SENSITIVITY ANALYSIS OF HYPORHEIC EXCHANGE TO SMALL SCALE CHANGES IN GRAVEL-SAND FLUMEBED USING A COUPLED GROUNDWATER-SURFACE WATER MODEL

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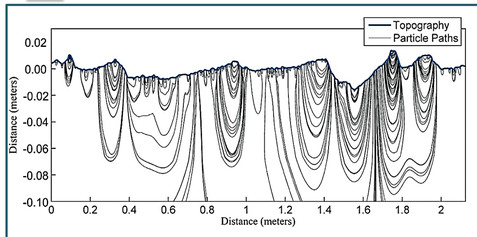
1 MOTIVATION

- Distribution of the hyporheic streamlines and residence time (HRT) is a crucial factor under streambed to understand the transport of nutrients, sediment metabolic rates.
- Due to high heterogeneity in natural streambed, an efficient numerical model setup can prove to be pragmatic in comparison to tedious laboratory experiments
- A robust numerical method could bestow to trace a large number of particles from various seeding locations at the flumebed.
- All of these facts enforce the necessity of numerical modeling of flume experiments to perceive the hyporheic exchange mechanisms in sediment grain scale.

2 INTRODUCTION & AIM



Hydraulic head differences over a channel bed scale up with the obstacle size and have a larger impact on comparably shallow surface water [1].

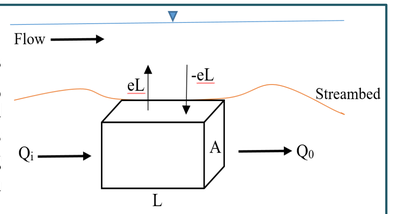
Hyporheic exchange at geomorphic scale (gravel particle scale)

Aims-

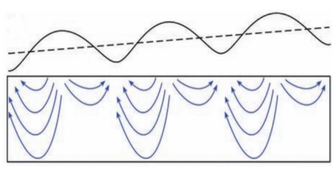
• To couple surface water and groundwater model to generate subsurface velocity vector field in an automated process in a scale of gravel particle size.
• To develop a numerical code to trace particle seeded from the bottom of the streambed hence top of the subsurface model domain.
• To explore the potential effects of particle size and distribution (gravel/sand) on hyporheic streamline and residence time distribution.

3 HYPORHEIC EXCHANGE

• Flow through an element of the streambed. L is length, A is cross-sectional area, Q_i and Q_o are the subsurface inflow and outflow, respectively, and e is the upwelling or downwelling hyporheic flux per unit length (L) of riverbed [2].



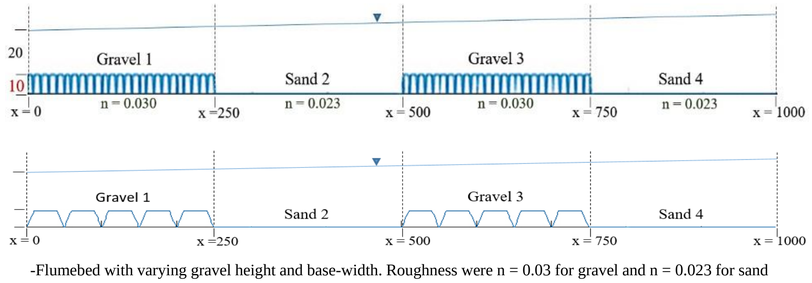
• Depth and spatial pattern of hyporheic exchange (vectors) as a function of the amplitude and wavelength of the hydraulic-head (dotted line) profile [1].



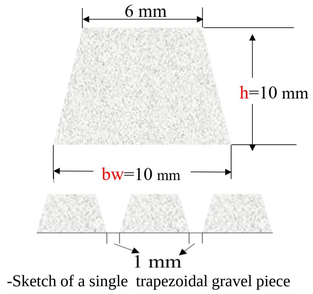
• Hyporheic exchange is driven by spatial changes in the hydraulic head gradient (d^2h/dl^2), spatial changes in the cross-sectional area of sub-surface (dA/dl), and spatial changes in hydraulic conductivity (dK/dl) [2].

$$e = \frac{d\left(-KA\frac{dh}{dl}\right)}{dl} = -KA\frac{d^2h}{dl^2} - K\frac{dA}{dl}\frac{dh}{dl} - A\frac{dK}{dl}\frac{dh}{dl}$$

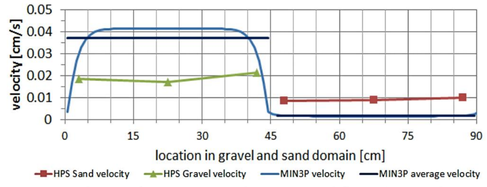
4 METHODOLOGY



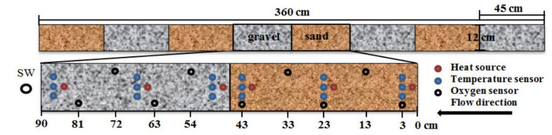
-Flumebed with varying gravel height and base-width. Roughness were n = 0.03 for gravel and n = 0.023 for sand



-Sketch of a single trapezoidal gravel piece

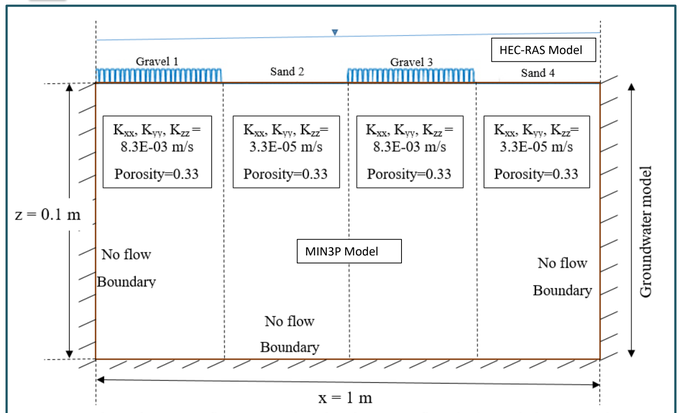


-Pore velocities from MIN3P and experimental flume (Heat Pulse Sensor velocity) used for validating the numerical model [3]



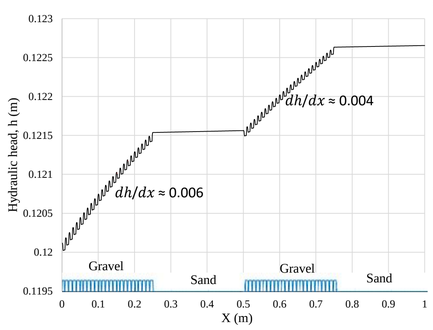
-Schematic representation of aerial view of experimental flumes, alternating sand and gravel compartments along the flume channel. Pore velocity were measured to validate the numerical model [3]

5 COUPLED GW-SW MODEL



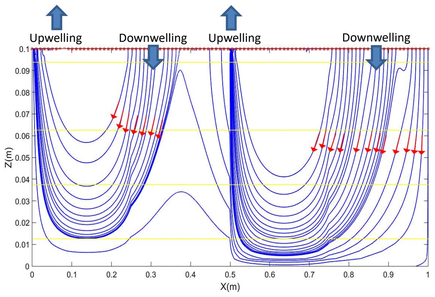
- 1D steady surface water flow was analyzed with varying flumebed morphology. Roughness coefficient were n = 0.03 for gravel and n = 0.023 for sand. Flow regime was set to be subcritical.
- MIN3P, a multicomponent reactive transport code for variably saturated porous media, was used to analyze fully saturated sub-surface flow field.

6 IMPACTS ON RESIDENCE TIME

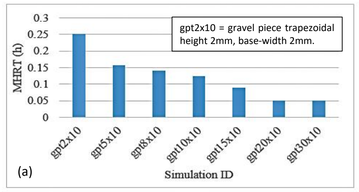


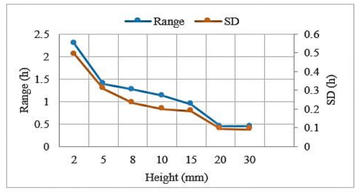
Distribution of hydraulic head over the length of flume bed generated from the coupled model. Hydraulic head gradients (dh/dx) were generated by the altering particle types.

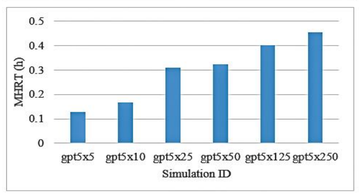
The "gpt10x10" stands for "gravel piece trapezoidal" with height and base-width 10mm each.

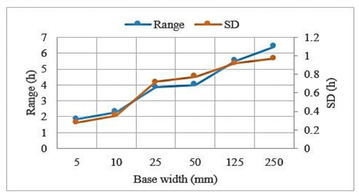


Distribution of streamlines of the particles seeded from the model surface (z=0.1). Hydraulic head distribution over flumebed was generated using HEC-RAS and imported to MIN3P as boundary condition. Shape and Length of streamlines are highly sensible to the boundary conditions both at surface water and groundwater domain.

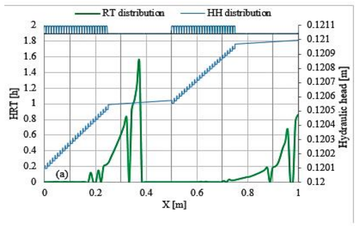


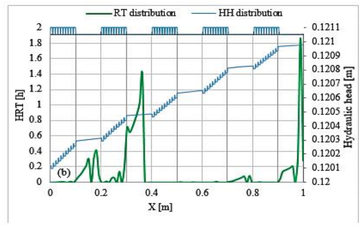


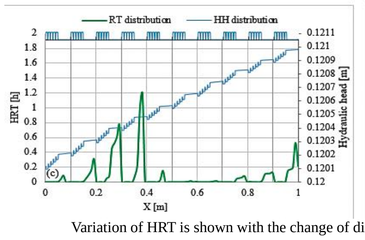


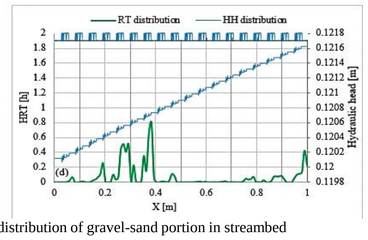


Impact of the size of gravel particle on mean, range and SD of mean hyporheic residence time (MHRT)



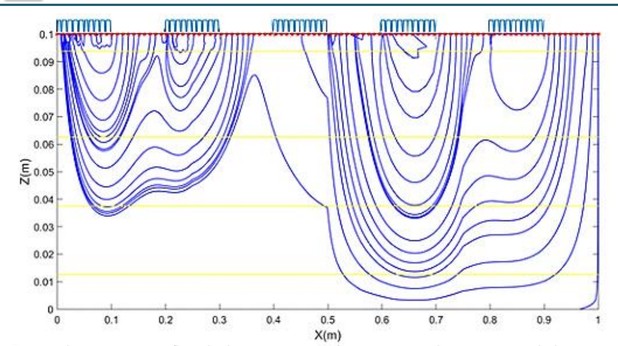






Variation of HRT is shown with the change of distribution of gravel-sand portion in streambed

7 HYPORHEIC STREAMLINE



- Due to the variation in flumebed geometry i.e. change in gravel piece size and shape as well as the distribution of gravel and sand portion, variation in the length, shape and distribution of streamlines were observed. Consequently, alterations in the magnitude of HRT were resulted which is crucial for the metabolism of micro-organisms living near streambed sediment.

8 CONCLUSION

- The hyporheic exchange, the extent of stay of particles/nutrients in subsurface is highly sensitive to the small-scale change in flumebed geometry.
- Size and shape variation of gravel piece alter hyporheic exchange.
- High number of seeding location is a prerequisite for better prediction.
- Stream bed morphology, hydraulic heads, flow field in the subsurface and hyporheic exchange are interlinked.
- Further quantification of the linkage among them to build a robust mathematical relationship is recommended.

References:

[1] J. M. Buffington, D. Tonina, Hyporheic Exchange in Mountain Rivers II: Effects of Channel Morphology on Mechanics, Scales, and Rates of Exchange, Geography Compass 3/3, 1038-1062, 10.1111, 2009.
[2] W. J. Vaux, Interchange of stream and intragravel water in a salmon spawning riffle. Washington, DC: US Fish and Wildlife Service Special Scientific Report, Fisheries 405, 1962.
[3] N. Altenkirch, S. Zlatanovica, K. Woodward, N. Trauth, M. Mutz, F. Mokenthin, Untangling hyporheic residence time distributions and whole stream metabolism using a hydrological process model, 12th International Conference on Hydroinformatics, HIC, 2016.