Using the GR4J and NC Models to Quantify the Hydrologic Effects of Biomass Production

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Background & Problem

- Expansion of domestic biofuels industry necessary
  - Range of domestically produced feedstocks must grow to include more significant amounts of:
    - Forest and agricultural residues
    - Dedicated energy crops
- Need to identify best management practices for producing and removing feedstocks from the land
  - Lack of reliable environmental data at the watershed scale
  - Research is needed to demonstrate the type of effects that feedstock production and removal may have on ecosystem health

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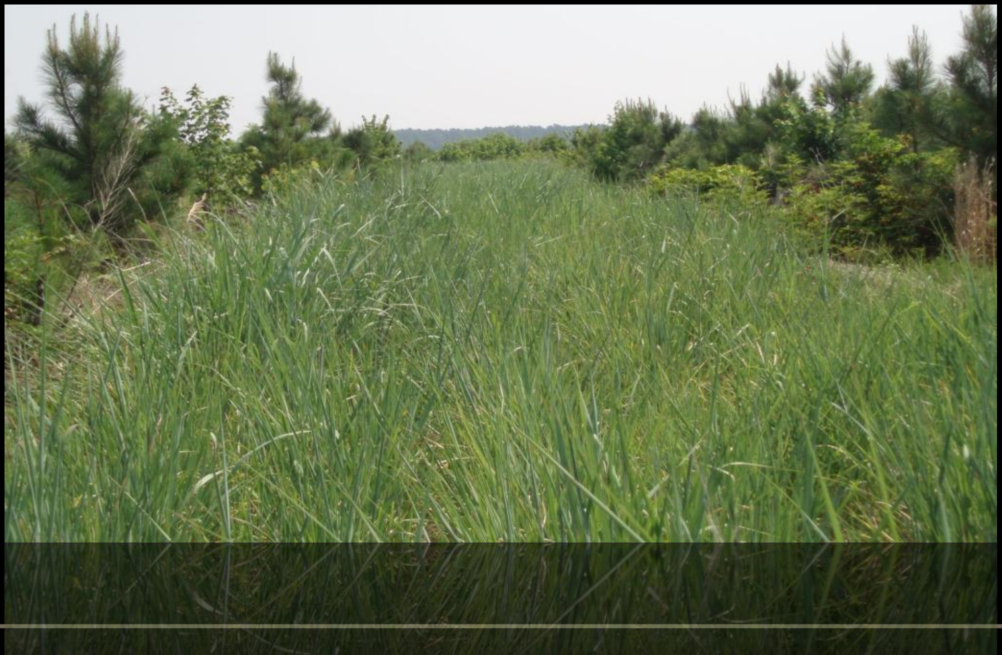
Research Focus

Goal

- Evaluate the effects of biomass cultivation on hydrology in managed pine forests of the southeast region of the U.S.

Biomass Cultivation Scenario:

- Intercropping pine trees with an energy crop (switchgrass)



Research Project

- Part of research initiated by a joint venture of Weyerhaeuser and Chevron: Catchlight Energy
  - Biofuels from resources such as existing forest residuals and intercropped energy crops
  - Research at watershed scale to provide assessment of ecological effects

Field Experimental Design

- 3 matched managed pine plantation research sites in the southeast region
- Paired watershed design
  - 4-5 watersheds (each), 20-40 ha in size
  - Some watersheds serve as controls/references while others are treated with a biomass cultivation scenario

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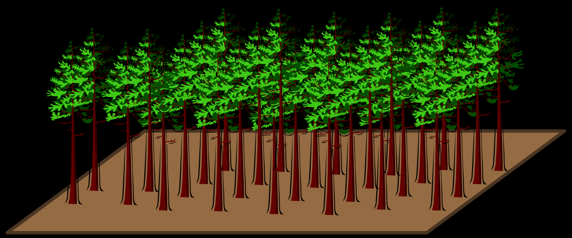
Field Experimental Design

Watershed Treatments

- **Young pine plantations (3-6 years old)**
  - Regular management (Control)
  - Switchgrass intercropping
    - Thinned and switchgrass planted
    - Clearcut, pine and switchgrass planted simultaneously
- **Switchgrass only**
- **Reference pine plantation (16-18 years old)**



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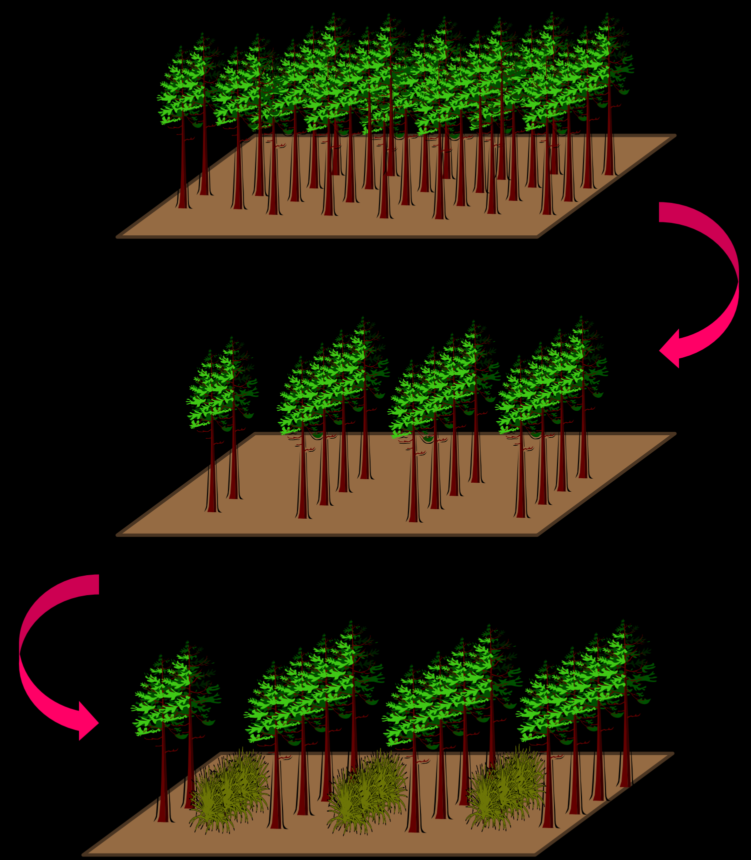

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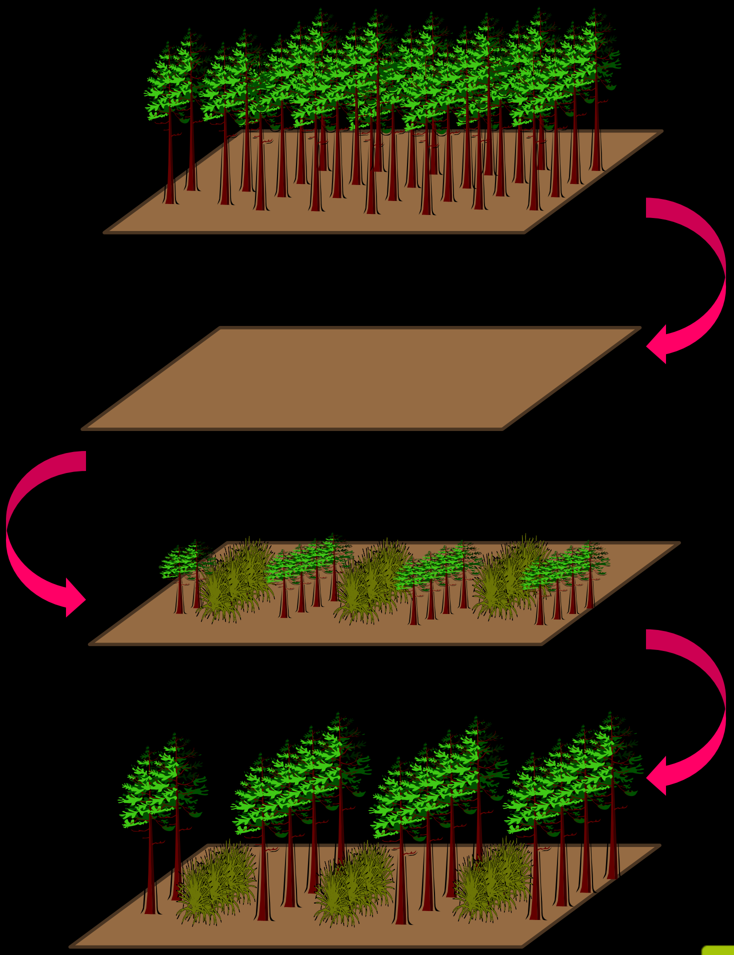

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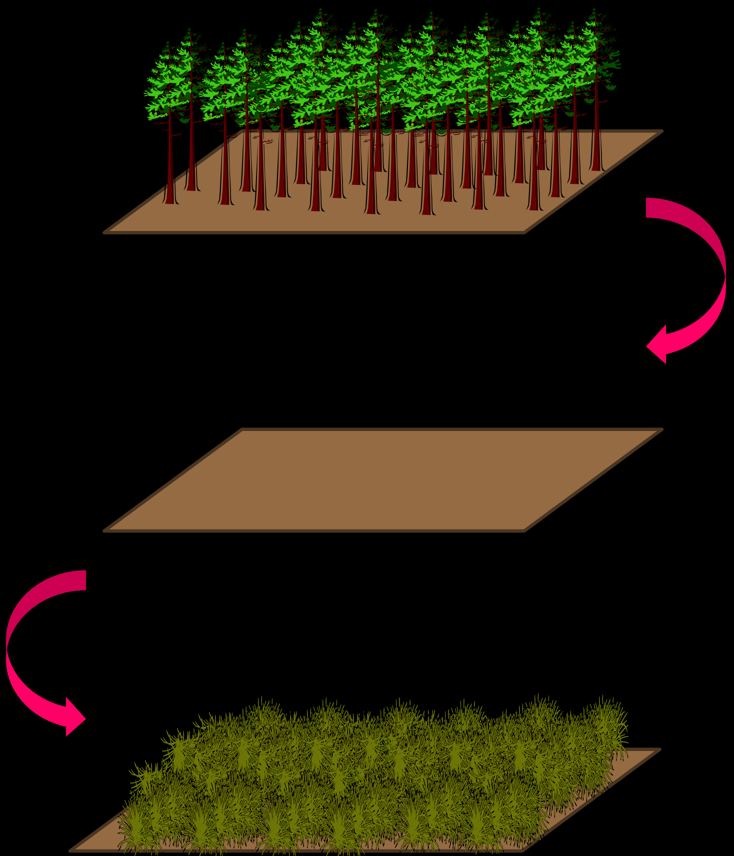

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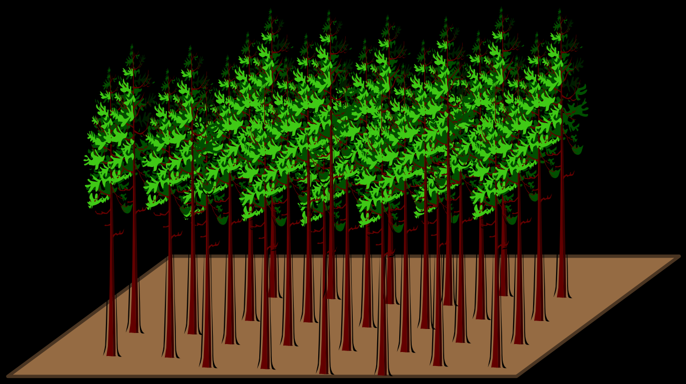
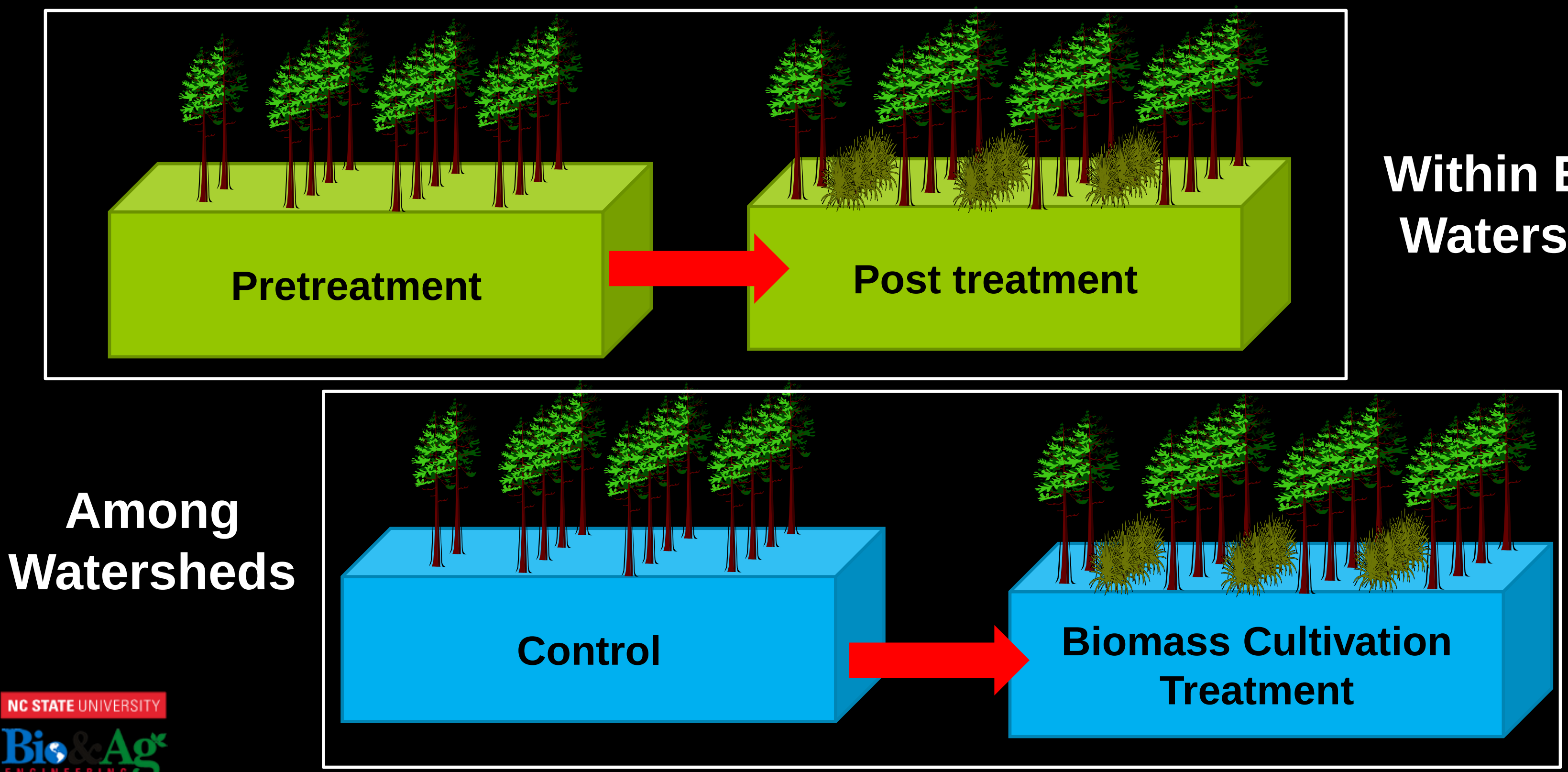


Objective

- Detect and quantify differences in discharge at the watershed outlets that could be attributed to the land cover conversion to biomass cultivation



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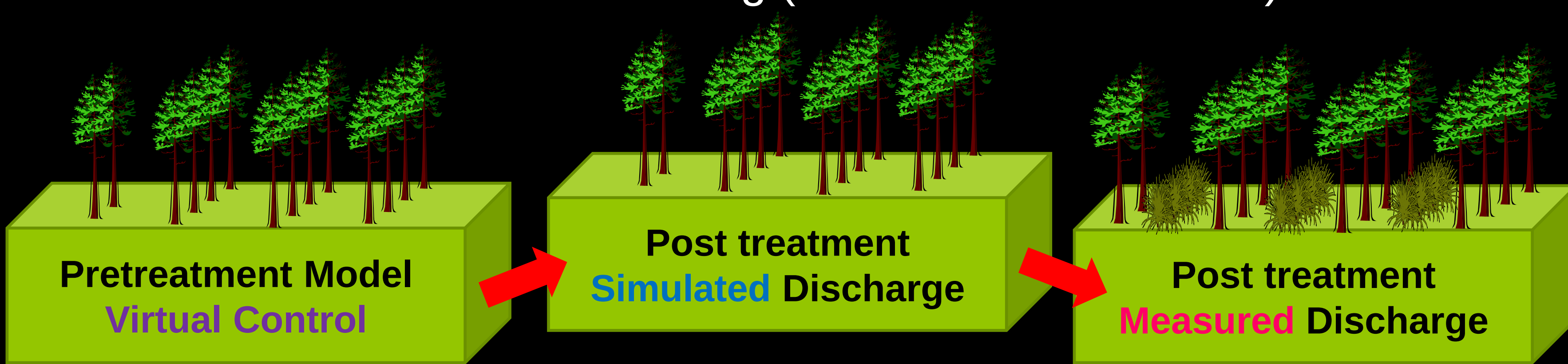
Concerns

If we compare observed data directly:

- Inter-watershed variability?
- Climatic variability between pretreatment and post treatment?

Methods

- Perform 2 main hydrological modeling methods available for detecting effects of a land cover change
    1. Rainfall-runoff modeling (within each watershed)



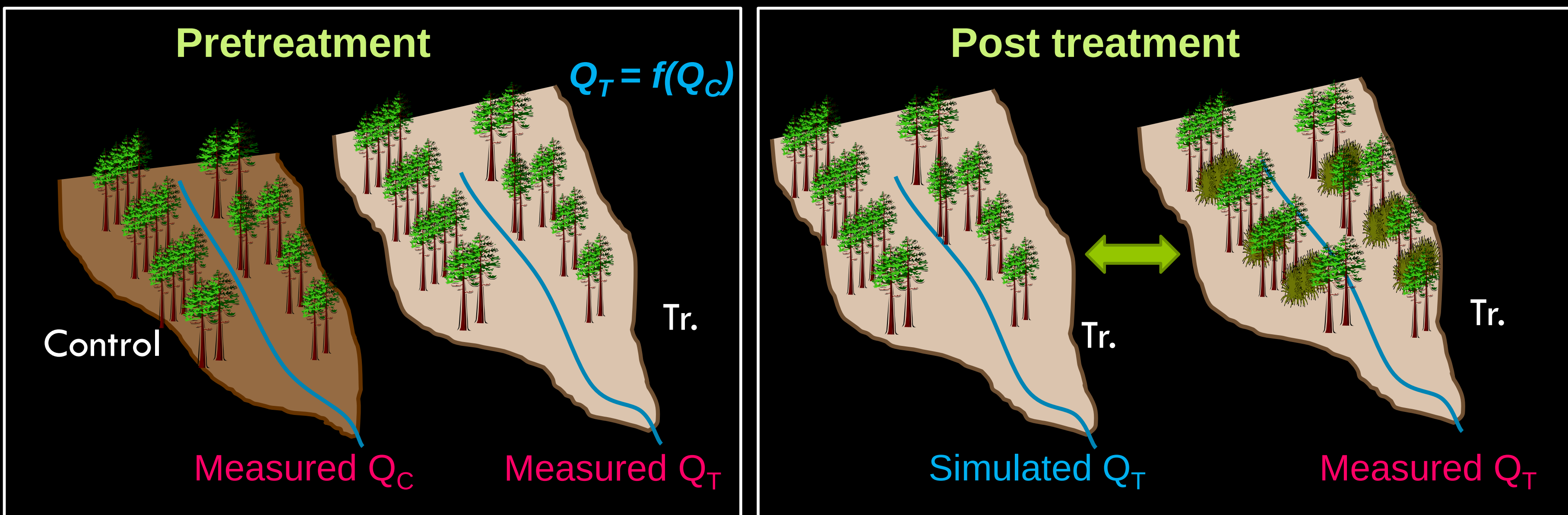
Model the measured rainfall-runoff behavior in the pretreatment period to simulate a virtual control.

Use this modeled relationship to simulate streamflow after treatment, as if no treatment were implemented.

Compare simulated streamflow to observed streamflow.

Methods

2. Paired watershed design modeling (among watersheds)

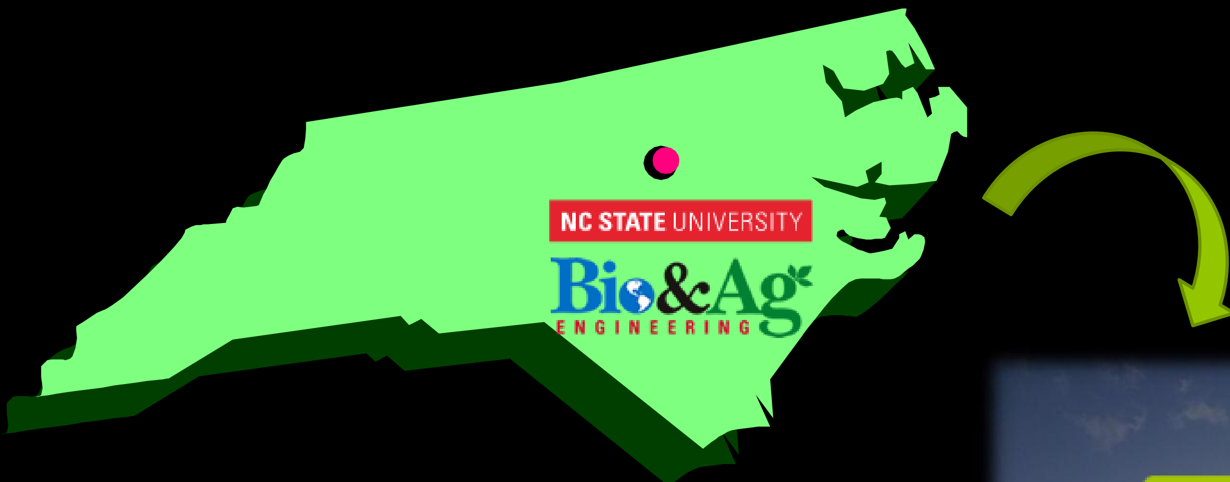


Model a relationship between the discharges of the control (Q_C) and treatment (Q_T) watershed.

Use this relationship to model the treatment discharge as if no treatment occurred.

Compare simulated and measured discharge.

Collaboration



Methods

Rainfall-runoff Model Selection

- **GR4J**[1]
  - Daily/hourly, lumped, empirical, rainfall-runoff model
  - 4 free parameters
  - 2 Inputs Only: Rainfall and PET
  - Very robust
    - No hydrological processes separately modeled
    - No spatial distribution of inputs or processes
    - Models rainfall-runoff transformation in the catchment as a whole
  - Belongs to a family of soil moisture accounting models
    - Soil treated as a series of stores in which rainfall is routed to and from with developed mathematical operators

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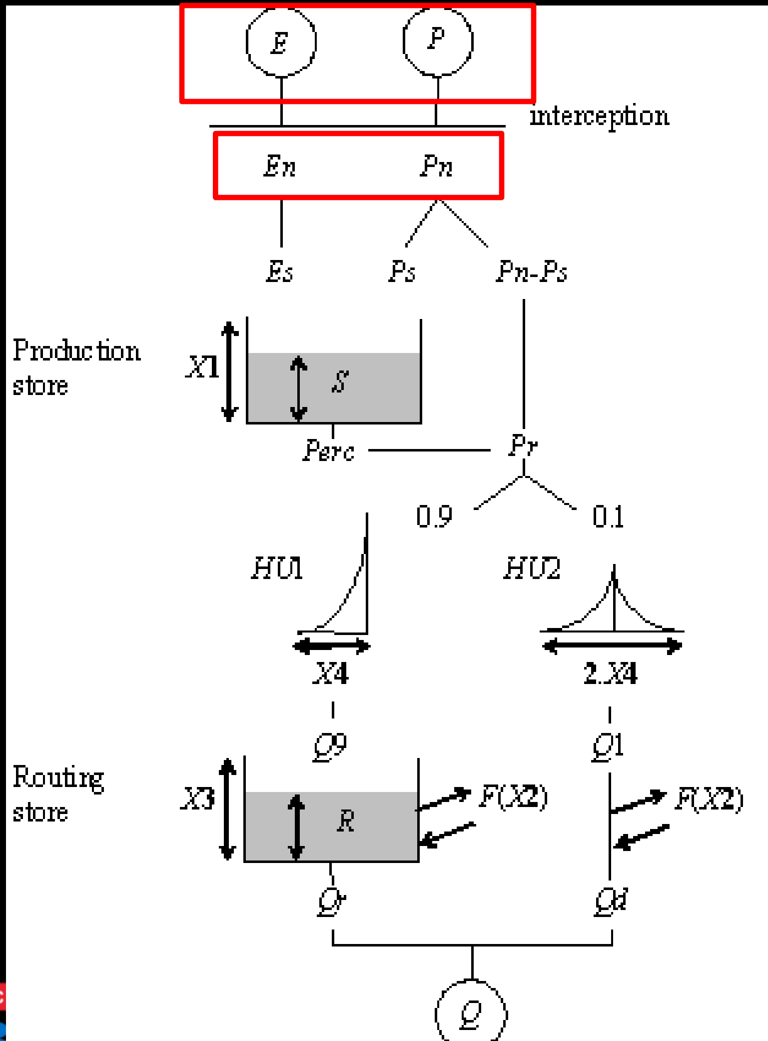
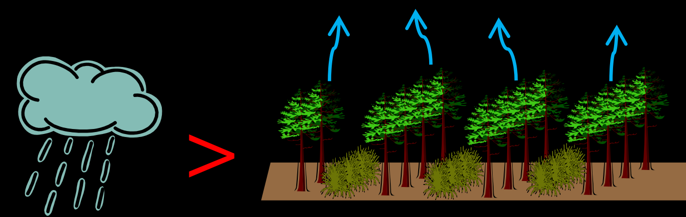
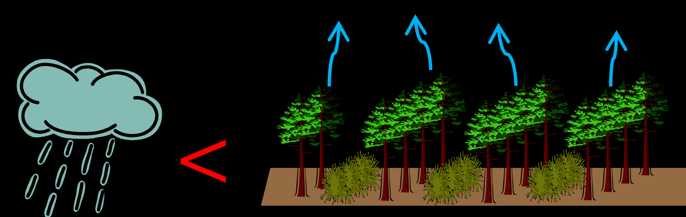


Mathematical structure of GR4J

- Inputs: PET and rainfall
- Net rainfall or PET?



$Pn = P - E$ and $En = 0$



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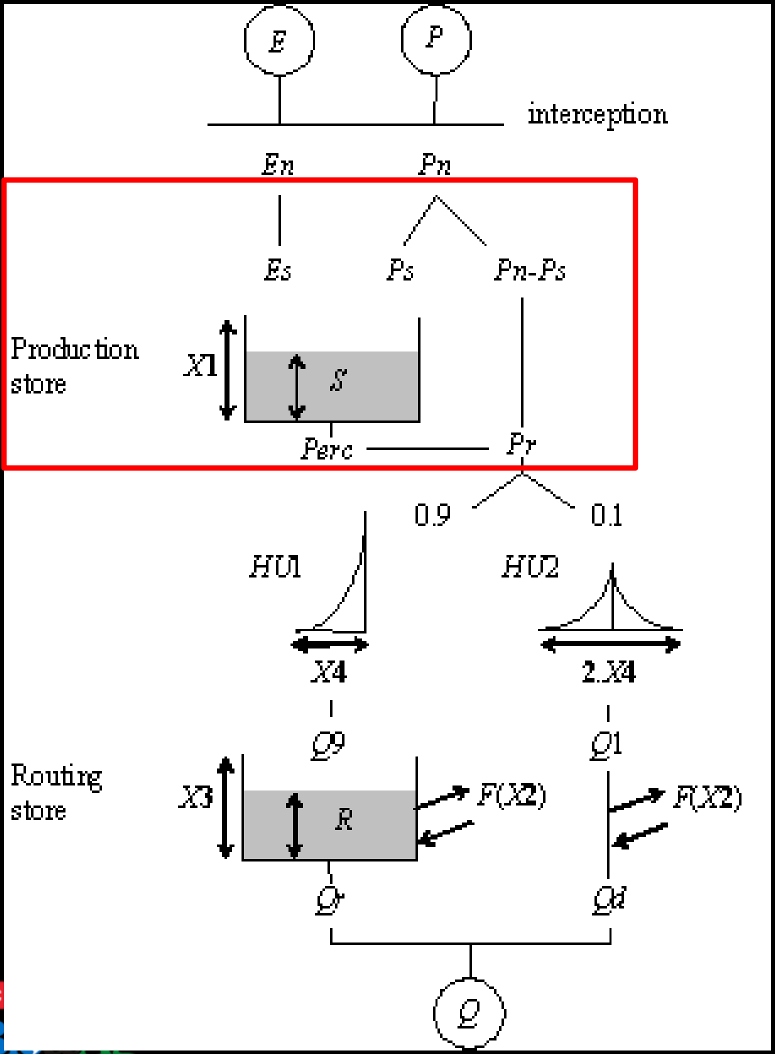


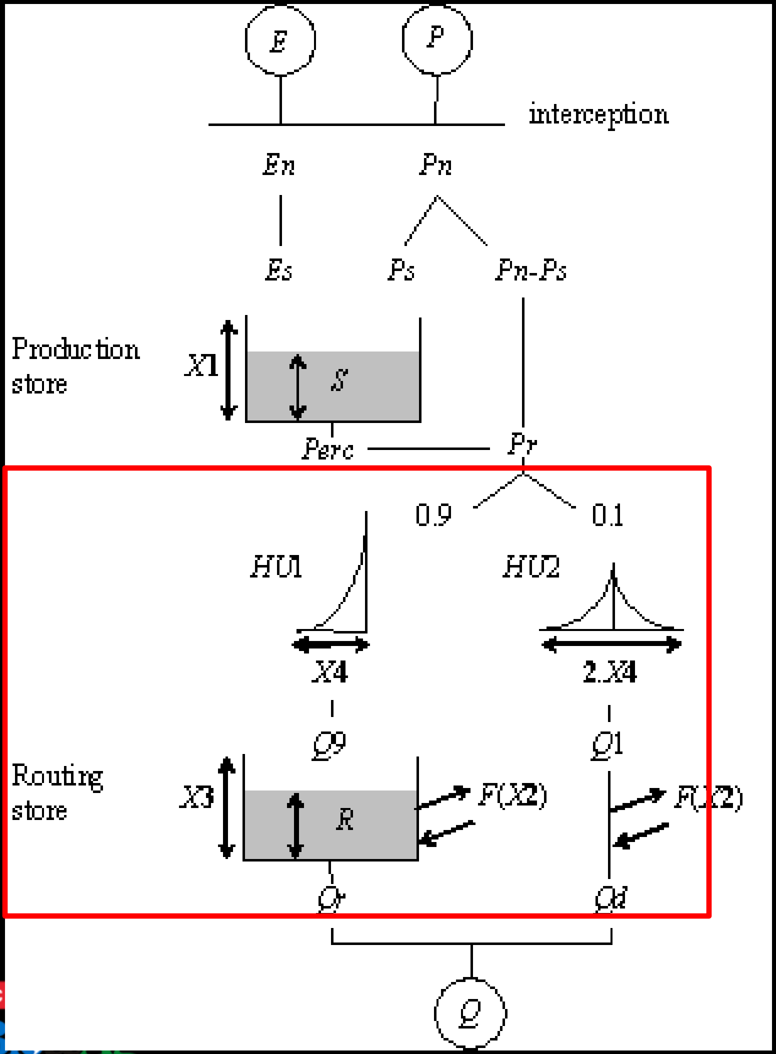
Mathematical structure of GR4J

- Production store and effective rainfall
- Routing by unit hydrographs
- Exchanges

4 Free Parameters

- Production store capacity
- Unit hydrograph time base
- Routing store capacity
- Groundwater exchange intensity

Methods



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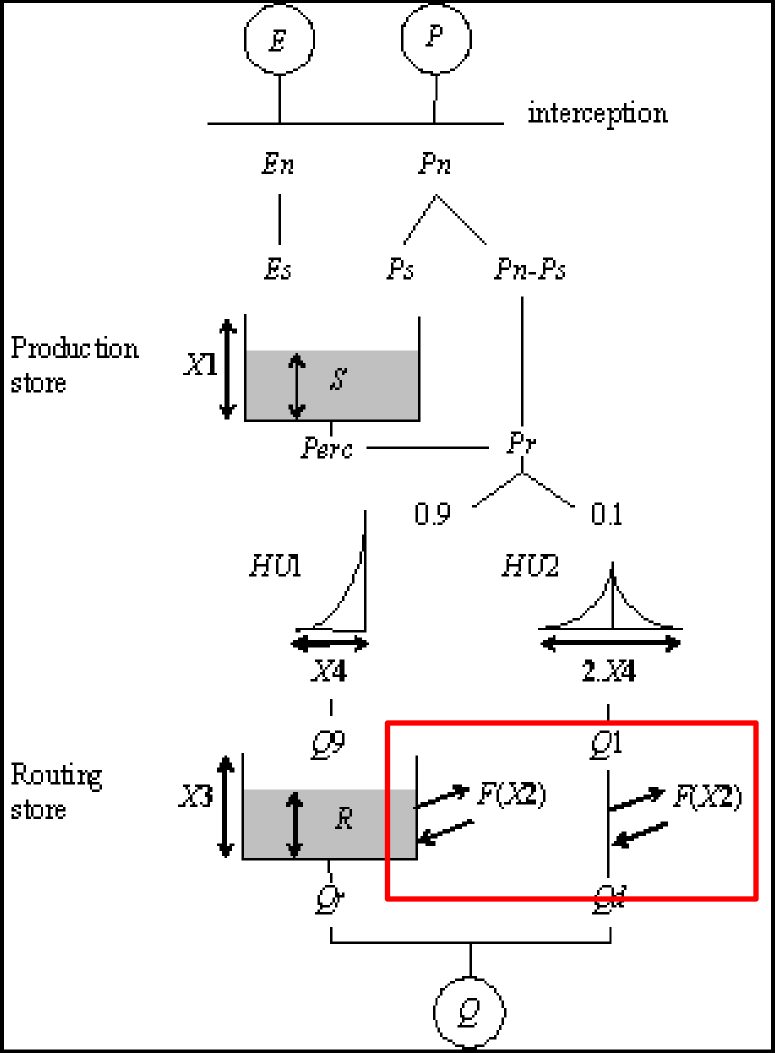

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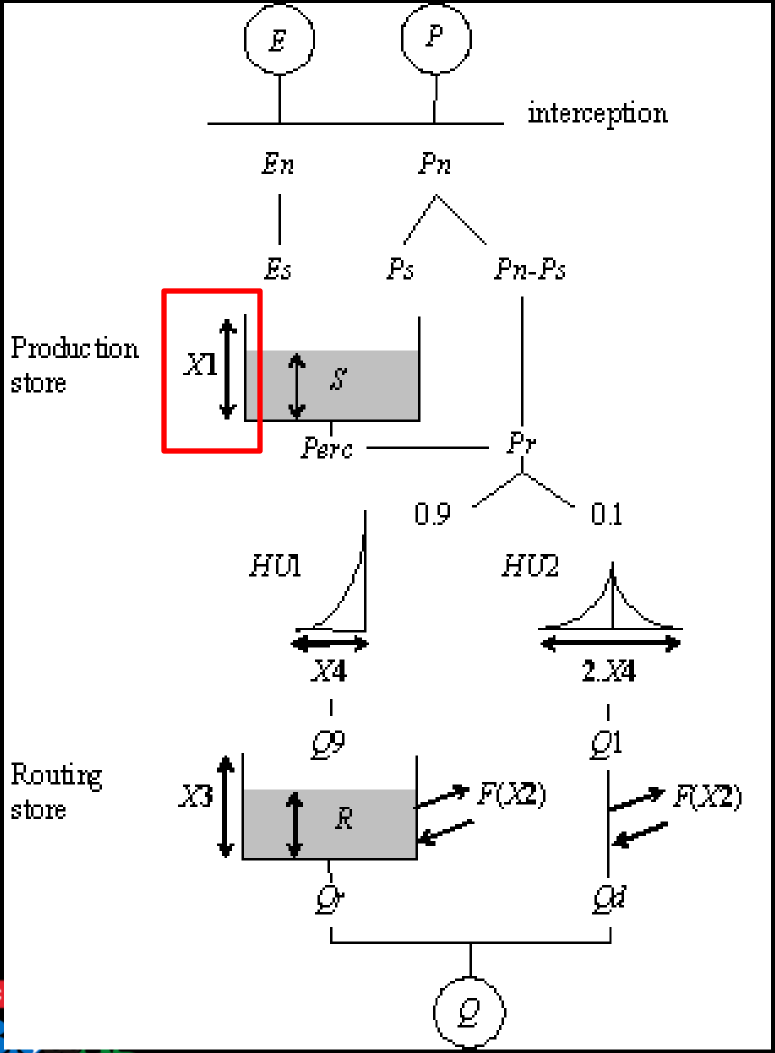

Mathematical structure of GR4J

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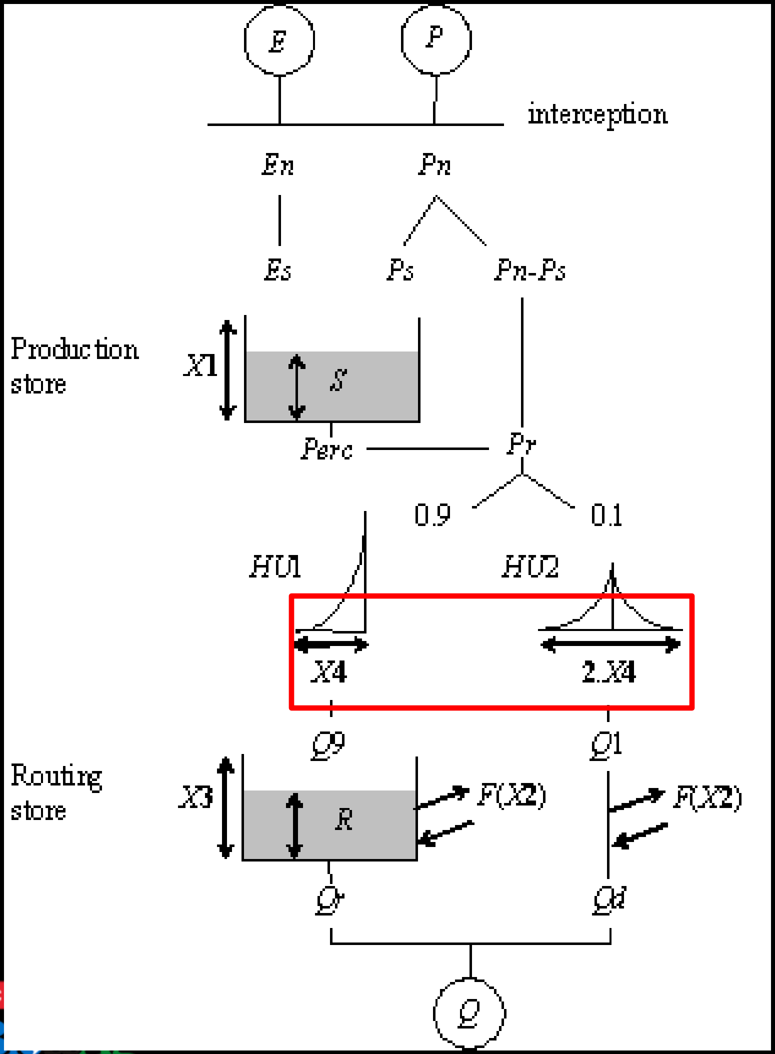

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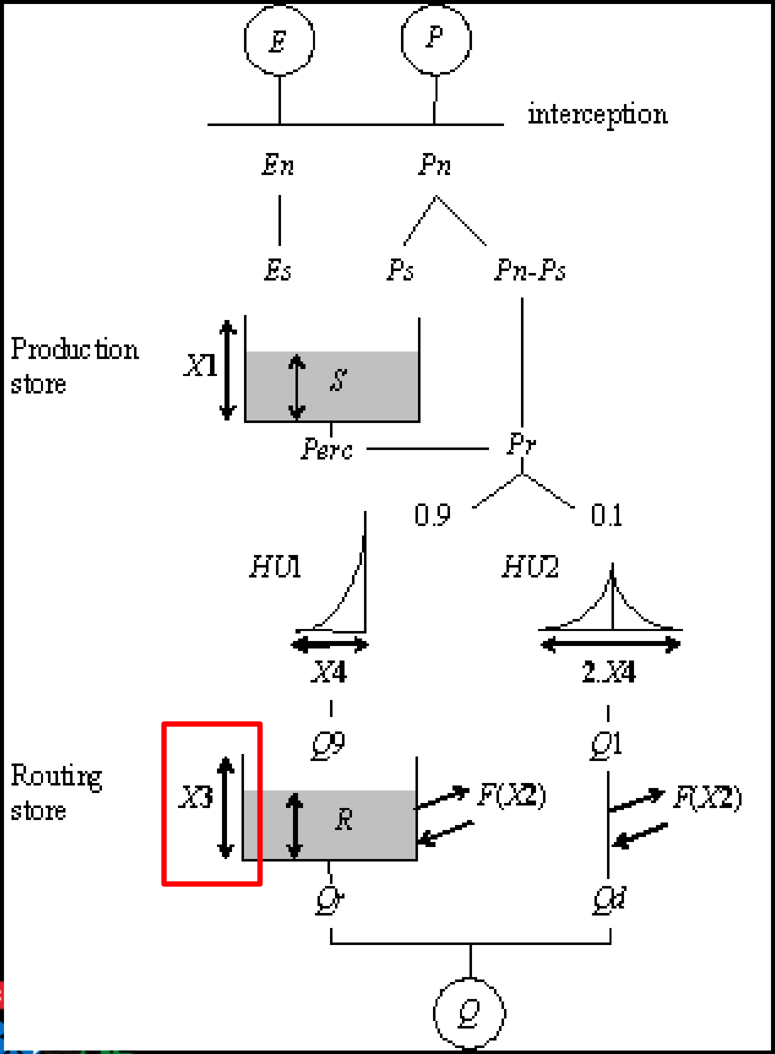

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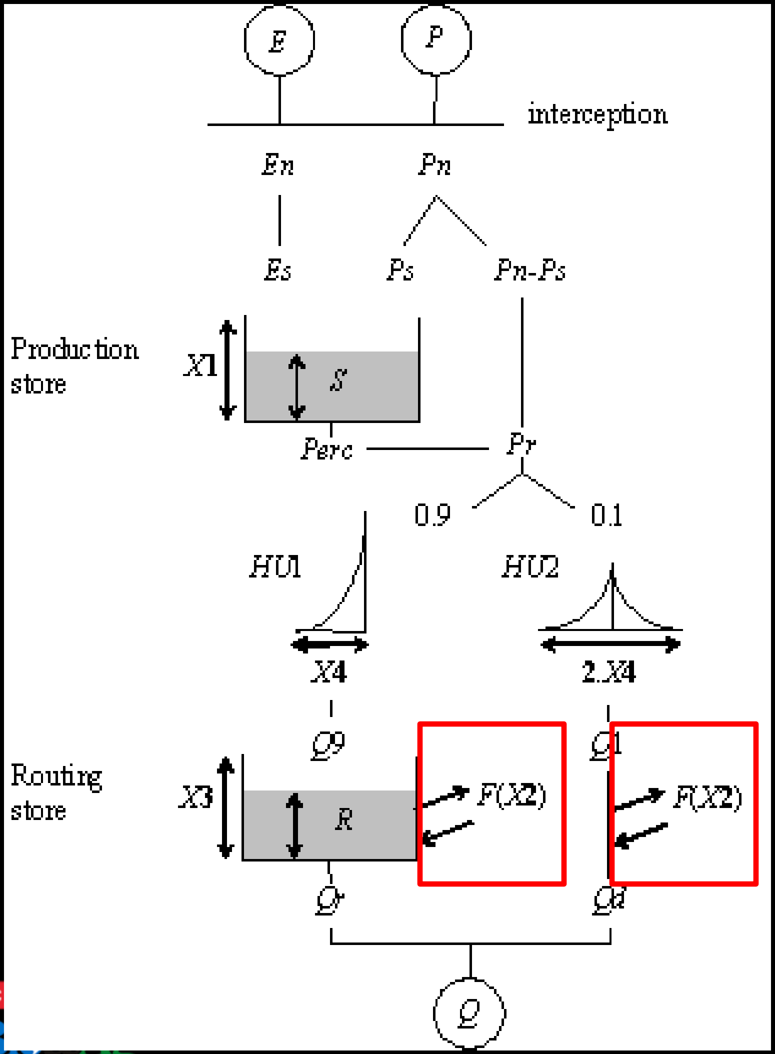

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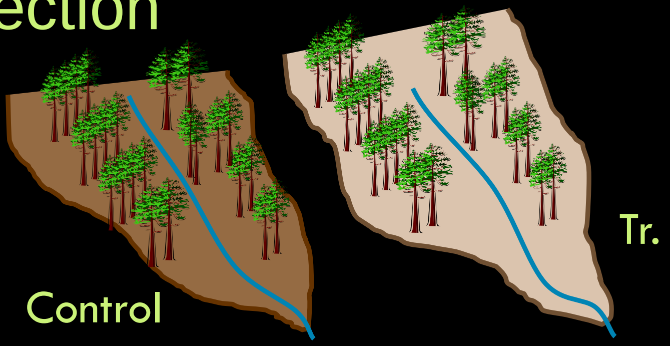
Paired Watershed Design Model Selection

- **NC (Neighbor Catchment)**[2]
  - Nature can provide a model itself
  - Input: Control watershed streamflow
  - 3 free parameters
  - Useful for paired catchment design and ungaged neighboring catchments
  - Daily/hourly time step
    - Mainly annual and monthly time steps used in the past to create linear relationships



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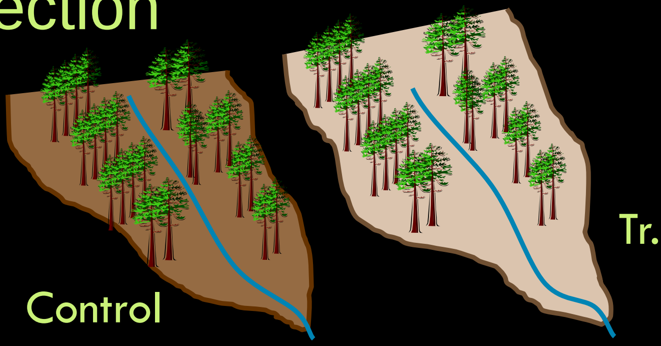

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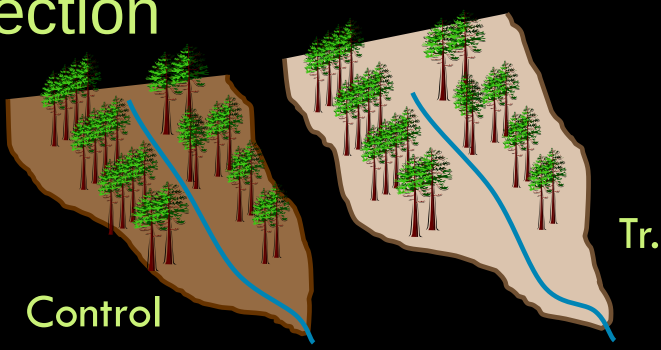

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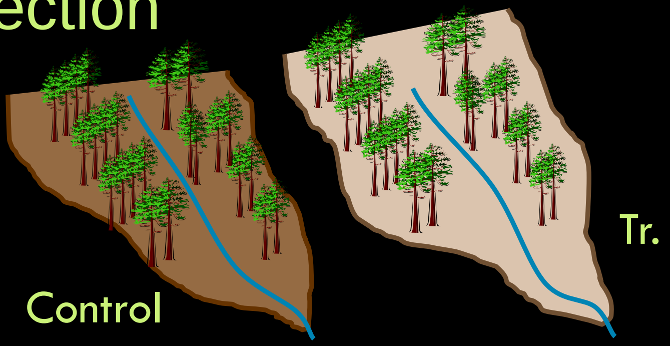

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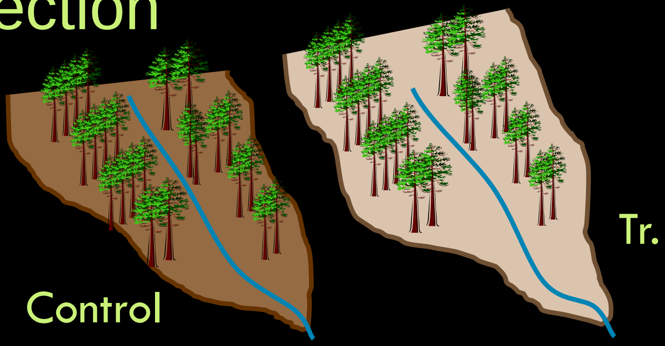

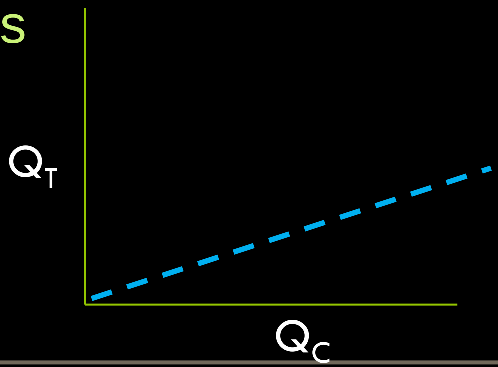

Methods

Mathematical Structure of NC

- Transforms hydrograph of control watershed to hydrograph of neighboring catchment
  - Attenuation/enhancement
  - Time lag
  - Volumetric correction

$$\frac{Q_T\,(j)}{\overline{Q_T}} = \left(\theta_2 * \frac{Q_C(j+\theta_3)}{\overline{Q_C}}\right)^{\theta_1}$$

$Q_T(j)$ = simulated treatment discharge on day j
Q_C(j) = simulated treatment discharge on day j
$\overline{Q_T}$ = mean avg. daily treatment discharge
$\overline{Q_C}$ = mean avg. daily control discharge

Parameters
θ_1 = power scaling factor
θ_2 = positive multiplying scaling factor
θ_3 = algebraic noninteger lag (days/hours)

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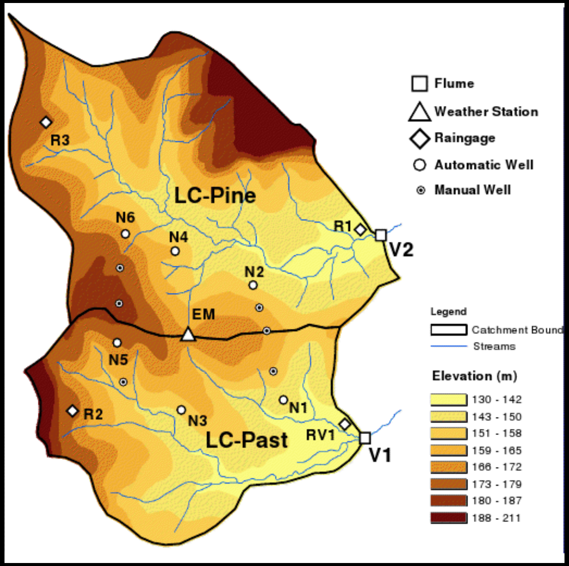
Modeling

- Test models on afforestation study in Uruguay
  - Paired watershed experimental design
  - Conversion of pasture to pine trees
  - 2 small adjacent watersheds
    - LC-Past: Grazed pasture, 69 ha (CONTROL)
    - LC-Pine: Grazed pasture converted to pine, 108 ha
    - Pretreatment period: July 2000-June 2003
    - Post treatment period: July 2003-June 2010



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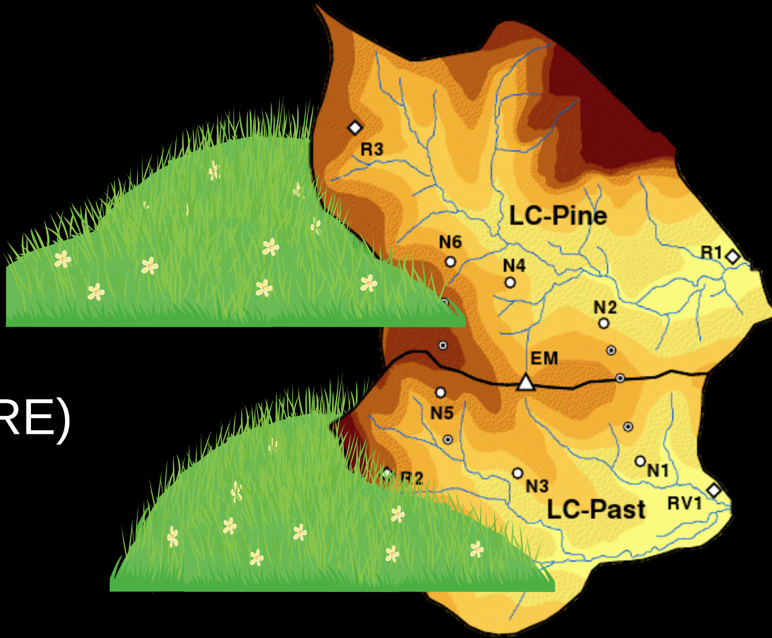
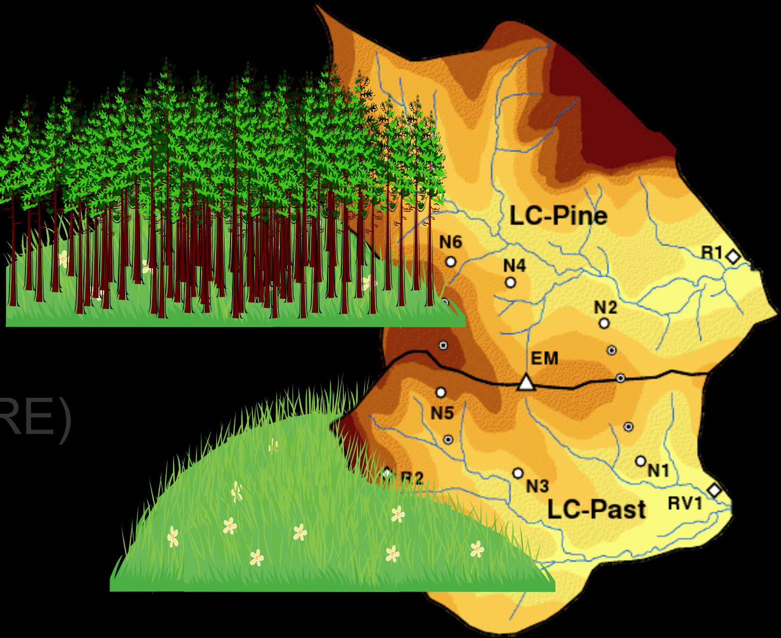


- Calibration
  - 3 Year Pretreatment Period (PASTURE)
    - GR4J:
      - Modeling LC-Pine
      - Inputs: Daily rainfall and PET
    - NC:
      - Modeling LC-Pine
      - Input: Daily LC-Past discharge
  - Local search algorithm used to find optimum parameter sets
  - Based on maximization of Nash-Sutcliffe criterion or water balance criterion
- Simulation
  - 7 Year Post Treatment Period (PINE)
  - Simulate LC-Pine discharge using optimum parameter sets for each model

Modeling



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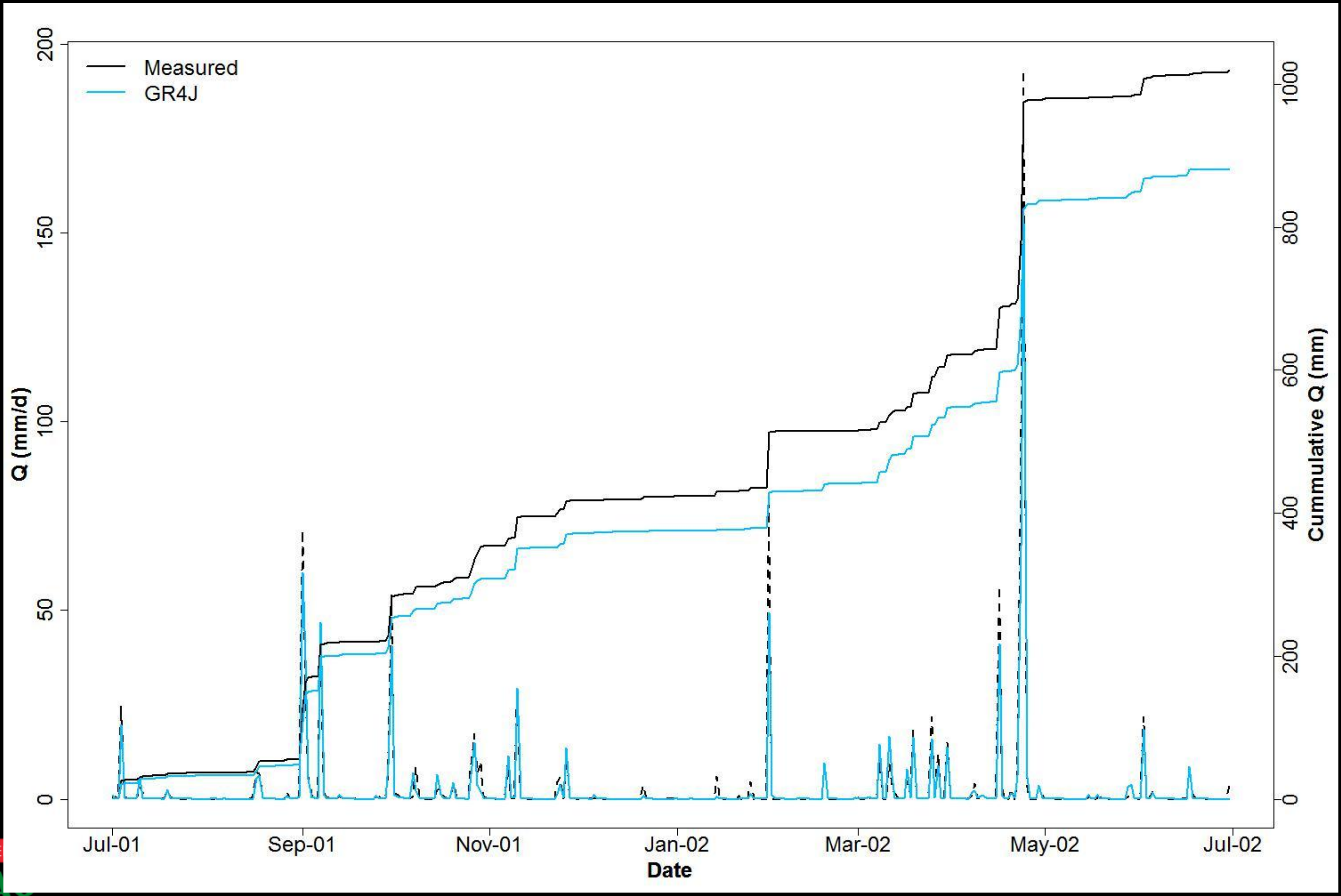
Preliminary Results



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Acknowledgements