An Integrated Density-Dependent Flow and Solute Transport Model for Simulating Groundwater-Seawater Interaction and Nutrient Transport in Taoyuan Coastal Area.

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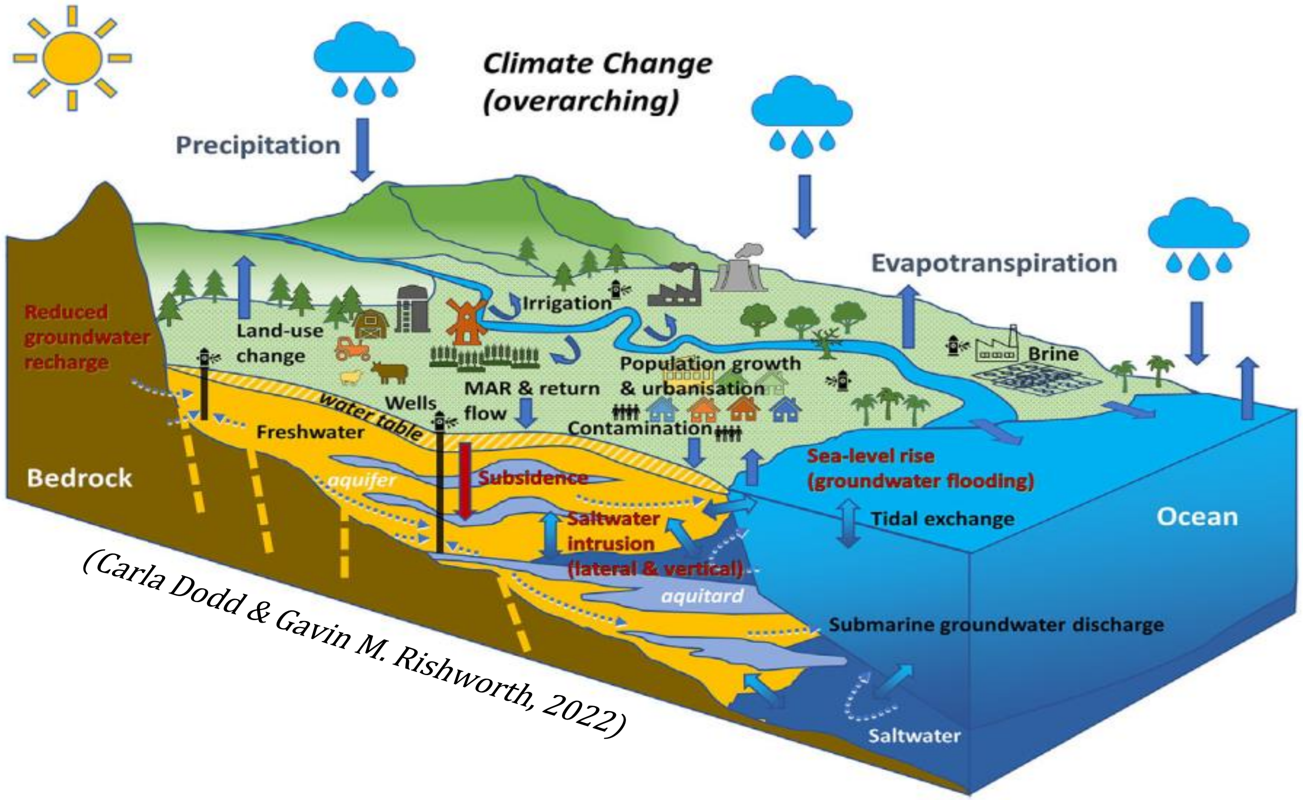


Fig: *Groundwater resources and pollutant transport process in coastal area*

- Groundwater is a critical natural resource required for human development, however its resources threatened by seawater intrusion and coastal pollution ***(Kemper 2004; Alley 2006).***

- **Overgrowth nutrients** such as nitrate (NO_3^-) and phosphate (PO_4^{3-}), have the potential to **negatively impact drinking water and the biota** of coastal ecosystems ***(Duarte et al., 2010).***

Groundwater resources and eutrophication in coastal area

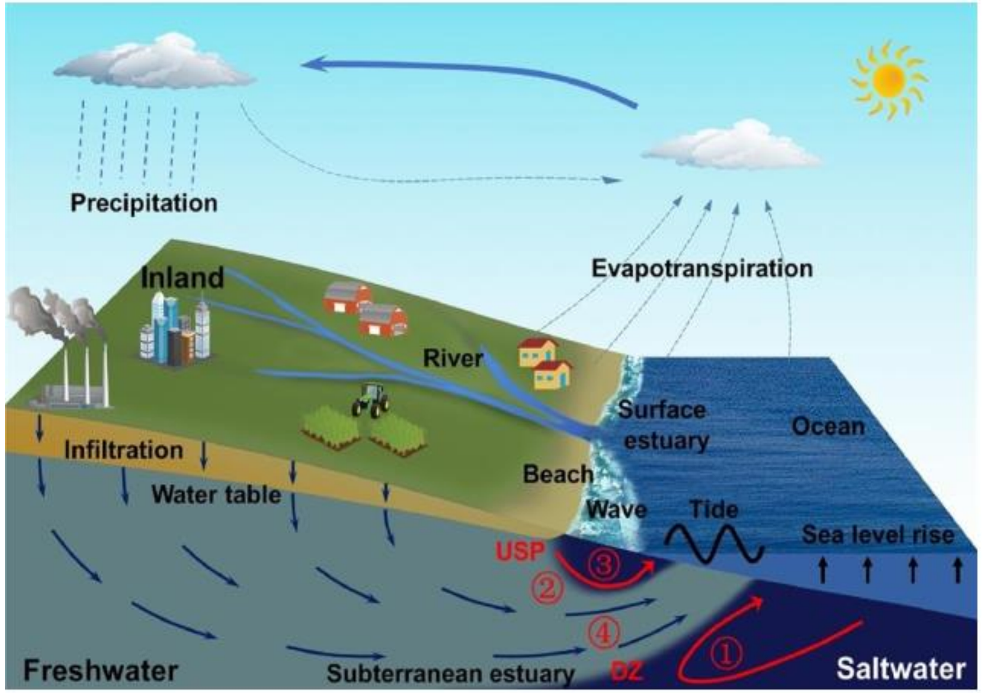


Fig: Submarine groundwater discharge contributes to transport pollution (Murgulet, 2021)

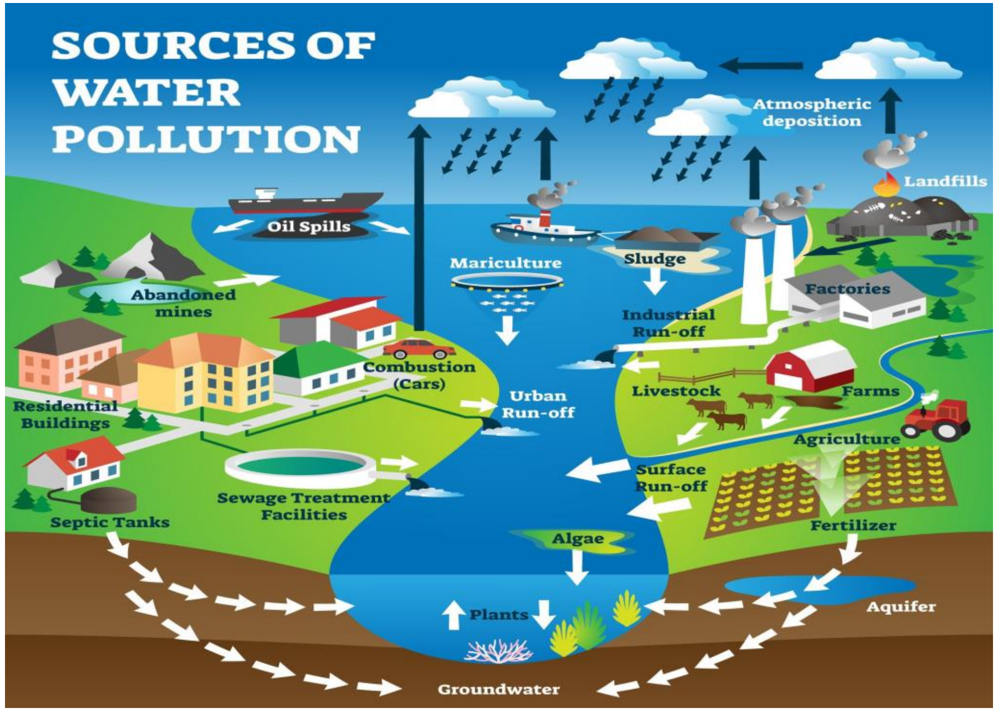


Fig: Point source and non-point source of pollution (www.breavardfl.gov)

- **Seawater - Groundwater interaction** are important natural processes of coastal areas that **controlling processes such as Submarine Groundwater Discharge (SGD), Seawater intrusion...**
- SGD is hydrological process that effect directly to the transport of pollutants from land to sea, aggravate pollution in this area.

1. Objective

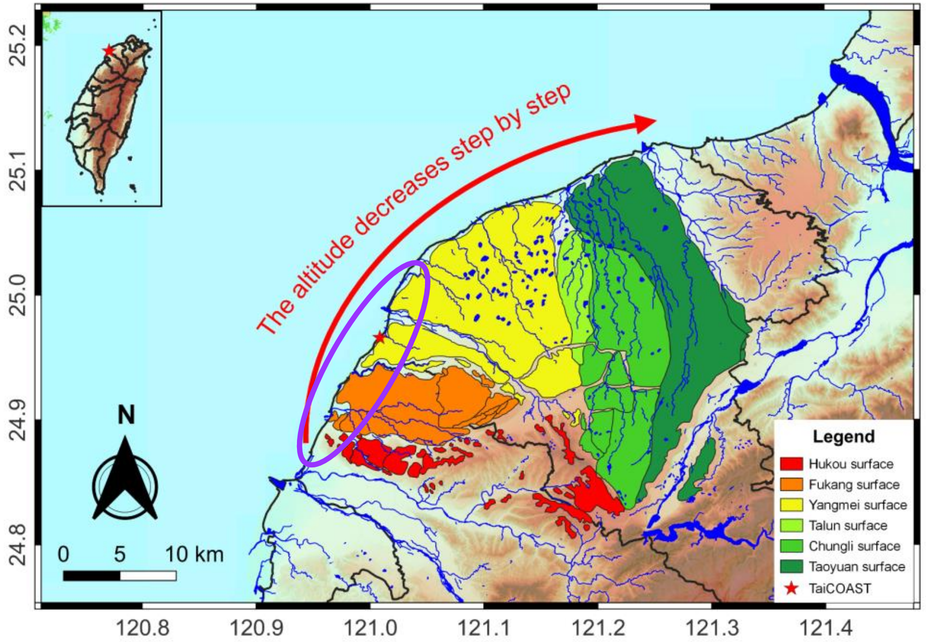
- Developing **a Density-Dependent Flow and Solute Transport Integrated model** capable of simulating seawater intrusion, SGD, and nutrient transport in coastal areas.

- **Discussing about the interaction processes between seawater and freshwater**, along with accompanying phenomena in coastal areas such as SGD and SI.

- Evaluating the impact of aquifer material complexity on solute transport in coastal aquifers

Study area

Taoyuan coastal area and Datan Algal Reef



- The **Datan Algal Reef is a unique biotic ecosystem** that provides habitat for several threatened and endangered species.
- However approximately **75% of the reef**, particularly in the northern region, has been **damaged by industrial pollution** over the past 50 years.

Polycyathus Chaishanensis (endemic coral species species)

Equations

- The fluid flow behavior in a porous matrix follows the equation adopted from fluid flow in porous media following Darcy's law (Darcy, 1856):

$$\boldsymbol{q} = \frac{\boldsymbol{k}}{\boldsymbol{\mu}}(\boldsymbol{\nabla p} + \boldsymbol{\rho^* g \nabla D}) \qquad (1)$$

- Fluid density dependent salinity equation

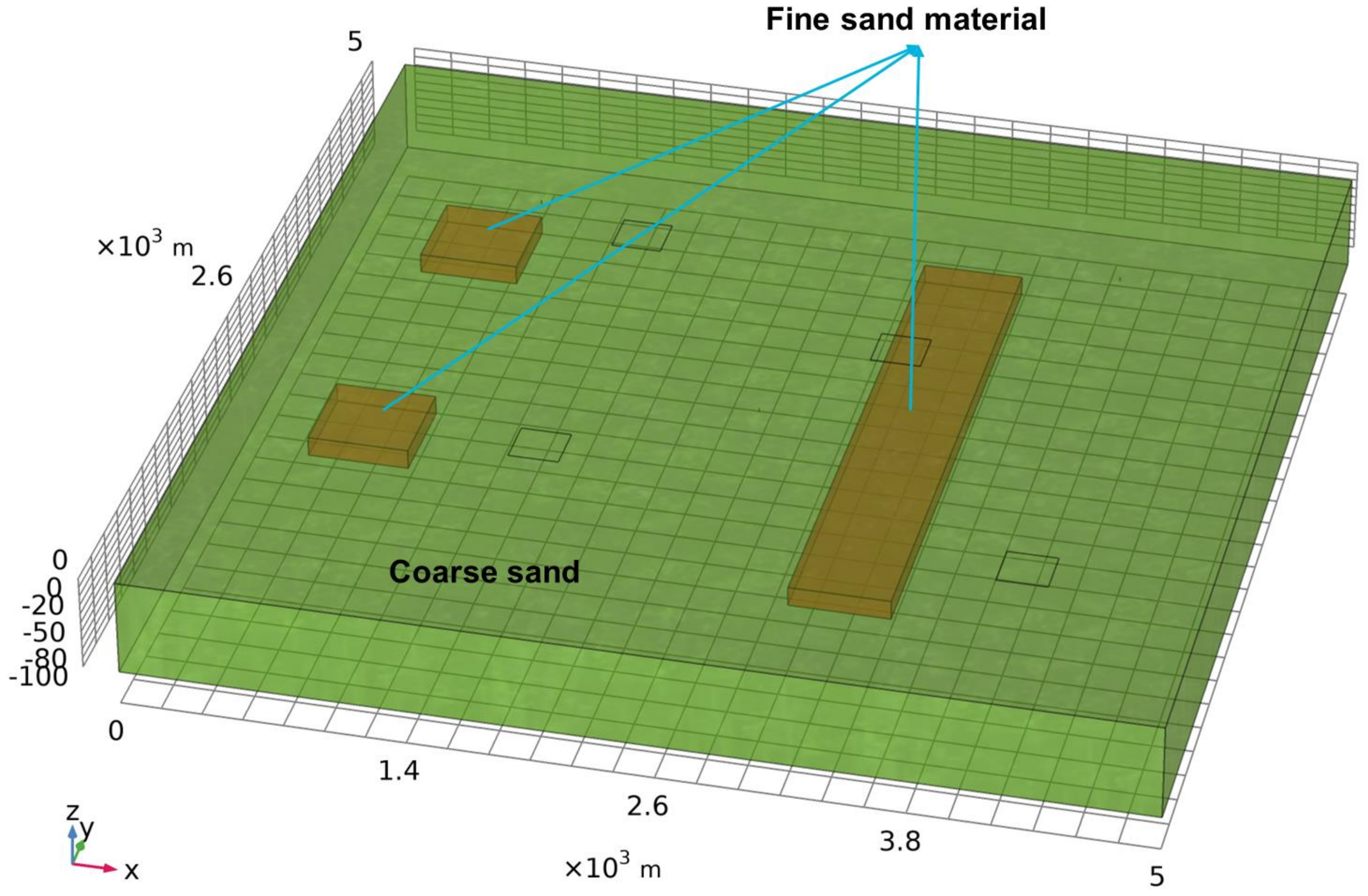
$$\boldsymbol{\rho^*} = \boldsymbol{\rho_f} + \frac{\boldsymbol{\rho_c + \rho_f}}{\boldsymbol{C_s - C_f}}\boldsymbol{C_1} \qquad (2)$$

- Solute transport equation:

$$\underbrace{\boldsymbol{n_e}\left(\boldsymbol{1} + \frac{\boldsymbol{\rho_b K_d}}{\boldsymbol{n_e}}\right)}_{Absorption} \cdot \frac{\boldsymbol{\partial C_{1,2}}}{\boldsymbol{\partial t}} + \underbrace{\boldsymbol{q_i \nabla C_{1,2}}}_{Advection} - \boldsymbol{\nabla} \cdot \underbrace{\left[\boldsymbol{n_e}(\boldsymbol{D_H} + \boldsymbol{\nabla C_{1,2}}\right]}_{Diffusion} = \boldsymbol{0} \qquad (3)$$

- Dhere D_H is the diffusion dispersion and ∇C_1 is the changed salinity of fluid, ∇C_2 is the changed Nitrate (NO_3) concentration of fluid; $1 + \frac{\rho_b K_d}{n_e}$ is retardation factor, ρ_b *is Bulk density*, K_d is linear sorption coefficient.

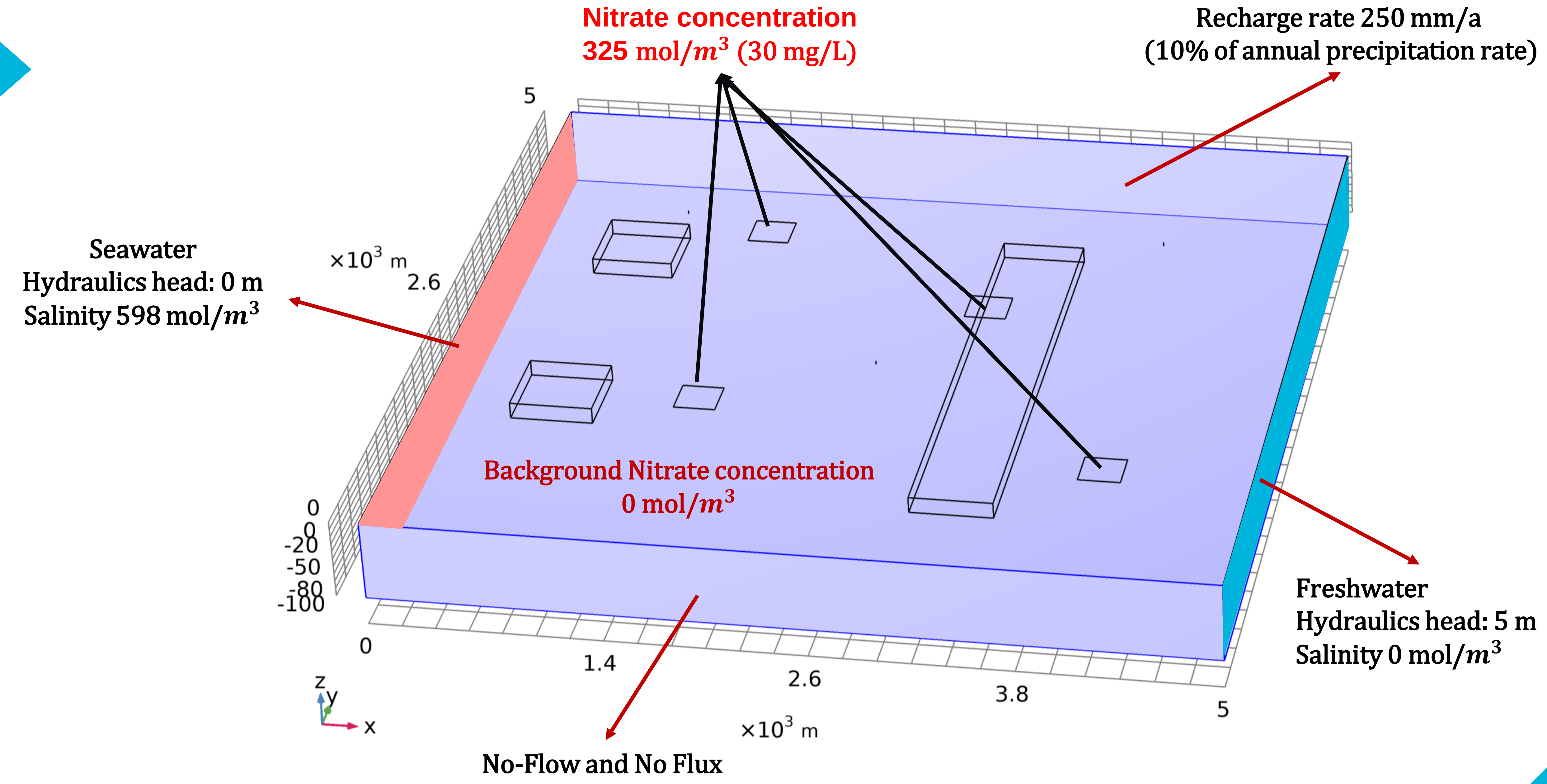
Model setting



X:Y:Z = 5000:5000:100 m

Polluted Agricultural Zone: 250*250m

Hydraulic and Hydro-chemical Boundary Conditions



Model applications

Scenario 1: Seawater – Freshwater interaction

- The steady state of model
- Seawater-freshwater transition and SGD estimation

Scenario 2: Effect of agriculture development on groundwater quality and SGD

- Simulate 30 years over development of agriculture and their effects on groundwater quality
- **Pump in turn of 4 production wells and All well** with pumping rate 4320 m^3/day for each well in the dry season

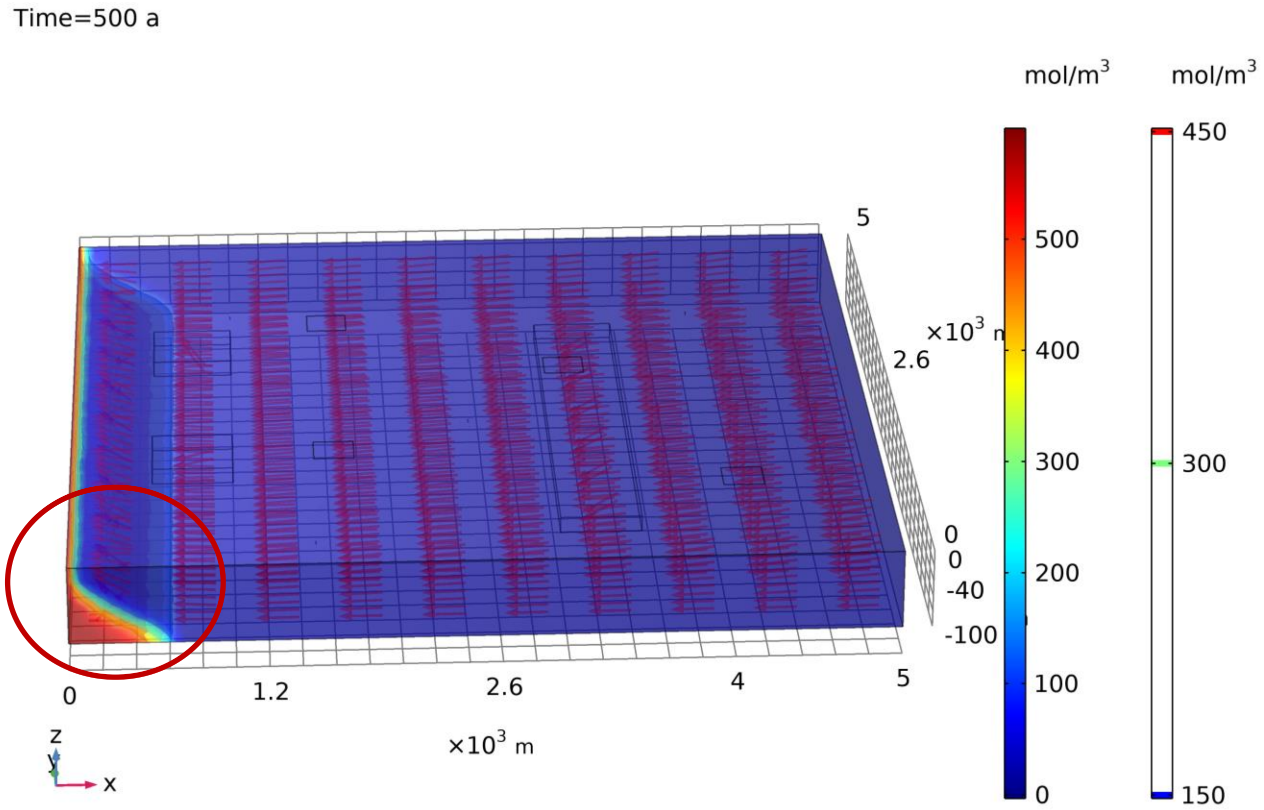
Scenario 3: Coastal development effect on coastal groundwater quality

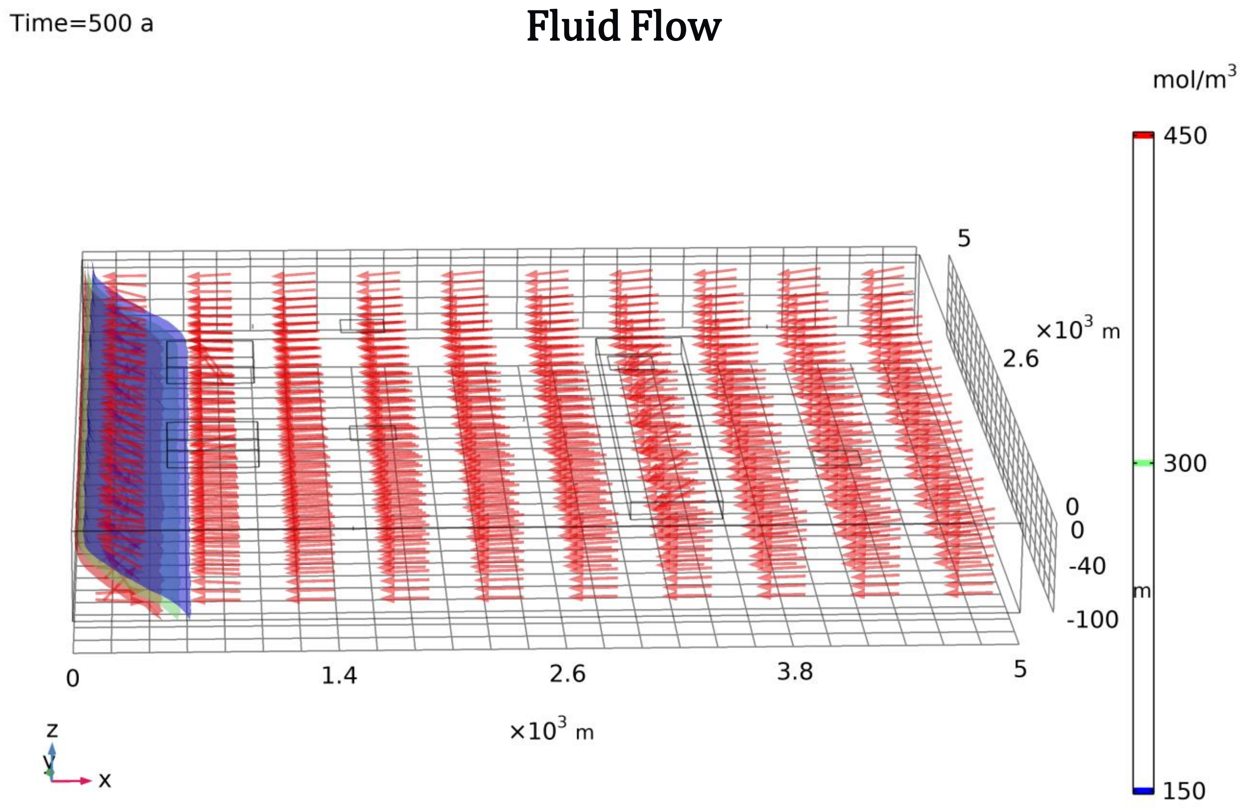
- After 30 years agriculture developed, a part of agricultural land converted into industrial zone

Table. Parameters setting

Parameters	Values	Unit
Fine sand porosity	0.395	-
Fine sand effective porosity	0.375	-
Fine sand density	2090	kg/m^3
Fine sand hydraulic conductivity	5×10^{-5}	m/s
Coarse sand porosity	0.385	-
Coarse sand effective porosity	0.380	-
Coarse sand density	1988	kg/m^3
Coarse sand hydraulic conductivity	6×10^{-4}	m/s
Fresh water density	1000	kg/m^3
Seawater density	1025	kg/m^3
Seawater salinity	35	PPT
Freshwater salinity	0	PPT
Dynamic viscosity	8.9×10^{-4}	Pa·s

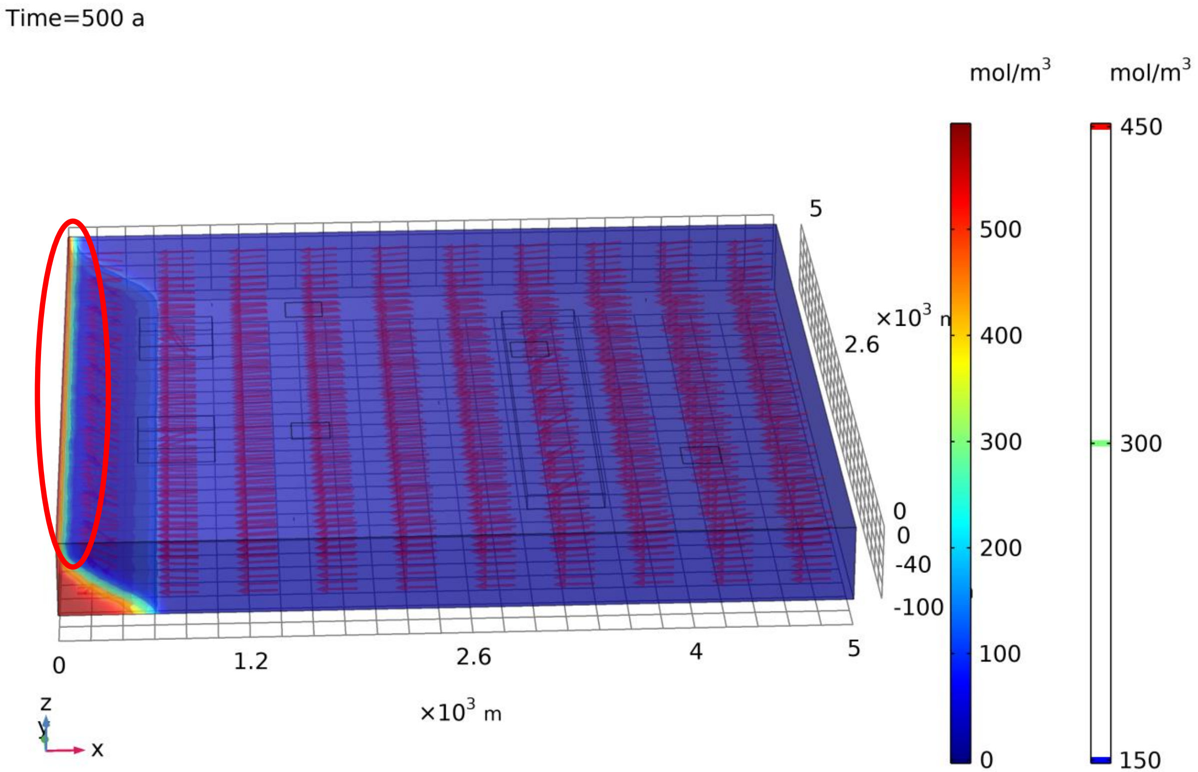
Scenario 1: Steady state condition

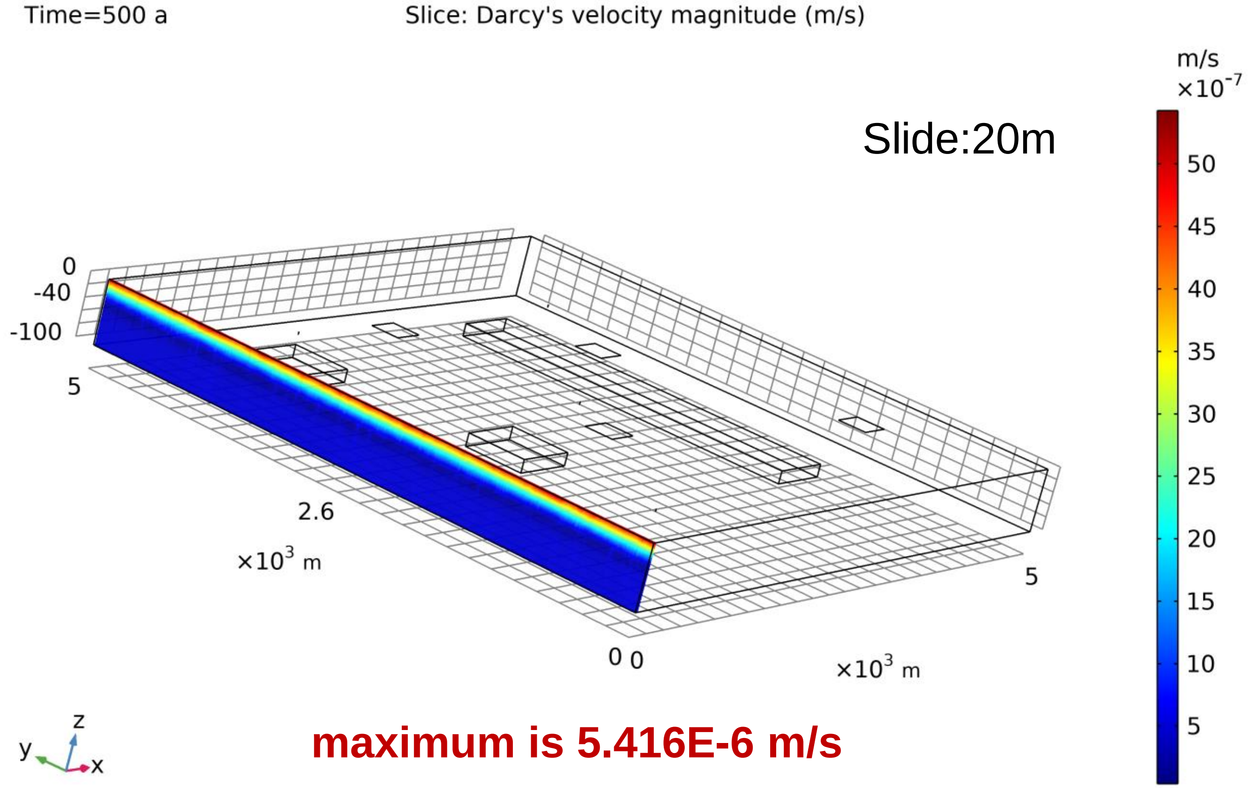




- Model reached steady-state condition after 500 years of simulation.
- **Toe position (brackish water has salinity 150** $\mathrm{mol}/\ m^3$**) located around 610 m further inland**

SGD and Seawater – Groundwater interaction

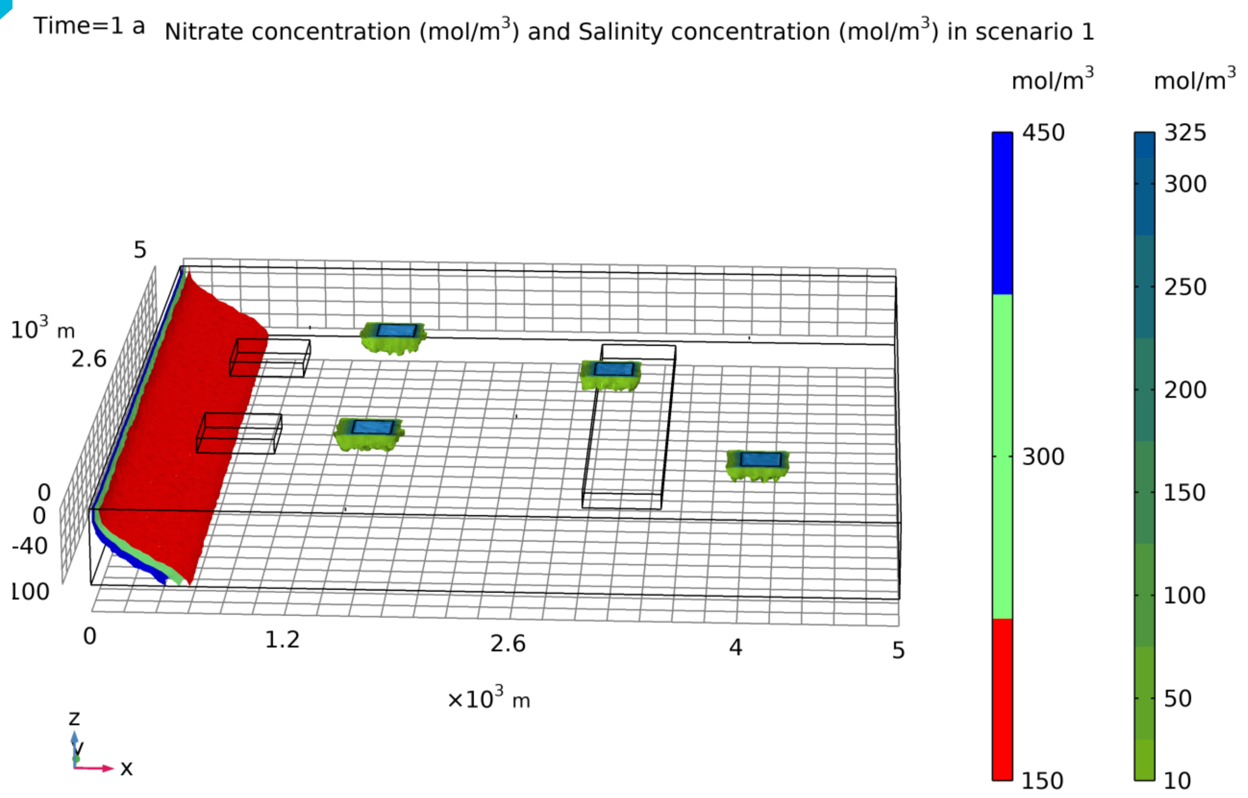


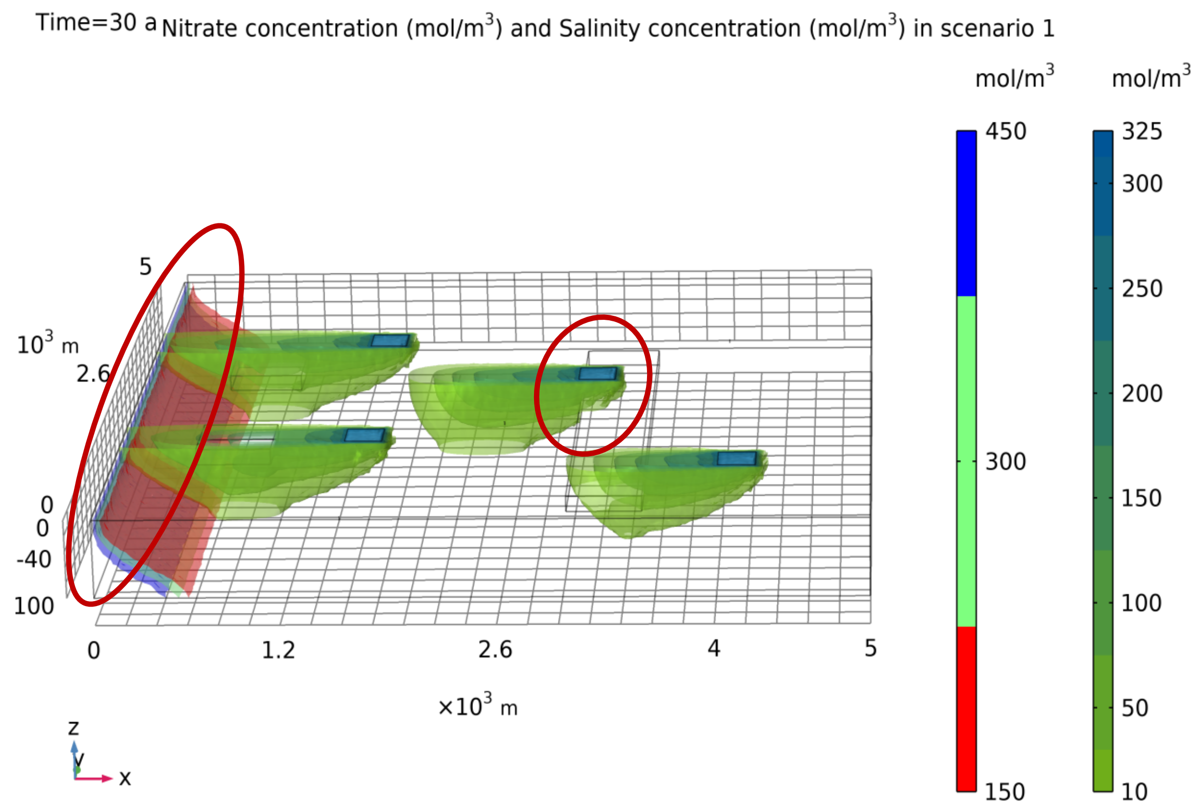


- The interaction between seawater and groundwater **creates a transition zone where freshwater floats above seawater**, flowing along the top of the domain or SGD.
- The flow velocity is highest near the coastline, reaching a maximum of $\mathbf{5.416 \times 10^{-6}\ m/s}$, and gradually decreases further inland.

Scenario 2: Effect of agriculture development on groundwater quality and SGD

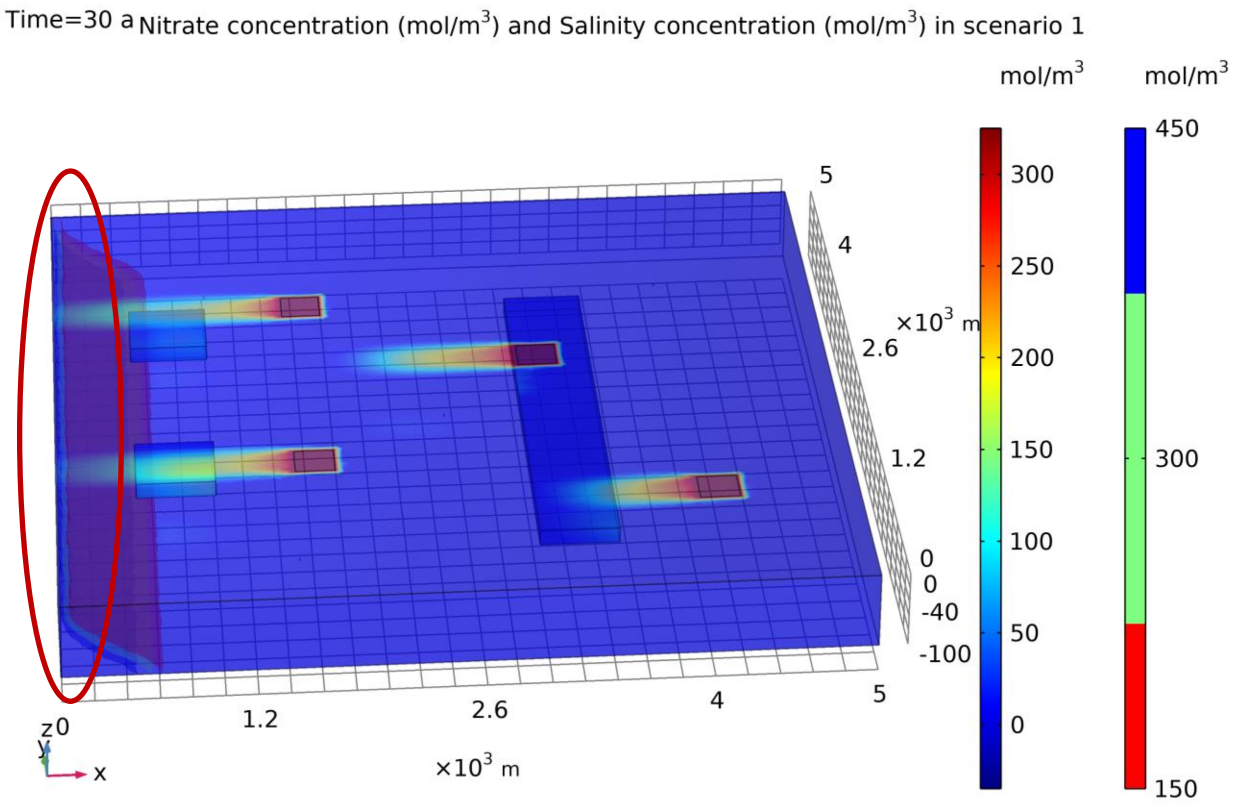
Scenario 2-1: 30 years of agricultural development without pumping



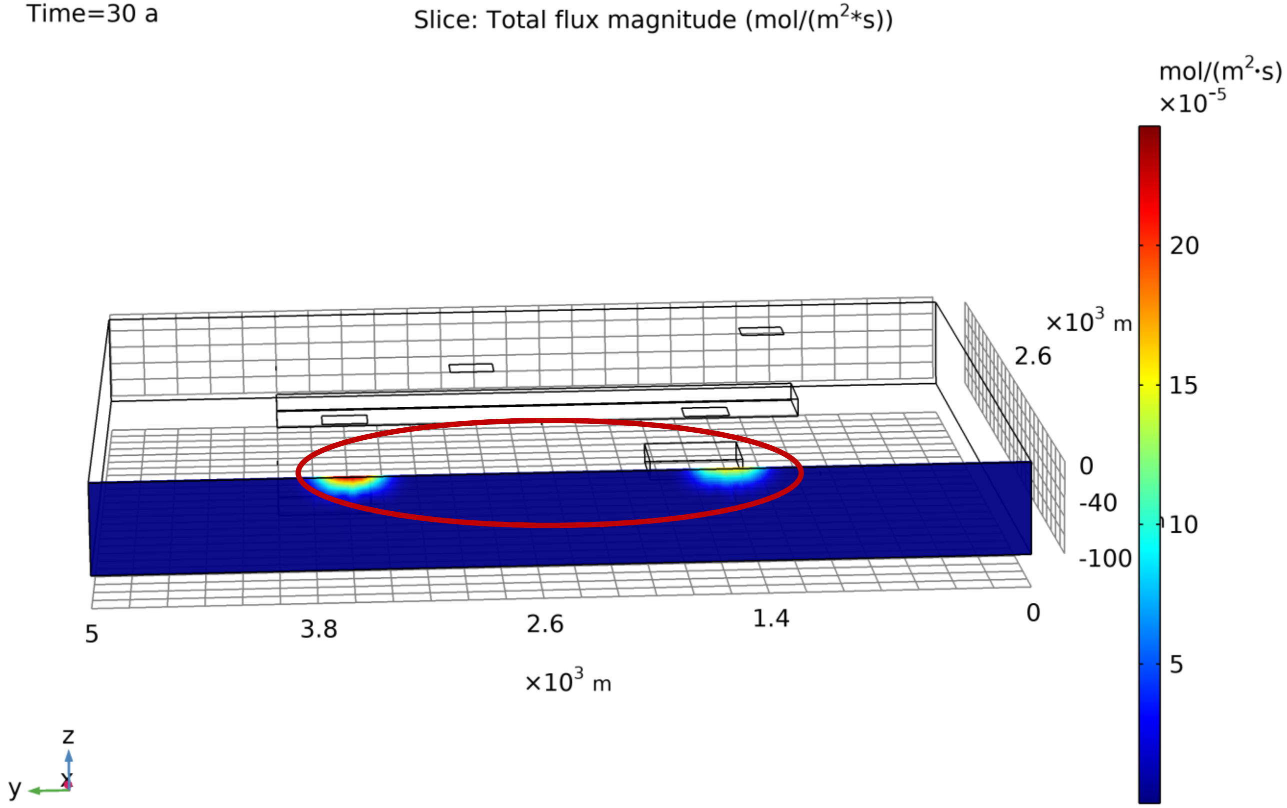


- After **30 years of simulation**, nutrient pollutants from agricultural areas have spread extensively, infiltrating the aquifer and being transported along groundwater flow.
- **Fine sand has lower permeability and porosity**, causing nitrate to accumulate within the material, which significantly affects its transport behavior.

Surface view



Slide view



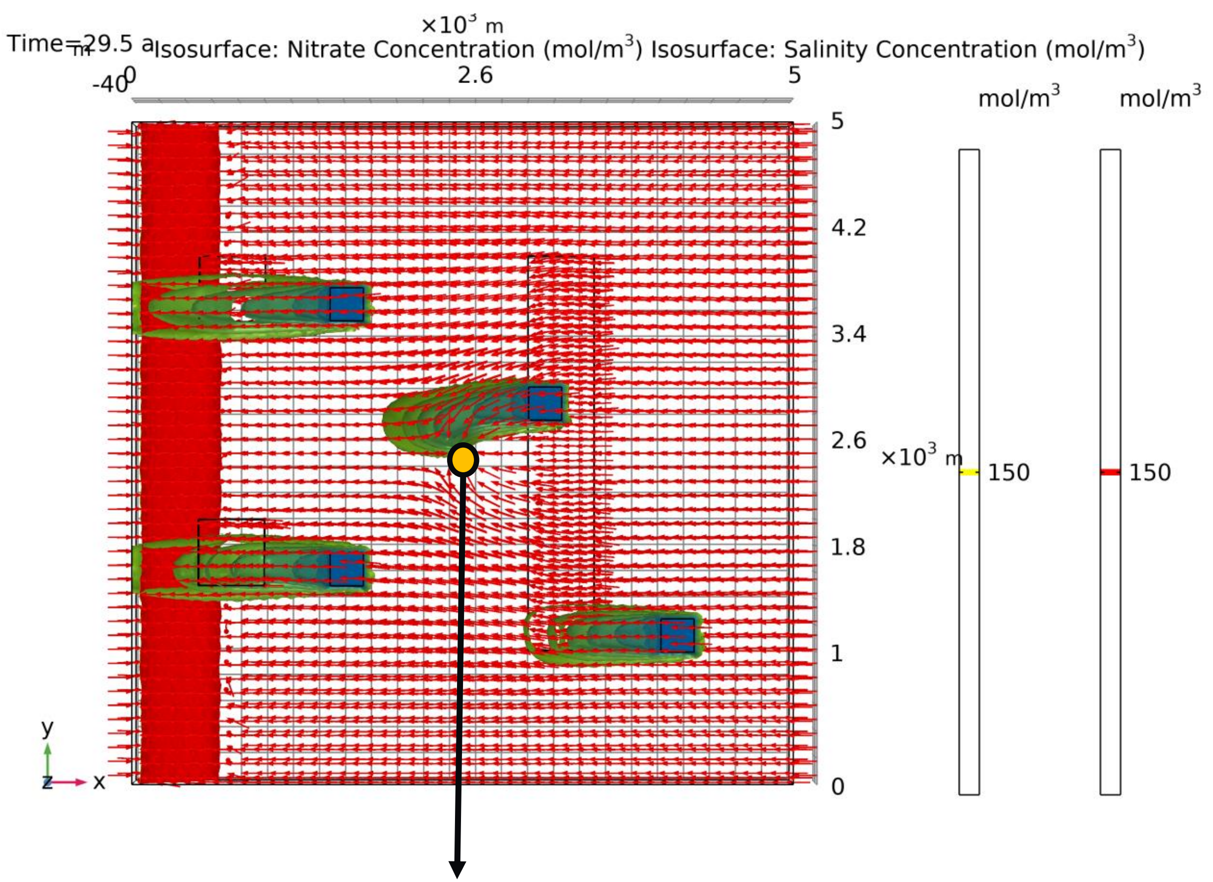
*SGD carries approximately 2.427E-4 Mol/(m² *s) Nitrate to shoreline .*

- The **SGD process** carries nitrate from the bottom of the domain to the surface, resulting in a **higher nitrate flux at the top** compared to deeper zone.

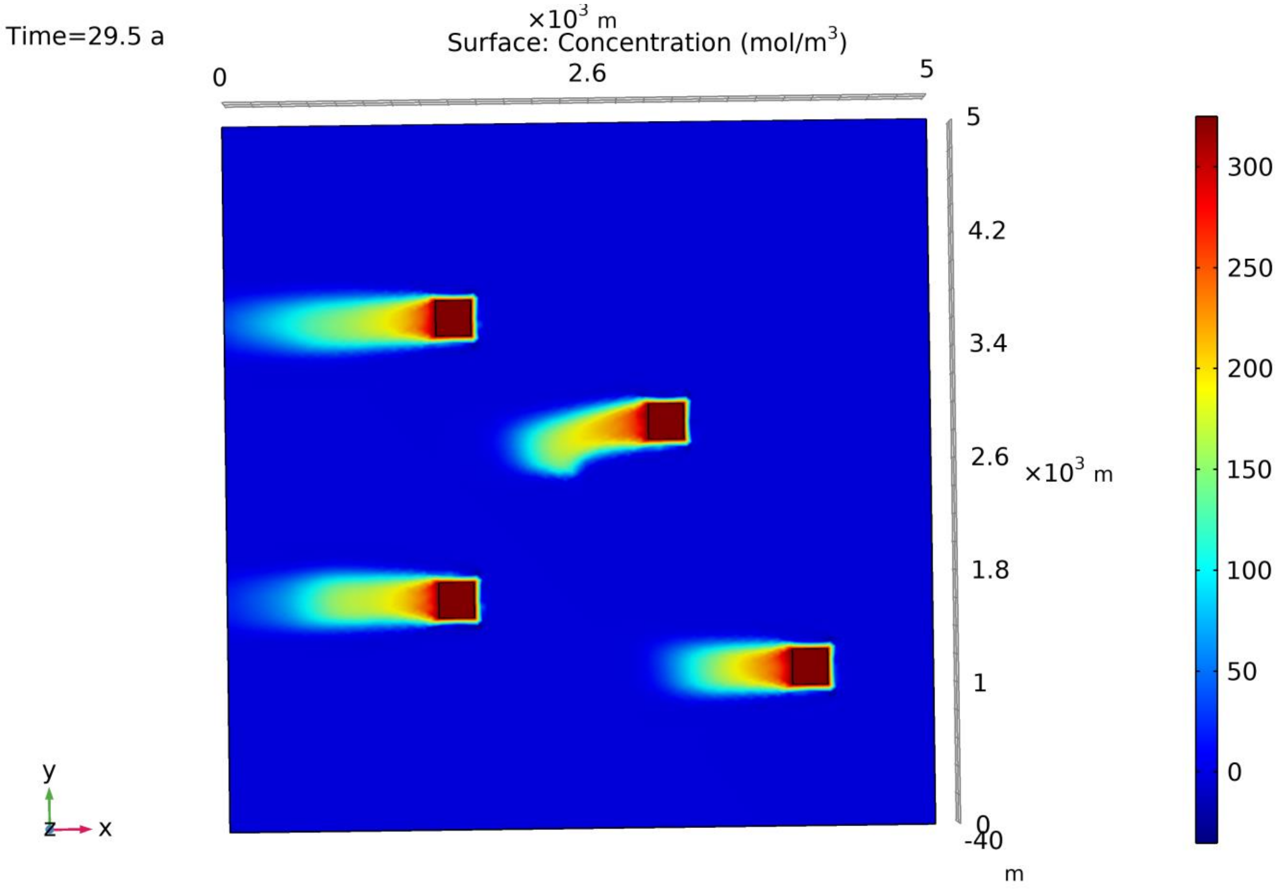
Effect of pumping and agriculture pollution on groundwater quality

Scenario 2-2: 30 years agriculture development with pumping

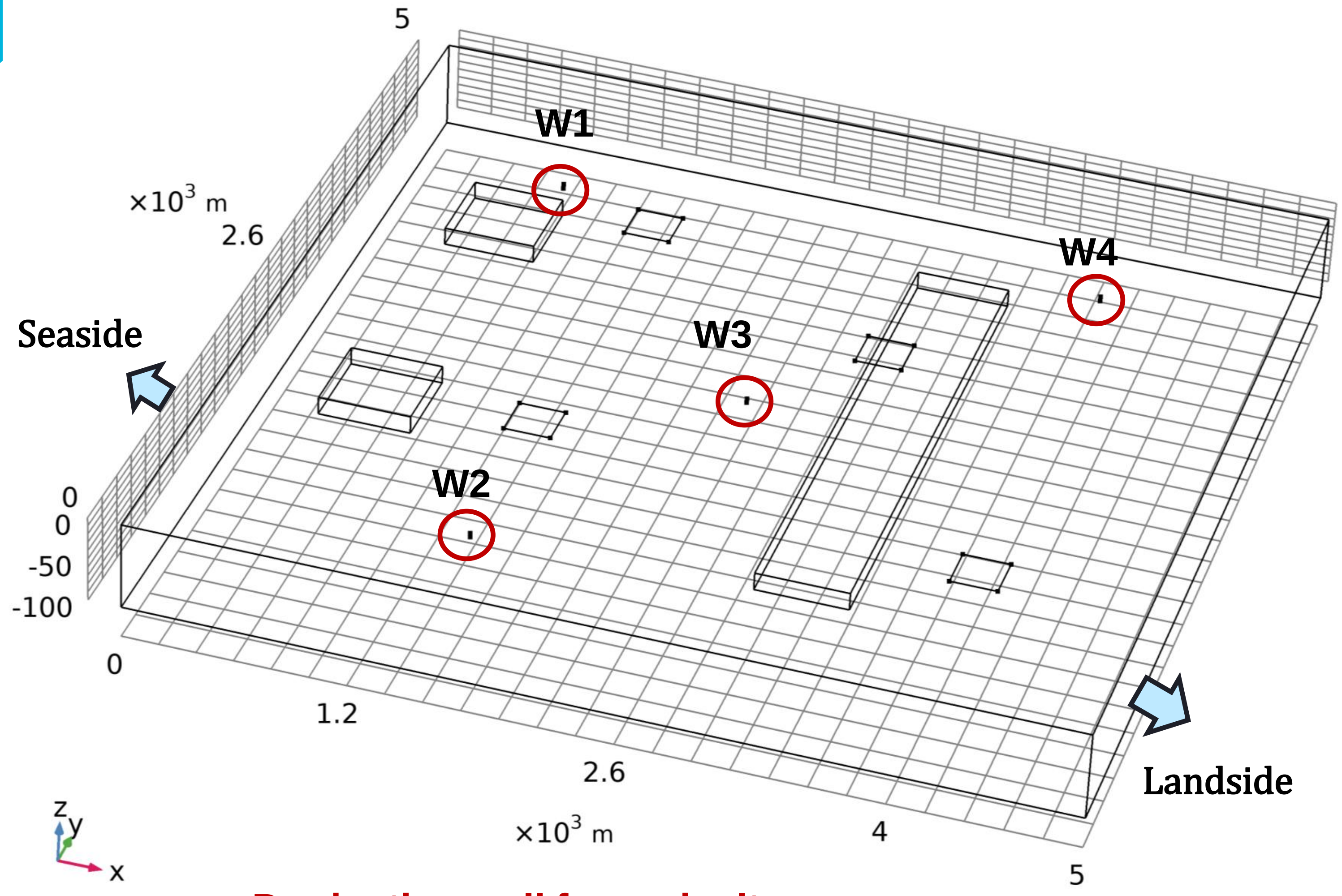
Open production well W3, with pumping rate 4320 m^3/day, in 6 months of dry season



Pumping well



Effect of pumping and agriculture pollution on groundwater quality



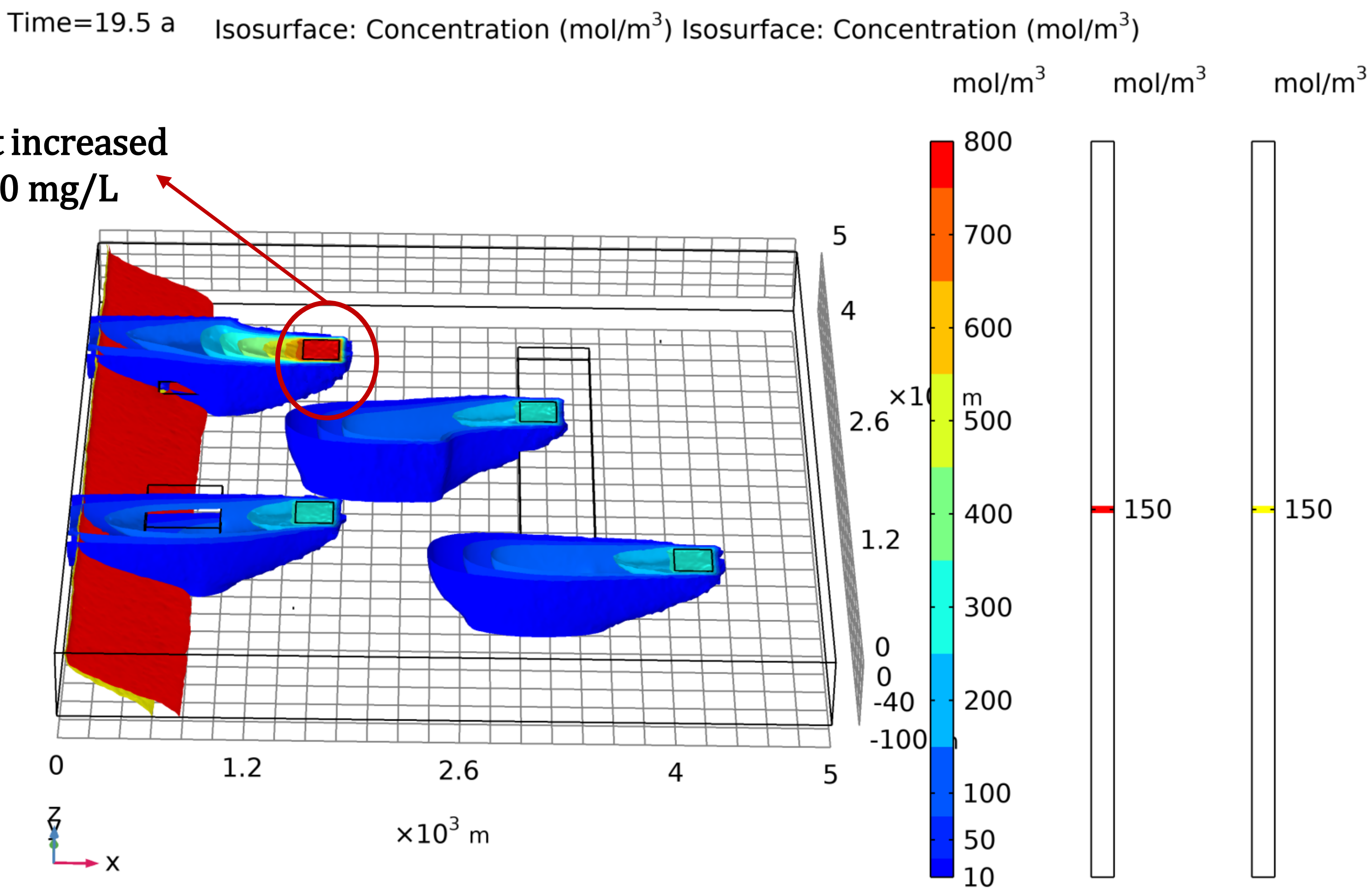
Production well for agriculture

Table. SGD quantitative and Nitrate transport to the aquifer

Pumping well	SGD (m/s)	Nitrate flux (mol/m^2.s)
Steady State	5.41E-6	2.427E-4
Pumping at well W1	5.30E-6	1.87E-4
Pumping at well W2	5.39E-6	2.12E-4
Pumping at well W3	5.33E-6	2.049E-4
Pumping at well W4	5.39E-6	2.187E-4
Pumping at all well	**4.85E-6**	**6.5E-5**

Scenario 3: Effect of industrial development to groundwater quality

Nitrate leakage into environment increased from industrial area to 75 from 30 mg/L



Intrusion Steady-state

- After 30 years of agricultural development, **the area gradually transformed into industrial development**. In 20 years, a former agricultural area transformed into an industrial zone.
- Nitrate flux rate increase **3.27E-4 (mol/m^2.s)** (pump all is 6.5E-5) and SGD become **4.838E-6 m/s.**

4. Conclusions

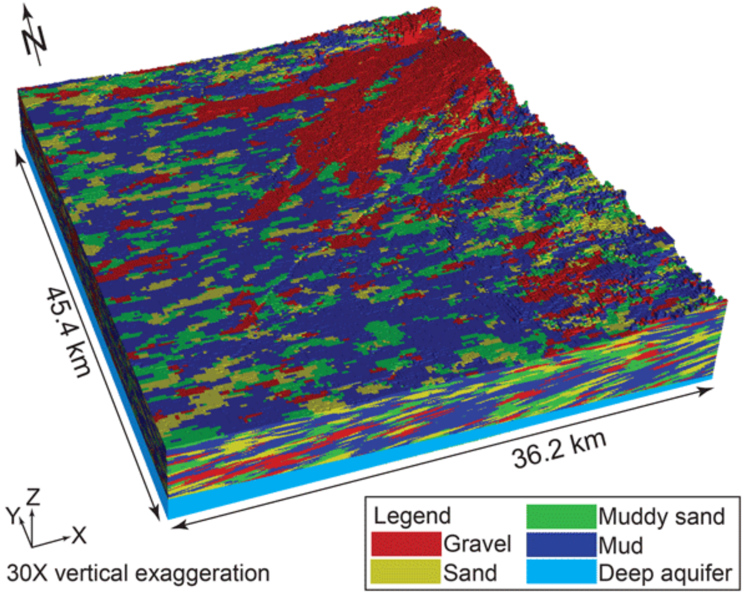
- The density-dependent flow and solute transport integrated model, **capable of simulating SGD, SI, and Nutrient pollution (NO_3, NH_4, PO_4…) dissolved oxides (e.g., FeO_x^-, MnO_x…),** provides an effective tool for developing coastal water resource management scenarios.

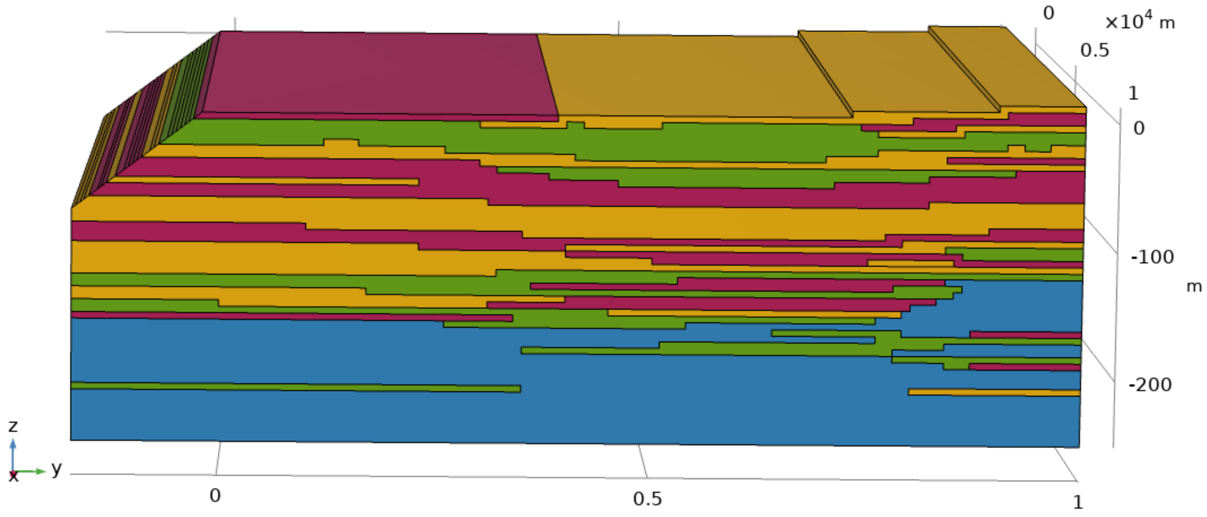
- The groundwater-seawater interaction, along with hydrological mechanisms such as SGD and aquifer material **directly impacts the transport of pollutants within aquifers**.

- **Lower permeability and porosity materials**, such as fine sand, can impede nitrate transport, leading to its **accumulation within the matrix or acting as a barrier** to further movement

5. Future works

- The complexities of the geological landscape are not fully accounted for, and detailed values for the absorption process are missing; therefore, future models will be improved.
- The concentration of eutrophic substances in the coastal area is influenced by river transport, necessitating the development of another surface water model to simulate the transport of pollutants by rivers and streams.





Thanks for your attention