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On the Streamwise Transport of Vertically Drifting Particles in Shear Flows with Boundary Adsorption and Desorption

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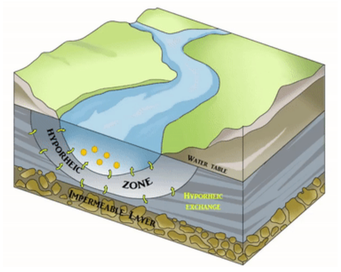
Background

Boundary adsorption–desorption is one of the key controlling factors in the transport of particles in river environments, profoundly influencing environmental and ecological processes such as pollutant migration, sediment transport, and the dispersion of early life stages of aquatic organisms. In the context of open-channel flow, this dissertation systematically investigates the transport characteristics of three types of particles that undergo vertical motion, namely pollutants (solute), suspended sediment, and drifting fish eggs, under reversible/irreversible adsorption–desorption boundary conditions at the riverbed.




Pollutants (solute)


Suspended sediment


Drifting fish eggs

Particle type	Diameter	Mean vertical velocity	Boundary condition
Pollutants (solute)	< 1 nm	None	Bed sediment pollution (reversible adsorption, irreversible adsorption)
Suspended sediment	< 0.1 mm	Vertically downward	Suspended sediment erosion and deposition (reversible adsorption)
Drifting fish eggs	0.5–4.5 mm	Vertically downward	Bed surface mortality (irreversible adsorption)

Method

Governing equation :

Bulk concentration; Settling velocity

$$\frac{\partial C}{\partial t}+u(z)\frac{\partial C}{\partial x}+V_s\frac{\partial C}{\partial z}=K_x\frac{\partial^2 C}{\partial x^2}+\frac{\partial}{\partial z}\left(K_z\frac{\partial C}{\partial z}\right)$$

Flow velocity profile; Diffusion coefficient

Boundary condition:

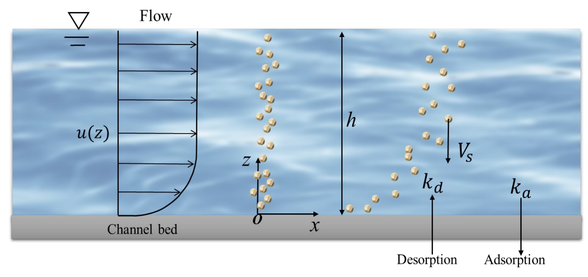
$$\frac{\partial C}{\partial z}\Big|_{z=0}-k_{ia}C\Big|_{z=0}=\frac{\partial C_s}{\partial t}=k_aC\Big|_{z=0}-k_dC_s$$

k_{ia}: Irreversible adsorption coefficient; k_a: Reversible adsorption coefficient; k_d: Desorption coefficient; C_s: Surface concentration at the channel bed

Initial condition:

$C|_{t=0}=\delta(x)P(z)$: Initial distributions on the surface

$C_s|_{t=0}=P_s$: Initial distributions in the bulk



Numerical simulation

- Direct numerical simulation (DNS)
- Particle tracking

Validation

Analytical solutions

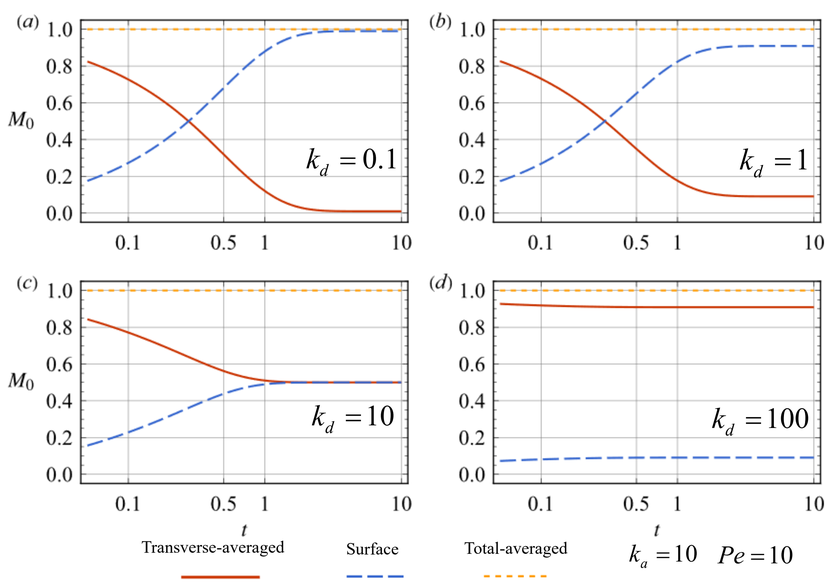
Concentration moment method → Separation of variables

- Transverse-averaged concentration
- Drift
- Dispersivity

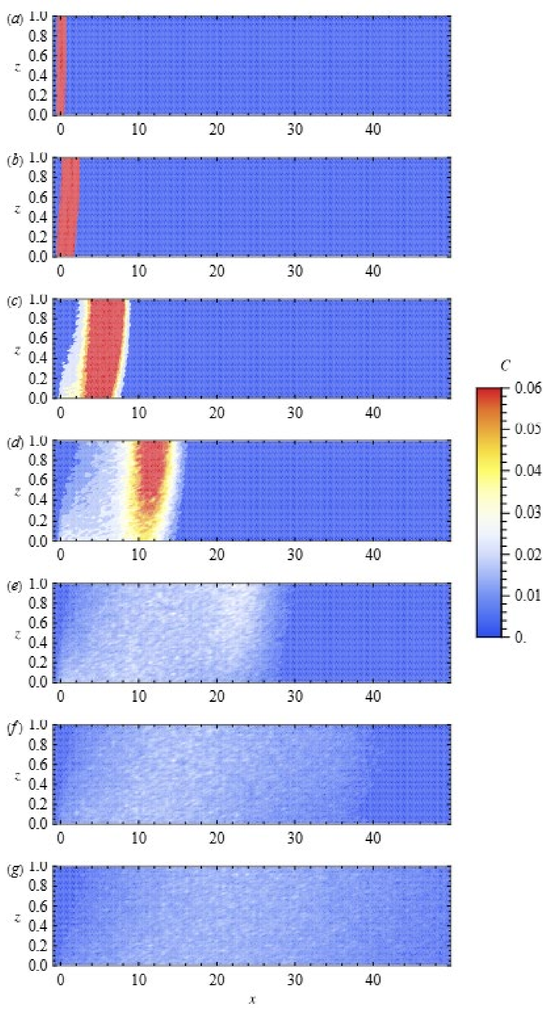
Results

SOLUTE

Temporal evolution of the transverse-averaged moment

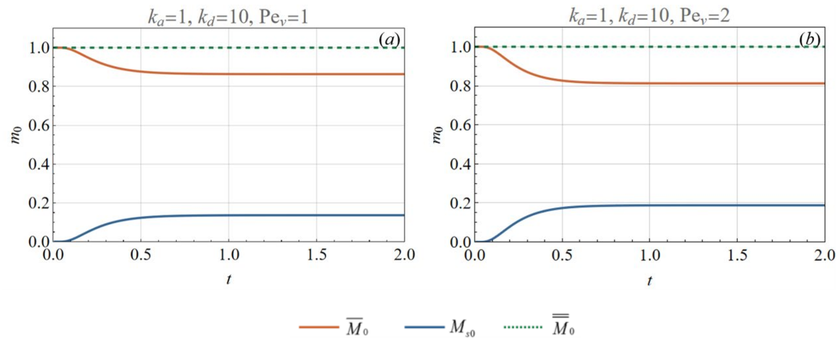


Two-dimensional concentration distribution by numerical simulation



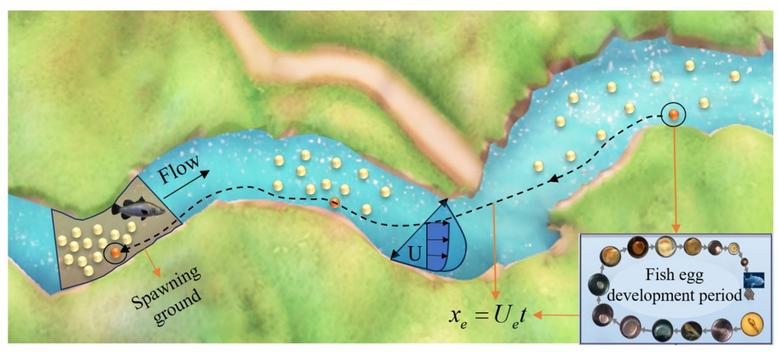
SUSPENDED SEDIMENT

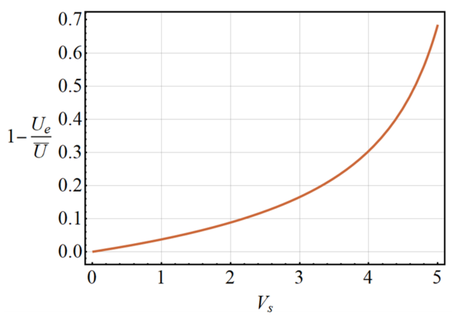
Temporal evolution of the transverse-averaged moment

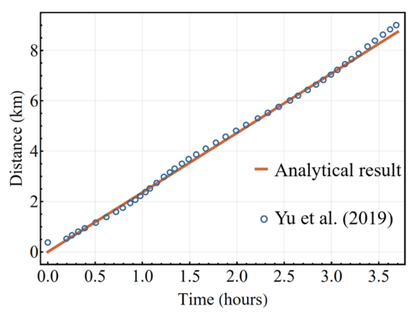


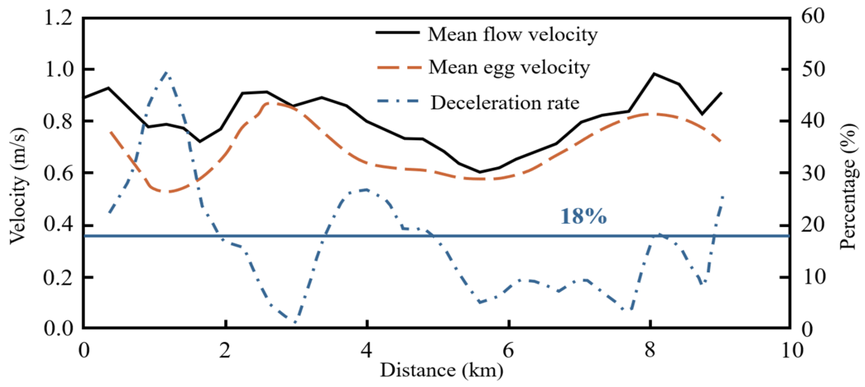
DRIFTING FISH EGG

The identification of the spawning ground









Reference

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