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Implementing a groundwater module into CABLE

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Outline

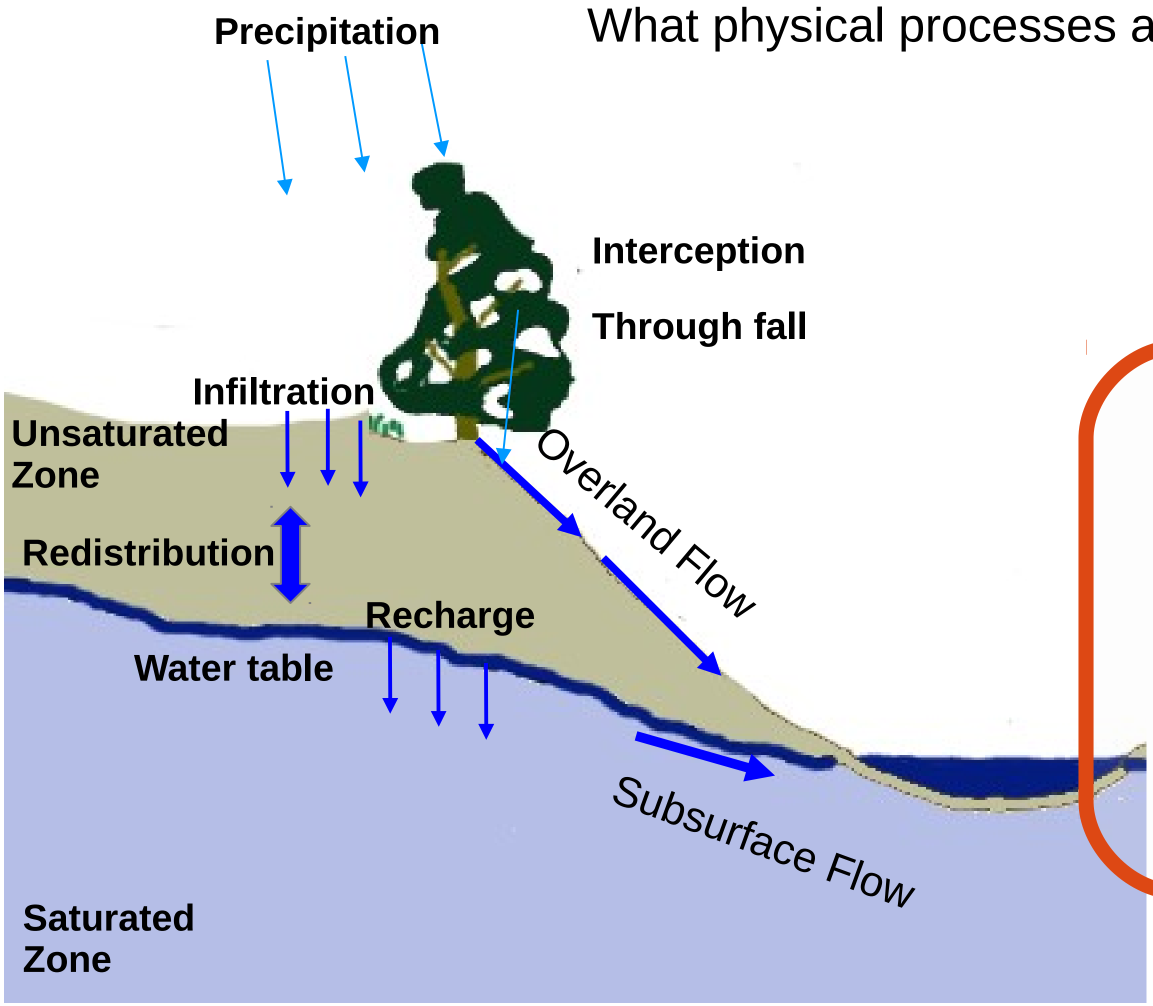
1) **Overview of Hydrology**

2) **Infiltration, Surface, and Subsurface fluxes**
   Parameterizations

3) **Groundwater (aquifer)**
   1D conceptual
   Explicit representation

4) **Soil Moisture**
   Vertical redistribution

What physical processes are relevant?



Hill slope neighboring a water body (lake or river)

- Interception
- Through fall
- Infiltration
- Overland Flow
- Unsaturated/Saturated zone
- Redistribution
- Water table
- Recharge
- Subsurface flow

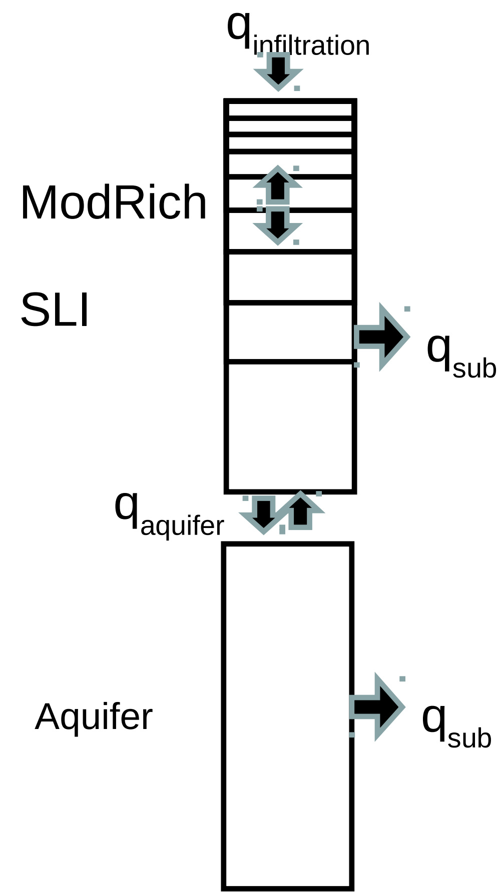
1D Conceptual groundwater model

Simple bucket model of mass conservation:

$$\frac{d\Theta_{gw}}{dt} = q_{aquifer} - q_{\mathrm{sub}}$$

Provides bottom boundary condition for Richards Equation

Parameterize the fluxes using Z_{∇} , θ, K, and others



Limitations (of current implementation):

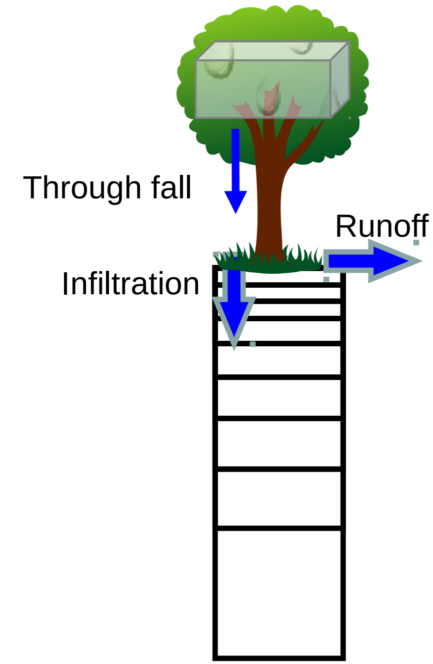
- No transfer between grid cells
- Subgrid scale fluxes from conceptual model
- Neglects groundwater coupling with
  - Stream flow
  - Flood plains
  - Anthropogenic removal

Infiltration

Limit flux into soil based on state of soil
Depends on surface layer moisture, ice, soil properties
For through fall over unsaturated soils:

$$q_{\mathrm{infl,max}} = K_{sat,srf} F_{\mathrm{infl}} \left[\theta, \theta_{sat}, \frac{\partial \psi}{\partial \theta} \right].$$

F_{infl} can be one of many functions
$q_{infl,max}$ is the maximum infiltration



Infiltration limited by

1) K_{sat} Hydraulic conductivity of the soil
2) θ relative to θ_{sat}
3) ψ (soil potential) changes

Surface Runoff

$$q_{srf} = F_{sat}\, q_{thr} + (1 - F_{sat})(q_{thr} - q_{infl}^{max})$$

Subsurface Runoff

$$q_{sub} = G[z_{elv}]\, \Gamma[Z_{\nabla}]$$

Runoff Based on TOPMODEL concepts

Subsurface Runoff: Topographic gradients drive subsurface fluxes

$$q_{sub} = T_i \tan[B]$$

B: slope
T_i: Transmissivity (conductance)

Horizontal transmissivity (i.e. conductivity) declines exponentially with Z_{∇}

Simplified parameterization:

$$q_{sub} = q_{max}\, e^{-f Z_{\nabla}}$$

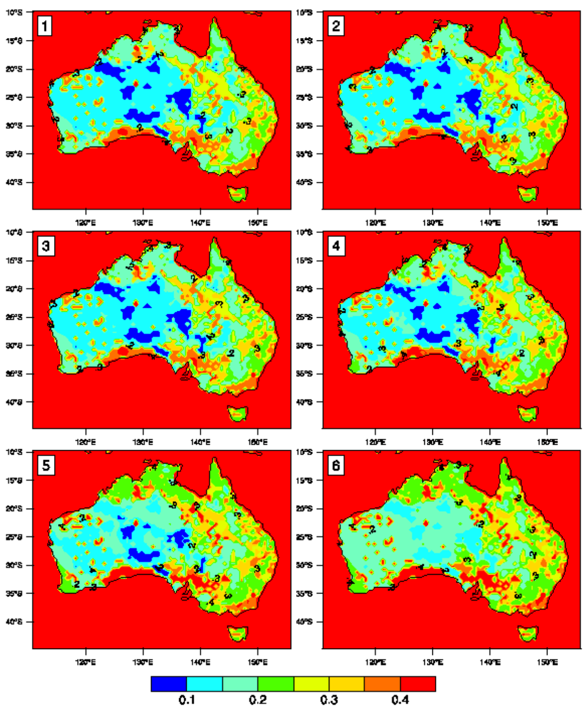
λ_m: Grid cell mean λ
Z_{∇} : Grid cell mean water table depth
f: Tunable parameter (~0.2)

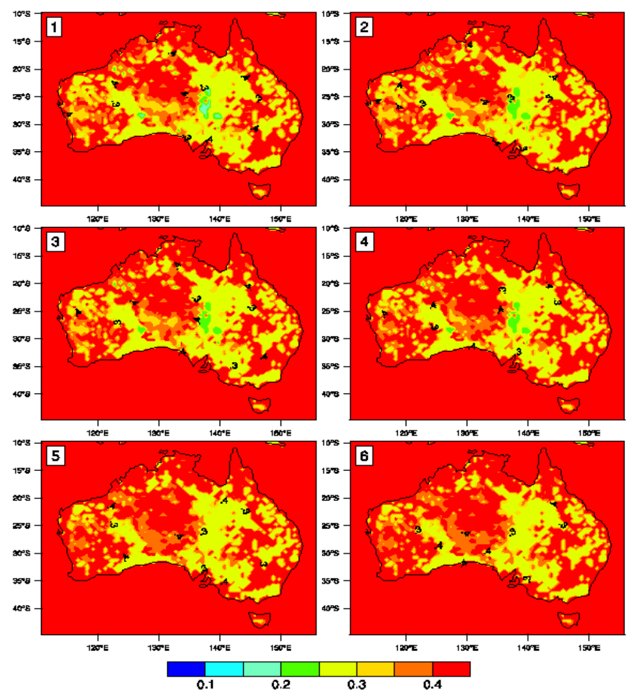
Alternative that combines the topographic index and K_{sat} into q_{max}

Many tunable parameters

- Subsurface Runoff
- Surface Runoff
- Groundwater

In the process of tuning the parameters to give a reasonable simulation





2D groundwater model: Explicit horizontal fluxes and Z_∇ dynamics:

Model grid resolves topography driven fluxes

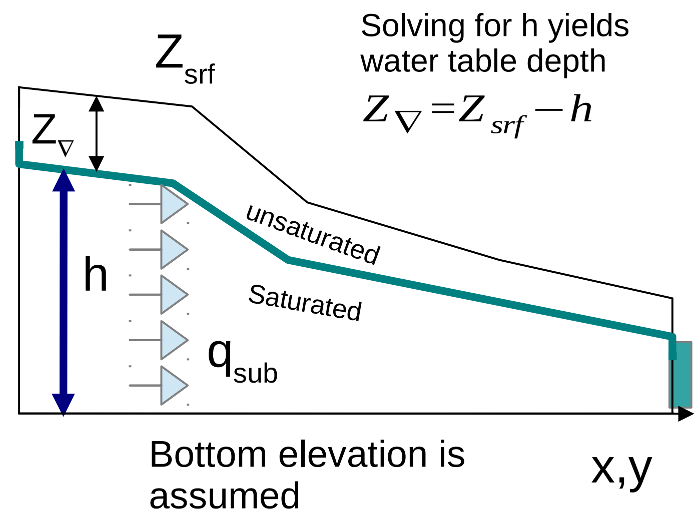
- Increasingly computationally viable
- Unknown aquifer and soil properties remain problematic

Common among hydrologists, used by at least 1 LSM

Simplifying Assumptions (Dupuit-Forchheimer)

- Z_∇ is relatively flat with a hydrostatic saturated zone
- Horizontal fluxes & K invariant with respect to z

Solves for the thickness of the saturated layer:



Darcy's Law: $$q_{\mathrm{sub}} = -kh\nabla_{\mathrm{xy}}[h]$$

h: thickness of saturated zone
xy: horizontal direction

Conservation of mass: $$\frac{\partial h}{\partial t} = \frac{\partial}{\partial x}\left[-kh\frac{\partial h}{\partial x}\right] + \frac{\partial}{\partial y}\left[-kh\frac{\partial h}{\partial y}\right]$$

Simplified 2D simplified equation for groundwater dynamics (i.e. Z_∇)

Explicit horizontal transport between grid cells

Computationally expensive compared to 1D models

Soil and groundwater properties are poorly constrained due to limited observations