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

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Abstract

In many streams, discharge is often anticipated to be the residual between the inputs to watersheds (precipitation, groundwater inputs), outputs (evapotranspiration, groundwater outflow), and changes to water storage. This basic water balance approach fails to capture many of the aspects that drive streamflow, namely the sequence between fluxes and storages that must occur prior to streamflow generation. This is further complicated by the limitations of ever estimating total water storage, namely due to subsurface heterogeneity, poorly defined boundary conditions, and difficulties of associated with measuring certain fluxes (GW in and outflows) and storage reservoirs (soil water). From a hillslope perspective, the relationship between watershed storage and discharge is not so 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 spurs the filling of other storage components (groundwater storage). These thresholds are complex, time varying, with non-linear and hysteretic activations, and result in much more complex transit times than a simple water balance would suggest. We use records from ~13 years of intensive hydrologic monitoring at 3 adjacent low-relief, groundwater driven headwater streams that drain the Savannah River Site in the Upper Atlantic Coastal of Plain to explore the sequential storage thresholds that govern stream discharge at the site. Coupled with a spatially discrete water table model and remotely sensed estimates of surface water storage, we provide a more robust estimate of total water storage and help elucidate how much water is going unmeasured via deep groundwater flow pathways

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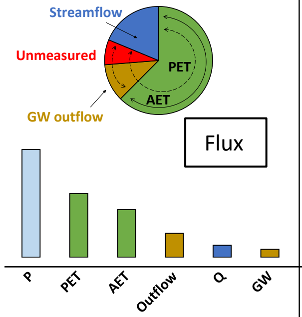
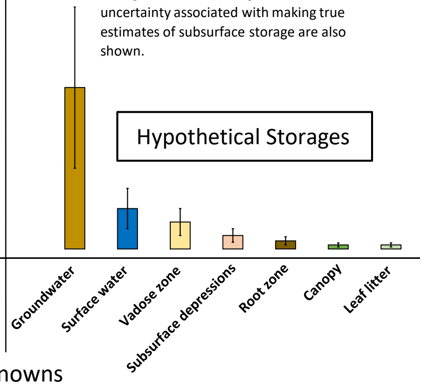
Introduction

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.



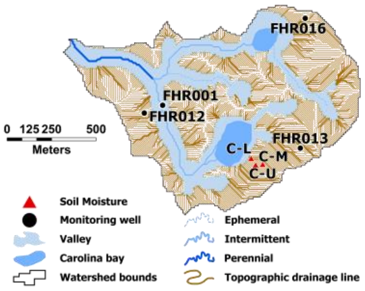
Characterizing the biggest unknowns

Portion of water going unmeasured

- Vadose zone
- Groundwater
- Subsurface depressions (fill and spill storage)
- Leaf litter
- GW flux

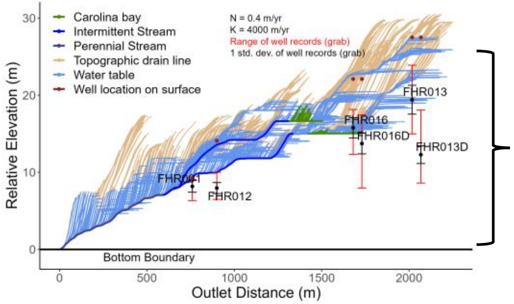
Difficult to estimate on landscape scale

- Root zone
- Surface water (wetlands included)
- Canopy storage

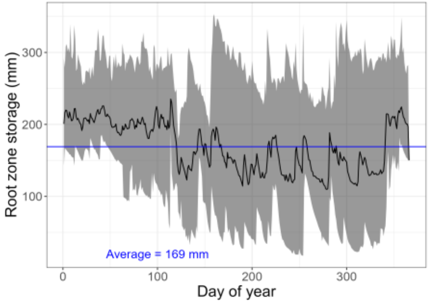


(above) Planform view of Watershed C, well and soil moisture monitoring shown. Topographic drainage lines show the direction of surface water routing to valleys and eventually streams.

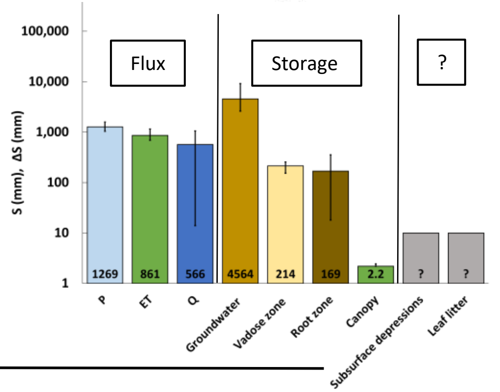
(right) Longitudinal profile of WS C of Upper Fourmile Creek (upper right) WS C of Upper Fourmile Creek shown in the planform with monitoring wells and soil moisture locations. Potential thickness of the unmeasured portions of ground and vadose zone water shown with the black brackets. Depending on where 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.



(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)



(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.



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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