Are channels standalone? Analysis of channel-land interactions using PAWS+CLM

Chaopeng Shen and Kurt Smithgall

Civil and Env. Engr.

Penn State Univ

Outline

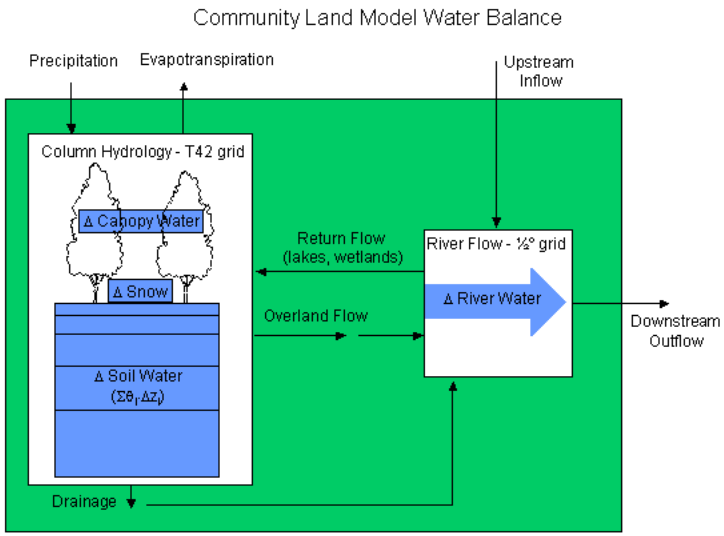
- Land-channel interactions
- Existence of the fan of influence (FoI) of streams
- Systematic experiments to quantify FoI

River transport model in the land model

- River Transport Model (RTM) in CLM, or VIC
- Recent updates in MOSART greatly enhanced in-channel process representation (temperature, velocity)

No feedback!

Does channel processes influence upland dynamics?

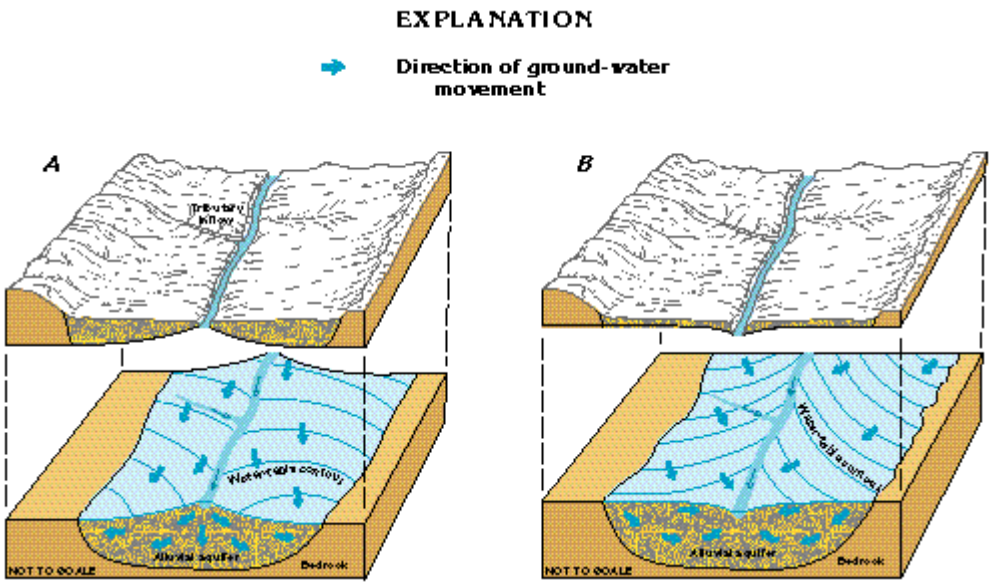


Column (T42): Precipitation + Return - Evapotranspiration - Total Runoff
River (½°): Inflow + Total Runoff - Return - Outflow
Grid Cell (T42): Precipitation + Inflow - Evapotranspiration - Outflow

http://www.cgd.ucar.edu/tss/clm/components/hydrocycle.html

Channel-land interactions

- Channels serve as boundary conditions for groundwater flow
- Bank storage and return flow
- Flood innundation
- Hyporheic exchange



http://pubs.usgs.gov/ha/ha730/ch_f/F-text2.html

Research questions

Using a physically-based hydrologic-land surface model (PAWS+CLM), we attempt to understand:

- Does the density of simulated channel network influence upland hydrology and BGC?
- What are the controlling factors of the influences?
- What are the spatial extent and magnitudes of the influences?

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- Land-channel interactions
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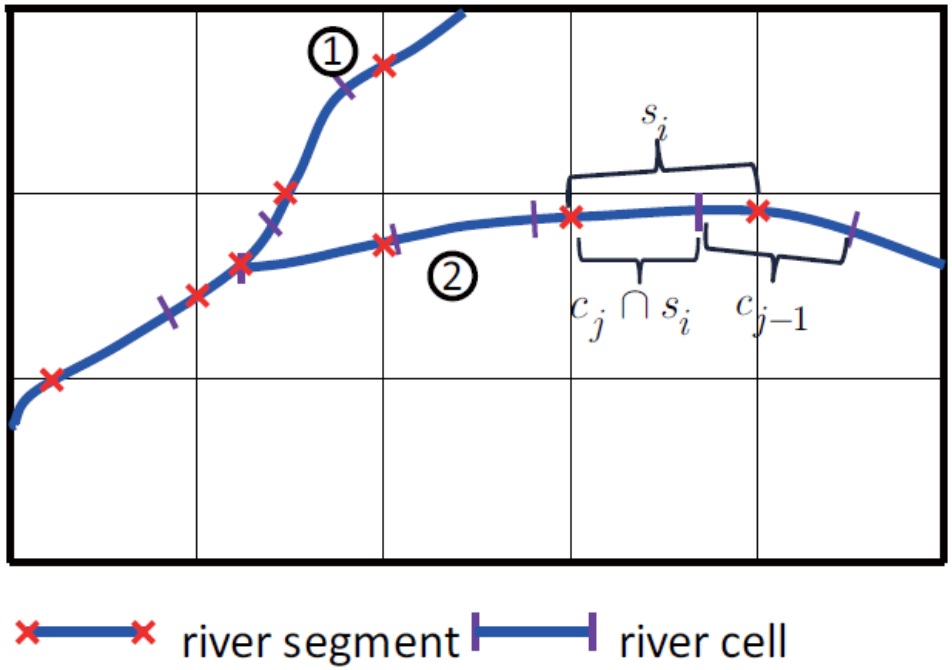
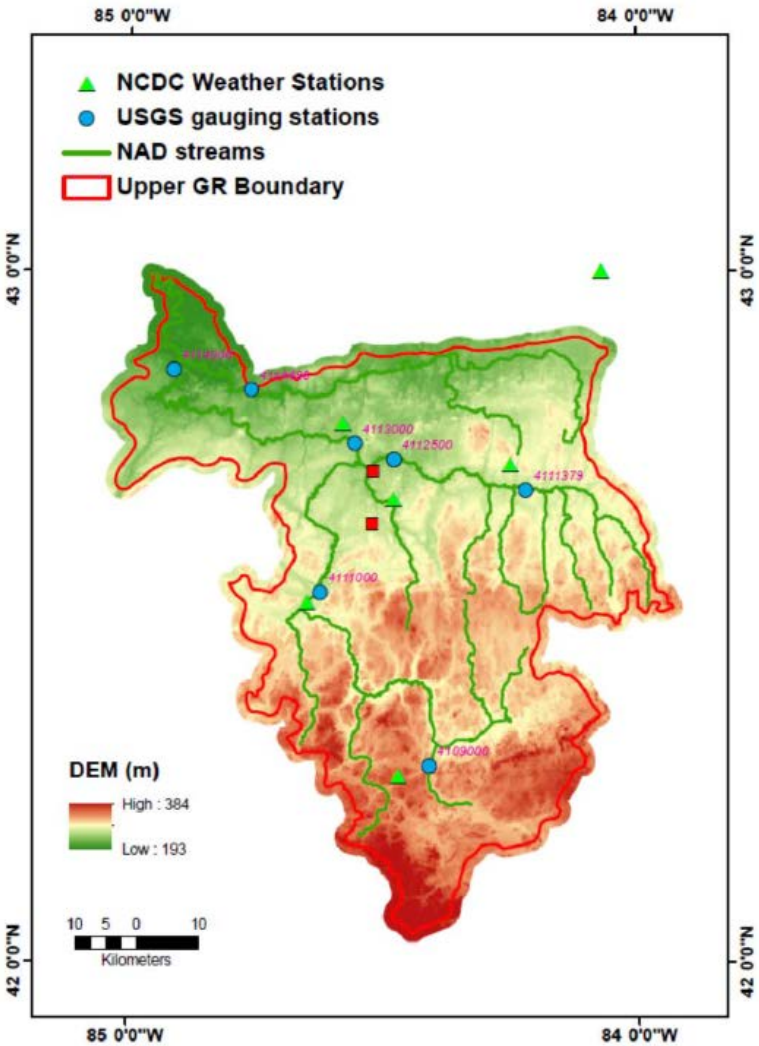
Channel-land interactions represented in PAWS+CLM

- Overland flow (OVN) with lowland storage (9-point adaptive FV scheme)
- Explicitly represented channel network (DiW or DyW)
- Overland-channel exchange
- GW-channel exchange (Darcy's law)
- Lowland-GW exchange (Darcy's law)



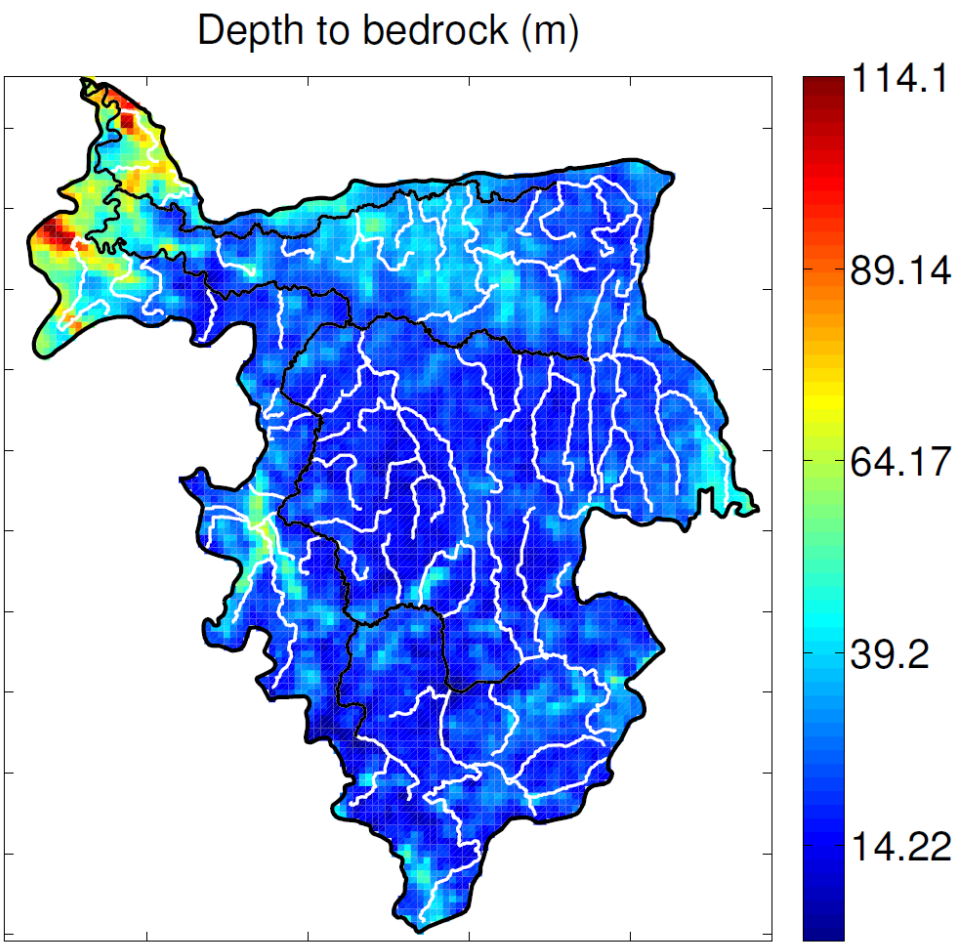
Test basin

- Upper Grand (4527 km^2)
- Humid-continental climate
- Annual precip ~900mm
- Stream network is dense



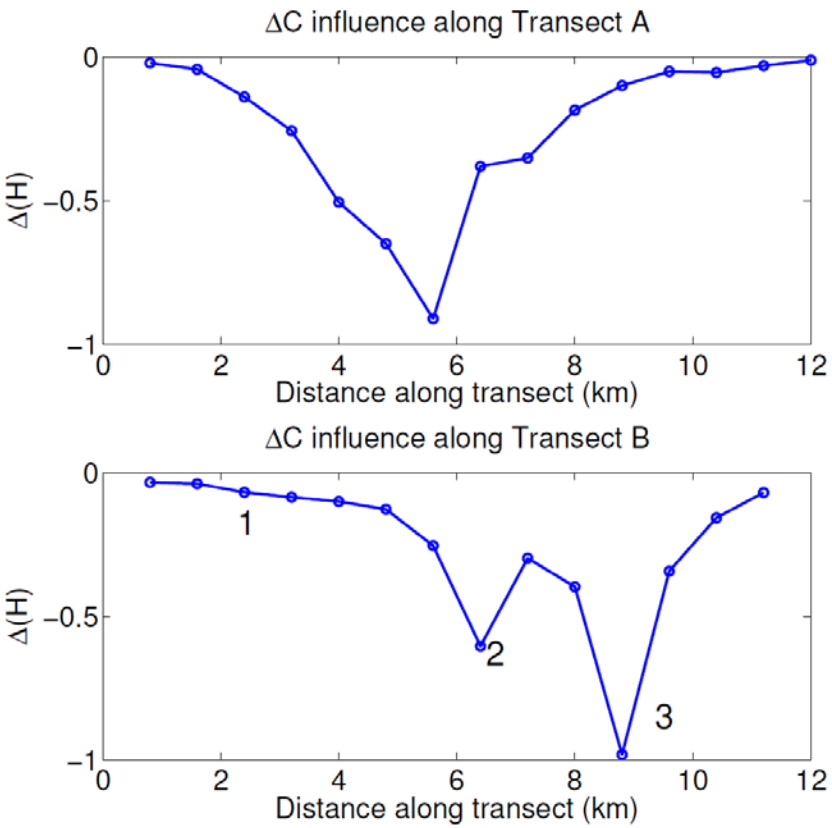
An initial investigation

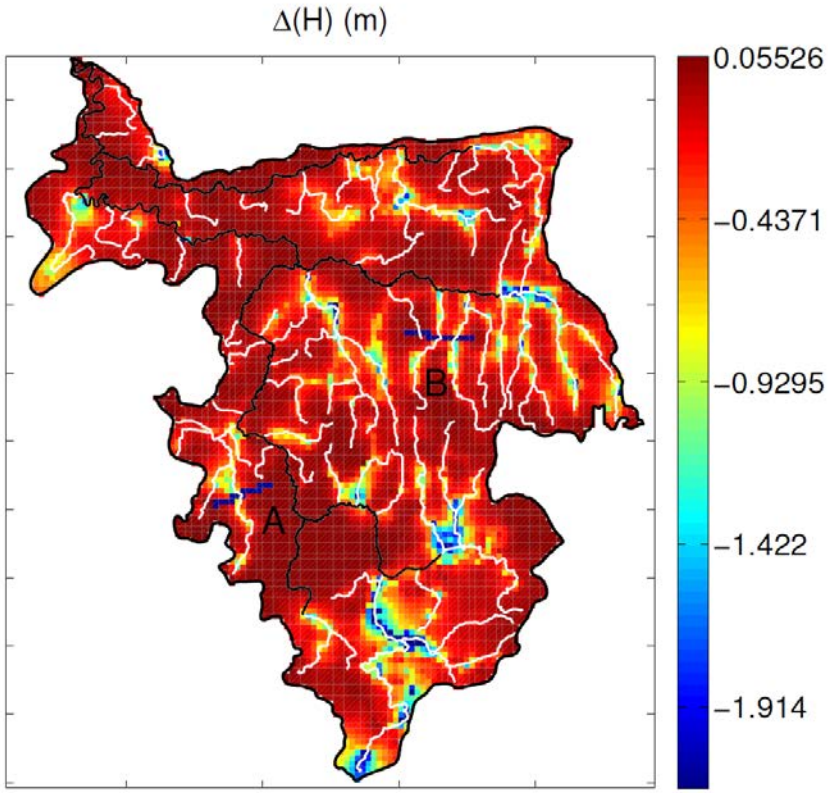
- We removed channels from a base simulation with dense channel network (0.3011 km/km^2)
- Removed channel segments→ΔC
- OVN takes the role of channel network



Groundwater level dropped near ΔC

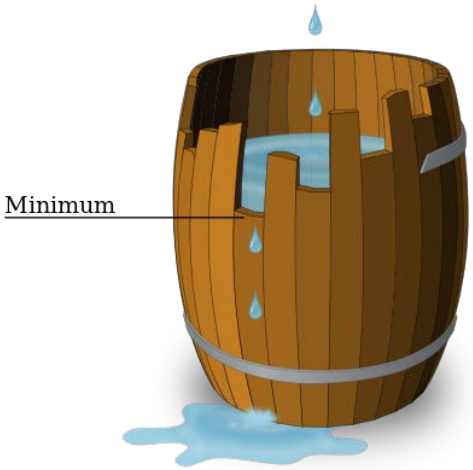
- We notice a “fan of influence” (FoI) of the streams.
- The FoI for variable *v* is defined as the zone where significant change in *v* is observed due to the presence of channels





Mechanisms 1: GW exfiltration via river bed

- Increased baseflow: Liebig's barrel.
- Elevation often decline sharply near streams, which are often thin features not captured by land grid.

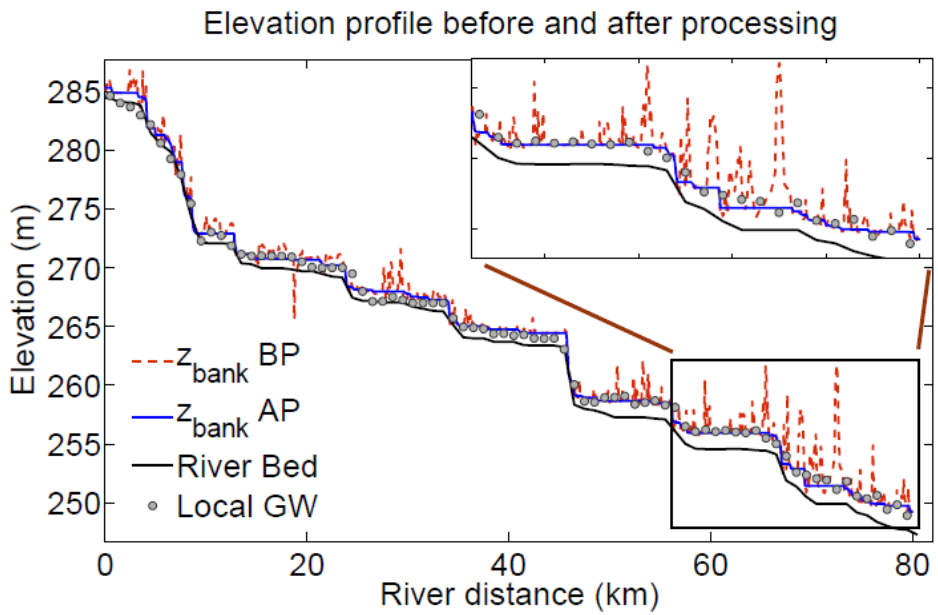


http://en.wikipedia.org/wiki/Liebig%27s_law_of_the_minimum

- Only significant for gaining streams (higher order streams)

Negative feedback between channel stage and GW level

- In fact, our extracted river bank elevation agreed well with local GW level.



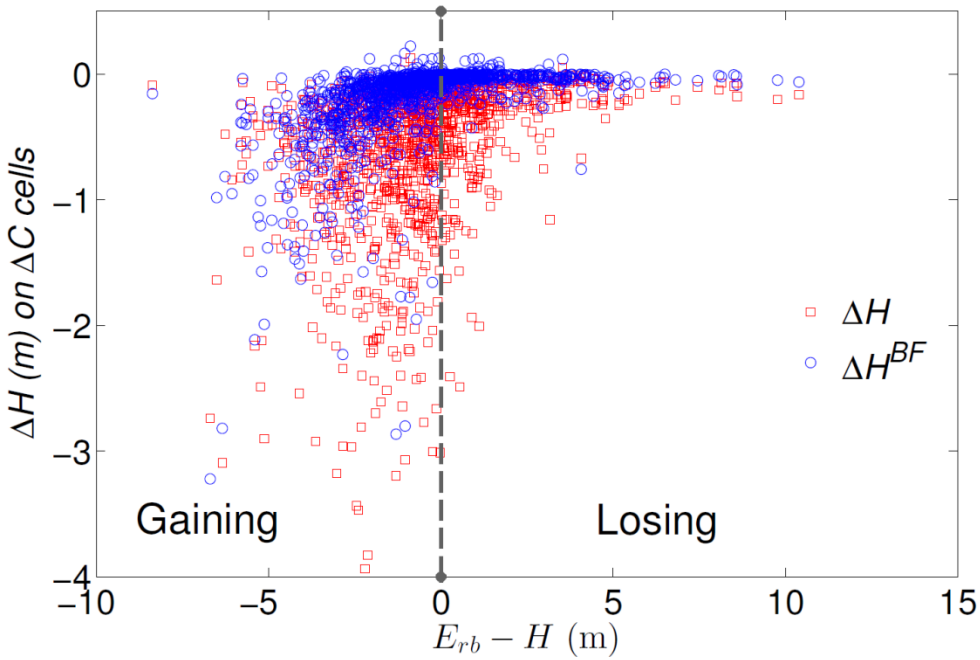
Shen, C., Niu, J. and Fang, K.: Quantifying the effects of data integration algorithms on the outcomes of a subsurface–land surface processes model, Environ. Model. Softw., 59, 146–161, doi:10.1016/j.envsoft.2014.05.006, 2014.

Baseflow only simulations

(BF) removes surface flow.

BF sims help single out effects of GW flow

$\Delta H^{BF}(\Delta C)$ is only significant near ΔC segments that were gaining baseflow.



E_{rb}: river bed elevation

Controlling factors of $\Delta H^{BF}(\Delta C)$

- Regression analysis reveals that $\Delta H^{BF}(\Delta C)$ is controlled by *L* and its spatial auto-correlation
- $L = \frac{(E_{rb} - H)}{\Delta z_b} \times K_{rb} \times w \times l$

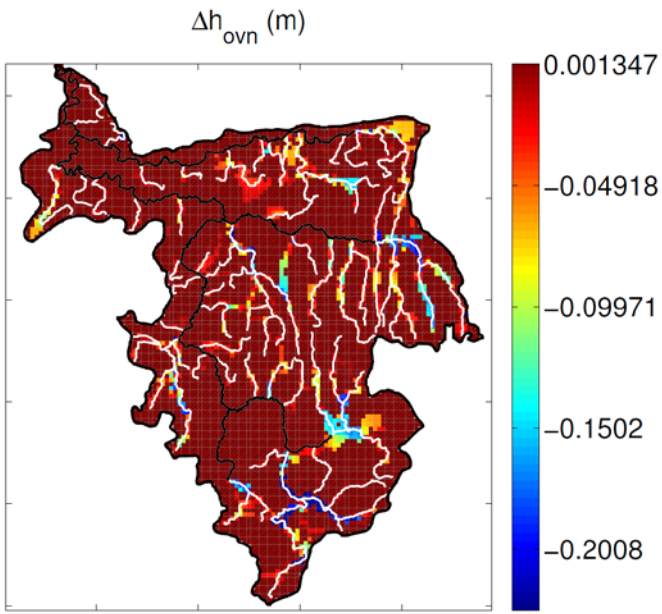
This the baseflow formula in PAWS

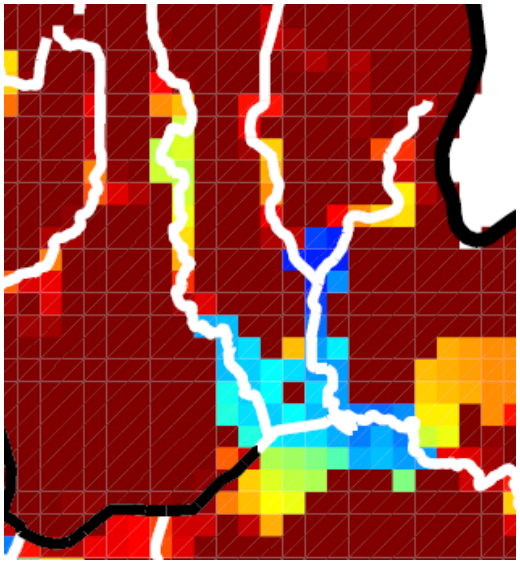
(K_{rb}: hydraulic cond. river bed material, w, river width, l, length of intersecting river segments)

- Multiple regress using L, its autocorrelation index and first order interaction explained 70% of the variance in $\Delta H^{BF}(\Delta C)$

Mechanisms 2: Faster conveyance by streams

- Although sinks are removed from elevation grid, and overland is capable of eventually directing all runoff downstream, channel network is much more efficient at conveyance.
- Therefore, channel network reduces surface ponding storage and re-infiltration

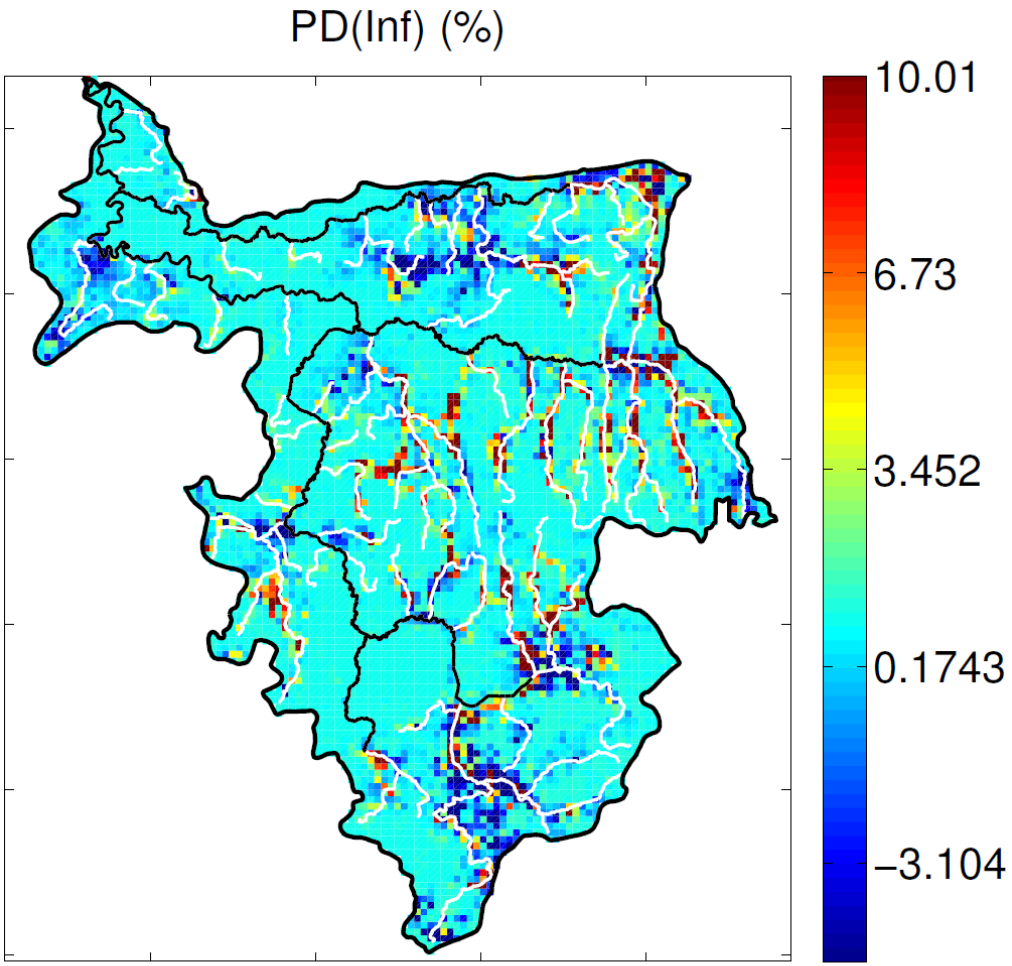




Influence of streams on fluxes…

- Infiltration

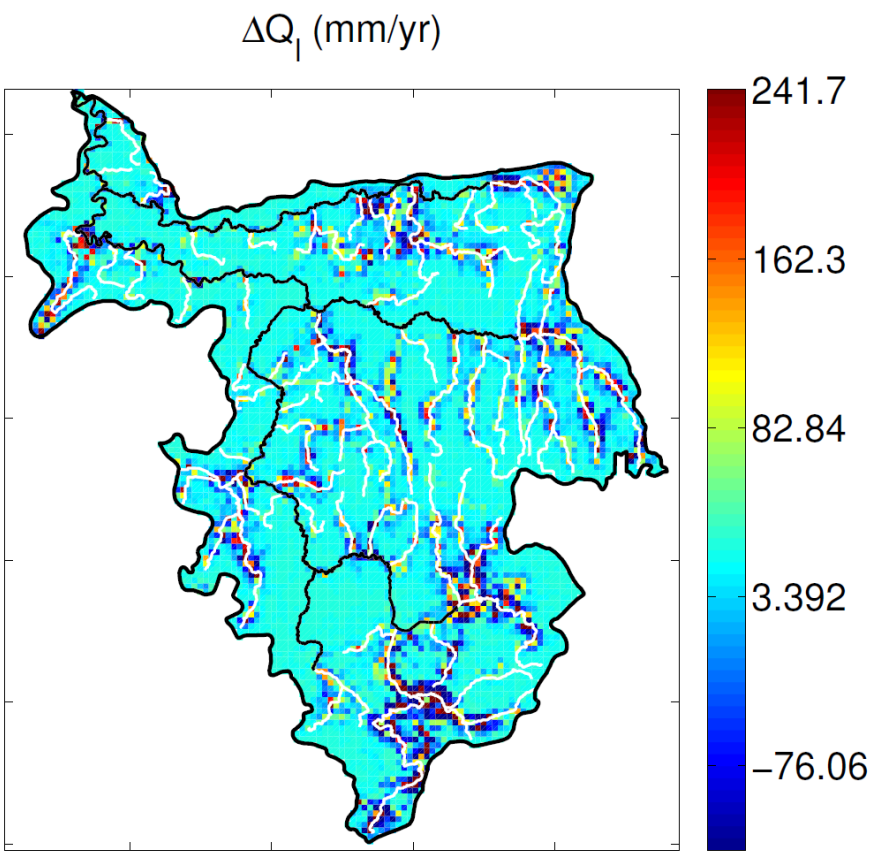
More infiltration on ΔC-cells.



Influence of streams on fluxes…

- $Q_L = \frac{\partial}{\partial x}\left(T_x \frac{\partial H}{\partial x}\right) + \frac{\partial}{\partial y}\left(T_y \frac{\partial H}{\partial y}\right)$

ΔC-cells have a lot more inflow, while adjacent cells lose more water

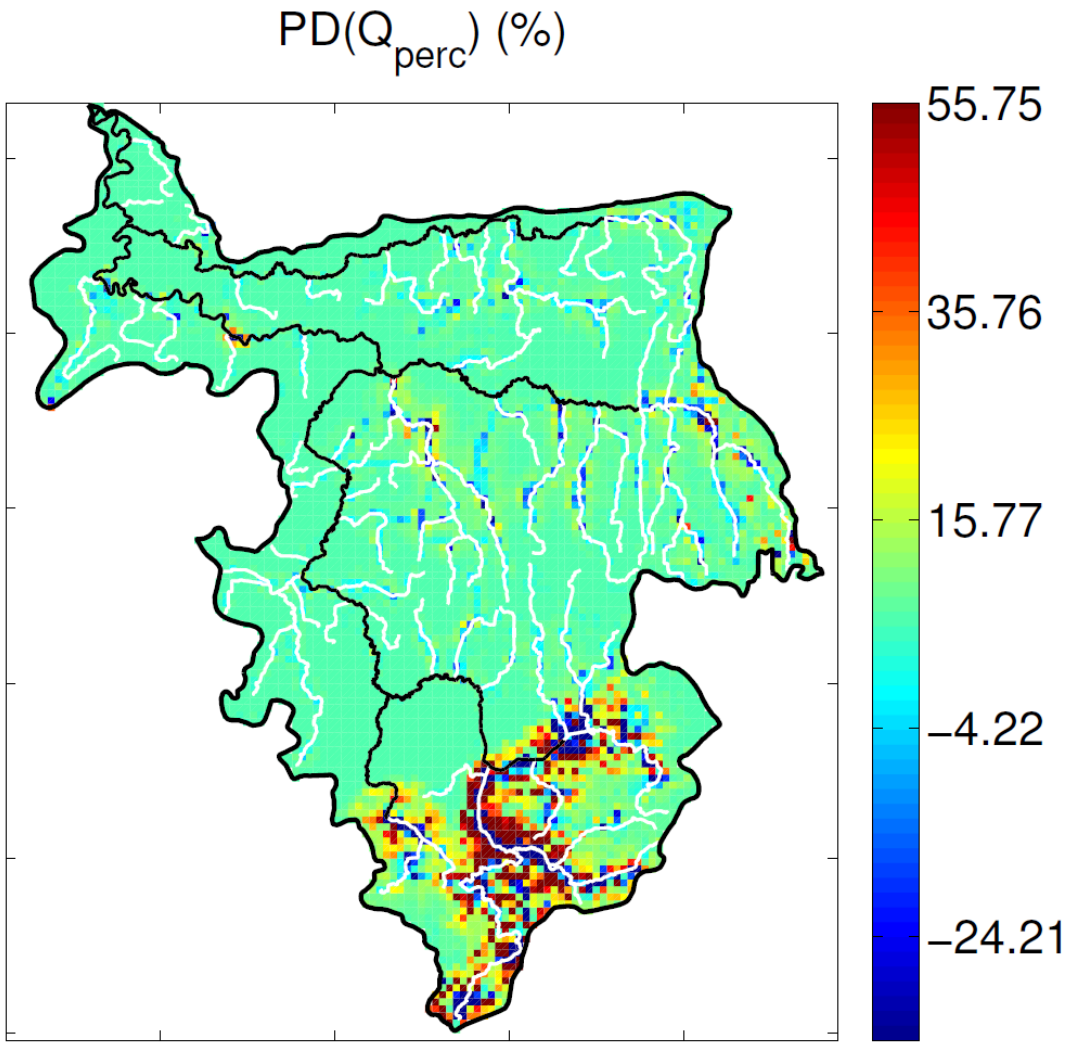


Influence of streams on fluxes…

- Q_{perc}
  Deep percolation

More deep percolation in adjacent cells, which then exiltrate under channel bed.

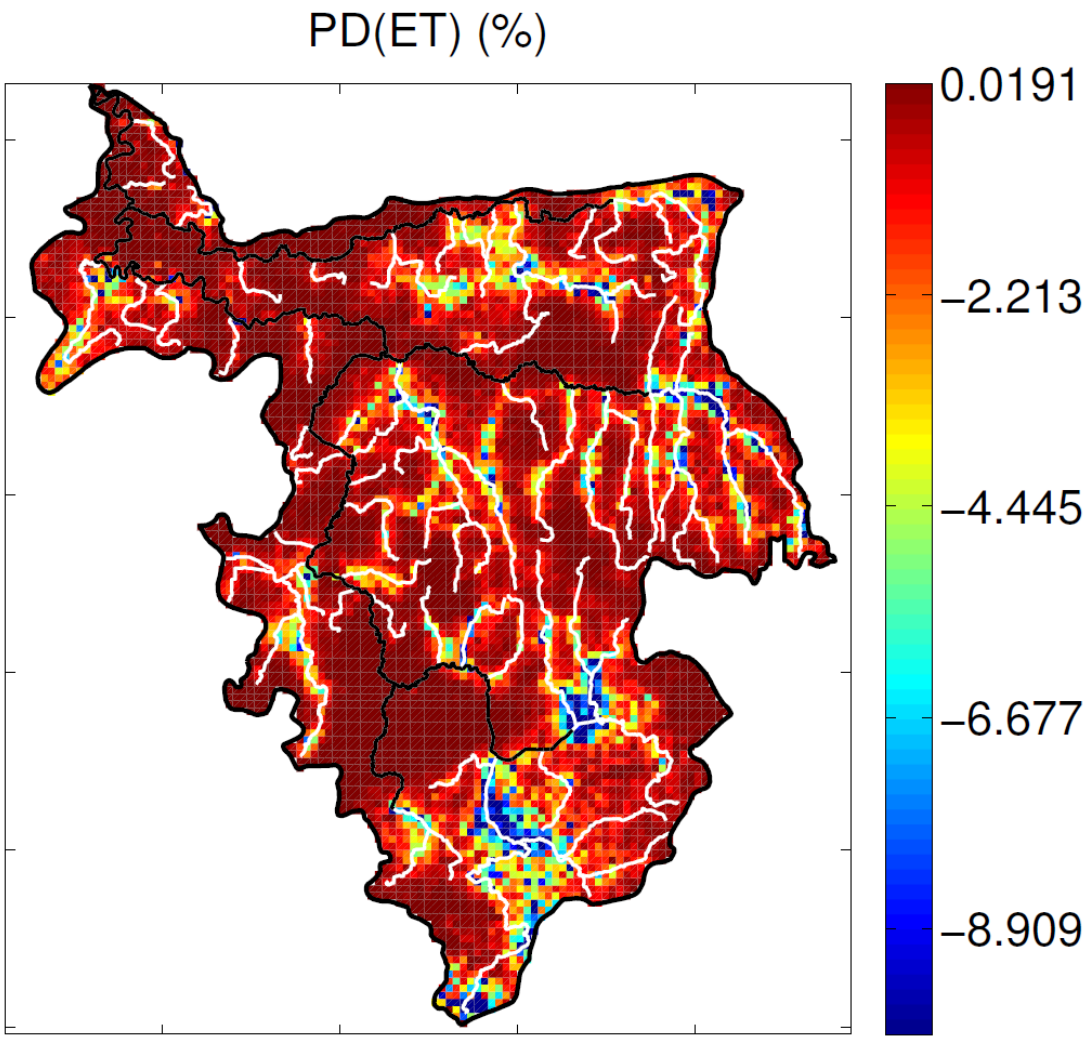
Stronger flow componets in all directions!



Influence of streams on fluxes…

- ET

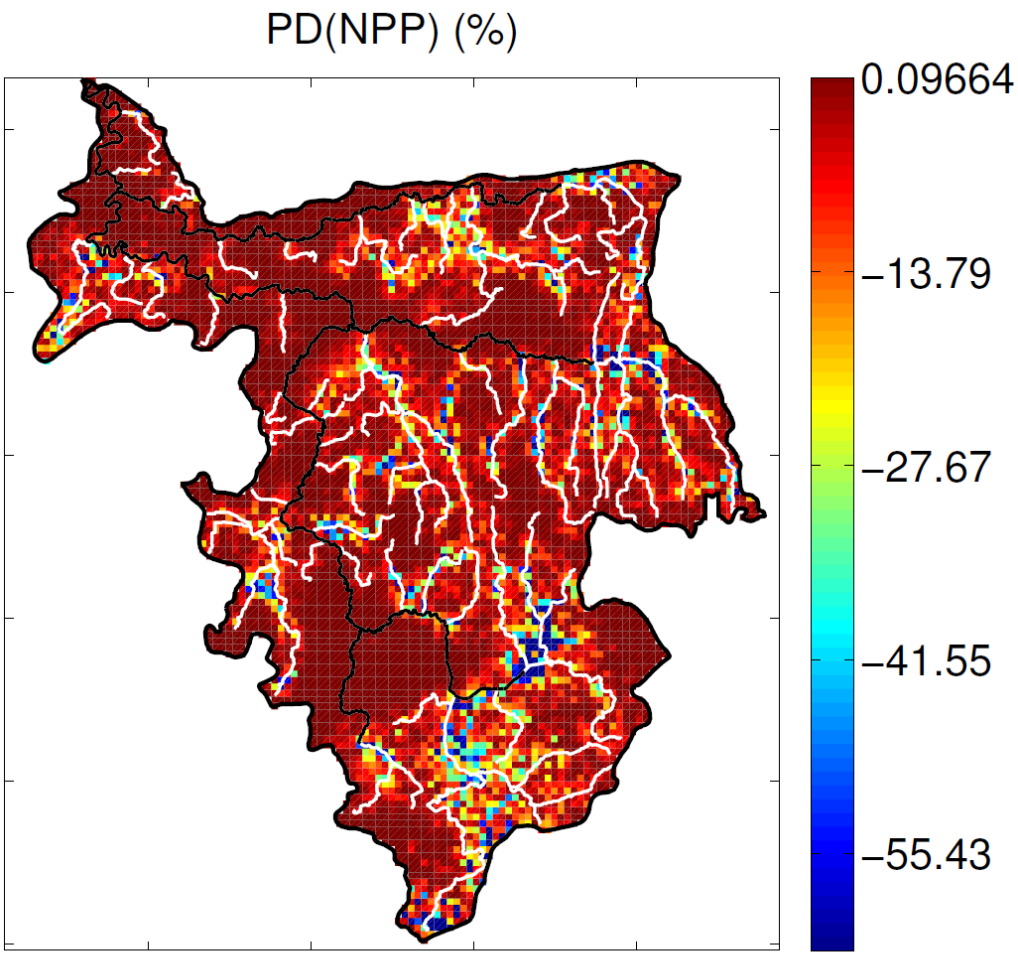
Max 10% due to lowered water table



Influence of streams on fluxes…

- NPP

Influence is seen far upland. Quite significant for areas with low NPP

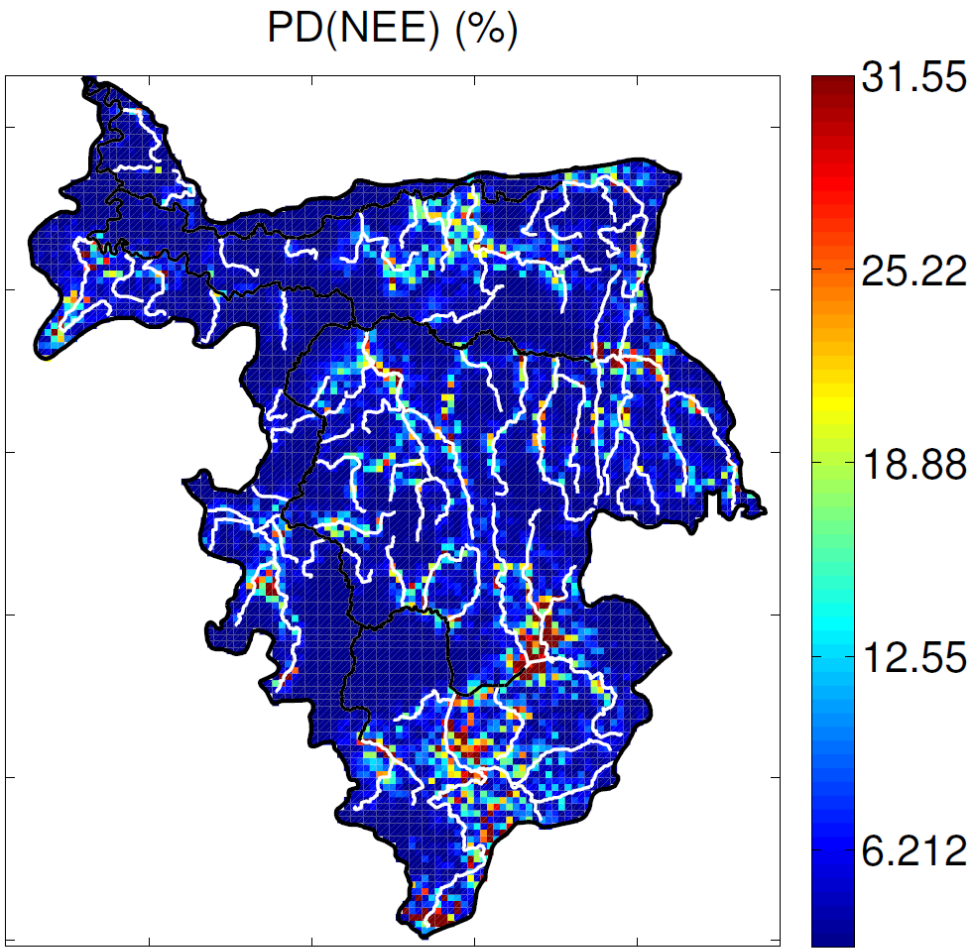


Influence of streams on fluxes…

- NEE

Positive NEE

Mainly due to reduction in NPP



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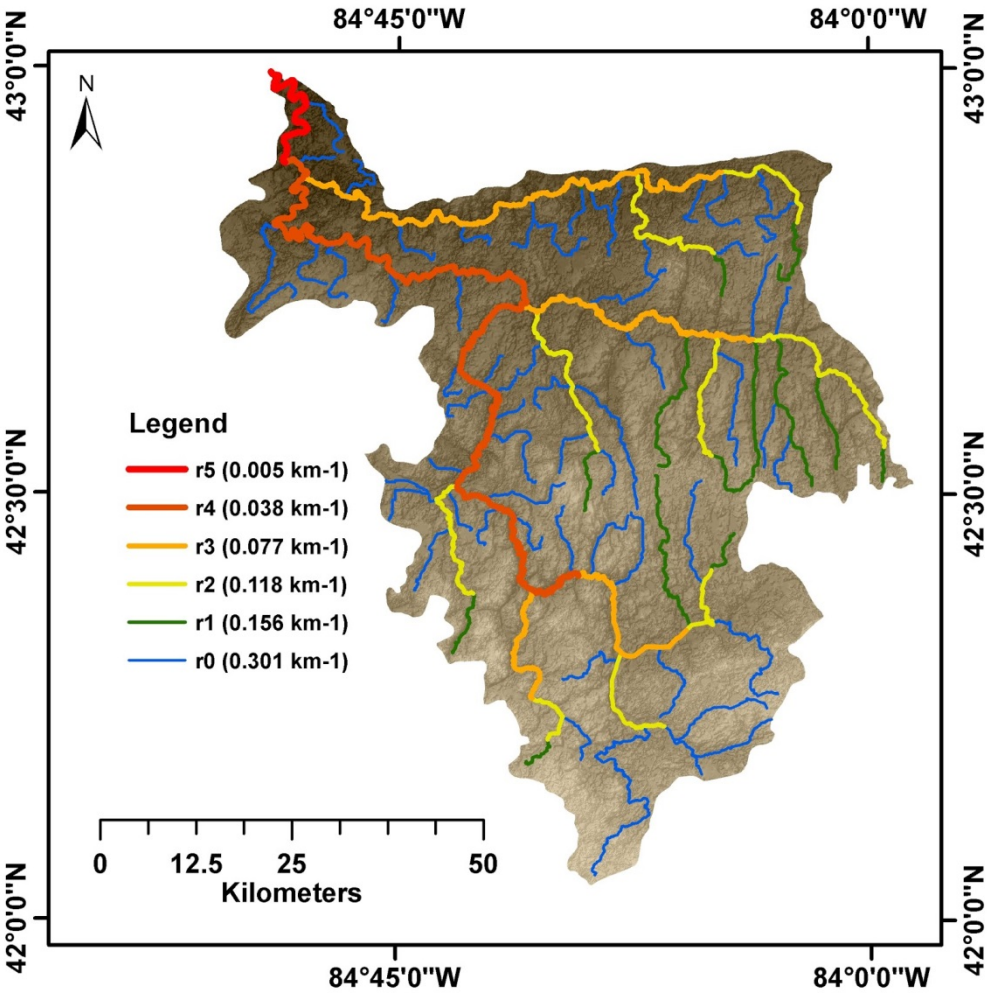
Factorial experiments

Resolution (m) / D level (km/km^2)	1 (200)	2 (400)	3 (800)	4 (1600)	5 (3200)
0 (0.301)	S_{r0x1}	S_{r0x2}	$\underline{S_{r0x3}}$	S_{r0x4}	S_{r1x5}
1 (0.156)	S_{r1x1}	S_{r1x2}	$\boldsymbol{S_{r1x3}}$	S_{r1x4}	S_{r1x5}
2 (0.118)	S_{r2x1}	S_{r2x2}	S_{r2x3}	S_{r2x4}	S_{r2x5}
3 (0.156)	S_{r3x1}	S_{r3x2}	$\underline{S_{r3x3}}$	S_{r3x4}	S_{r3x5}
4 (0.038)	S_{r4x1}	S_{r4x1}	S_{r4x3}	S_{r4x4}	S_{r4x5}
5 (0.005)	S_{r5x1}	S_{r5x1}	S_{r5x3}	S_{r5x4}	S_{r5x5}

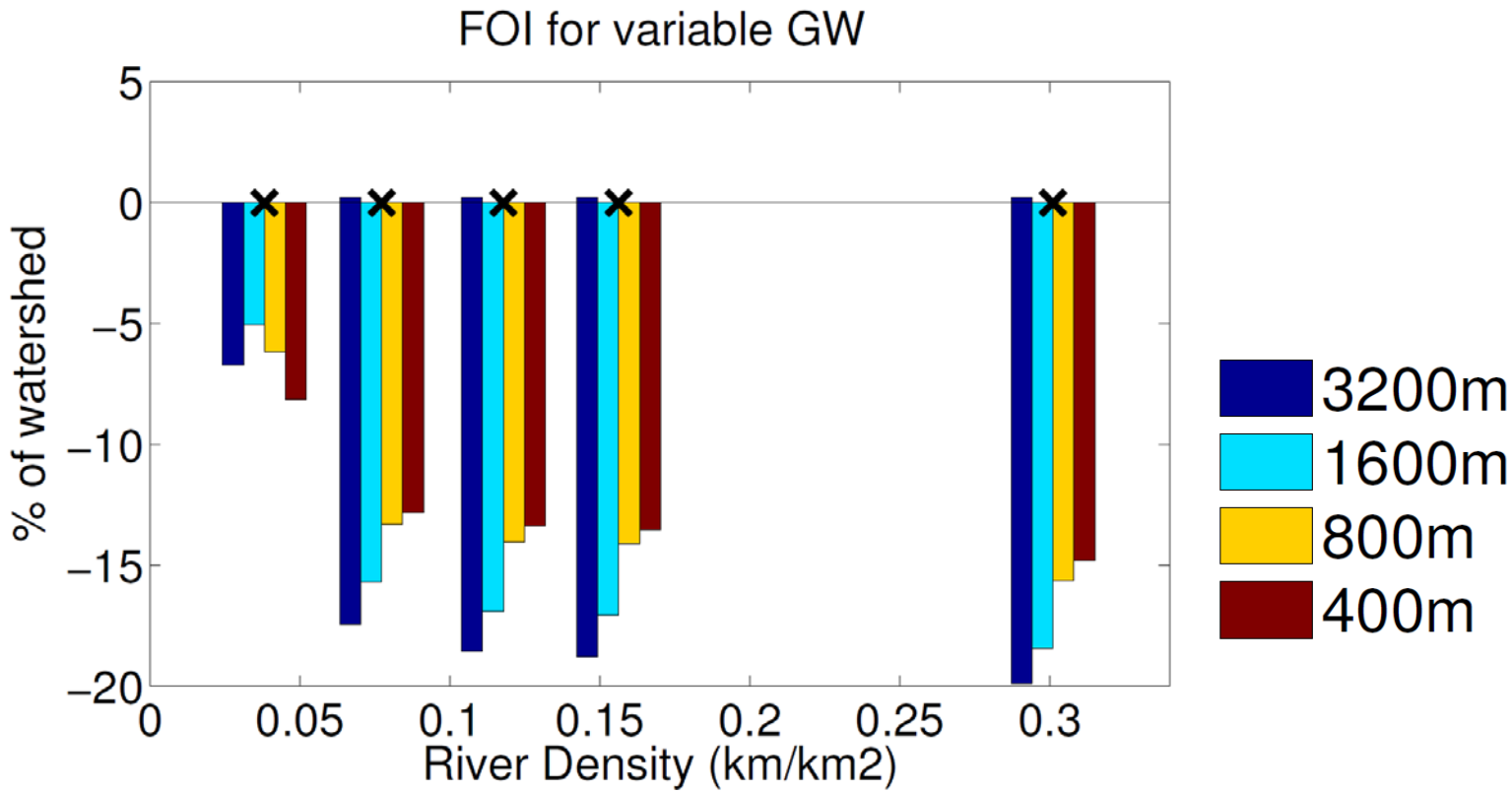
Varying channel density

- Systematically trimmed tributaries, first order streams, short and thin streams



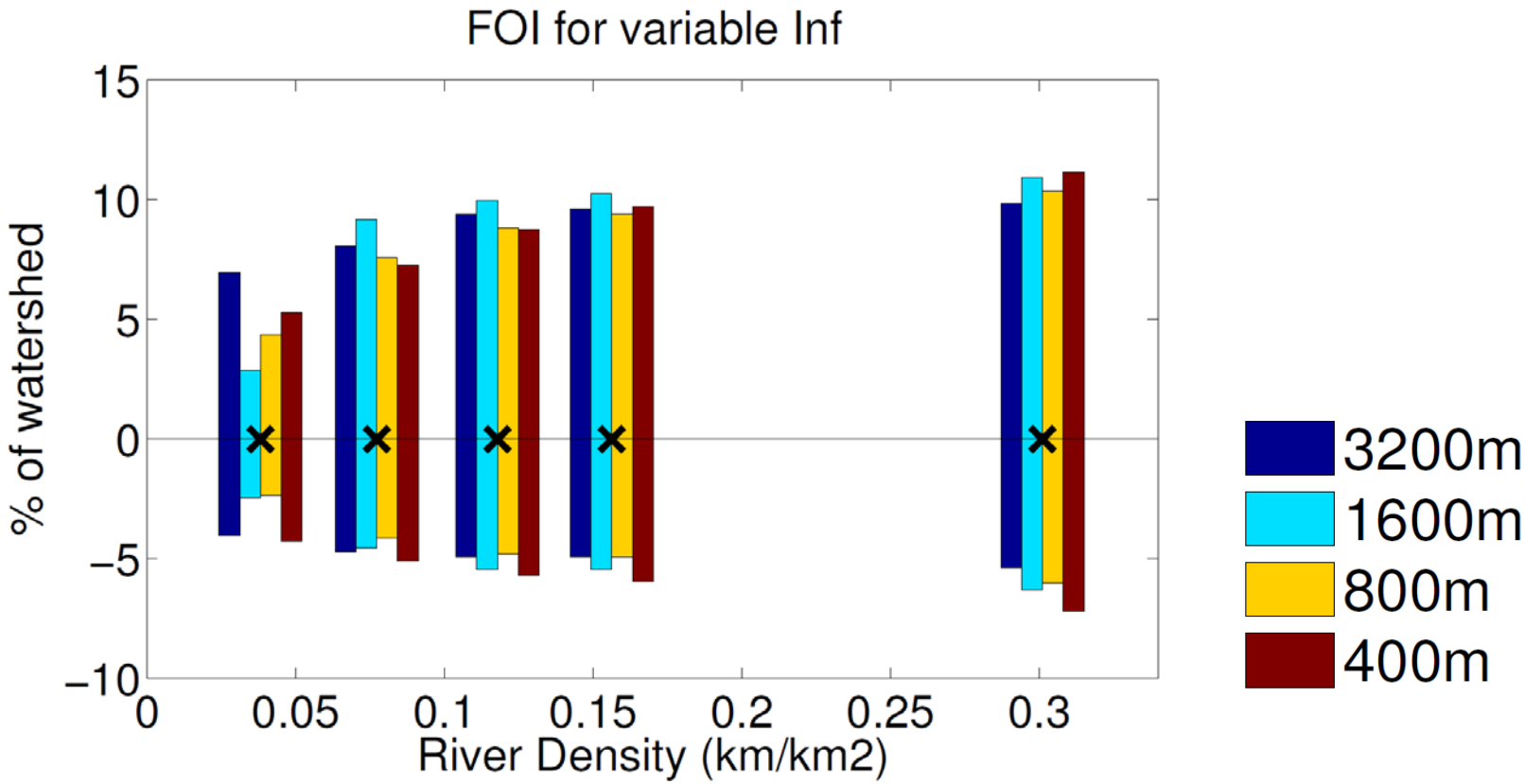
Area of the Fan of Influence as a function of *D* and grid resolution

- FoI is assessed at 10% change as compared to blank simulation, where *D=0*



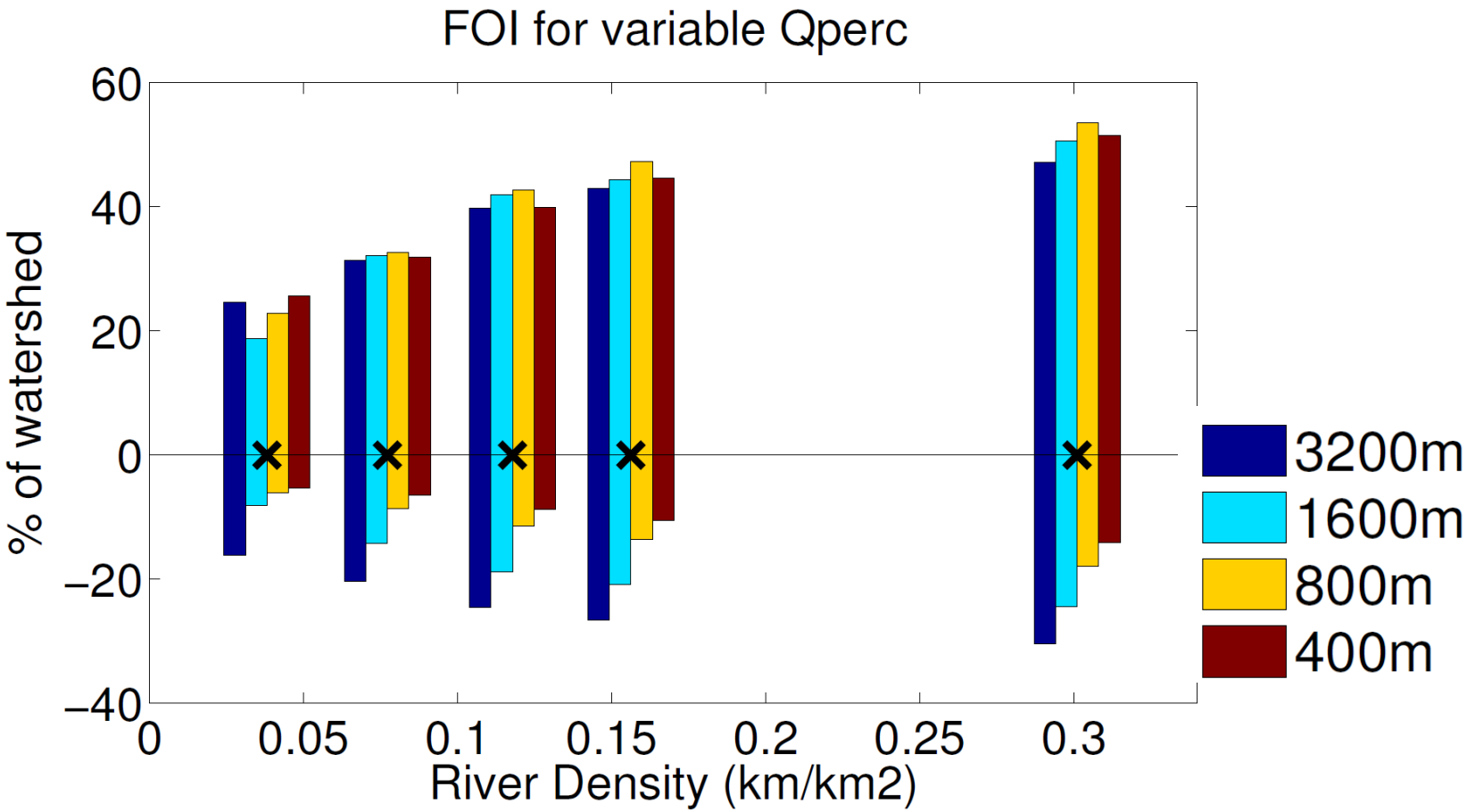
Area of the Fan of Influence as a function of *D* and resolution

- FoI(Inf) is very localized



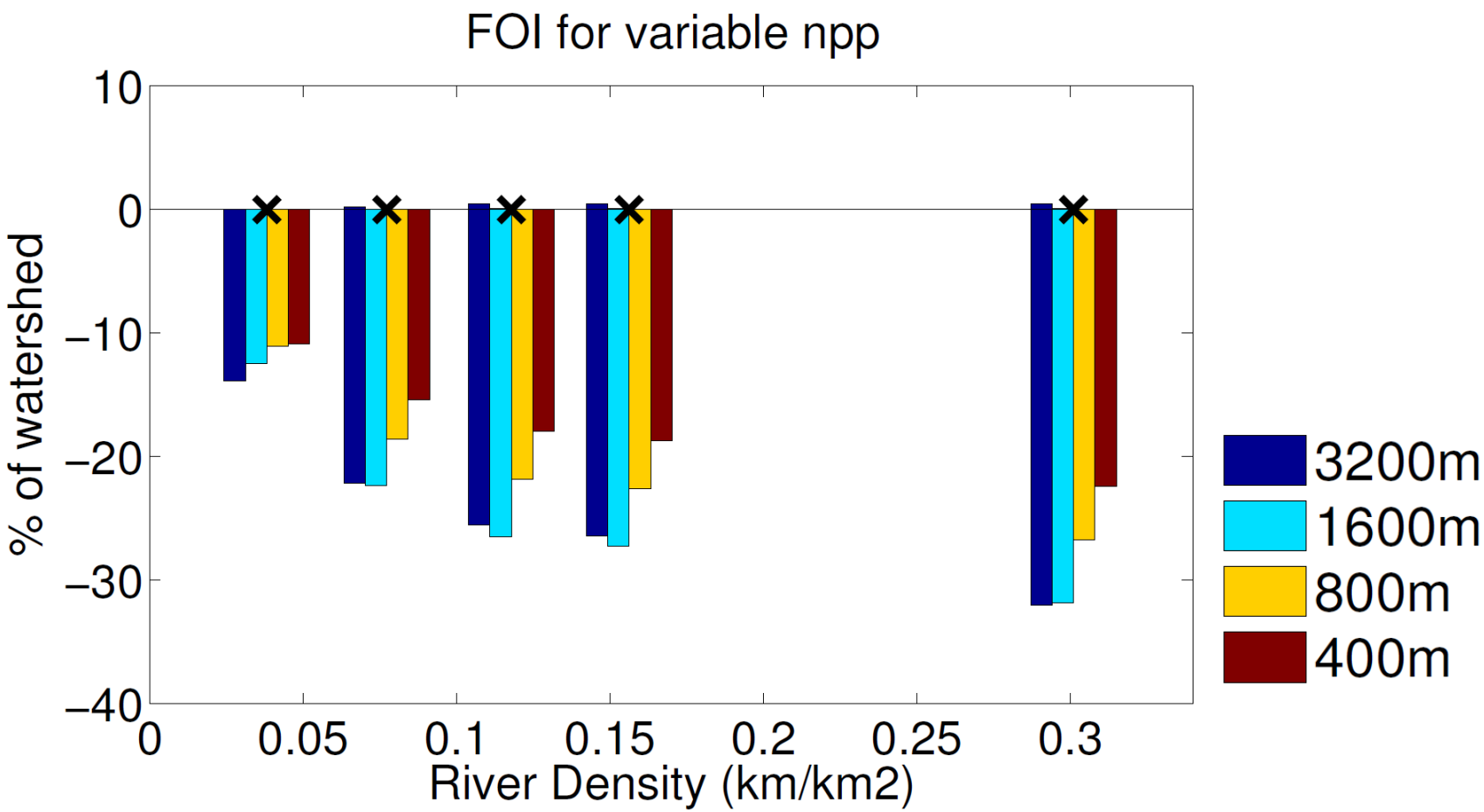
Area of the Fan of Influence as a function of *D* and resolution

- Impacts on Q_l and Q_{perc} are very wide-spreading



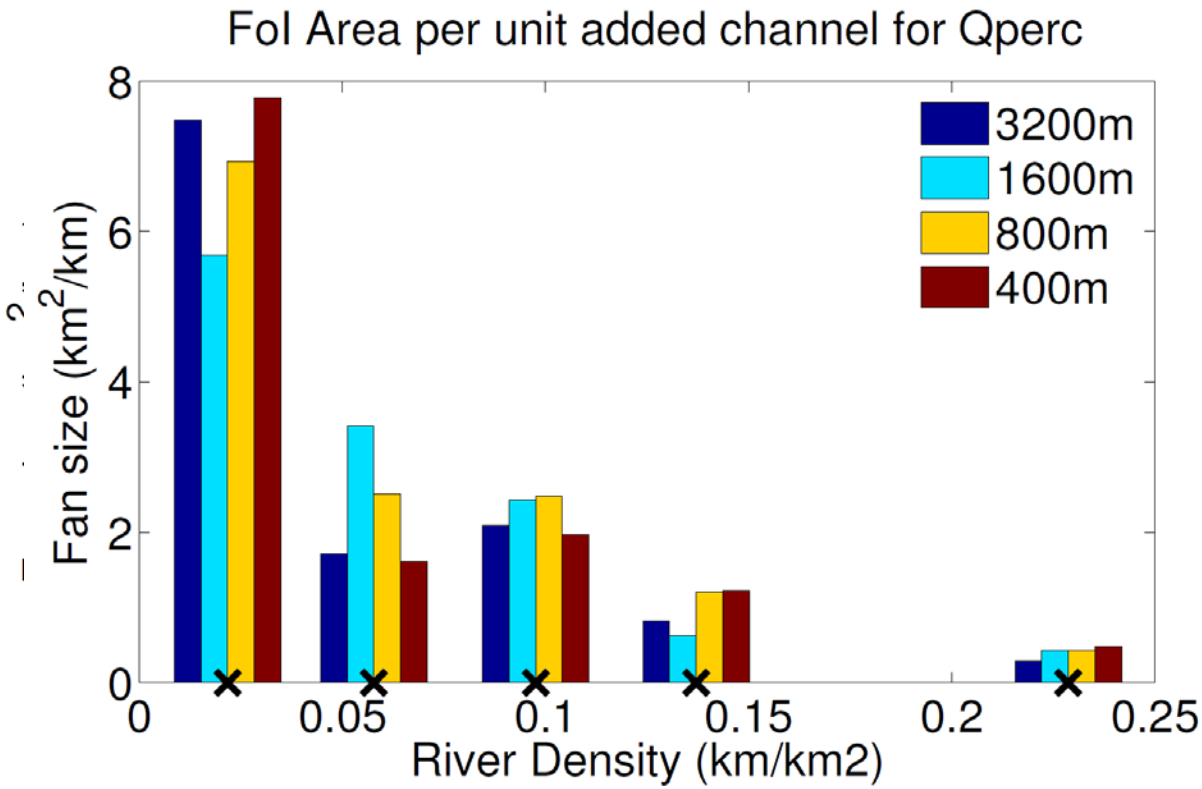
Area of the Fan of Influence as a function of *D* and resolution

- NPP and NEE have wider FOI than ET



Area of the Fan of Influence of unit stream length

- We calculate the area of FoI for each unit of stream by numerically approximating the $\frac{\partial FOI(D)}{\partial D}$ at the midpoint of the interval for only the dominant sign.



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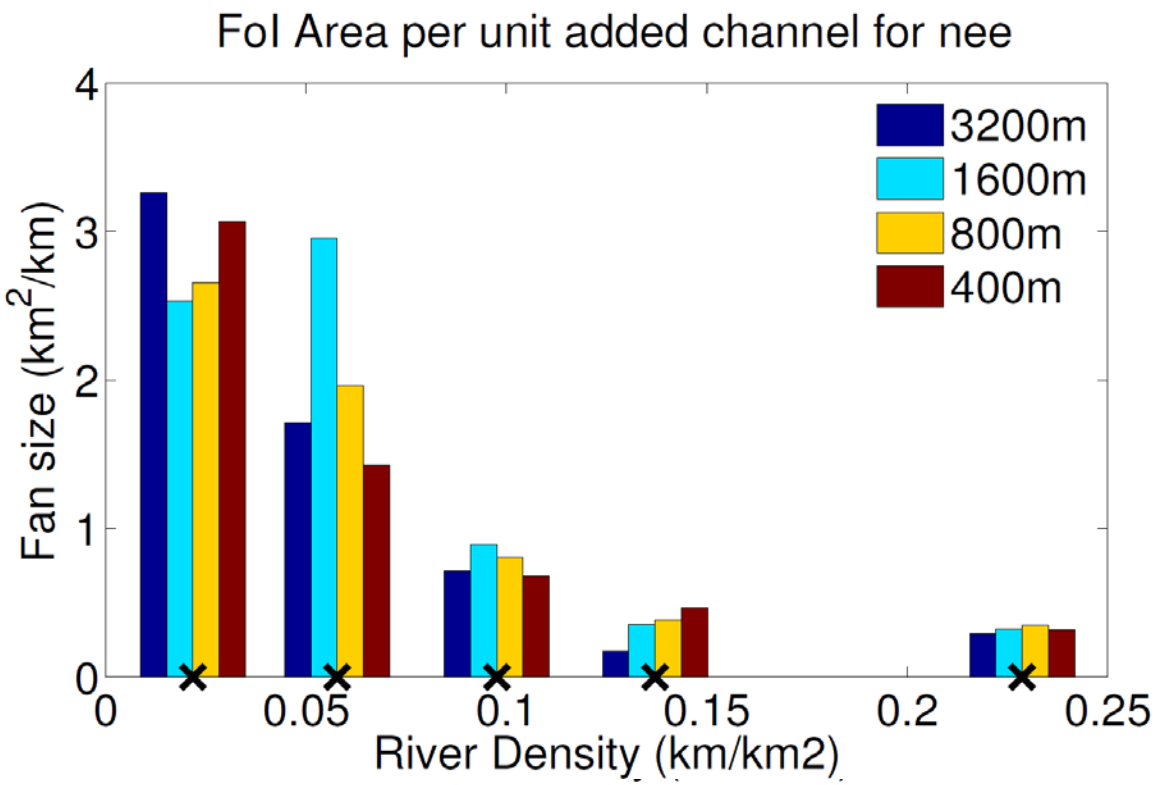
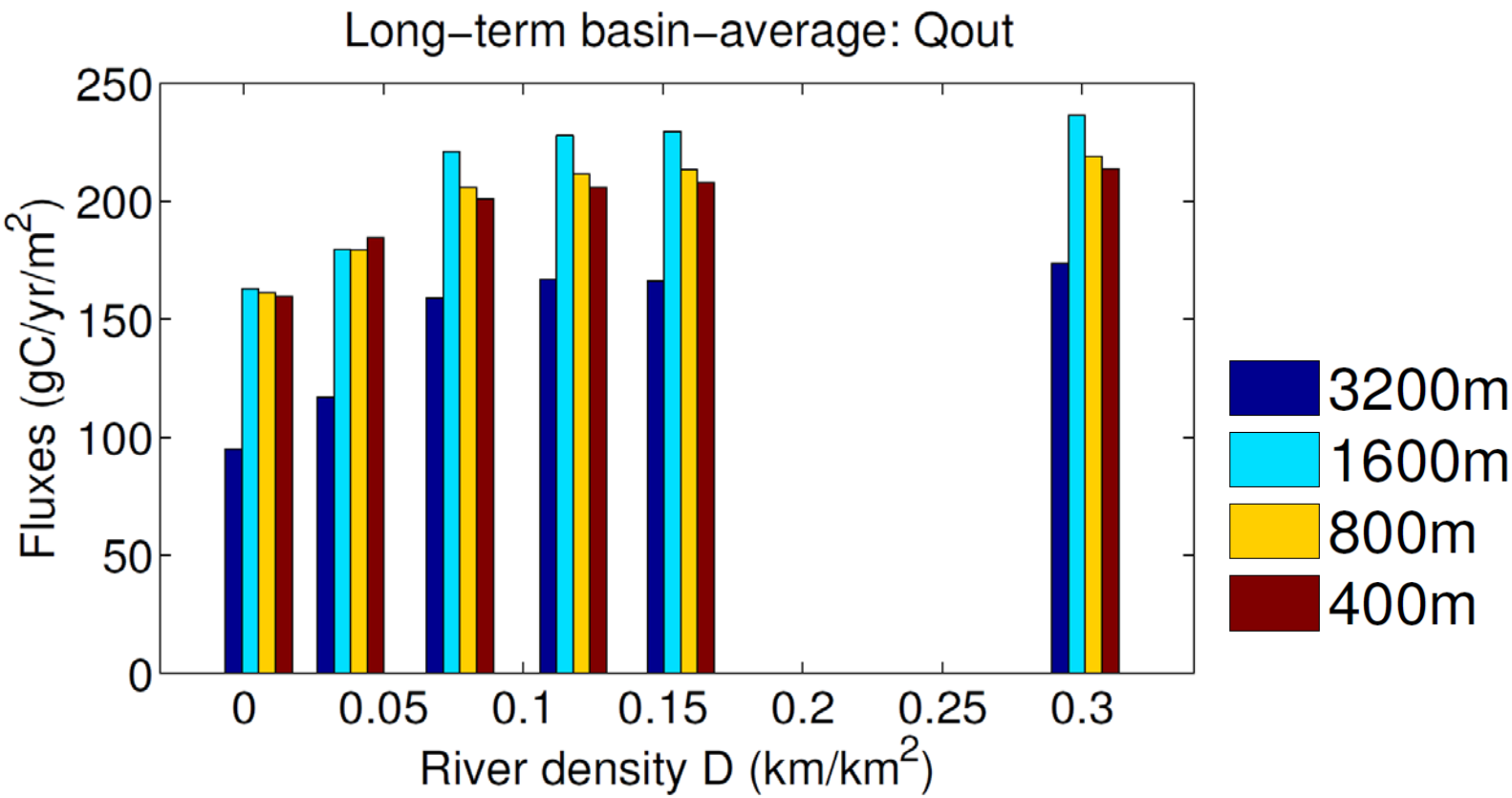


Basin-average fluxes

- Impacts on the overall annual average basin flux are limited, except for Basin outflow



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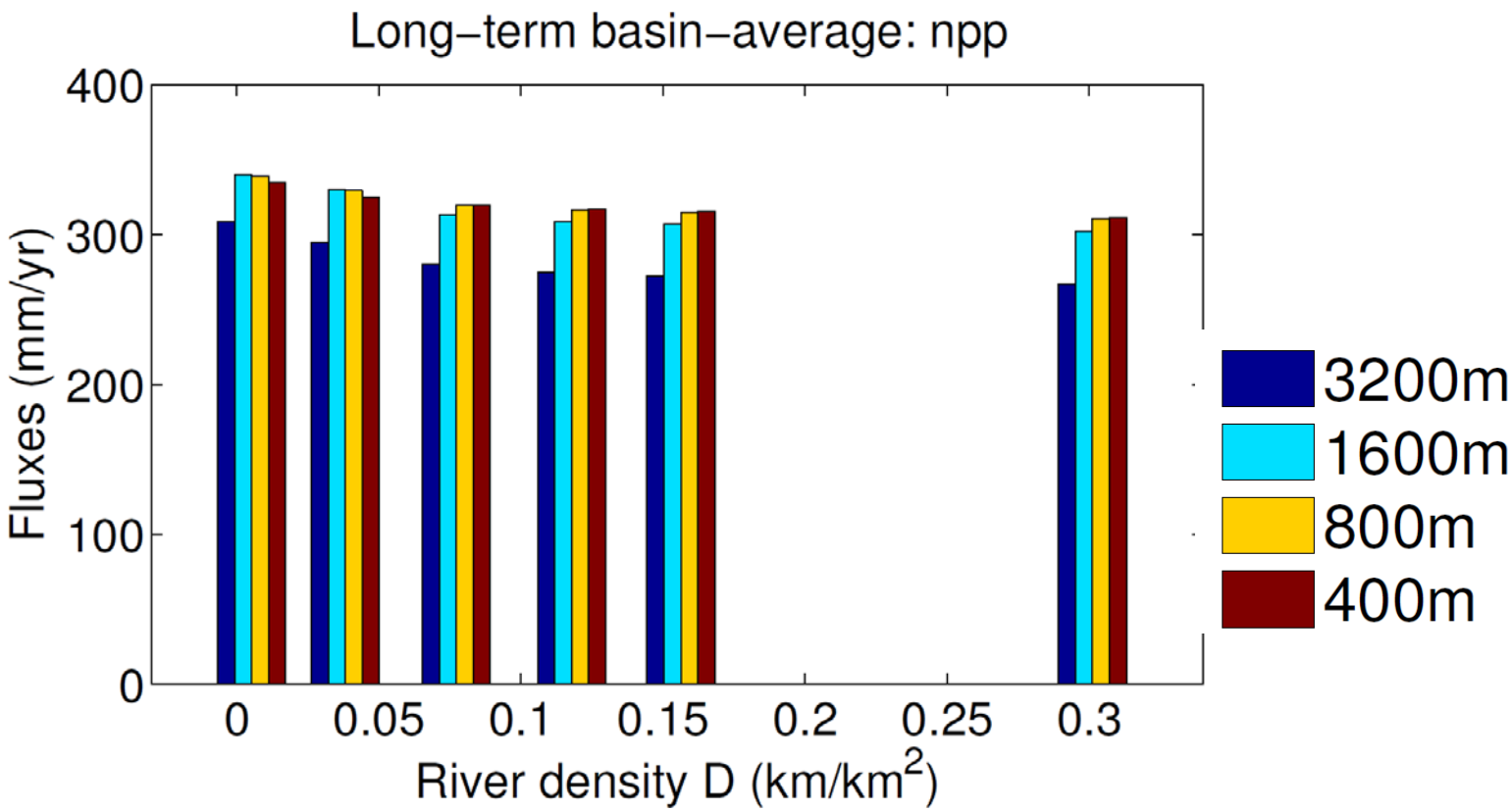

Conclusions

- The existence of rivers influences upland hydrologic and land surface fluxes. The impact forms a Fan of Influence that reaches far and wide into the hillslope for some variables.
- Simulated channel heavily alters the flow network, which may have implications on the residence time and fate of biogeochemical species and residence
- The impacts of channel network is mainly due to (1) groundwater baseflow and insufficient resolution of gradients adjacent to streams (<=100m); and (2) more efficient conveyance of water downstream by streams. The former is most apparent with larger, perennial segments. The latter is present even with small, ephemeral streams. This understanding may help us build scale-aware models to overcome these difficulties.
- The impacts on basin-average fluxes is limited (so not the end of the world), but creates large spatial heterogeneity
- Increasing grid resolution cannot reduce the effect of channel density