Impacts of engineering baffles on the hyporheic exchange in a straight channel with floodplain

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EGU2020-13224

Goal: To investigate impacts of engineering baffles on the hyporheic exchange (HE) in a straight channel with floodplain and quantify the impacts of key factors such as streamflow, baffle amplitude and wavelength on the HE.

I Introduction

The hyporheic zone (HZ) is the region of saturated sediment surrounding a stream which connects surface water and groundwater flow. The overlying water with dissolved matters infiltrates into the HZ, stays there for some time and interacts with groundwater, and exfiltrates out of the HZ, resulting in hyporheic exchanges (HEs). The HEs support physicochemical and biological reactions that are essential to river ecosystem functions.

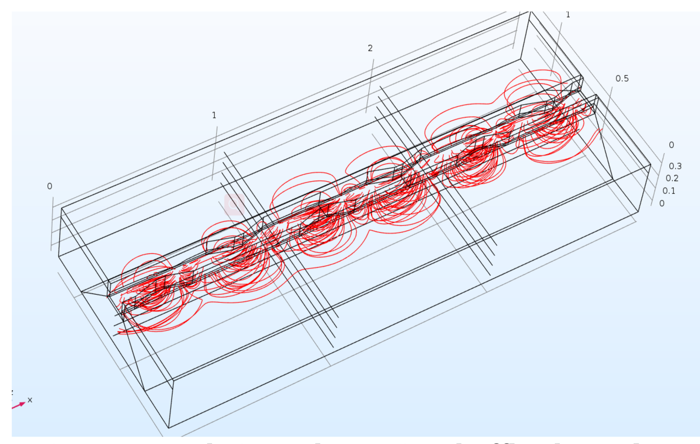


Fig. 1. Hyporheic exchange in a baffle channel with floodplain

In recent decades, more and more stream restoration projects involve the recovery of HE, however, effective guidance in restoring HE is still missing. Therefore, this study aims to examine the effectiveness of different engineering baffle designs (e.g., amplitude and interval) in restoring HZ in a straight channel with floodplain using flume experiments and numerical simulations.

II Methodology

The flume model was built in a recirculating box to simulate different hydrological conditions (e.g., streamflow) and baffle designs (e.g., baffle amplitude, interval). Tracer experiments were performed, and results were used to quantify the impacts of baffles designs on the HE fluxes.

Experiment setup

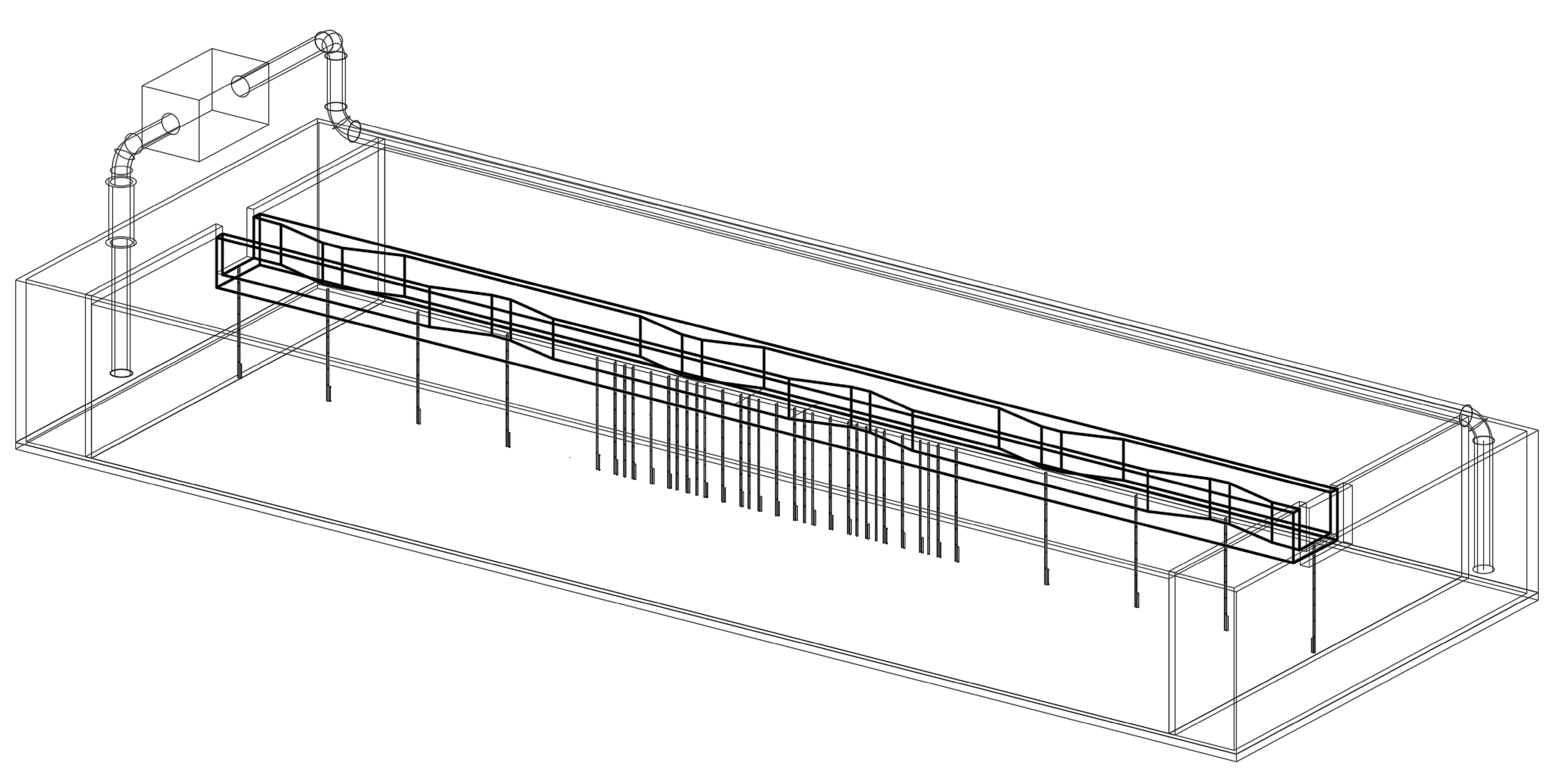


Fig. 2. Schematic experiment setup (unit of mm)

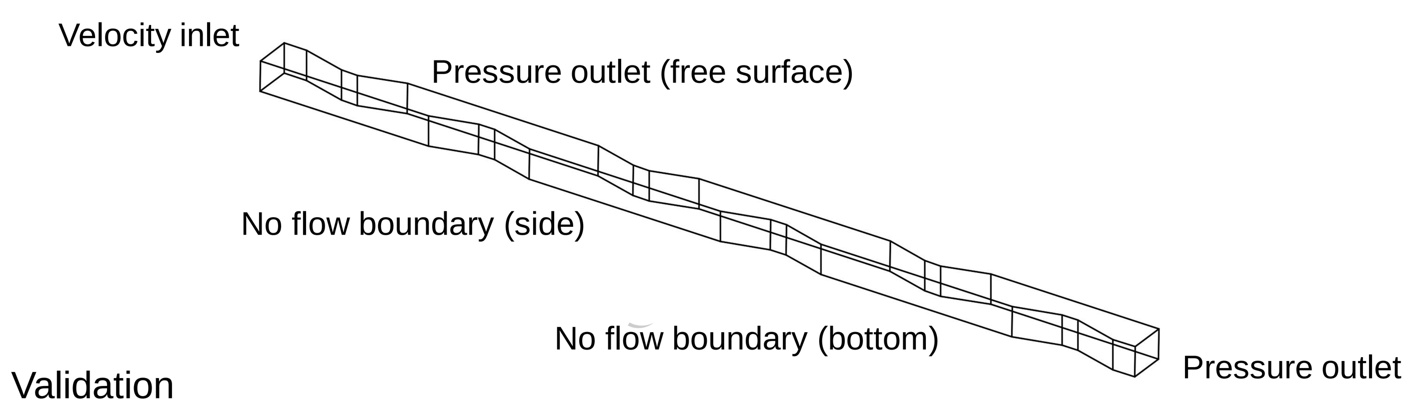
Fig. 3. Pictures of surface water flow in the baffle channel

Numerical simulation

Surface water model and validation

Setup

- ANSYS Fluent
- Two phase simulation using volume of phase method (VoF)
- Reynold-average Navier-Stokes (RANS) equations using the finite-volume method (FVM)
- Realizable k-ϵ Turbulence closure model
- Boundary conditions as below



Validation

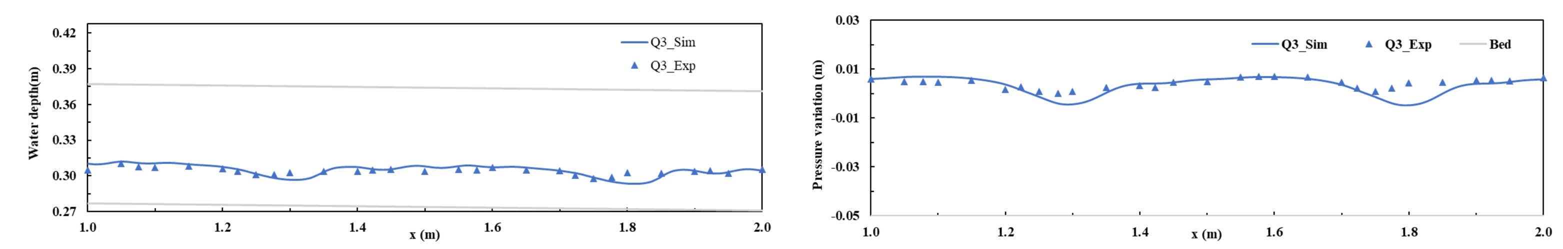
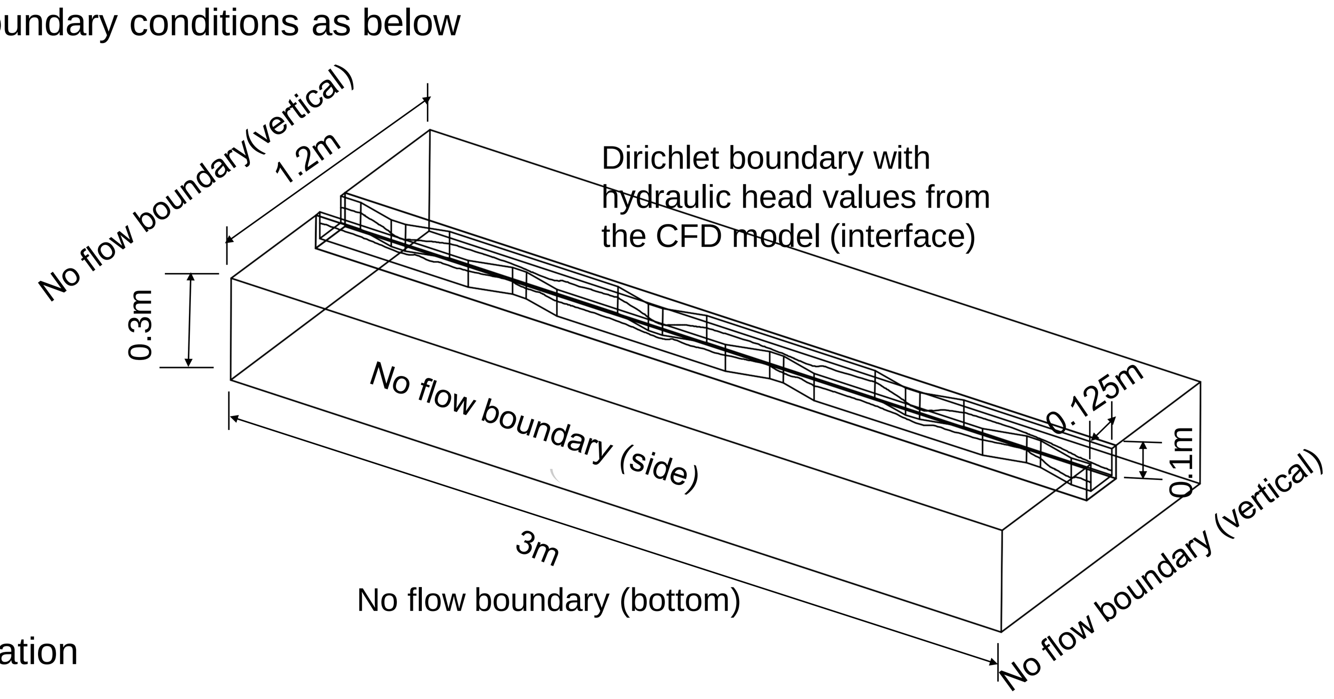


Fig. 4. Comparison of the simulated and measured water depth and pressure variations along streambed for moderate discharge of Q_3. The pressure variations are defined as pressure differences between pressures at various taps and pressure at x=1.0 m. The surface flow in the figure is from left to right.

Groundwater model and validation

Setup

- COMSOL
- Richard's equation using the finite-volume method (FVM)
- Boundary conditions as below



Validation

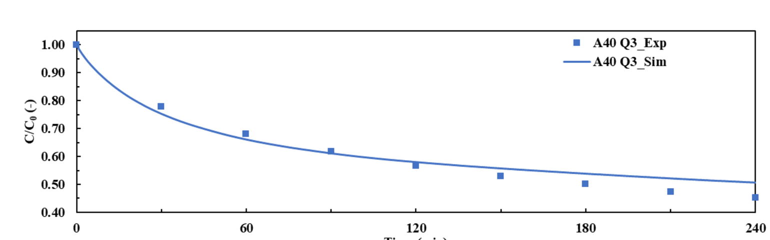
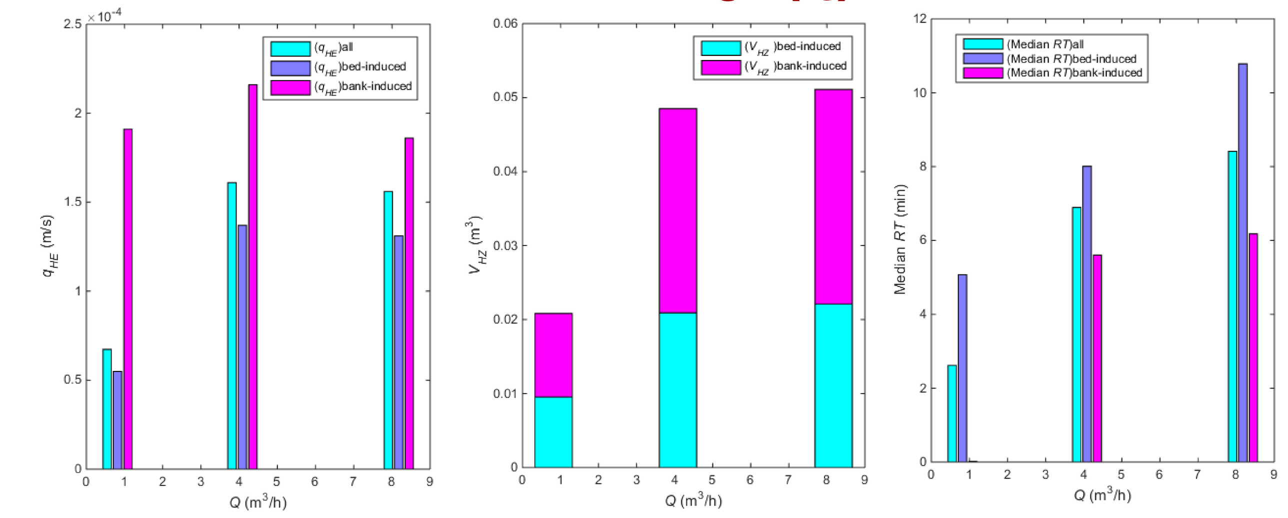


Fig. 5. Comparison of predicted and measured normalized in-stream tracer concentration $C(t)/C_0$ for moderate discharge of Q_3. The figure only shows initial 240 minutes of the data for better comparison.

III Results

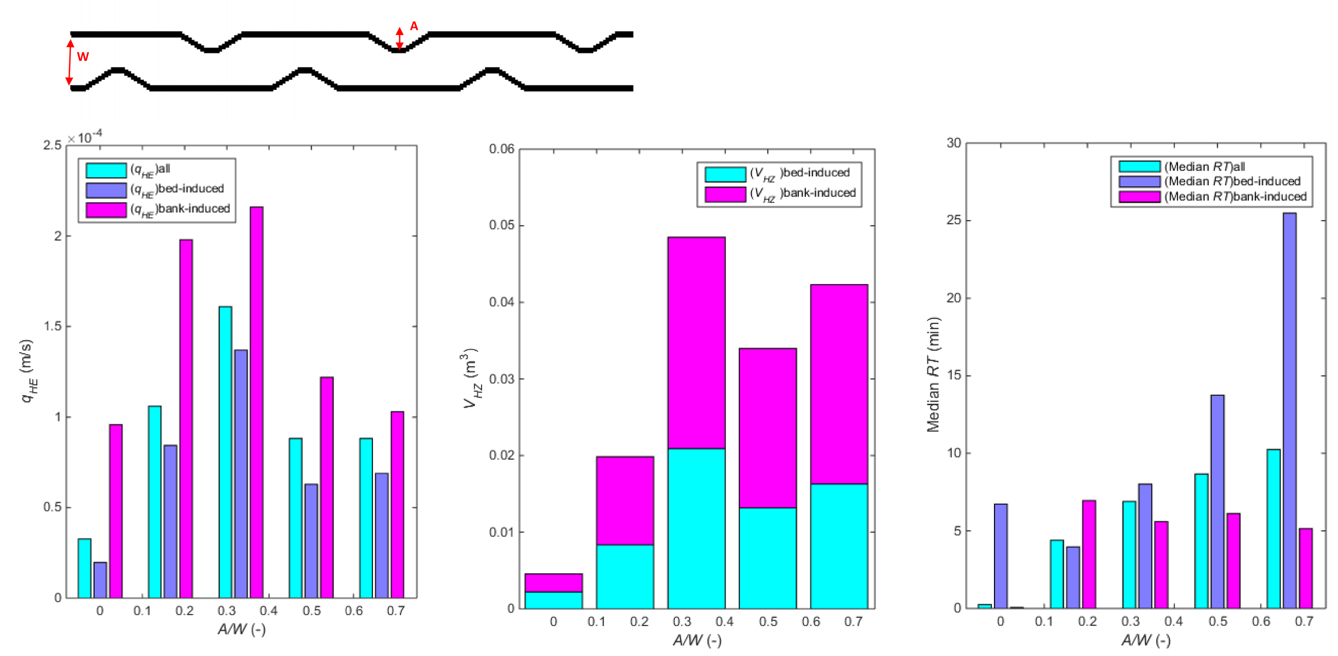
Impacts of surface flow discharge (Q) on the HE



Note: surface flow discharge (Q); HE flowrate (Q_{HE}); HE flux (q_{HE}); HZ volume (V_{HZ}); Median residence time (*MRT*)

The flux of the HE showed a threshold behavior with peak at moderate discharge. The HZ volume and median RT were generally positive related to discharge.

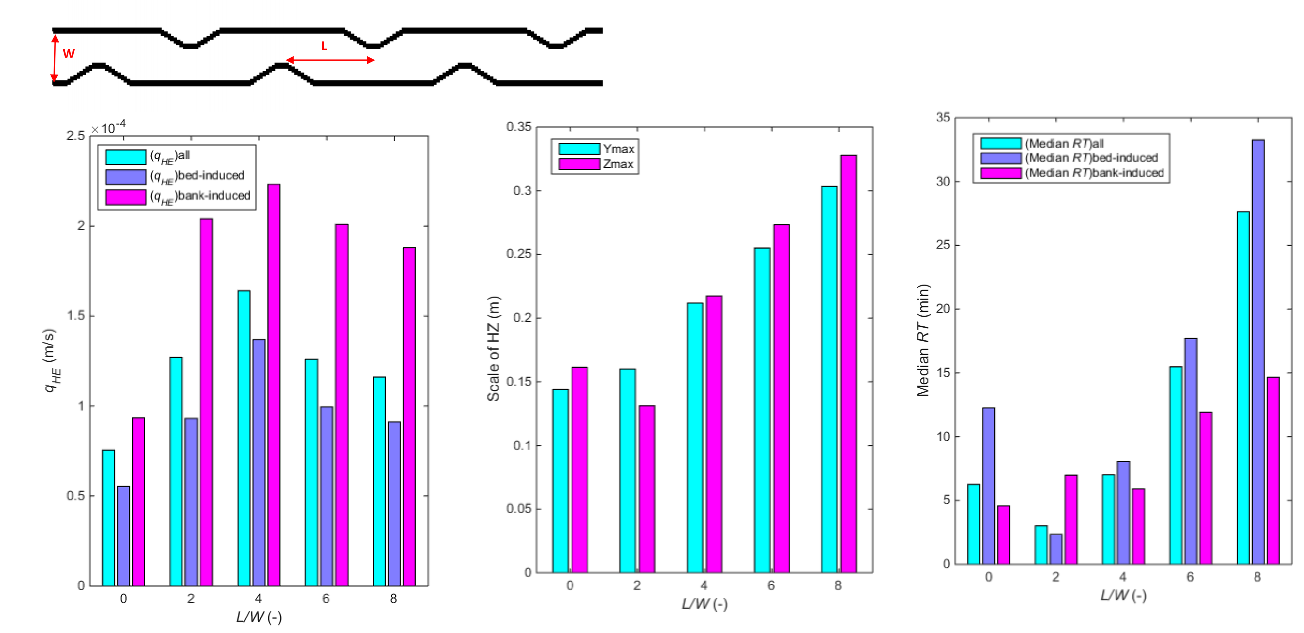
Impacts of baffle amplitude (A) on the HE



Note: baffle amplitudes (A); stream width (W); HE flowrate (Q_{HE}); HE flux (q_{HE}); HZ volume (V_{HZ}); Median residence time (*MRT*)

For fixed baffle interval of four times the stream width, the flux and volume of HE peaked at baffle amplitude of around one third of stream width, while the MRT increased with increasing amplitude.

Impacts of baffle interval (L) on the HE



Notes: baffle intervals (L); stream width (W); HE flowrate (Q_{HE}); HE flux (q_{HE}); Horizontal max travel distance of particles (Ymax); Vertical max travel distance of particles (Zmax); Median residence time (*MRT*)

For fixed baffle amplitude of one third of the stream width, the flux of HE peaked at baffle interval of around four times the stream width, the volume of HE was positively correlated to interval while the MTR had the lowest value at the interval of around two times the stream width.

IV Conclusions and future work

Conclusions

o A threshold behavior is observed for impacts of surface flow discharge, baffle amplitude and interval on the HE flux in a straight baffle channel with floodplain.

oThe HZ volume is generally positive correlated to discharge, baffle amplitude and interval while the median residence time shows more complex patterns.

o The HE on the streambed dominate the HE but the HE on bank is significant and should not be ignored in straight baffle channels.

Future work

o Investigate impacts of channel bed slope on the HE in straight baffle channels.

o Investigate impacts of groundwater flow on the HE in straight baffle channels.

V References and Acknowledgements

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The work described in this poster was fully supported by a grant from the Research Grants Council of the Hong Kong Special Administrative Region, China (Project No. HKU17203815).