Modeling watersheds as spatial object hierarchies: Structure and dynamics

Published by Band LE, Brun SE, Fernandes RA, Tague CL & DE Tenenbaum, 2000.
Transactions in GIS, 4(3):181-196.

Introduction

Watersheds:

- process occur across media on a range of temporal & spatial scales.
- human activity interacts with this processes
  - water quality problems
  - policy & management focus on human/biophysical interaction

It is a challenge for spatially distributed models to represent the landscape where these interactions can be addressed across a range of scales.

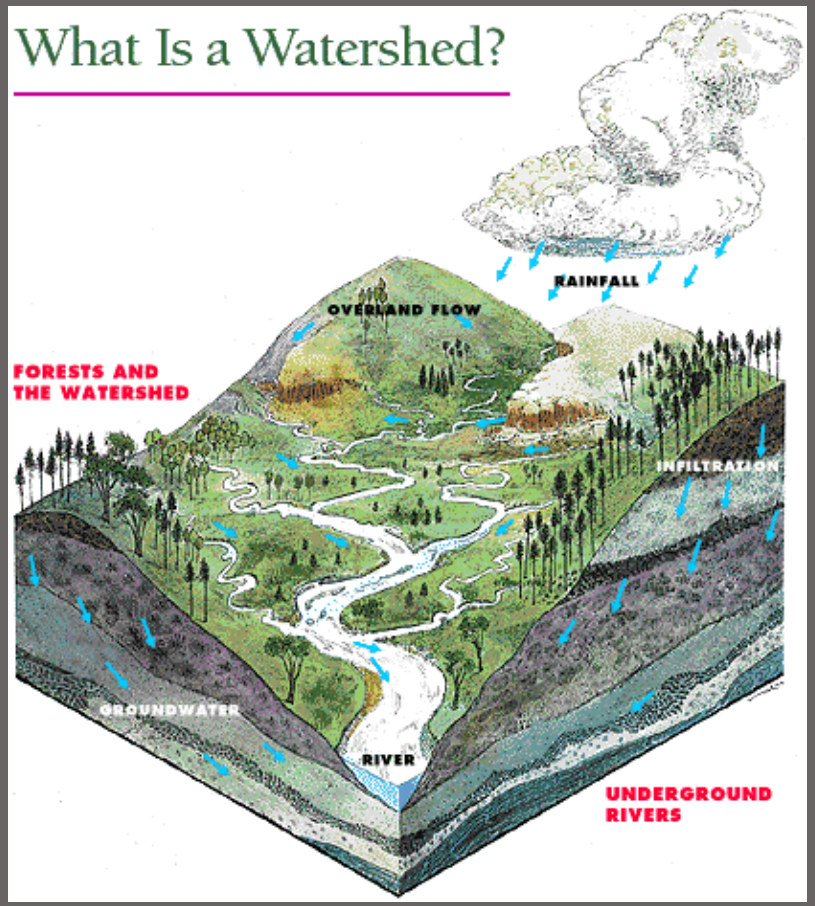


Photo Credit: Berks County, PA: Watershed Program

Introduction

Objectives:

- "Describe a spatial object-oriented (OO) framework to model watershed systems, with a focus on computing the spatial and temporal distribution of watershed hydrological and ecosystem flux."

- "We focus on the development of landscape object classes required to represent watershed form, the distribution and dynamics of flow fields characterizing surface and shallow subsurface processes, and interaction with individual and institutional activity."

Band et. al, 2000

Background

Specific goals and design criteria for the watershed system we describe include:

1. a formal representation of the watershed as a landscape object hierarchy in which classes correspond to identifiable landforms and surface cover organized and addressed around the stream network;

2. the ability to scale the simulations from small, instrumented experimental catchments to large regional watersheds using progressively simplified and generalized landscape and process representation within the component hierarchy;

3. the ability to accept forcing variables (e.g. meteorological fields) from multiple sources including point or spatially distributed observations, and model (e.g. atmospheric) output;

4. the representation of human interactions by estimating flux (addition and abstraction of water, carbon and nutrients) and the effects of altered surface cover and drainage flowpaths;

5. the ability to couple with models representing atmospheric boundary layer dynamics, as well as groundwater models.

Band et. al, 2000

RHESSys

- **Regional Hydrological Ecological Simulation System**

- RHESSys:
  - spatial data and simulation system
  - solves coupled soil/canopy water, carbon and nutrient budgets over a set of surface patches which are defined in a set of hillslope hydrologic flow fields within a watershed
  - incorporates GIS operations

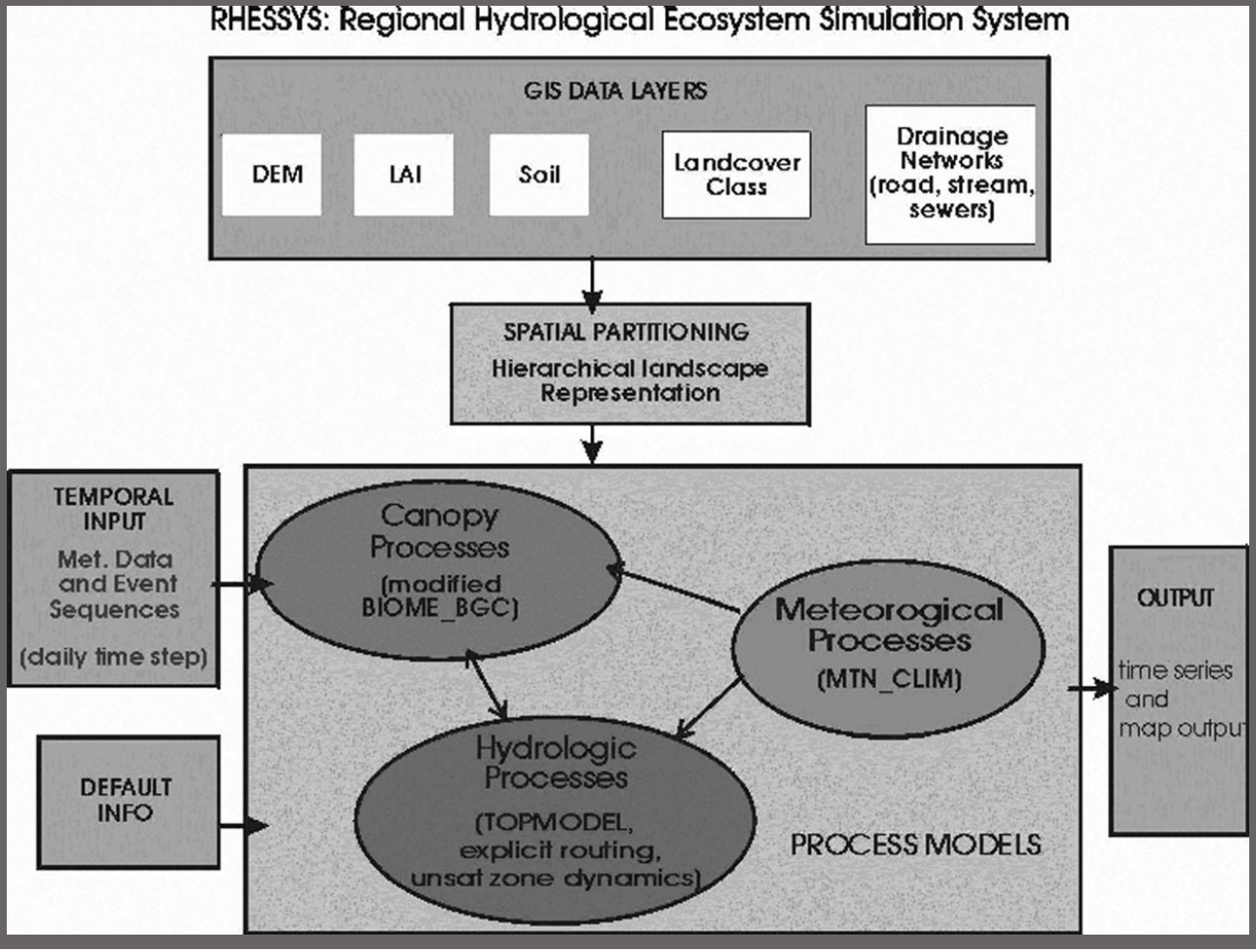
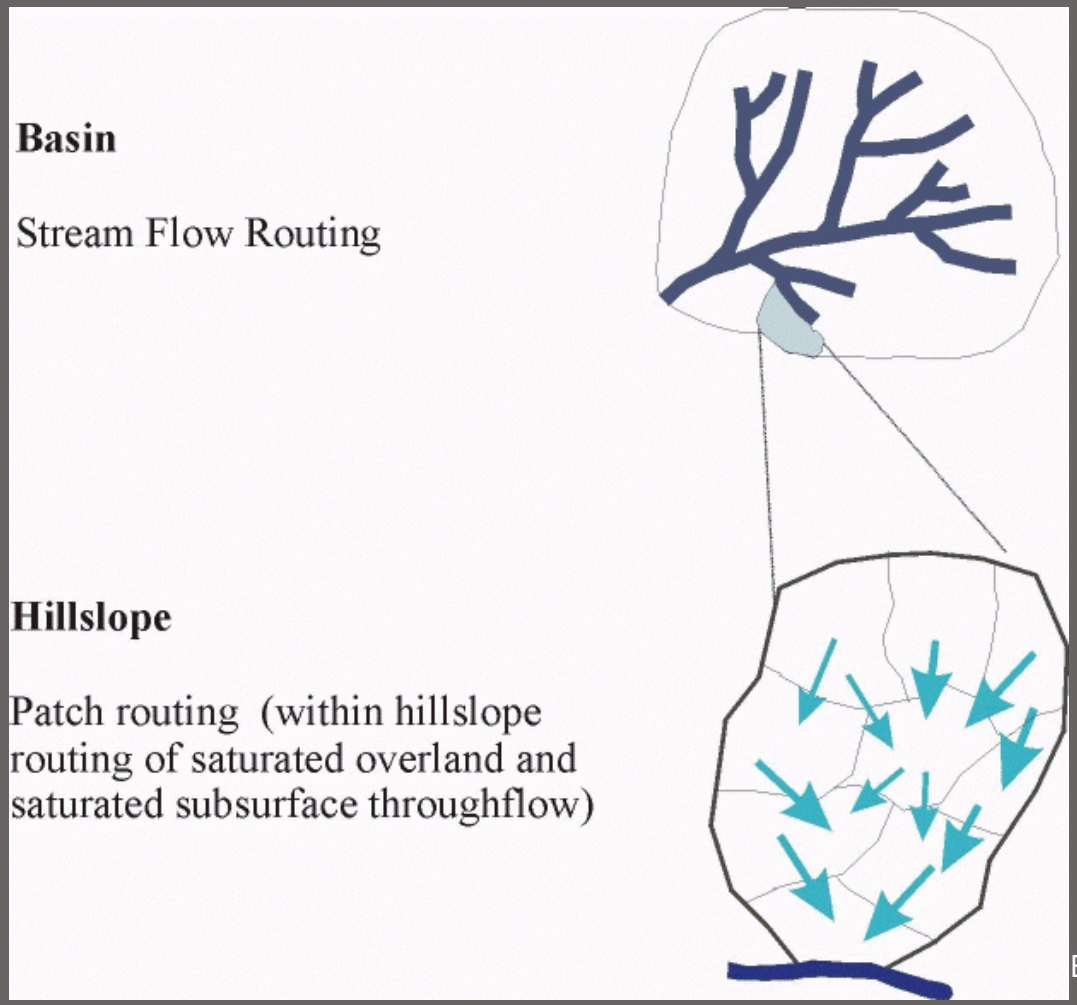


Figure 1 Structure of RHESSys consisting of a GIS capable of organizing the spatial information required to instantiate the landscape object hierarchy, and a spatially distributed object-oriented simulation model that operates on daily to sub-diurnal time steps to compute water, carbon and nutrient budgets. Temporal events are prescribed prior to simulation through the TEC file, and can include simple controls on data output, or redefinition of object attributes due to disturbance, land use change, or data assimilation from satellites (e.g. phenology).

Band et. al, 2000

Landscape Representation

Watershed c-> hillslope c->climate zone c->patch c->canopy strata
(c-> denotes spatial containment)



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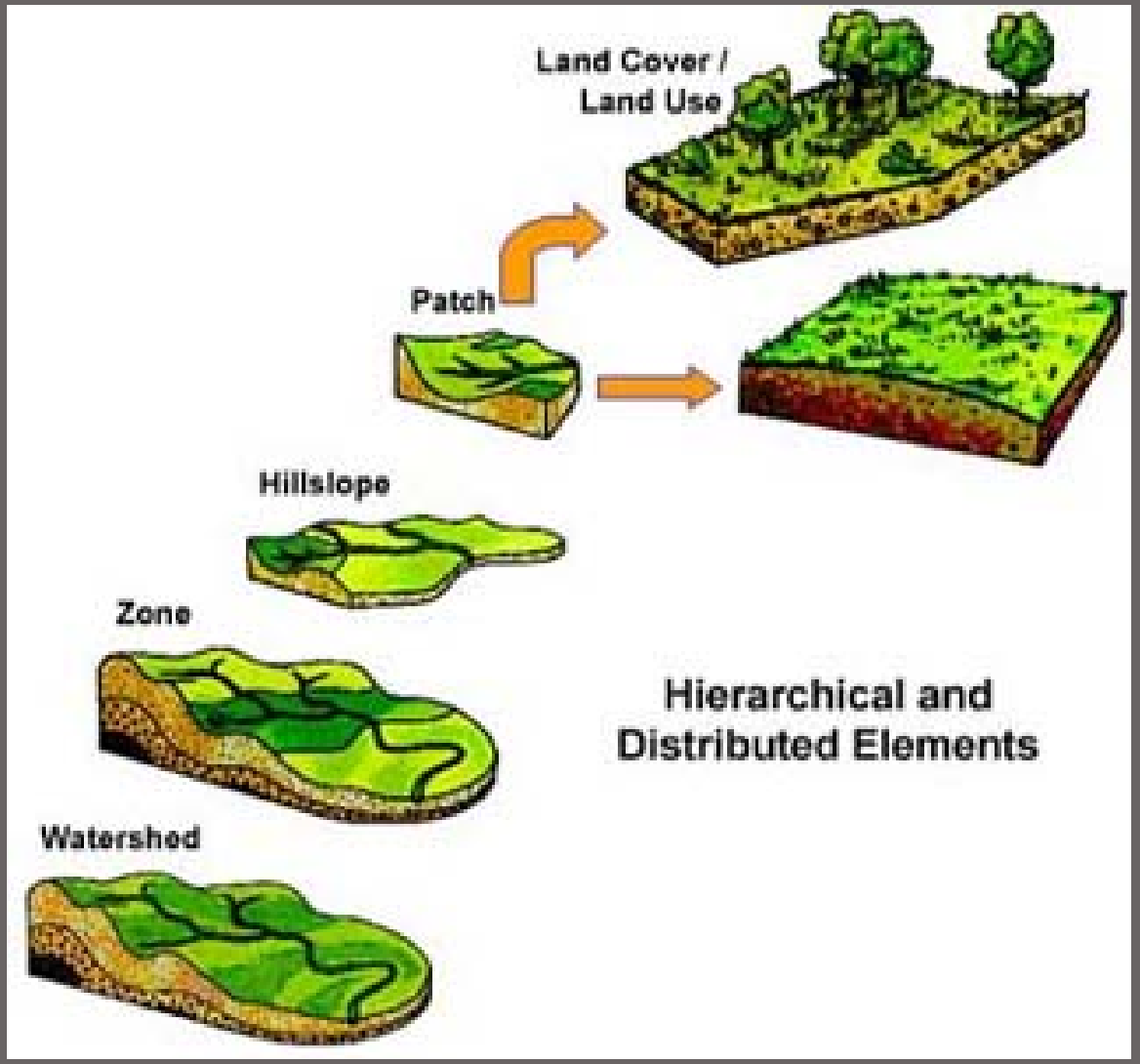
Landscape Representations

- **World class:** entire area (spatial and temporal) within which watershed dynamics will be addressed
  - identifies links to the set of inputs
  - it contains a set of basin class objects that define separate or contiguous watersheds.
- **Basin class:** watershed area above a specified outlet
  - contains stream network
  - cumulative unit for ecosystem & hydrological processes
- **Hillslope class:** defined areas which drain to a common stream link
  - drains into a stream link which is shared with the hillslope object draining into the opposite side of the link
  - can be used to aggregate processes or stores contained in lower parts of the hierarchy

Landscape Representations

- **Zone class:** areas of similar climate
  - Made of one or more patches
  - Linked to set of input climate time series
- **Patch class**: highest resolution spatial unit
  - can be an overlay of several themes (i.e. vegetation & wetness index)
  - Human activity defined at patch level (i.e. storm drains)
- **Canopy Stratum class:** inherits spatial partitioning from parent patch
  - defines multiple vertical layers
  - canopy physiological & biogeochemical processes are defined within this class (i.e. photosynthesis)
  - in urban areas, includes rooftops & pavements

Landscape Representations



http://fiesta.bren.ucsb.edu/~rhessys/data/pics/distributed_elements325.jpg

GIS Input and Structure of Landscape Description in RHESSys

- Worldfile: the full hierarchy at a given instance of time
  - can be generated via spatial data within a GIS environment with a specific interface program, or during a model simulation at any given time step
  - Within the worldfile, each level of spatial hierarchy has an association
    - Identifier
    - State Variable
    - Link to default variables
    - Link to a climate station
- This framework's GIS interface with RHESSys can be used in GRASS or ArcVlew

ArcView Interface

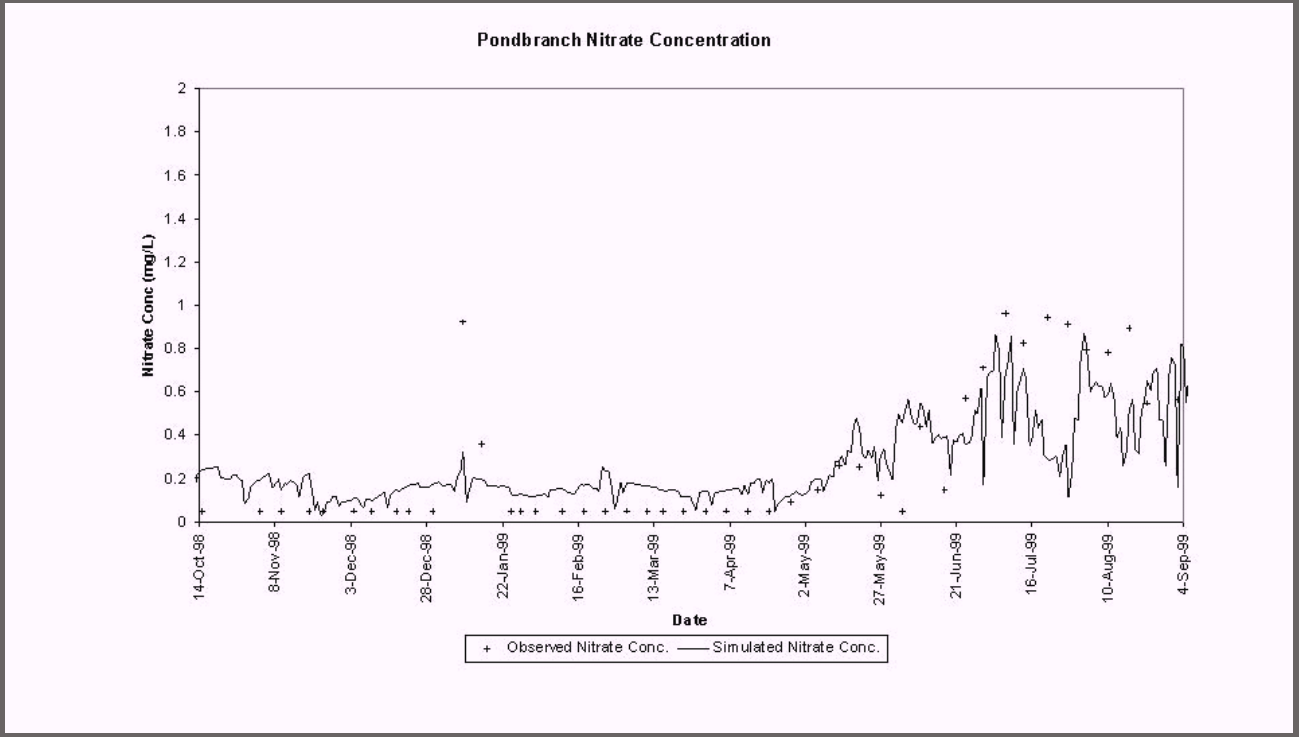
RAIMEnt:

RHESSys Arc-view Integration & Modeling Environment

- provides enhanced functionality and a tighter coupling of the GIS/modeling environment
- includes additional features such as a model tracking & documentation facility, visualization of spatial data output.

Model and Spatial Data Handling Illustration

- Used on a catchment within the Baltimore Ecosystem Study
  - use of the modeling and spatial data system to generate time series of basin nitrate concentrations in stream flow



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Model and Spatial Data Handling Illustration

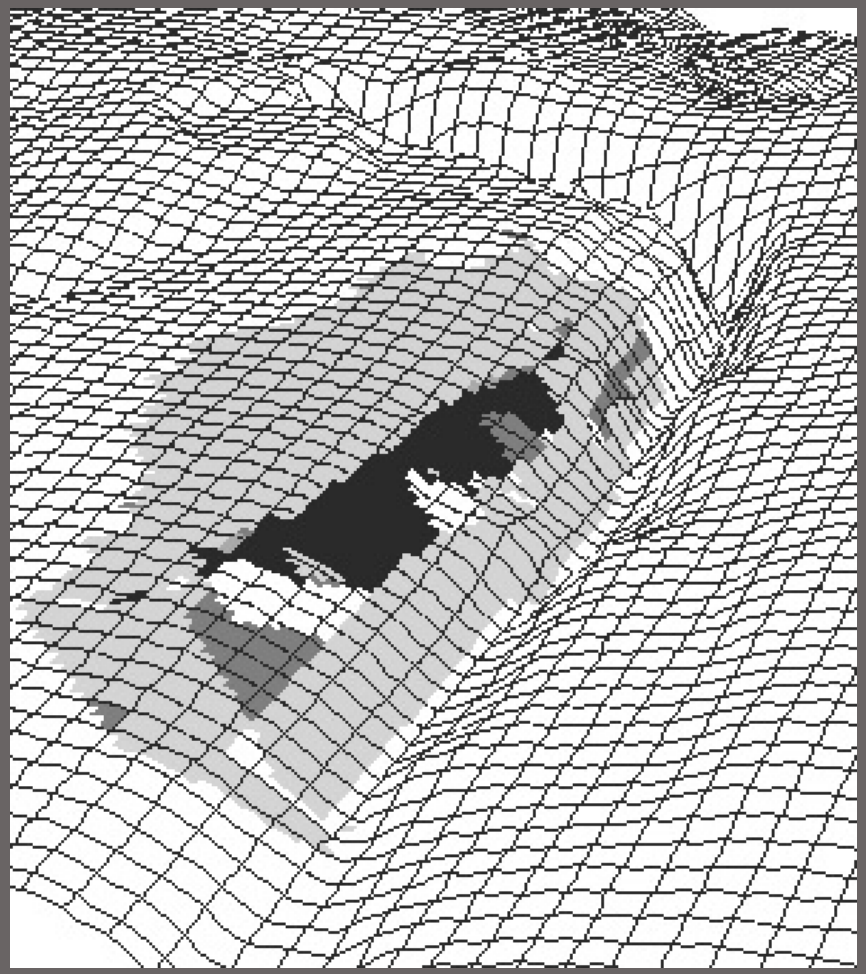

Figure 4 Spatial fields of standing stem carbon defined at the patch level for hillslope 1(Plate 2) with grey values ranging from 1.4 kg.C.m-2 to 1.7 kg.C.m-2. Differences are largely accounted for by variations in soil moisture, with the steep midslope area being better drained and typically experiencing greater soil water limitations through the summer growing season.

Band et. al, 2000

Conclusions

- Implemented a spatially distributed hydroecological model as an object oriented containment hierarchy.
- Processes are defined as member functions for specific landscape classes (hillslope, patch etc.), corresponding to the scales at which they occur within watersheds.
- Allows for interaction of processes occurring over a wide range of space & time scales
- Further work needs to be done to define socioeconomic indices at the patch level.