Watershed storage and sequential storage thresholds in a hillslope flow system driving discharge regimes

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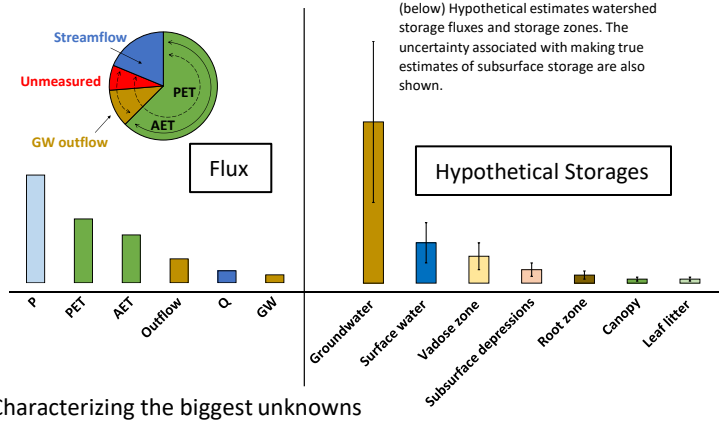
Introduction

Discharge is anticipated to be the residual between the inputs to watersheds (precipitation, groundwater inputs), outputs (evapotranspiration, groundwater outflow), and changes to water storage. However, the relationship between watershed storage and discharge is non-linear. There are sequences of storage thresholds which must be breached prior to other storage units being activated. As storage units fill (i.e., fill and spill storage + surficial soil storage) they activate other hydrologic processes (percolation) that spur the filling of other storage components (groundwater storage). Capturing this sequence is limited by problems of estimating total water storage due to subsurface heterogeneity, poorly defined boundary conditions, the expense of monitoring at a density sufficient to capture spatial variation, and difficulties with measuring certain groundwater fluxes and vadose zone reservoirs. We explore the uncertainties and unknowns associated with estimating watershed storage at Upper Fourmile Creek, South Carolina. We make rough estimates of some of the more complex storages and identify problems with estimating specific storages.

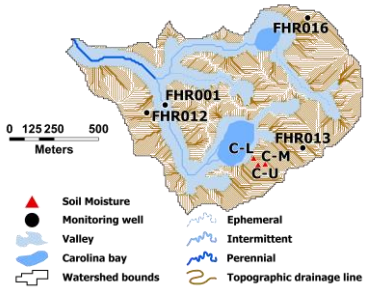


(below) Hypothetical estimates watershed storage fluxes and storage zones. The uncertainty associated with making true estimates of subsurface storage are also shown.

Characterizing the biggest unknowns

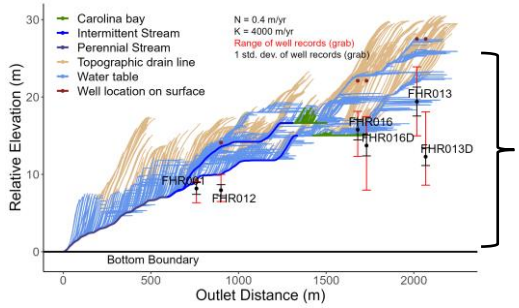
Portion of water going unmeasured
- Vadose zone
- Groundwater
- Subsurface depressions (fill and spill storage)
- Leaf litter
- GW flux

Difficult to estimate on landscape scale
- Root zone
- Surface water (wetlands included)
- Canopy storage

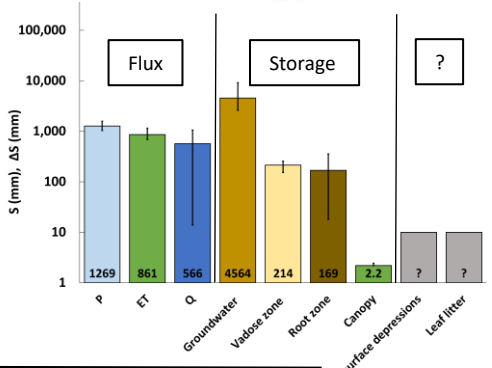


(above) Planform view of Watershed C, well and soil moisture monitoring shown. Topographic drainage lines show the direction of surface water routing to valleys and eventually streams.

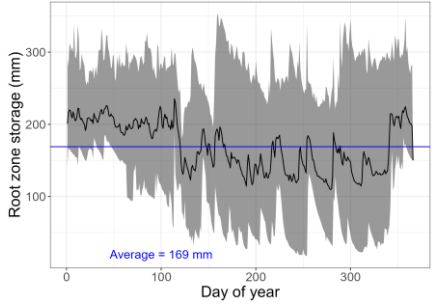
(right) Longitudinal profile of WS C of Upper Fourmile Creek (upper right) WS C of Upper Fourmile Creek shown in the planform with monitoring wells and soil moisture locations. Potential thickness of the unmeasured portions of ground and vadose zone water shown with the black brackets. Depending on where you are in the watershed, there could be 30m of unmeasured ground and vadose zone storage below you. Note the increase in water level variation in upslope versus riparian wells.



(right) Estimates of watershed storages and fluxes in Watershed C of Upper Fourmile Creek. Groundwater and vadose storage estimates are taken from the results of the Dupuit water table model. Root zone estimates are estimated from 6-years of soil moisture measurements down to 1 meter within the trench of Watershed C, and canopy storage was estimated from the interception data presented by Caldwell et al. (2018) and rainfall frequency estimates of Kilgo and Blake (2005). Recharge, precipitation, and ET were estimated using a combination of eddy flux, long-term gage, and data from in situ instrumentation. Error bars reflect range of calculated values and not a degree of error. Note the log scale on these estimates.



(below) Seasonal variability of root zone soil moisture within Watershed C. Storage can range from as little as 70 mm to 330 mm. Previous studies have shown an interflow generation threshold of around 70 mm at this research site (Jackson et al. 2016)



Takeaways

- Subsurface storage (GW, vadose zone, root zone) highly spatially variable, difficult to accurately measure
- Interannual variability in root zone storage?
- Recharge highly variable year to year.
- Difficult to measure GW flux, subsurface depressional storage, leaf litter storage.
- Surface water storage estimates could be made using remotely sensed data.

Acknowledgements

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Reference

Caldwell, P. V., Jackson, C. R., Miniat, C. F., Younger, S. E., Vining, J. A., McDonnell, J. J., & Aubrey, D. P. (2018). Woody bioenergy crop selection can have large effects on water yield: A southeastern United States case study. *Biomass and Bioenergy, 117*(July 2018), 180–189. https://doi.org/10.1016/j.biombioe.2018.07.021

Jackson, C. R., Du, E., Klaus, J., Griffiths, N. A., Bitew, M. M., & McDonnell, J. J. (2016). Interactions among hydraulic conductivity distributions, subsurface topography, and transport thresholds revealed by a multitracer hillslope irrigation experiment. *Water Resources Research, 52*, 6186–6206. https://doi.org/10.1002/2013WR015173

Kilgo, J. C., and J. I. Blake (2005), Ecology and Management of a Forested Landscape, 479 pp., Island Press, Washington, D. C.

Sayama, T., McDonnell, J. J., Dhakal, A., & Sullivan, K. (2011). How much water can a watershed store? *Hydrological Processes, 25*(25), 3899–3908. https://doi.org/10.1002/hyp.8288