The Role of Heterogeneity in Modeling Eco-hydrologic Responses to Urbanization

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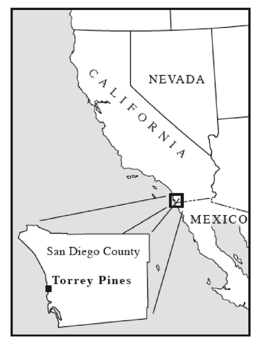
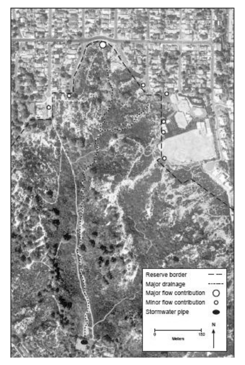
Heterogeneity in Drainage Organization

How do assumptions about neighborhood level urban surface water drainage patterns impact modeled storm flow?

Study Site

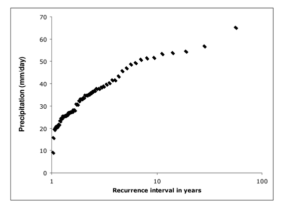




Residential development comprises approximately 25% of Torrey Pines State Reserve. Development is concentrated in the upper portion of the watershed; so there is significant potential for re-infiltration of surface runoff generated by impervious surfaces in the developed portion.

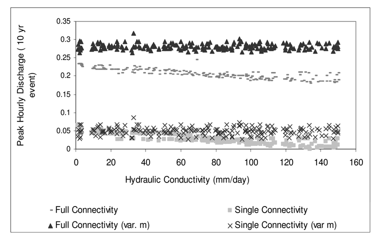
Semi-arid; Precipitation 25cm/year;
Vegetation-Coastal Sage Scrub

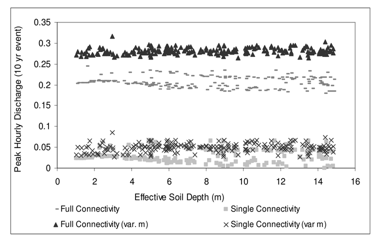
RHESSys was used to estimate runoff production under developed and undeveloped land use. To assess impacts under a wide range of storm events, the model was run continuously for 1949-2001 using meteorological data from the nearby San Diego Airport.



Two development scenarios were considered a) All storm sewers were hydrologically connected to the stream; b) Only one storm sewer was hydrologically connected to the stream; the remaining runoff diffused to downslope.

Uncertainty Analysis





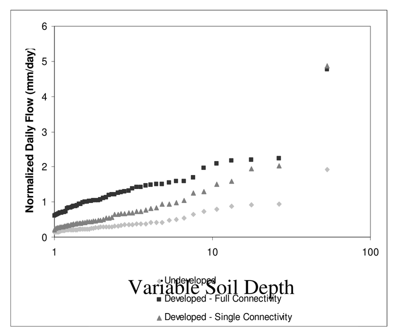
Stream gage data was not available for this watershed; RHESSys, as with most hydrologic models, requires calibration. However, in lieu of calibration, we ran the model over the full range of reasonable parameters values. Analysis shows that conclusions about the impact of development on streamflow were robust across uncertainty in parameter values.

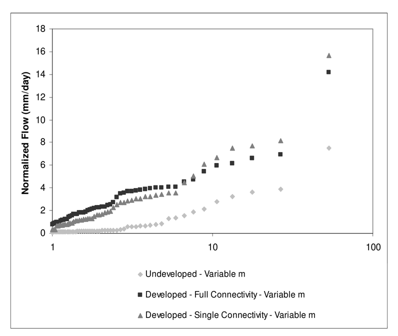
We also consider a 3rd scenario that allows soil depth to vary spatially (increasing downslope) in order to assess the impact of the common assumption of a spatially uniform soil profile (within a given soil "type").

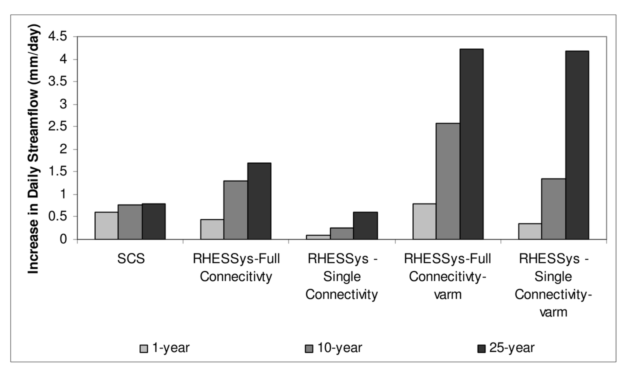
Impact of drainage organization and development on distribution of storm flow events (historic climate record)

Model results show a significant impact of development across the full range of storm events with greater flow increases for larger runoff events. Connectivity matters such that a fully connected storm sewer network increases response, particularly for small to intermediate storm sizes.

However, if soil depth increases downslope; the magnitude of urban impacts increase and the relative role played by storm sewer connectivity is diminished;







RHESSys estimates of the impact of urbanization are similar to those derived using more traditional curve number approach (Thompson, 1999), if full storm sewer connectivity is assumed.

Tague, C., and Pohl, M. (submitted) "GIS-based hydrological modeling for urban and environmental planning", *Annals of Association of American Geographers*

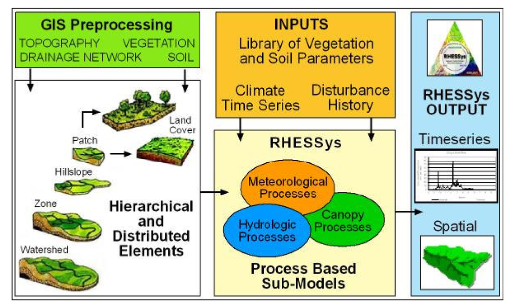
Summary

RHESSys estimates demonstrate robustness across mean values for soil parameters but show important sensitivity to spatial heterogeneity in soil depth - such that assuming a variable soil depth leads to significantly greater estimates of increases in urban runoff with upslope urbanization.

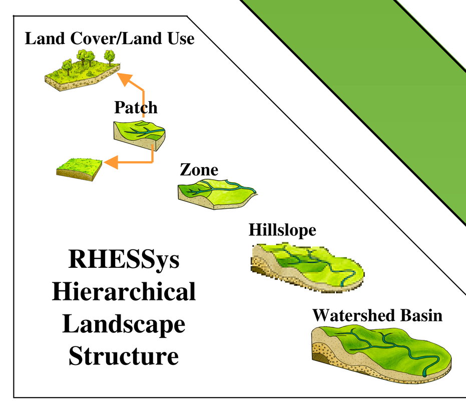
The extent of storm sewer connectivity matters. With a more diffuse storm sewer network (where erosion and hydrologic connection of the stream through gullies is reduced), impacts on storm flow are much lower - except at very high flows where streamside return flow (and antecedent moisture in these areas) begin to contribute to runoff response.

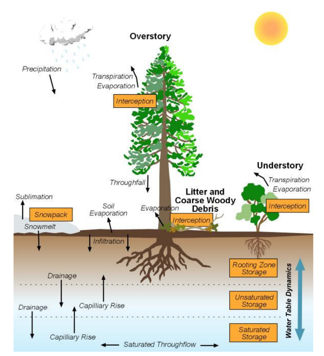
RHESSys

RHESSys is a GIS-based, hydro-ecological modeling framework designed to simulate carbon, water and nutrient fluxes. By combining a set of physically based process models and a methodology for partitioning and parameterizing the landscape, RHESSys is capable of modeling the spatial distribution and spatio- temporal interactions between different processes at the watershed scale.

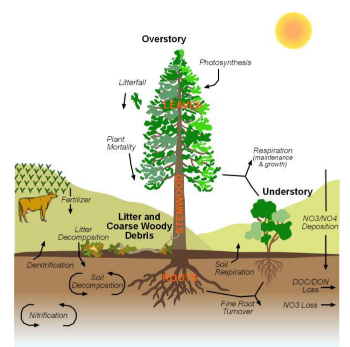


Tague, C. and Band, L. (2004) "RHESSys: Regional Hydro-ecologic simulation system: An object-oriented approach to spatially distributed modeling of carbon, water and nutrient cycling", *Earth Interactions*, 8:19, 1-42 (http://fiesta.bren.ucsb.edu/~rhessys/)

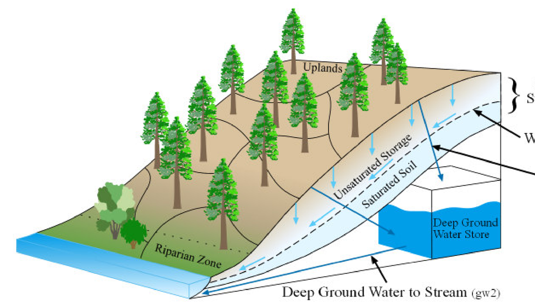




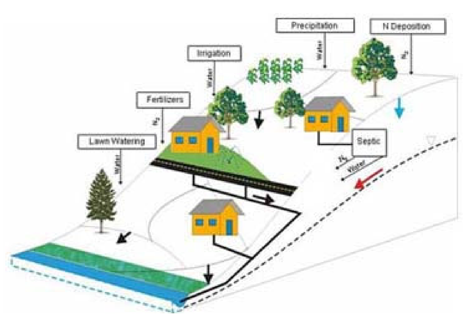
Vertical hydrologic processes



Carbon/Nitrogen processes



Lateral hydrologic processes

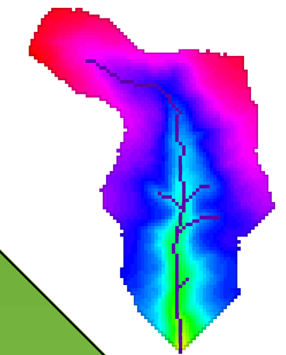


RHESSys allows estimates of sources and sinks of nitrogen along hydrologic flowpaths. Models, such as RHESSys, demonstrate how spatial structure influences hydrology and ecosystem function where spatial pattern includes a) distribution (a real proportion of different patch types within a watershed); b) configuration (relative position of these different patches in space); and c) the strength of connectivity between different patches.

Landscape Patch Heterogeneity and Scale

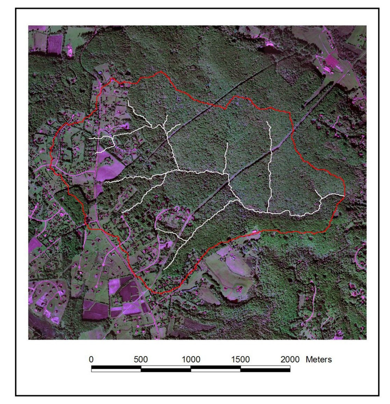
Does the scale of patch heterogeneity represented by the model impact estimation of ecosystem function (eg. riparian zone uptake of urban lawn fertilizer inputs?)

Study Site

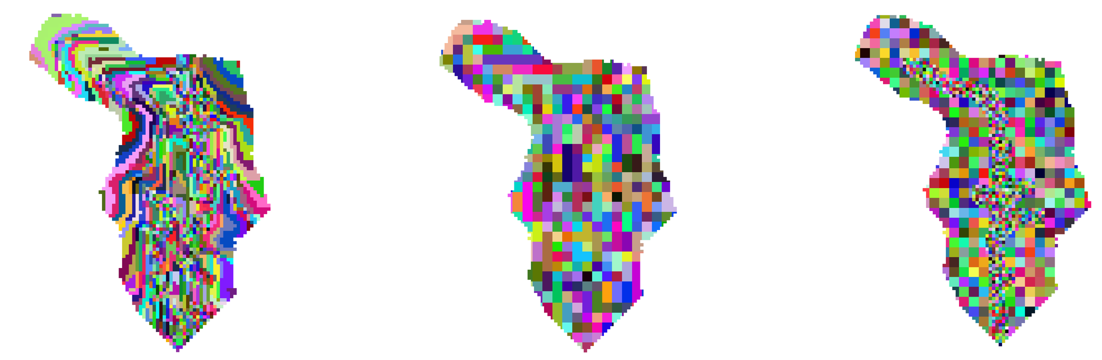


Using a small 2.8km2 watershed; we use RHESSys to investigate the role of fine-scale patch topographic heterogeneity in modeling N-cycling and export.

Humid oak-hickory forest;
annual precipitation 1100mm

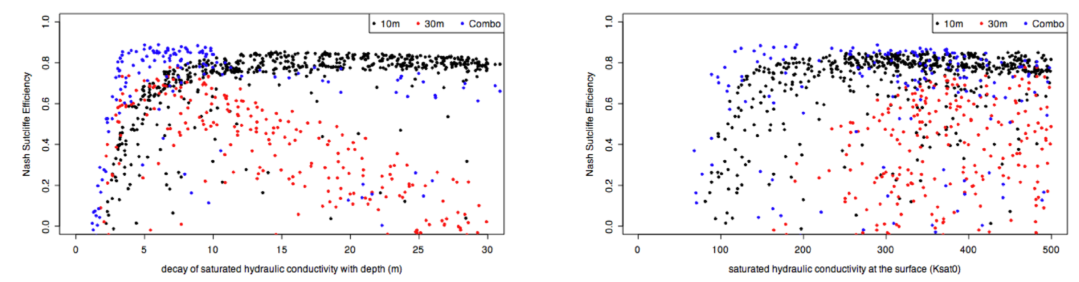


Consider the impact of different landscape patch definition



10 meter 30 meter Combination

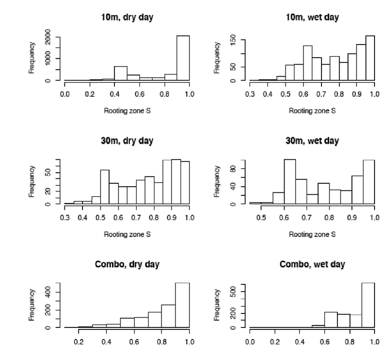
Calibrate model against observed streamflow

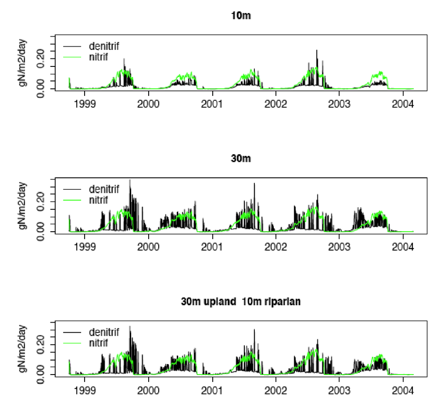


Landscape tesselation alters calibration results - note that highest performance is achieved using a 10m grid to define patches

What are implications for N export?

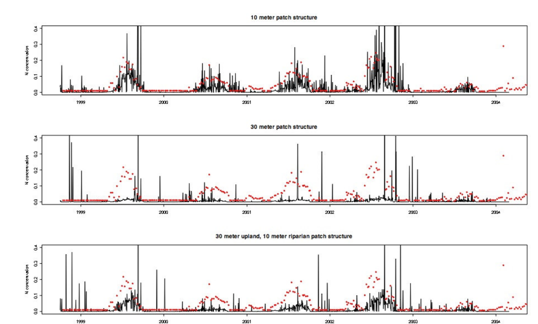
Patch tessellation significantly alters the estimated distribution of soil moisture - in particular for the dry period; a greater proportion of the watershed maintains a wet condition for the 10 meter patch structure - the intermediate patch tessellation (with 10m grids only in the riparian zone) also demonstrates this maintenance of a wet riparian zone during the dry period.





Observed nitrate export (red) shows elevated concentrations during the summer. The 10m patch tessellation is able to capture this pattern; high resolution in the riparian zone (Combination), however, shows improvement over 30m patches.

N-export pattern is linked to both flow driven export and nitrification-denitrification estimates. Summer denitrification is higher for coarser patch resolutions.



Summary

Varying the scale of patches used in RHESSys simulation of N-export for this humid watershed suggests that fine scale (10m heterogeneity) is an important control.

Lower soil moisture during the summer in the riparian zone leads to greater nitrification relative to denitrification. Fine scale (10m) riparian zone patches were necessary to capture the topographic heterogeneity that leads to appropriate a) flow diffusion/concentration; b) soil moisture distributions; and c) ecosystem function (denitirification/nitrification)