Supplementary S1. Derivation of the solution for the steady-state problem.

The governing equations for the steady-state problem are as follows

$$\frac{D_{\mathrm{i}}}{R_{\mathrm{d},i}}\frac{d^2\eta_i(x)}{dx^2}-\frac{v_i}{R_{\mathrm{d},i}}\frac{d\eta_i(x)}{dx}=0,\quad (i=1,2,3,4) \tag{1.1}$$

The steady-state problem's boundary conditions can be obtained using the earlier presumptions. For the steady-state problem, the inlet boundary condition is as follows:

$$\eta_1(0)=C_0 \tag{1.2}$$

For the steady-state problem, the outlet boundary condition is as follows:

$$\frac{\partial\eta_4(L)}{\partial x}=0 \tag{1.3}$$

Where L [M] represents the thickness of the entire SB/GCL/SB-aquifer system

In this problem, the following normalization can be applied to each interface's concentration and mass flux continuity conditions:

$$\eta_i(L_i)=\eta_{i+1}(L_i) \tag{1.4}$$

$$n_iD_i\frac{\partial\eta_i(L_i)}{\partial x}=n_{i+1}D_{i+1}\frac{\partial\eta_{i+1}(L_i)}{\partial x} \tag{1.5}$$

The solution satisfying all the relevant conditions of sub-problem 1 is as follows

$$\eta_i(x)=j_{i,1}e^{r_{i,1}\cdot x}+j_{i,2}e^{r_{i,2}\cdot x} \tag{1.6}$$

$r_{i,1}$ and $r_{i,2}$ can be expressed as follows

$$r_{i,1}=0,\ \ r_{i,2}=\frac{v_i}{D_i} \tag{1.7}$$

The coefficients $j_{i,1}$ and $j_{i,2}$ are determined in a similar manner to the coefficient determination in the transient-state problem. The boundary conditions (Eqs. (1.2) and (1.3)) and the continuity conditions (Eqs. (1.4) and (1.5)) for the steady-state problem are substituted into Eqs. (1.1) and (1.6) to obtain the desired results.

Supplementary S2. Derivation of the solution for the transient problem.

The governing equations for the transient -state problem are as follows

$$R_{\mathrm{d},i}\frac{\partial\delta_i\left(x,t\right)}{\partial t}=D_i\frac{\partial^2\delta_i\left(x,t\right)}{\partial x^2}-v_i\frac{\partial\delta_i\left(x,t\right)}{\partial x},\quad (i=1,2,3,4) \tag{2.1}$$

The following initial conditions apply to the transient-state problem since there was no initial contamination:

$$\delta_i\left(x,\ 0\right)=0,\ (i=1,2,3,4) \tag{2.2}$$

The boundary conditions for the transient-state problem can be derived as follows, based on the presumptions mentioned earlier.

The transient-state problem's inlet boundary condition is as follows:

$$\delta_i\left(0,t\right)=0 \tag{2.3}$$

For the transient-state problem, the outlet boundary condition is as follows:

$$\frac{\partial\delta_4\left(L,t\right)}{\partial x}=0 \tag{2.4}$$

For every interface in the transient-state problem, the concentration continuity conditions and mass flux continuity conditions can be normalized in the following ways：

$$\delta_i\left(L_i,\ t\right)=\delta_{i+1}\left(L_i,\ t\right) \tag{2.5}$$

$$n_iD_i\frac{\partial\delta_i\left(L_i,t\right)}{\partial x}=n_{i+1}D_i\frac{\partial\delta_{i+1}\left(L_i,t\right)}{\partial x} \tag{2.6}$$

The general solution that satisfies the transient-state problem can be defined as follows using the variable separation method:

$$\delta_i(x,t)=\sum_{\infty}^{m=1}Q_m g_{m,i}(x)e^{\alpha_i x-\beta_m t},\quad (i=1,2,3,4) \tag{2.7}$$

Where Q_m, α_i are coefficients, β_m is an eigenvalue, and $g_{m,i}$ is a characteristic function with respect to x, and can be described as

$$g_{m,i}(x)=\begin{cases} A_{m,i}\sin\left(\mu_i\varepsilon_{m,i}\dfrac{x}{L}\right)+B_{m,i}\cos\left(\mu_i\varepsilon_{m,i}\dfrac{x}{L}\right) & (\sigma\geq 0) \\ A_{m,i}\sinh\left(\mu_i\varepsilon_{m,i}\dfrac{x}{L}\right)+B_{m,i}\cos\left(\mu_i\varepsilon_{m,i}\dfrac{x}{L}\right) & (\sigma<0) \end{cases} \quad (i=1,2,3,4) \tag{2.8}$$

Where $\sigma=\beta_m-v_i^2/\left(4D_iR_{d,i}\right)$, by substituting Eq. (2.7) and Eq. (2.8) into Eq. (2.1) and setting t = 0, we obtain α_i

$$\alpha_i=\frac{v_i}{2D_i}, \quad (i=1,2,3,4) \tag{2.9}$$

Substituting the obtained α_i into Eqs. (2.1), (2.7), and (2.8), we can solve for $\varepsilon_{m,i}$

$$\varepsilon_{m,i}=\sqrt{\left|\beta_m-\frac{v_i^2}{4D_iR_{d,i}}\right|}, \quad (i=1,2,3,4) \tag{2.10}$$

Substituting Eq (2.9) and Eq (2.10) back into Eq (2.8), obtained

$$\mu_i=L\sqrt{\frac{R_{d,i}}{D_i}}, \qquad (i=1,2,3,4) \tag{2.11}$$

To obtain β_m, it is necessary to derive the transfer Eqs for the coefficients $A_{m,I}$ and $B_{m,i}$ by substituting Eqs. (2.7) and (2.8) into the continuity conditions given by Eqs. (2.5) and (2.6).

$$\begin{bmatrix} A_{m,i} \\ B_{m,i} \end{bmatrix}=P_{i-1}\begin{bmatrix} A_{m,i-1} \\ B_{m,i-1} \end{bmatrix}, \qquad (i=2,3,4) \tag{2.12}$$

where

$$P_i=\frac{e^{(\alpha_i-\alpha_{i+1})x_i}}{n_{i+1}D_{i+1}\mu_{i+1}\theta_{m,i+1}}\begin{bmatrix} A_i^{\#}H_i^{\#}+D_i^{\#}E_i^{\#} & C_i^{\#}H_i^{\#}-D_i^{\#}G_i^{\#} \\ A_i^{\#}F_i^{\#}-B_i^{\#}E_i^{\#} & B_i^{\#}G_i^{\#}+C_i^{\#}F_i^{\#} \end{bmatrix}, \quad (i=1,2,3) \tag{2.13}$$

where

$$A_i^{\#} = \begin{cases} \sin\left(\mu_i \varepsilon_{m,i} x\right) & \sigma_i \geq 0 \\ \sinh\left(\mu_i \varepsilon_{m,i} x\right) & \sigma_i < 0 \end{cases} \tag{2.14}$$

$$B_i^{\#} = \begin{cases} \sin\left(\mu_{i+1} \varepsilon_{m,i+1} x\right) & \sigma_{i+1} \geq 0 \\ \sinh\left(\mu_{i+1} \varepsilon_{m,i+1} x\right) & \sigma_{i+1} < 0 \end{cases} \tag{2.15}$$

$$C_i^{\#} = \begin{cases} \cos\left(\mu_i \varepsilon_{m,i} x\right) & \sigma_i \geq 0 \\ \cosh\left(\mu_i \varepsilon_{m,i} x\right) & \sigma_i < 0 \end{cases} \tag{2.16}$$

$$D_i^{\#} = \begin{cases} \cos\left(\mu_{i+1} \varepsilon_{m,i+1} x\right) & \sigma_{i+1} \geq 0 \\ \cosh\left(\mu_{i+1} \varepsilon_{m,i+1} x\right) & \sigma_{i+1} < 0 \end{cases} \tag{2.17}$$

$$E_i^{\#} = \begin{cases} n_i D_i \mu_i \varepsilon_{m,i} \cos\left(\mu_i \varepsilon_{m,i} x\right) - n_i D_i \alpha_i \sin\left(\mu_i \varepsilon_{m,i} x\right) & \sigma_i \geq 0 \\ n_i D_i \mu_i \varepsilon_{m,i} \cosh\left(\mu_i \varepsilon_{m,i} x\right) - n_i D_i \alpha_i \sinh\left(\mu_i \varepsilon_{m,i} x\right) & \sigma_i < 0 \end{cases} \tag{2.18}$$

$$F_i^{\#} = \begin{cases} n_{i+1} D_{i+1} \mu_{i+1} \varepsilon_{m,i+1} \cos\left(\mu_{i+1} \varepsilon_{m,i+1} x\right) - n_{i+1} D_{i+1} \alpha_{i+1} \sin\left(\mu_{i+1} \varepsilon_{m,i+1} x\right) & \sigma_{i+1} \geq 0 \\ n_{i+1} D_{i+1} \mu_{i+1} \varepsilon_{m,i+1} \cosh\left(\mu_{i+1} \varepsilon_{m,i+1} x\right) - n_{i+1} D_{i+1} \alpha_{i+1} \sinh\left(\mu_{i+1} \varepsilon_{m,i+1} x\right) & \sigma_{i+1} < 0 \end{cases} \tag{2.19}$$

$$G_i^{\#} = \begin{cases} n_i D_i \mu_i \varepsilon_{m,i} \cos\left(\mu_i \varepsilon_{m,i} x\right) + n_i D_i \alpha_i \sin\left(\mu_i \varepsilon_{m,i} x\right) & \sigma_i \geq 0 \\ n_i D_i \mu_i \varepsilon_{m,i} \cosh\left(\mu_i \varepsilon_{m,i} x\right) + n_i D_i \alpha_i \sinh\left(\mu_i \varepsilon_{m,i} x\right) & \sigma_i < 0 \end{cases} \tag{2.20}$$

$$H_i^{\#} = \begin{cases} n_{i+1} D_{i+1} \mu_{i+1} \varepsilon_{m,i+1} \cos\left(\mu_{i+1} \varepsilon_{m,i+1} x\right) + n_{i+1} D_{i+1} \alpha_{i+1} \sin\left(\mu_{i+1} \varepsilon_{m,i+1} x\right) & \sigma_{i+1} \geq 0 \\ n_{i+1} D_{i+1} \mu_{i+1} \varepsilon_{m,i+1} \cosh\left(\mu_{i+1} \varepsilon_{m,i+1} x\right) + n_{i+1} D_{i+1} \alpha_{i+1} \sinh\left(\mu_{i+1} \varepsilon_{m,i+1} x\right) & \sigma_{i+1} < 0 \end{cases} \tag{2.21}$$

Eqs. (2.14) into (2.21) for i = 1,2, 3

The characteristic values β_m are determined by the following equation

$$P_4 P_3 P_2 P_1 P_0 = 0 \tag{2.22}$$

The value P_0 is determined by substituting Eqs (2.7) and (2.8) into the inlet boundary condition of the transient -state problem (Eq (2.3))

$$P_0 = \begin{bmatrix} A_{m,1} \\ B_{m,1} \end{bmatrix} = \begin{bmatrix} 1 \\ 0 \end{bmatrix} \tag{2.23}$$

The value P_4 is obtained by substituting Eqs. (2.7) and (2.8) into the outlet boundary condition of the transient -state problem (Eq. (2.4))

$$P_4 = \begin{cases} \begin{bmatrix} \alpha_4 \sin\left(\mu_4 \varepsilon_{m,4}\right) + \mu_4 \varepsilon_{m,4} \cos\left(\mu_4 \varepsilon_{m,4}\right) \\ \alpha_4 \cos\left(\mu_4 \varepsilon_{m,4}\right) - \mu_4 \varepsilon_{m,4} \sin\left(\mu_4 \varepsilon_{m,4}\right) \end{bmatrix}^{\mathrm{T}} & \sigma \geq 0 \\ \begin{bmatrix} \alpha_4 \sinh\left(\mu_4 \varepsilon_{m,4}\right) + \mu_4 \varepsilon_{m,4} \cosh\left(\mu_4 \varepsilon_{m,4}\right) \\ \alpha_4 \cosh\left(\mu_4 \varepsilon_{m,4}\right) + \mu_4 \varepsilon_{m,4} \sinh\left(\mu_4 \varepsilon_{m,4}\right) \end{bmatrix}^{\mathrm{T}} & \sigma < 0 \end{cases} \tag{2.24}$$

The coefficients Q_m are obtained from the following orthogonality relationship

$$Q_m = \frac{\sum_{i=1}^{4} \int_{x_{i-1}}^{x_i} \delta_i\left(x\right) n_i R_{d,i} g_{m.i}\left(x\right) e^{-\alpha_i x}}{\sum_{i=1}^{4} \int_{x_{i-1}}^{x_i} q_i n_i R_{d,i} g_{m.i}^2\left(x\right)} \tag{2.25}$$

where

$$\begin{cases} q_1 = 1 \\ q_2 = e^{2\left(a_2 - a_1\right)x_1} \\ q_3 = e^{2\left(a_2 - a_1\right)x_1 + 2\left(a_3 - a_2\right)x_2} \\ q_4 = e^{2\left(a_2 - a_1\right)x_1 + 2\left(a_3 - a_2\right)x_2 + 2\left(a_4 - a_3\right)x_3} \end{cases} \tag{2.26}$$