RHESSys: Regional hydro-ecologic simulation system

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**RHESSys**

Regional Hydro-Ecological Simulation System

- RHESSys is a process-based spatially explicit model of coupled hydrologic and biogeochemical cycling processes
- Focus on terrestrial ecosystems and linkages with aquatic systems

RHESSys is designed to develop scenarios and virtual experiments that explore how the co-distribution of moisture, carbon and nitrogen stores and fluxes in spatial complex terrain

Aggregate watershed time varying behavior
Spatial patterns of ecosystem processes

Landscape representation

- The RHESSys architecture models the spatial distribution and spatial-temporal interactions between the different processes at the watershed scale.
- Each level is associated with a different process that has specific storage, flux and default variables appropriate for that level.

Carbon and nitrogen cycling

Multiple canopy layers - attenuate water, energy, wind
Time-series inputs of precip, fertilizer, irrigation, atm. N-deposition, temperature
Major stores - leaves, stems, roots, litter (4) and soil (4)
Plant nitrogen cycling is generally mechanistically tied to carbon cycling.
Vertical Hydrologic Processes

- 3-layer soil-rooting zone: unsaturated zone, saturated + deeper groundwater
- Multi-layer canopy moisture fluxes

Soil Moisture Controls on N-Cycling

\[ N_{\text{denitrif}} = f(H_2O, \text{soil texture, } T, \text{C, N availability}) \]

\[ N_{\text{nitrif}} = f(H_2O, \text{soil texture, } T, \text{C, N availability}) \]

(Century N-Gas Model, Parton et al., 1996)

Accounting for Spatial Variability due to Lateral Fluxes

- Fully Distributed Approach
- Aspatial Distribution Approach

RHESSys allows us to consider two different conceptual models of how drainage works: in the simplest model, we assume that all water moves through the soil following a shallow subsurface flow system (parameterized using \( m, k \)). Both \( m, k \) are patch level parameters.

For watershed with deeper groundwater aquifers, we consider a certain amount of bypass flow to a deeper groundwater aquifer (parameterized using \( gw_1, gw_2 \)). The parameter, \( gw_1 \) is defined at the patch level, \( gw_2 \) is defined at the hillslope level.

Hillslope to Stream

- Basin
- Stream Flow Routing
- Hillslope
- Patch routing (within hillslope routing of saturated overland and saturated subsurface throughflow)
A what scale does heterogeneity matter and how do we model those different scales?

Heterogeneity - Scales of interest
- Between watershed - differences in climate, vegetation, topography
- Between hillslopes - either side of a stream reach, different profiles
- Within hillslope - upland, midslope and riparian
- Within patch - hot-spots (hot-moments) of water, carbon and nutrients

Scales of connectivity
- Along terrestrial and fluvial flow paths

N-cycling example
- Baltimore Ecosystem Study (Control forested watershed: Pond Branch)
Watershed stream N-export

High Summer Stream nitrate conc. for both model and stream sampling

High in-stream N corresponding with lower summer denitrification, higher net nitrification due to drying of the soil

But this only occurs in riparian zone - within hillslope heterogeneity


Comparison of RHESSys Estimates of N-export For 30m versus 10m patches

30m patches - reduces estimate of N-flux, flashier export

RHESSYs and scale issues

- Within a complex landscape, model scale must be fine enough to capture - hydrologic convergence that creates important nexus of water, carbon and nitrogen
- For Pond Branch - 10m is reasonable for a small-scale (1-3rd order watershed) - what if sub-grid scale heterogeneity matters - or if we want to run model for a larger region
- Top-model type approaches (distribution functions within patches) - but retain connection across coarser patches - next RHESSys generation

Weaknesses

- Limited testing of the nitrogen cycling model
- Input data and parameter intensive
- Computation time for large watersheds
- Steep learning curve
- Current phenology model is static – to be updated soon
- Overly simplistic vertical distribution of nitrogen
- The current version of the model does not include in-stream nitrogen cycling and routing processes (planned for next version)
- DON and DOC fluxes are modeled as a simple proportion of mineralization rates
- Sensitivity to initial conditions or spinup of slow pools
Strengths

• Process-based representation of interactions and coupled feedbacks between water, carbon and nitrogen cycling
• Ability to account for both the role of spatial heterogeneity and spatial connectivity
• Ability to model human impacts through increases in nitrogen and water inputs as well as changes in the flow network through the construction of roads and sewer networks
• Ability to account for heterogeneity in different processes at different scales - New version to include sub-grid heterogeneity
• An adaptable, object-oriented modeling framework
• Multiple outputs present multiple opportunities for model evaluation (e.g., comparisons with observed streamflow data, stream chemistry, remote sensing of vegetation, SNOTEL measurements etc.)
• Assessment of hydrologic model in multiple settings

Nutrient Addition Experiments - to support development of in-stream RHESSys model

- Co-injection of conservative tracer (bromide) and reactive tracer (ammonium)
- Why ammonium?
- Reaches defined by stream characteristics (e.g., riffle-pools, debris dams)
- Reach length ~80-100 m
- Single addition covered 3-5 sequential reaches; 16 reaches in 4 days
- Fall 2003 and Summer 2004

Baisman Run Watershed

- Monitored as part of Baltimore Ecosystem Study LTER program
- Mid-size (3.8 km²) watershed
- Low-density residential in head waters, all on septic; forest in lower part
- Stream sampling suggests high rates of in-stream processing
- Longitudinal step change in nitrate loading is particularly suited for studying in-stream processing

Ammonium Uptake vs Flow

smaller X-section  →  higher ammonium uptakes (probably due to longer residence times and increased water/sediment)

Evidence of Nitrate Loss

N budgets using synoptic sampling and flow measurements

Large temporal variability
Nitrate loss can be significant … sometimes
**Role of Flow Path Alteration in Urbanization**

(A companion study)

Torrey Pines Watershed
- 60 hectares
- Chaparral vegetation
- Residential Development
- Precipitation (25 cm/year)

**Increases in peak flow due to construction of sewer network in a semi-arid environment**

**Application: Urbanization Impacts**

<table>
<thead>
<tr>
<th>Change</th>
<th>RHESSys Implementation</th>
<th>RHESSys File</th>
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</thead>
<tbody>
<tr>
<td>Change in flowpaths between patches</td>
<td>Change in routing due to roads and storm sewers</td>
<td>Change in flowpaths between patches</td>
</tr>
<tr>
<td>Change in vegetation type (forest-grass)</td>
<td>Change in vegetation type parameter</td>
<td>Flexible</td>
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