zone and the retention time of the tracer by trapping the solute to slow flow regions.

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