Modeling Nitrate Exporting Patterns during Storm Events for a Semi-arid Mountain Watershed

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Acknowledgement

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BioEarth Biosphere-relevant earth system model

Abstract

In steep semi-arid areas like coastal Southern California, most nitrate export occurs during storm events. Observed data from the Santa Barbara Long Term Ecological Research site shows that concentration and concentration-discharge relationships vary both throughout storm events and seasonally. Nitrate sources can be inferred from these data by comparing the arriving time of the nitrate concentration peak and that of the stream flow peak. For example, for small storm events in September or October after the long sever summer drought, nitrate concentration peak several hours earlier than stream flow peak, and may indicates the nitrate flux is from near-stream riparian areas. In contrast, storm events in the winter or early spring after a series of precipitation events tend to produce the nitrate concentration peaks several hours later than the stream flow peak, and indicates the nitrate flux is from hydrologically connected upslopes area.

To model these dynamics, hydrologic models must be able to capture temporal shifts in hydrologically connected source areas as well as seasonal shifts in nitrogen availability associated with ecosystem biogeochemical cycling. We assess the ability of Regional Hydro-Ecologic Simulation System (RHESSys), to reproduce the seasonal/multi-yearly nitrate's export patterns and compare the success of different model implementations. Specifically we compare a new developed hourly time-step implementation versus a daily time-step model and a model implementation where lateral routing is based on the "fill and spill" hypothesis versus the more traditional approach based on subsurface transmissivity functions. Results highlight the importance of both the hourly time-step and the threshold based response of a "fill and spill" connectivity model.

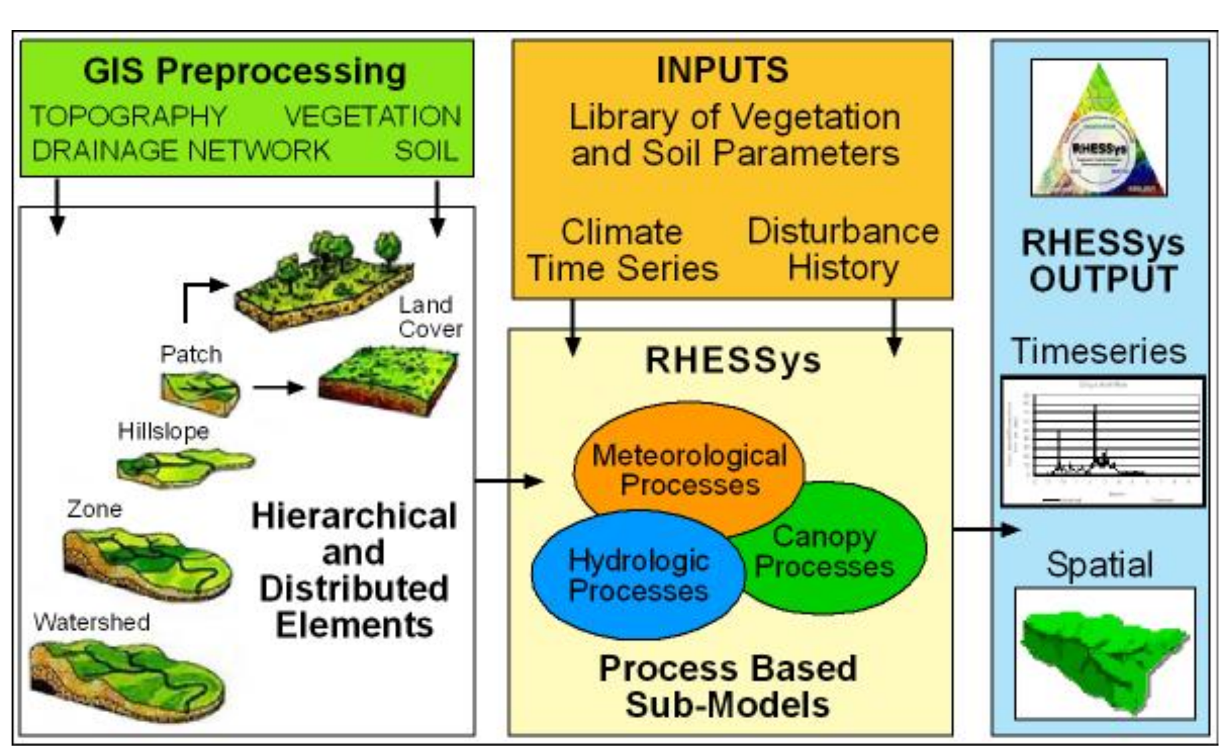
Approach

RHESSy (REGIONAL HYDRO-ECOLOGIC SIMULATION SYSTEM) is a GIS-based, hydro-ecological modeling framework designed to simulated carbon, water and nutrient fluxes at the watershed scale (Tague and Band, 2004)

Updates to RHESSys as part of this study:

1. Subsurface routing and macro-flow recharge-discharge have been downscaled to an hourly timestep.
2. Nitrogen export calculations updated to an hourly timestep. (ET and biogeochemistry reaction modules, such as nitrification, denitrification, remain at a daily timestep).
3. An alternative routing "fill and spill" has been implemented by defining a saturation deficit threshold for subsurface flow: when sat deficit is less than the threshold (the watertable exceeds the threshold), fast lateral flow will be generated; otherwise, only a small amount of the leakage will be generated.

Figure 1: Overview of RHESSys input data, hierarchical structure, internal processes, and output data.



The three mechanisms for subsurface flow

In RHESSys, three mechanisms for subsurface flow are implemented: 1. "fill and spill" mechanism, 2. Macropore flow mechanism, and 3. permeable subsurface flow.

Figure 2. "Fill and Spill": fast lateral subsurface flow is generated when water table exceeds a threshold.

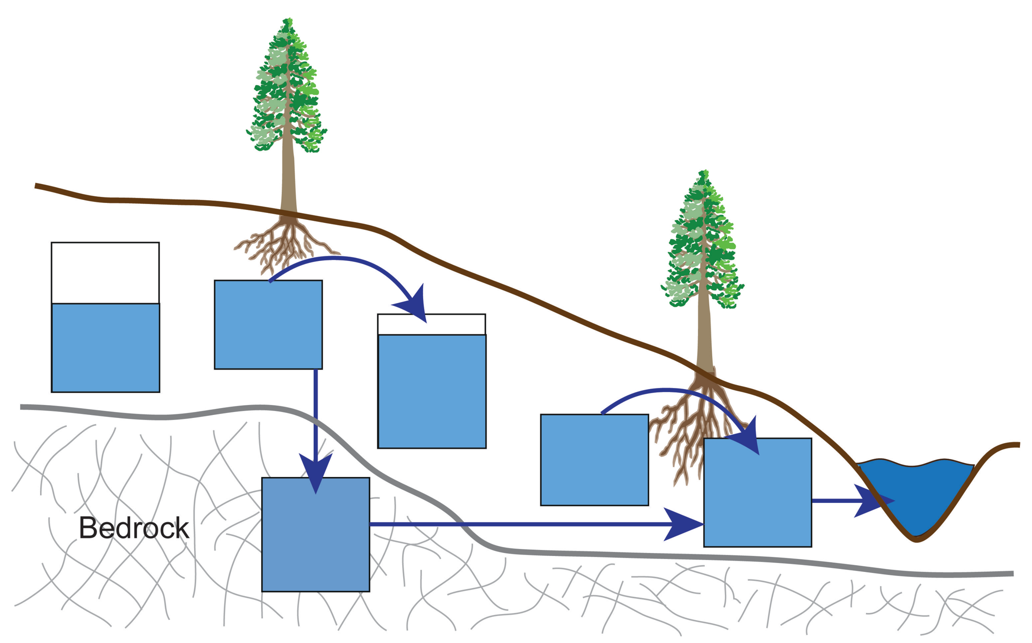


Figure 3. Macropore flow: fast macropore flow connects subsurface with deep ground water and downstream flow.

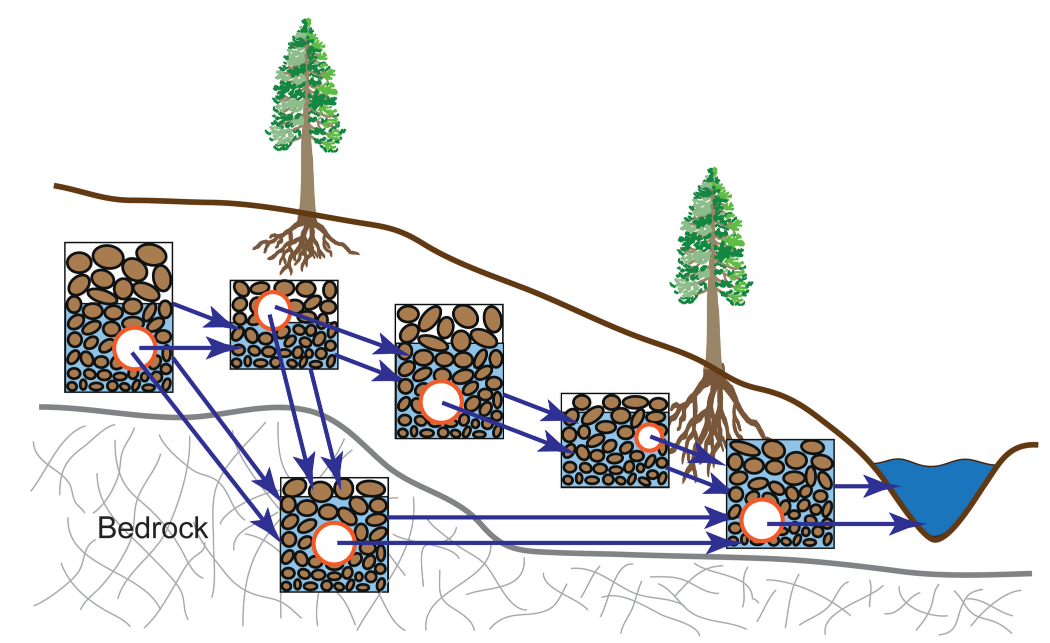


Figure 4. Permeable subsurface flow: subsurface flow is generated based on soil transmissivity at the water table level.

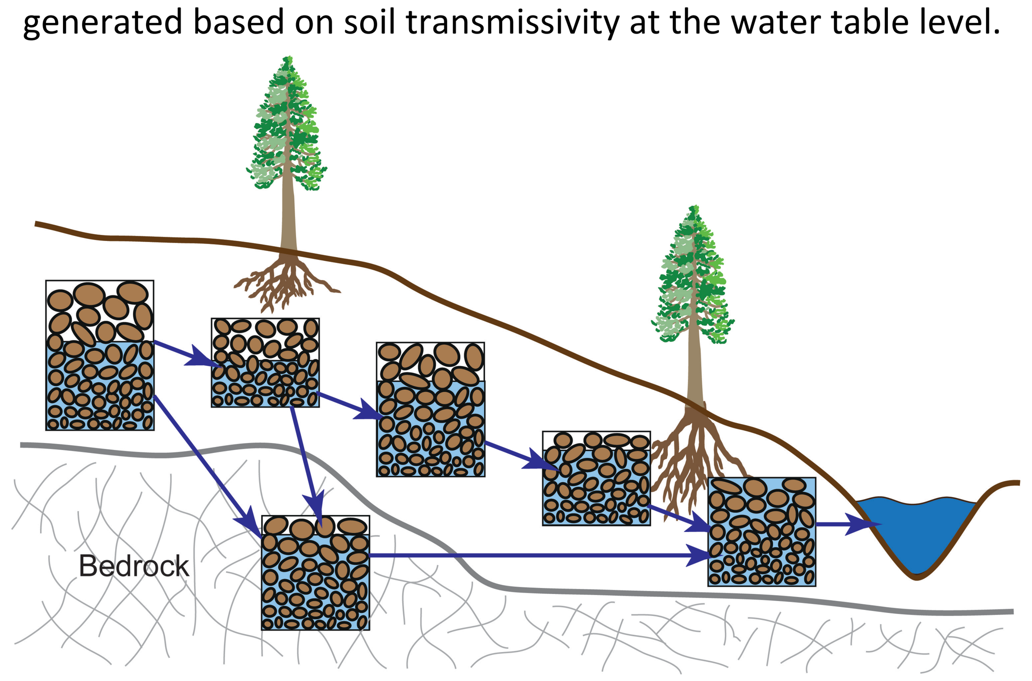
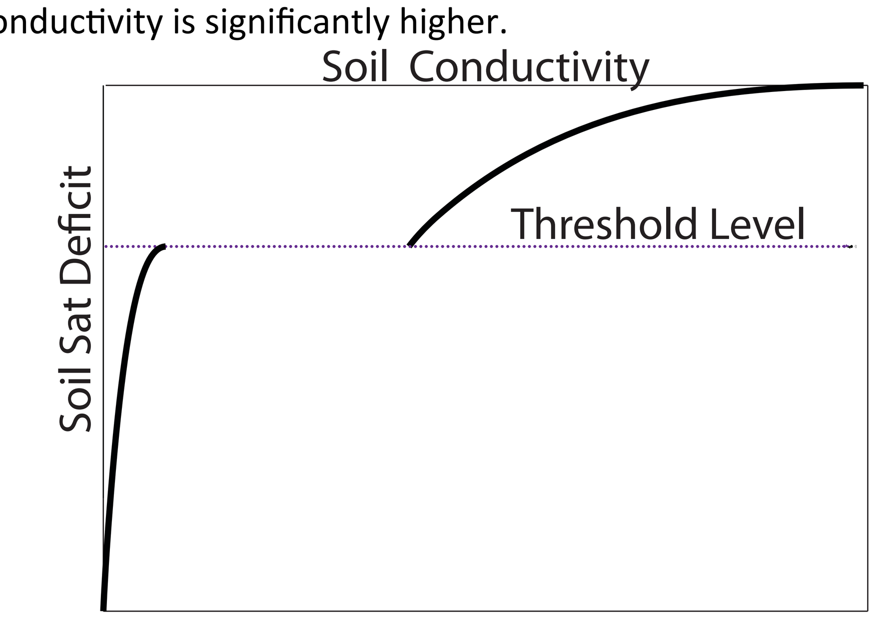


Figure 5. In "fill and spill", the soil conductivity 'jumps' at the threshold of soil sat deficit level: above the threshold, the soil conductivity is significantly higher.



Study Area

Figure 6. Location of Rattlesnake Watershed

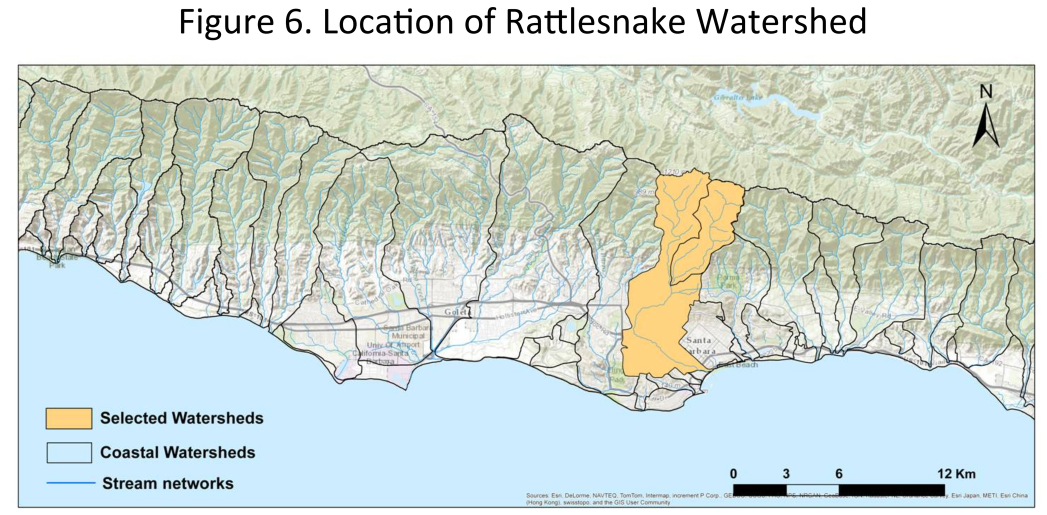
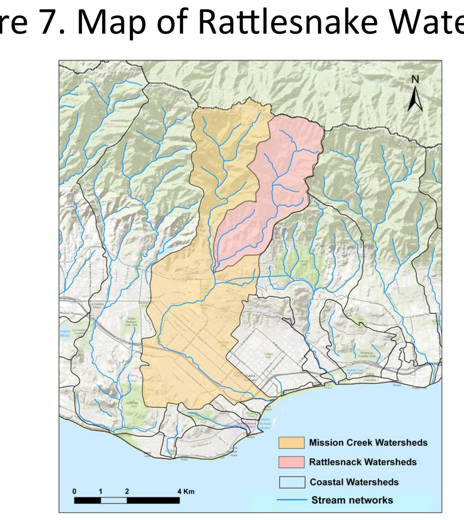


Figure 7. Map of Rattlesnake Watershed

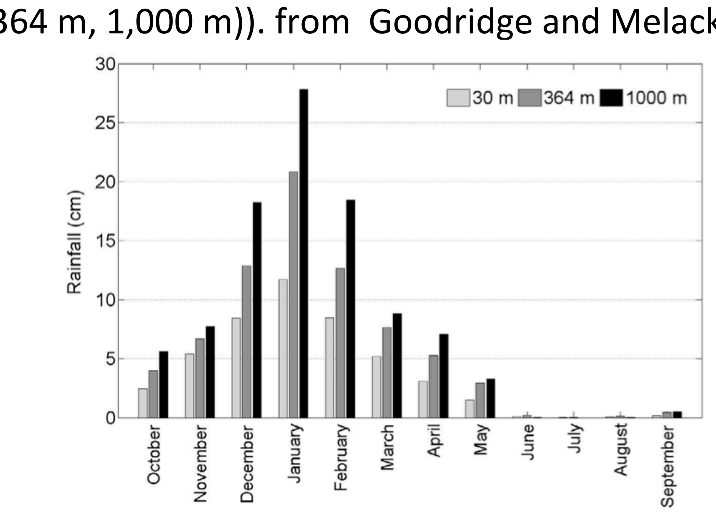


Rattlesnake watershed is a small undeveloped watershed in Southern California, with the size of 8.29 km2. The climate is Mediterranean climate, with dry summer and warm wet winter. Over 80% of annual precipitation typically falls between December and March. In the mountain area, there is substantial orographic enhancement of rainfall.

High frequency climate and stream flow/chemistry data is available from the Santa Barbara Long Term Ecological Research site (SB-LTER).

Streamflow (hourly), Precip (5-min), Streamflow (hourly), Solute concentration data (hourly during storm, weekly).

Figure 8. Precipitation data in three Santa Barbara precipitation gauges located at different elevations (30m, 364 m, 1,000 m)). from Goodridge and Melack (2012)



Model Results

Using the Nash-Sutcliffe Efficiency (NSE) of daily streamflow as the performance metric, we calibrated 4-6 soil parameters. For the fill and spill we require 2 additional parameters to define threshold for the transition to higher connectivity.

Parameter calibration results differ for the different flow realizations (graph show accumulative frequency of NSE across parameter values).

Figure 9. Distribution of M

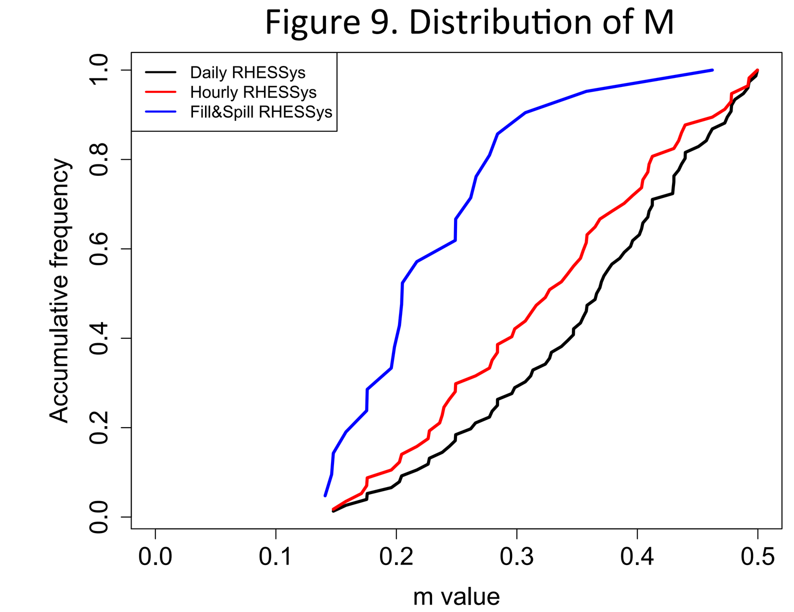


Figure 10. Distribution of K

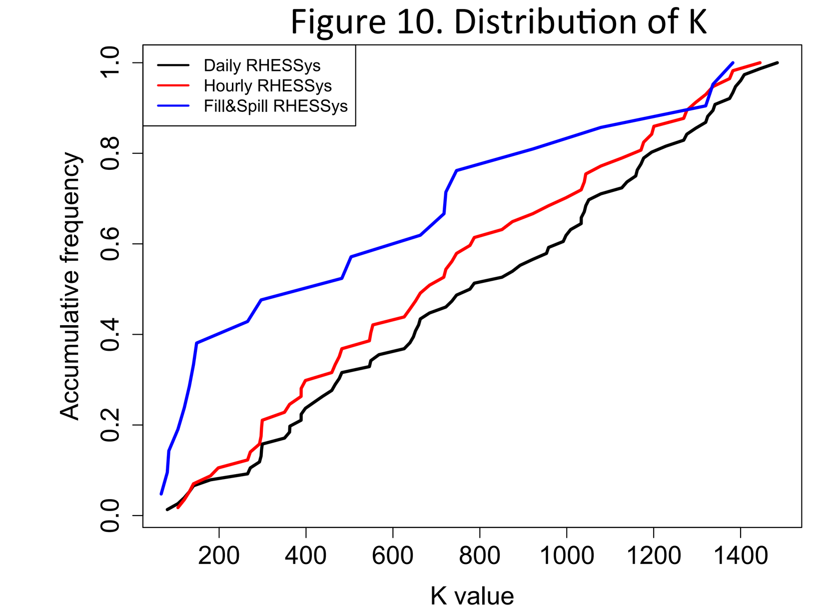


Figure 11. Distribution of Soil Depth

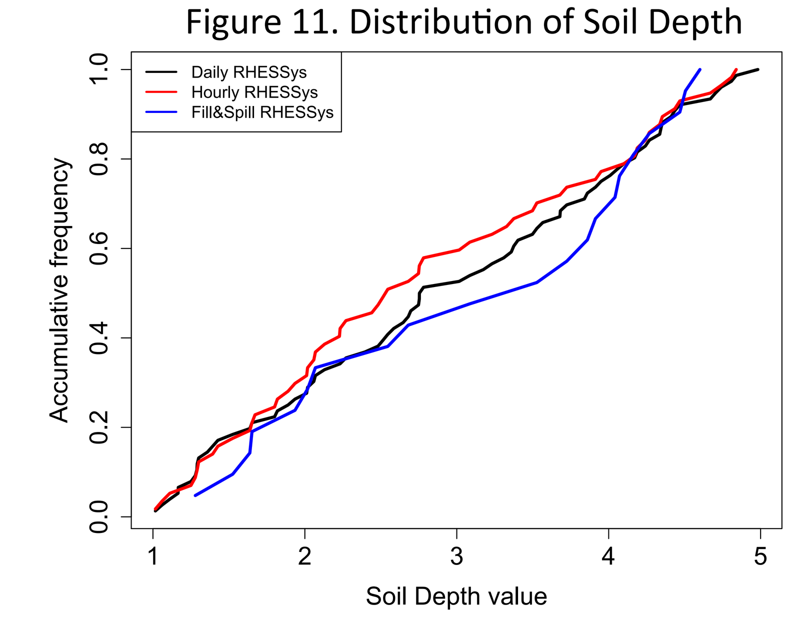


Figure 12. Distribution of GW1

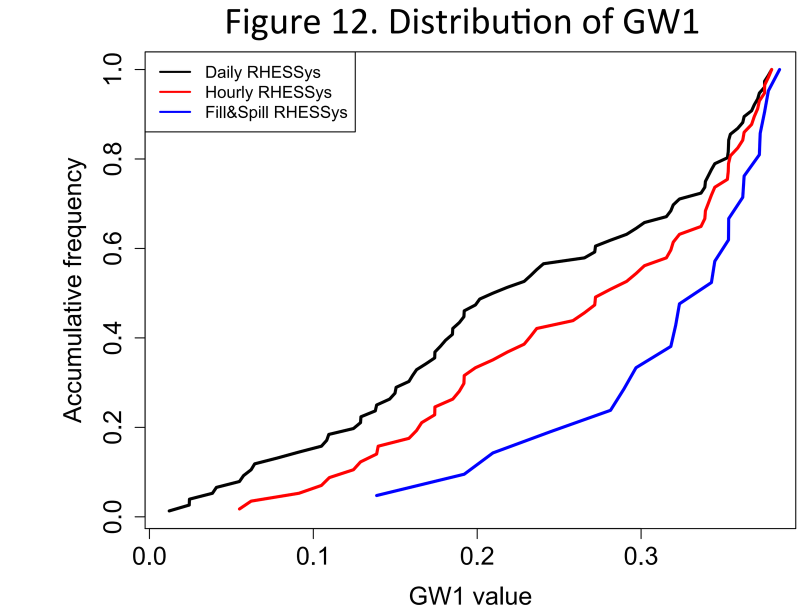


Figure 13. Streamflow, daily vs hourly RHESSys

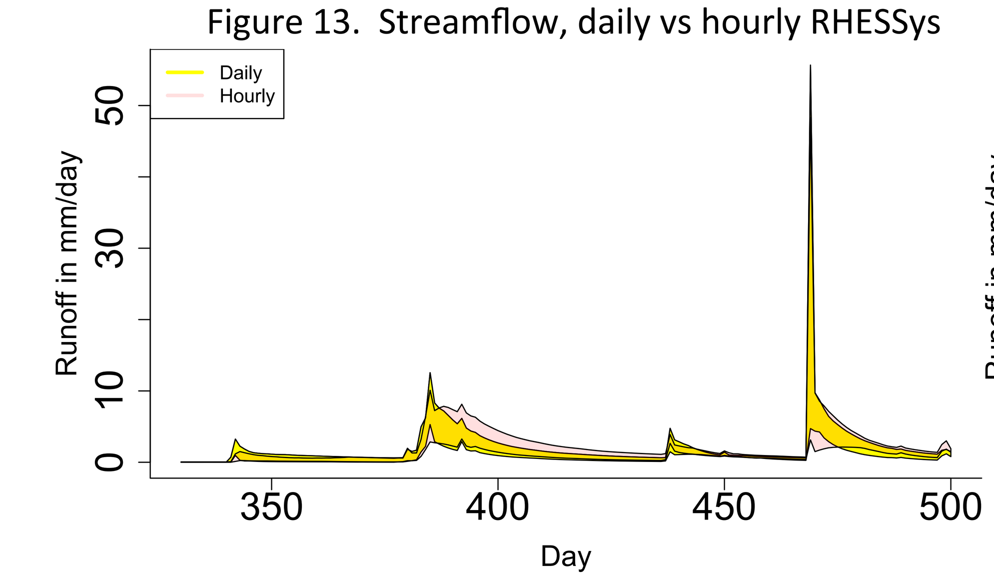


Figure 14. Streamflow, hourly vs fillspill RHESSys

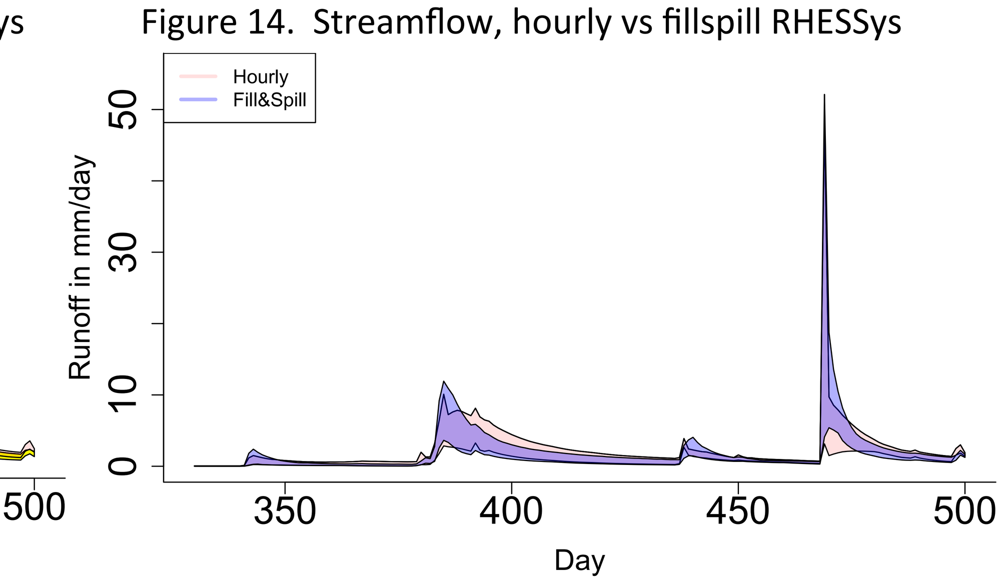
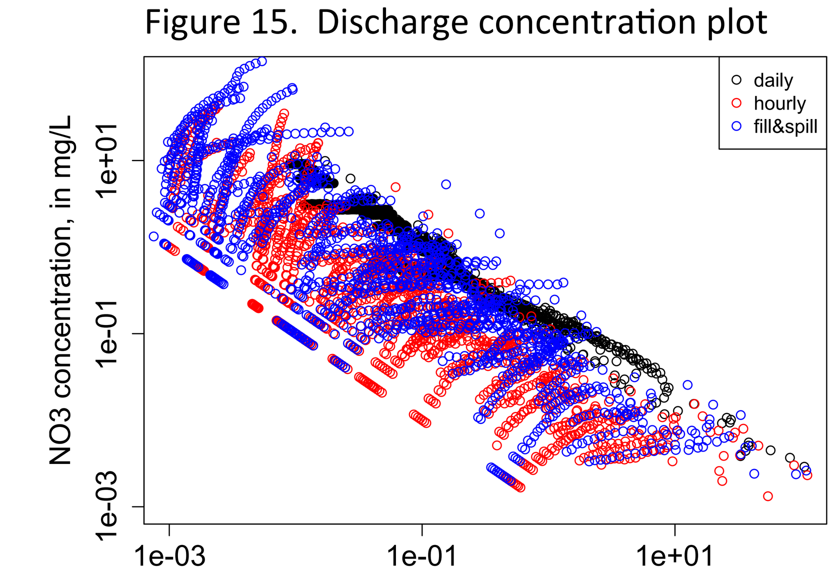


Figure 15. Discharge concentration plot



The discharge concentration plot shows that: for single storm event, the concentration will increase with larger runoff in hourly and fillspill RHESSys.

The calibration result of streamflow shows that the three version of RHESSys has similar performances (NSE.max.daily = 0.7361, NSE.max.hourly = 0.7375, NSE.max.fillspill = 0.7476).

Besides, daily version will tend to produce more runoff for peak flow, while the fillspill version will produce more flow in the recession period but less flow in the low flow condition.

Next Step

Refine RHESSys estimates of chaparral N-uptake and cycling.

Compare N-export across routing models for a range of N-deposition and climate scenarios