Evaluate the impact of hydrodynamic pressure on hydrologic exchange fluxes and resident time for a large-scale river section over a long-term period

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Abstract

Quantifying hydrologic exchange fluxes (HEF) and subsurface water residence times (RT) are important for managing the water quality and ecosystem health in dynamic river corridor systems. Laboratory-scale experiments and models have shown that hydrodynamic pressure variations on the riverbed induced by dynamic river flows can strongly impact HEFs and RTs. In this study, the impacts of hydrodynamic pressure on HEFs and RT for a 30 km section of the Columbia River in Washington State over a three-year period were quantitatively evaluated using a coupled transient three-dimensional (3D) multi-phase surface and subsurface water flow transport approach. Based on comparisons between model simulations with and without considering hydrodynamic pressure, we found that hydrodynamic pressure increase the net HEFs by 7% of flowing into river from subsurface domain, and also leads to a reduction of the area with long RT, and increase of area with short RT.

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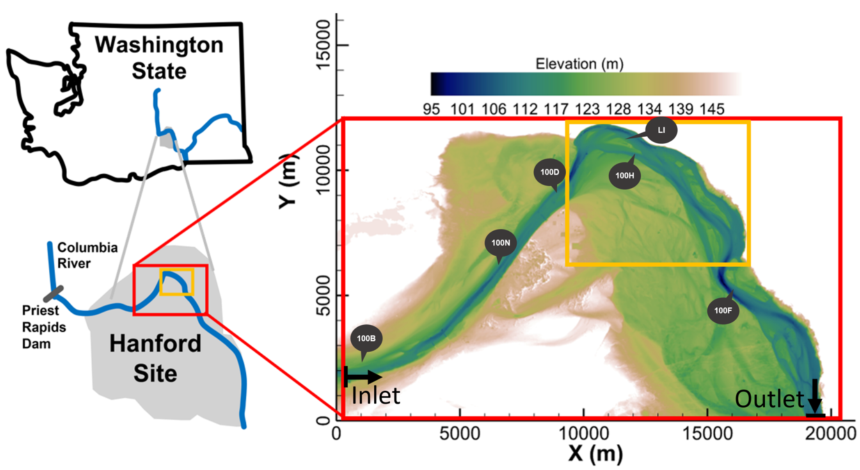
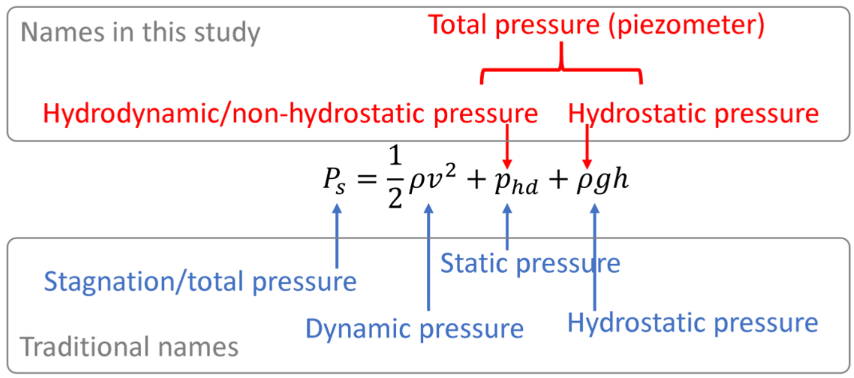
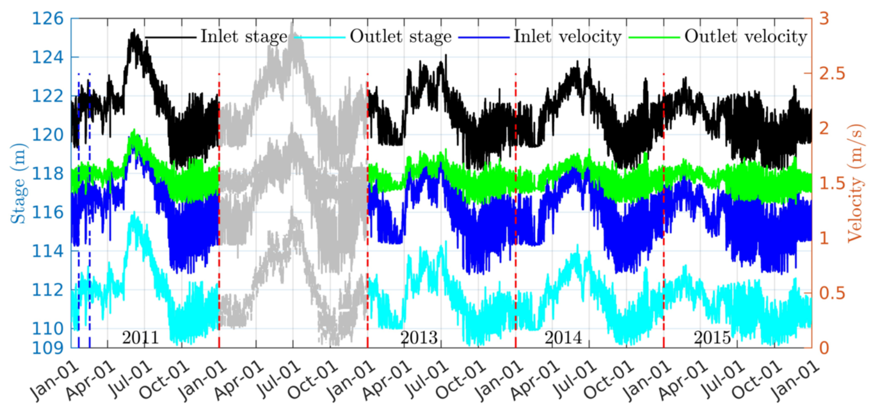
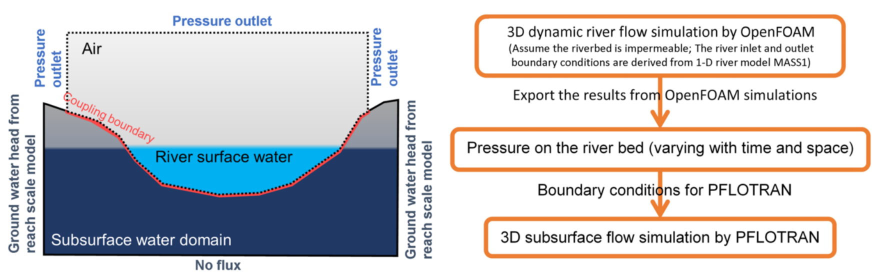
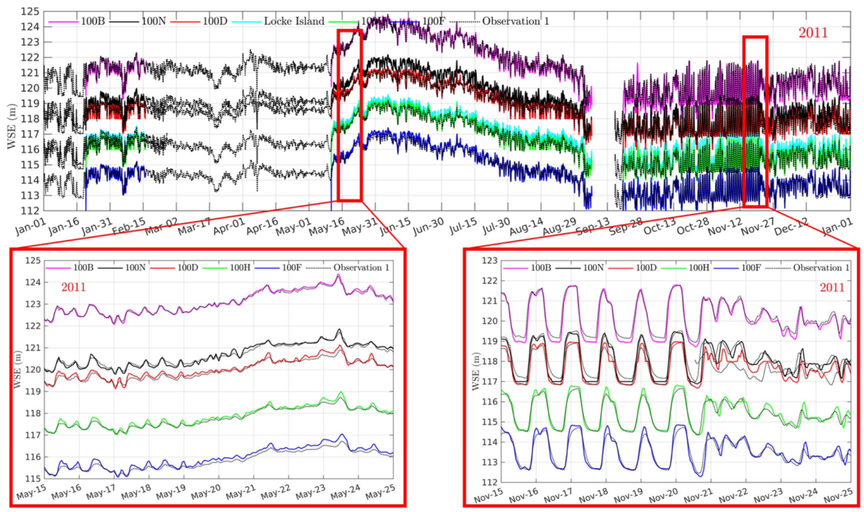



Names in this study
Total pressure (piezometer)
Hydrodynamic/non-hydrostatic pressure
Hydrostatic pressure
$P_s = \frac{1}{2}\rho v^2 + p_{hd} + \rho g h$
Stagnation/total pressure
Static pressure
Dynamic pressure
Hydrostatic pressure
Traditional names

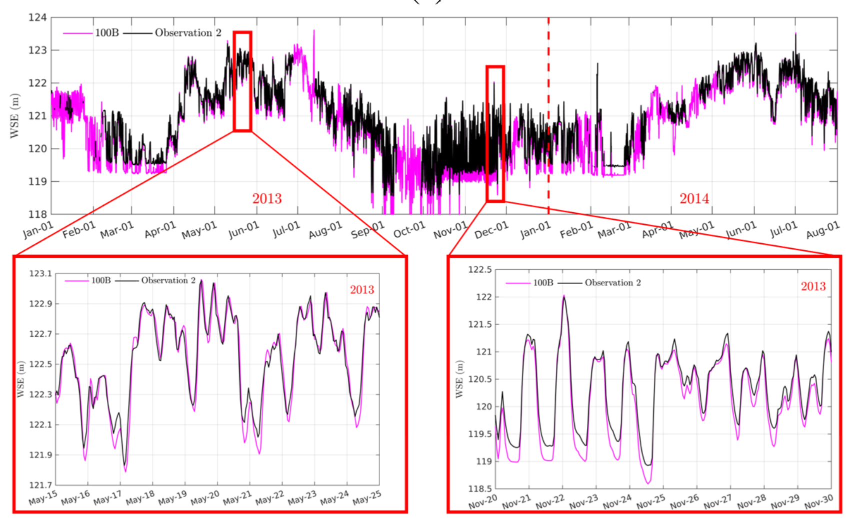

Inlet stage
Outlet stage
Inlet velocity
Outlet velocity
Stage (m)
Velocity (m/s)
126
124
122
120
118
116
114
112
110
109
3
2.5
2
1.5
1
0.5
0
2011
2013
2014
2015
Jan-01
Apr-01
Jul-01
Oct-01


Pressure outlet
Pressure outlet
Pressure outlet
Air
Coupling boundary
River surface water
Subsurface water domain
Ground water head from reach scale model
Ground water head from reach scale model
No flux
3D dynamic river flow simulation by OpenFOAM
(Assume the riverbed is impermeable; The river inlet and outlet boundary conditions are derived from 1-D river model MASS1)
Export the results from OpenFOAM simulations
Pressure on the river bed (varying with time and space)
Boundary conditions for PFLOTRAN
3D subsurface flow simulation by PFLOTRAN

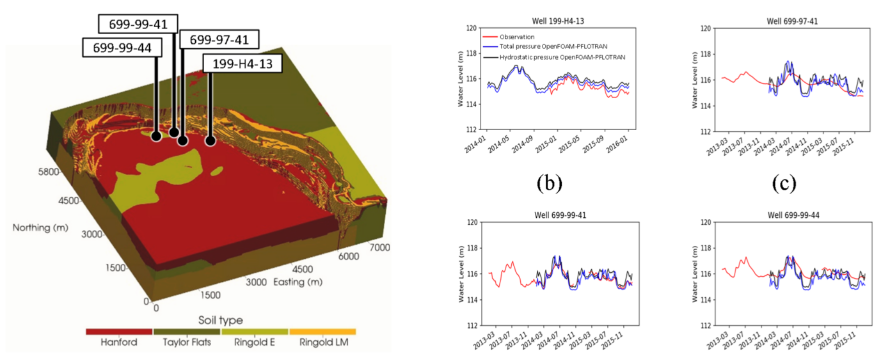
(a) (b)


100B
100N
100D
Locke Island
100H
100F
Observation 1
WSE (m)
2011

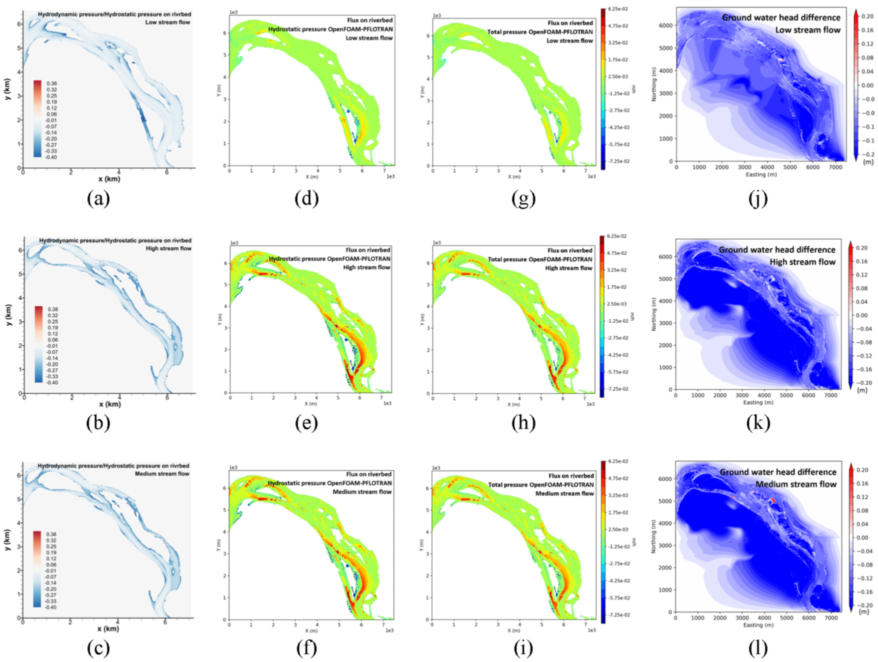
(a)


100B
Observation 2
WSE (m)
2013
2014

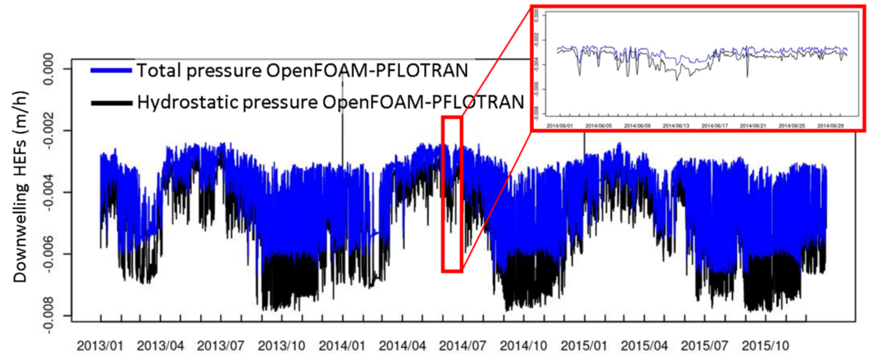
(b)


699-99-41
699-99-44
699-97-41
199-H4-13
Northing (m)
Easting (m)
Soil type
Hanford
Taylor Flats
Ringold E
Ringold LM
Well 199-H4-13
Well 699-97-41
Well 699-99-41
Well 699-99-44
Observation
Total pressure OpenFOAM-PFLOTRAN
Hydrostatic pressure OpenFOAM-PFLOTRAN
Water Level (m)

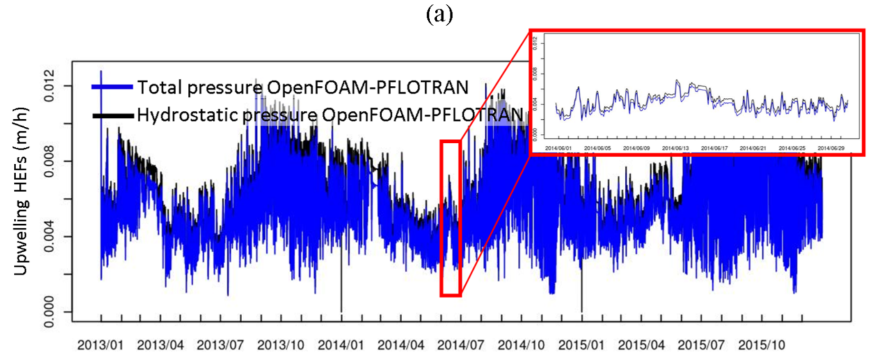
(a) (b) (c) (d) (e)



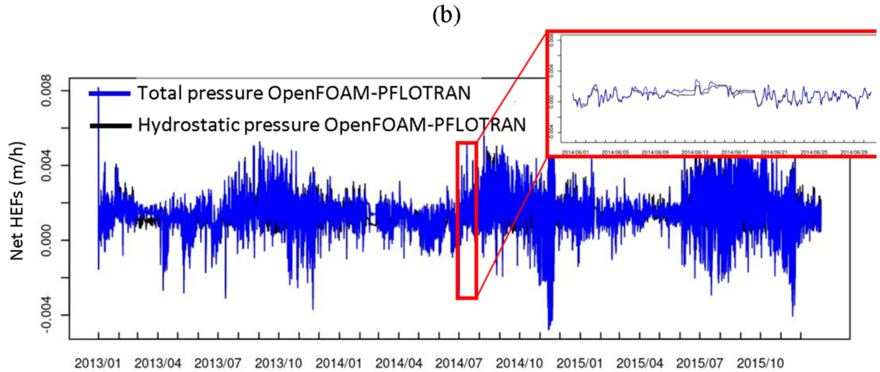
Hydrodynamic pressure/Hydrostatic pressure on rivrbed
Low stream flow
High stream flow
Medium stream flow
x (km)
y (km)
Flux on riverbed
Hydrostatic pressure OpenFOAM-PFLOTRAN
Total pressure OpenFOAM-PFLOTRAN
Ground water head difference
Easting (m)
Northing (m)
(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)
(j)
(k)
(l)


Total pressure OpenFOAM-PFLOTRAN
Hydrostatic pressure OpenFOAM-PFLOTRAN
Downwelling HEFs (m/h)
0.000
-0.002
-0.004
-0.006
-0.008
2013/01
2013/04
2013/07
2013/10
2014/01
2014/04
2014/07
2014/10
2015/01
2015/04
2015/07
2015/10

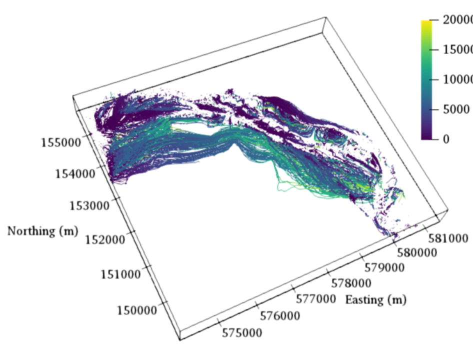
(a)

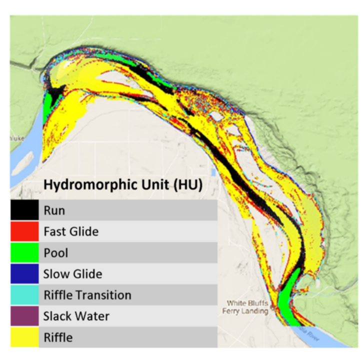

Total pressure OpenFOAM-PFLOTRAN
Hydrostatic pressure OpenFOAM-PFLOTRAN
Upwelling HEFs (m/h)
0.012
0.008
0.004
0.000
2013/01
2013/04
2013/07
2013/10
2014/01
2014/04
2014/07
2014/10
2015/01
2015/04
2015/07
2015/10

(b)


Total pressure OpenFOAM-PFLOTRAN
Hydrostatic pressure OpenFOAM-PFLOTRAN
Net HEFs (m/h)
0.008
0.004
0.000
-0.004
2013/01
2013/04
2013/07
2013/10
2014/01
2014/04
2014/07
2014/10
2015/01
2015/04
2015/07
2015/10

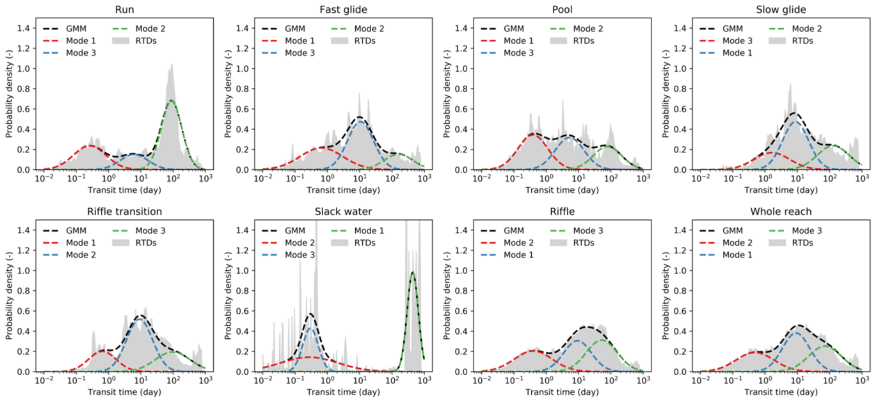
(c)


Residence time (hr)
20000
15000
10000
5000
0
Northing (m)
155000
154000
153000
152000
151000
150000
Easting (m)
575000
576000
577000
578000
579000
580000
581000


Hydromorphic Unit (HU)
Run
Fast Glide
Pool
Slow Glide
Riffle Transition
Slack Water
Riffle
White Bluffs Ferry Landing

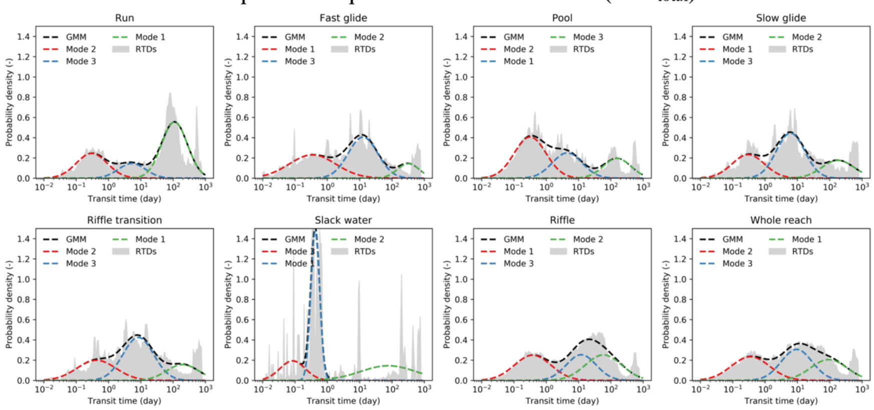
(a) (b)

Hydrostatic pressure OpenFOAM-PFLOTRAN (OFP_{static})



(a)

Total pressure OpenFOAM-PFLOTRAN (OFP_{total})



(b)