Groundwater and groundwater recharge in mountain hydrology

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Important subsurface processes above the mountain front

Divided into three groups.

These are processes that control:

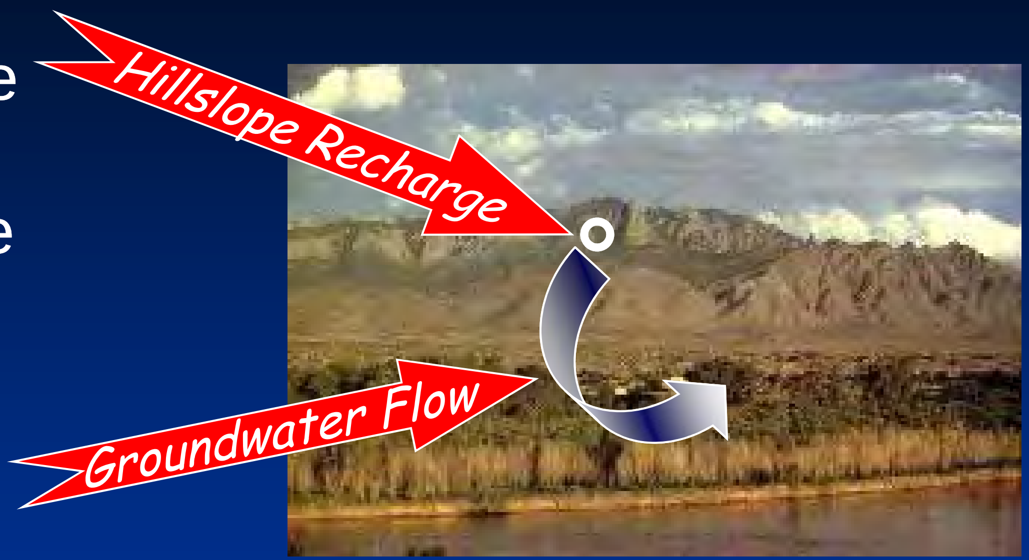
- how much water enters the mountain block at the surface and near surface, i.e. deep percolation into the mountain block leading to mountain block recharge
- how water moves through the block, interacting with geology and surface features (streams, meadows), i.e. mountain vadose & groundwater hydrology
- how water leaves the block and enters the adjacent basin, i.e., mountain front recharge

Sandia Mountains & Albuquerque Basin

Important spatial scales above the mountain front

Deep percolation at the hillslope scale, across the soil bedrock interface, leading to recharge at the mountain water table

Groundwater flow (& upwelling) at the mountain scale, through the entire mountain bock.

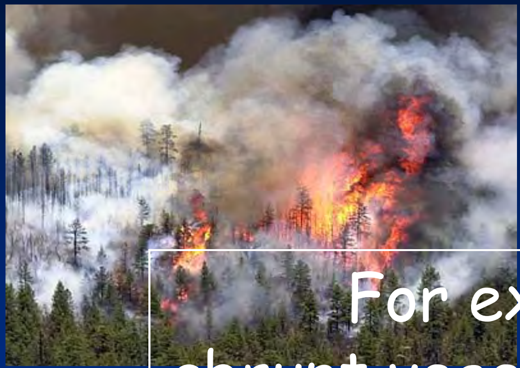


Sandia Mountains & Albuquerque Basin

Motivation

How does recharge and groundwater flow above the mountain front change if, e.g., the vegetation cover changes?

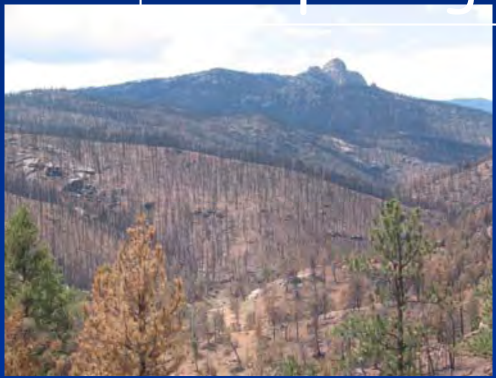
Rodeo-Chediski Fire



Logging

For example,
abrupt vegetative change

Hayman Fire
Burn Area

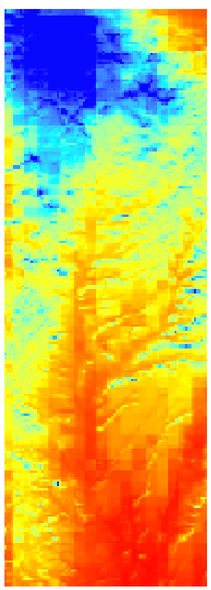


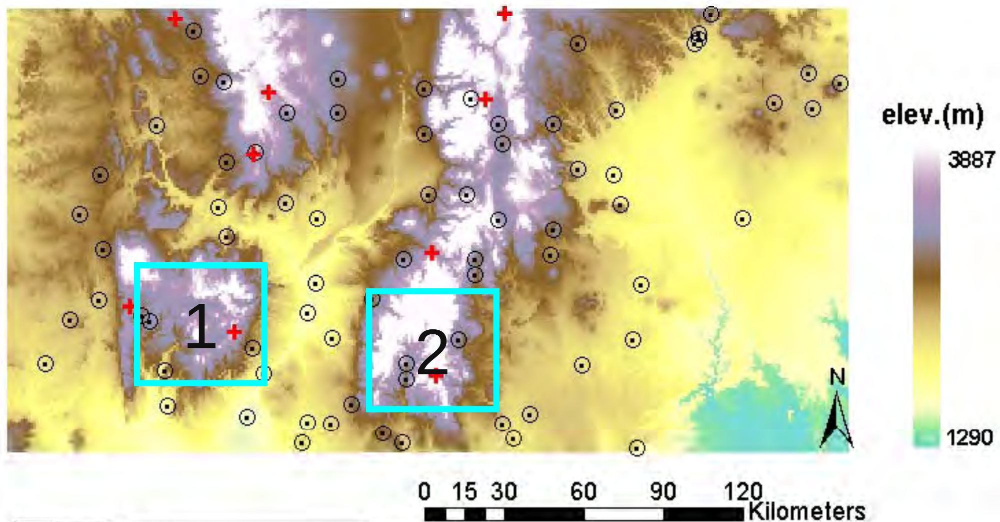
Beetle Kill

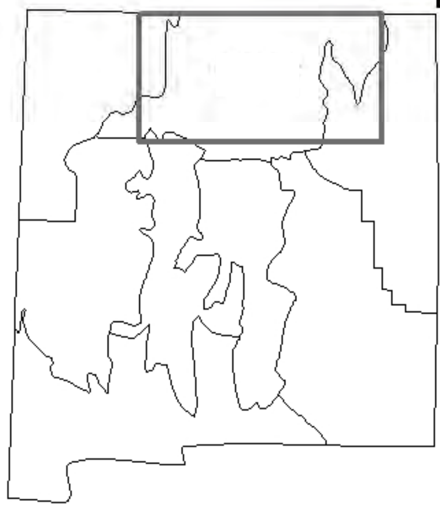
Maps of potential total deep percolation

Northern NM mountains

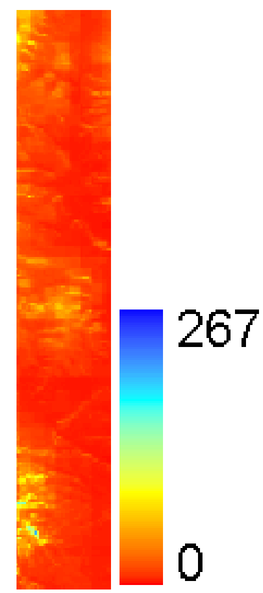
Jer … ns





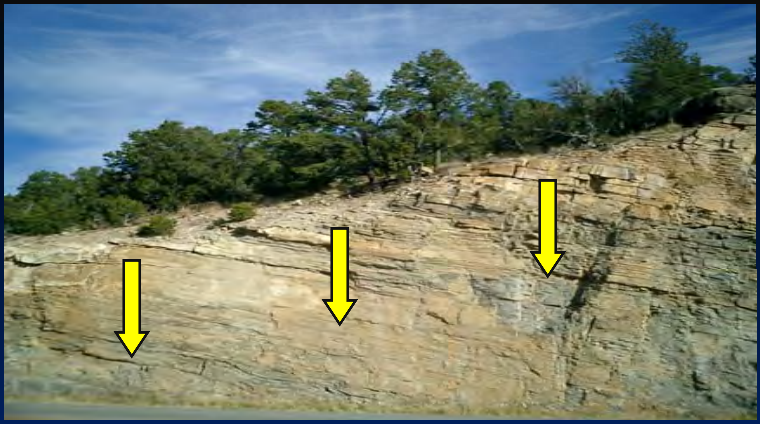


1. **Jemez Mountains**
2. **Southern part of Sangre de Cristo Mountains**



Hillslope scale

- Concerns the roles of
  - –precipitation,
  - –evapotranspiration,
  - –vegetation, and
  - –vadose zone processes in the thin mantel of soil overlying the bedrock.

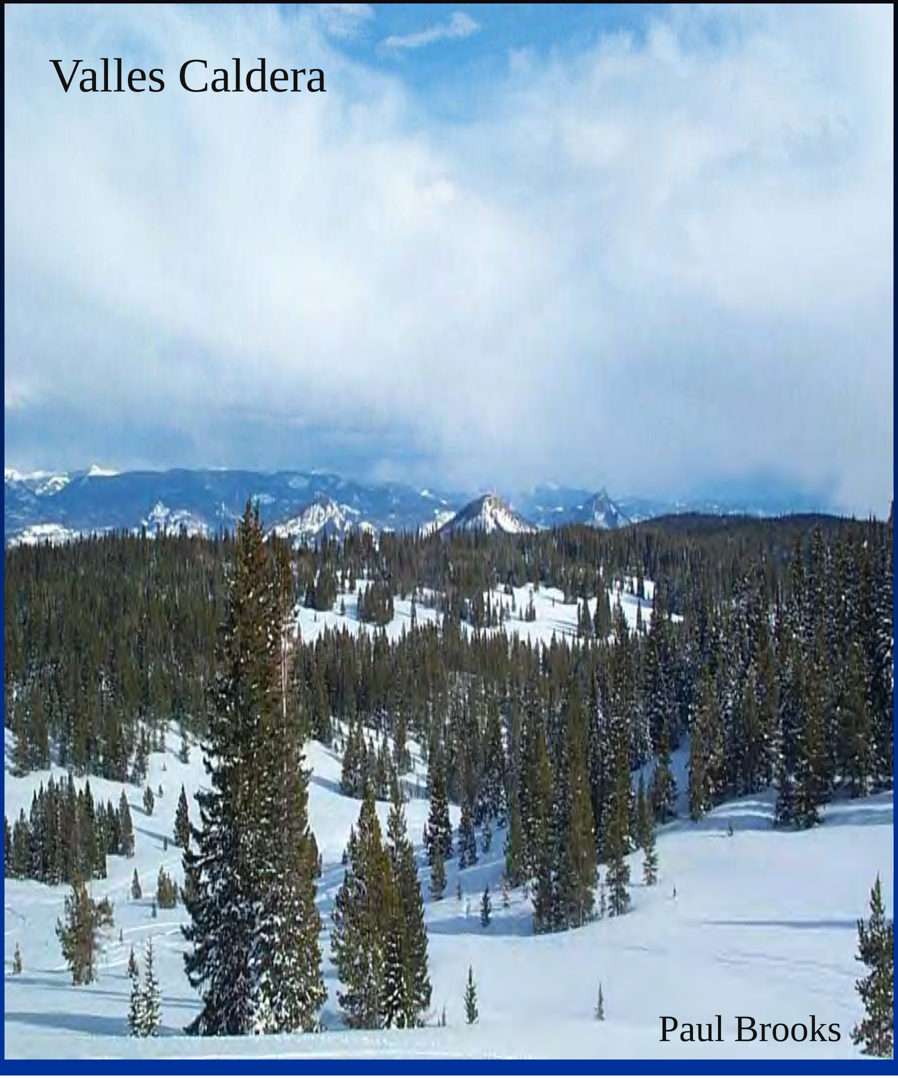


- Unlike typical hillslope studies,
  - -which assume impervious bedrock,
  - -the focus is on partitioning of water to the bedrock, and
  - -the controls on that partitioning

Characteristics above the mountain front (semi-arid)

MORE
- Precip.
- Snow
- Veg. LAI
- Actual ET
- RO
- Recharge

LESS
- PET
- Soil

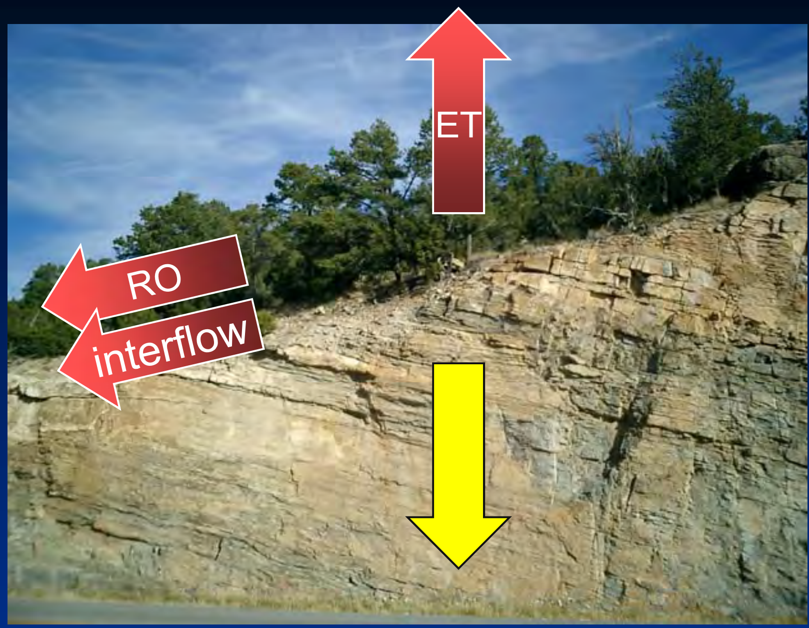


Three Hillslopes

Ponderosa and Pinon-Juniper forest (east slope of Sandias)

Important aspects
at the hillslope scale:

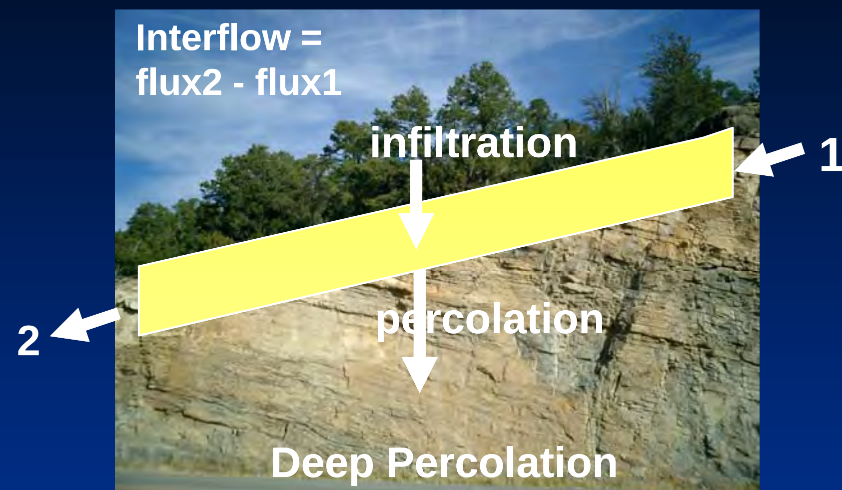
- Partitioning of rainfall and snowmelt into
  - vegetation-controlled evapotranspiration,
  - surface runoff,
  - interflow in the soil above the bedrock, and
  - deep percolation into bedrock, especially its fractures and faults.



Simple Hillslope Model

- 2D Hillslope scale, 10 to 100 m
- Shallow soil cover (~1m) overlying bedrock (>1m)
  - Several kinds of soil profiles
  - Soils with and w/o macropores
- Two types of bedrock
  - Unwelded tuff (no fractures)
  - Granite (with fractures)
  - Smooth and rough bedrock surfaces

Spatial Domain:



Guan and Wilson, 2004 and 2005

Simple Hillslope Model

- Simulations with Richard's Equation
  - Hydrus 2D
  - Macropores and fractures handled with a composite function
- Sloped surfaces with and without vegetation
  - With vegetation includes ET and snowmelt
    - Energy balance (TVET)
    - Snow and interception

- Two temporal conditions
  - Steady state with prescribed infiltration at the soil surface representing the climate condition
    - No explicit ET or snow
  - Transient with ET and snow
    - Daily times steps = no RO
    - Minute time steps =RO (not shown)
    - Years of simulations under different weather and climate conditions, eg
      - Snowmelt contributions
      - Monsoon contributions
      - Variable PET/P

Relative Water Availability, R

Deep percolation is largely determined by

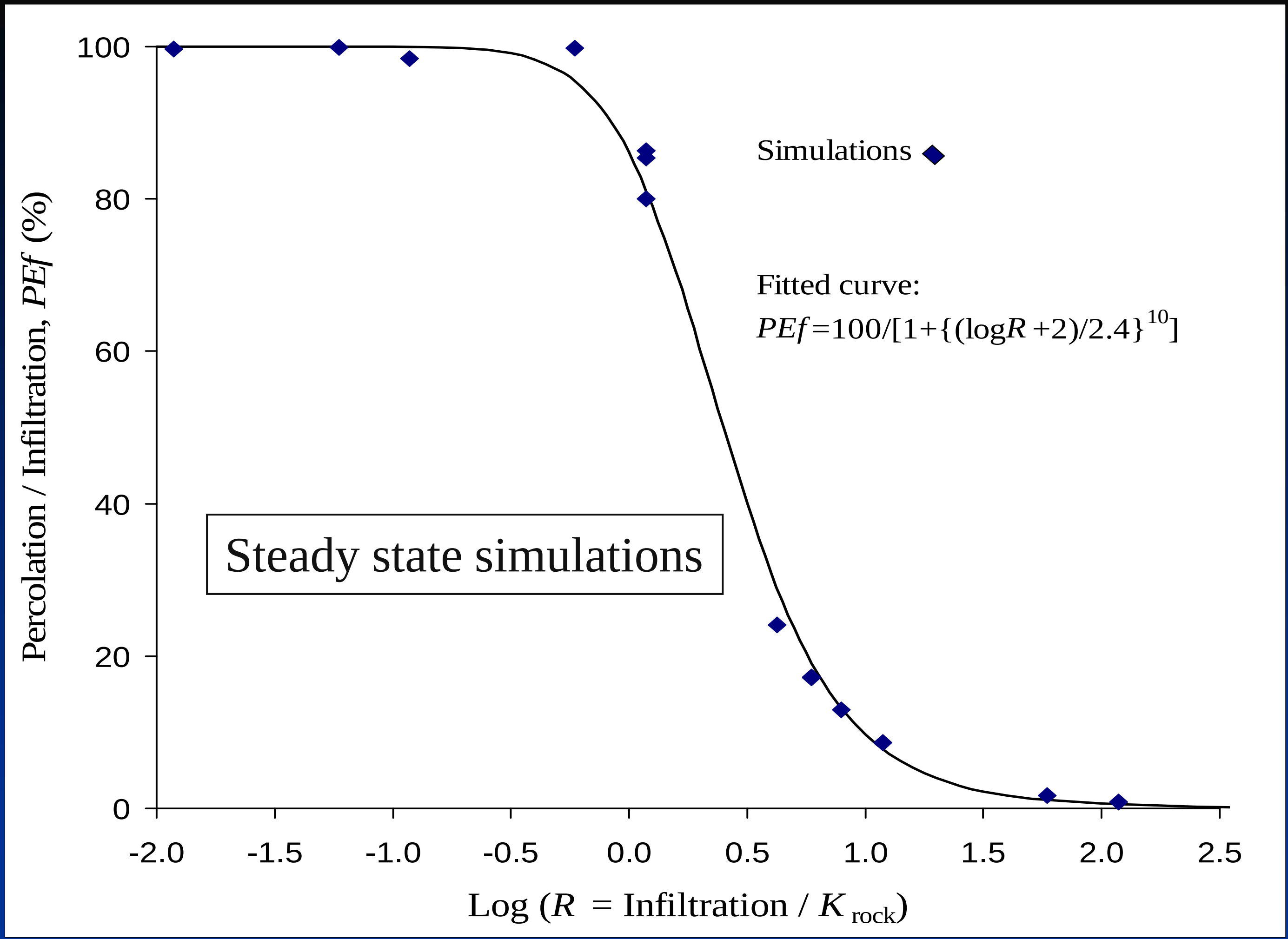
R = water availability / bedrock conductivity

– water availability (net infiltration) depends on
  - slope steepness and aspect,
    e.g., due to its affect on ET, and
  - vegetation and climate.

– bedrock conductivity depends on
  - matrix and fracture characteristics

Relative Water Availability, *R*

Percolation / Net Infiltration, %

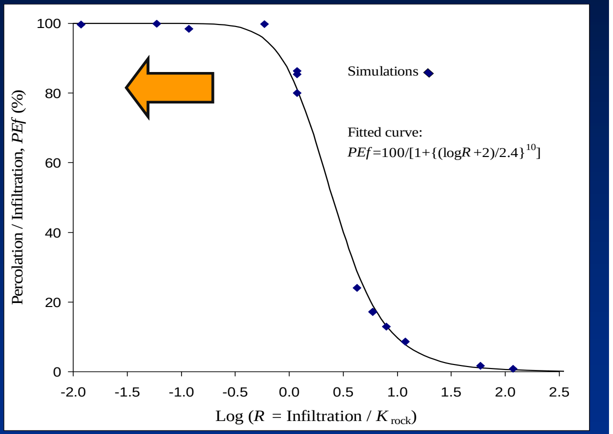


Log [R = net Infiltration / K_{rock}]

Relative Water Availability, *R*

The primary controls on deep percolation are water availability and bedrock conductivity.

R<<1 *(limited by water availability)*



– little water available and bedrock can handle all of it.

– percolation similar to net infiltration

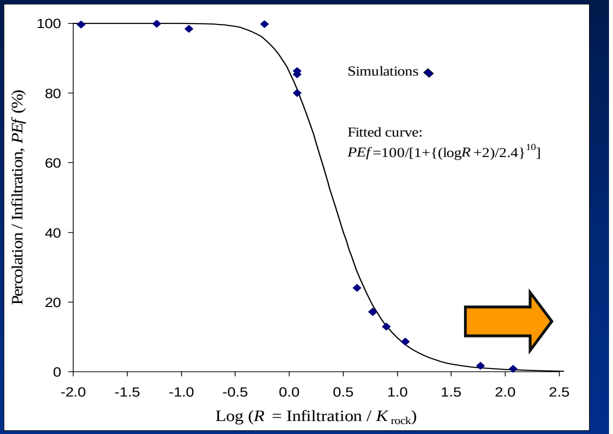
– very sensitive to climate variability and change.

Relative Water Availability, R

The primary controls on percolation are water availability and bedrock conductivity.

R>>1 *(limited bedrock conductivity)*

- much more water than the bedrock can handle.
- percolation limited by the bedrock saturated conductivity &
  (at least for steady state conditions)
- is insensitive to climate and vegetation change.



Relative Water Availability, R

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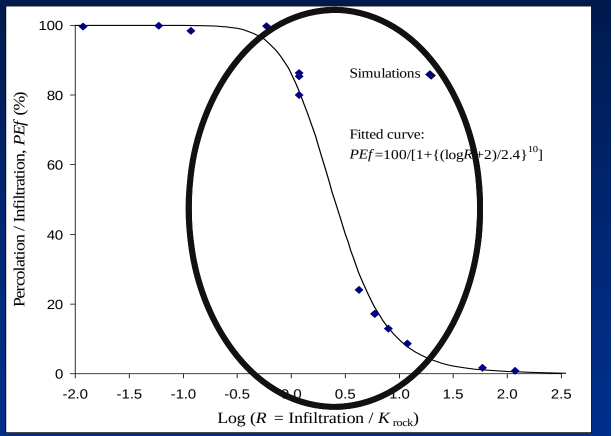


- Most sensitive near R =1 to 10
  - percolation processes change rapidly
- The control switches
  - from water availability to bedrock
- Switch can occur locally due to
  - lithology, vegetation or local climate,
  - even changing along or across a single ridgeline or meadow.

Significant quantities of recharge?

- Low relative water availability, R, suggest high percolation efficiencies,
  - But it could simply be a very dry climate with little water available to recharge.
- High relative water availability, R, can simply indicate “impermeable” bedrock
- In either case deep percolation might be negligible.

Significant quantities of recharge?

But it doesn't take much bedrock conductivity to create significant percolation in semi-arid climates,

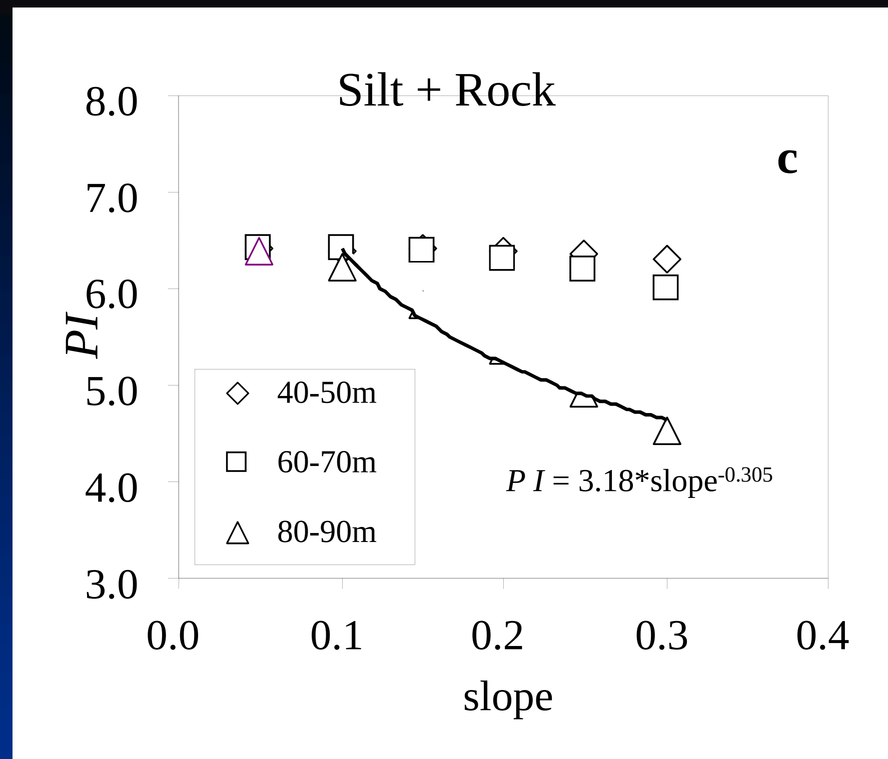
- say recharge rates of 30mm/yr or more.
- you get this with a threshold bedrock permeability of 1.0×10^{-16} m^2 or more
  - at or above which deep percolation can be significant.

Higher bedrock conductivities yield higher *potential* recharge rates,

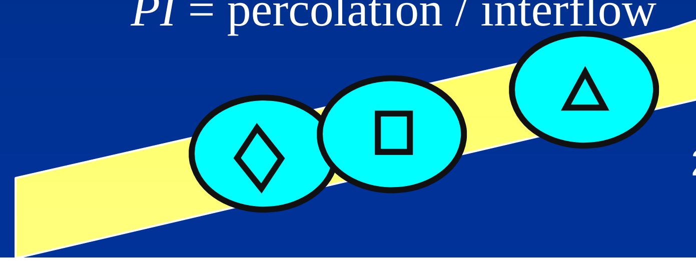
- 100's – 1000's mm/yr

Slope Steepness

- More recharge on less steep slopes
- More recharge downslope
  - where the moisture redistributes
  - and soil becomes saturated
  - especially for finer grained soils



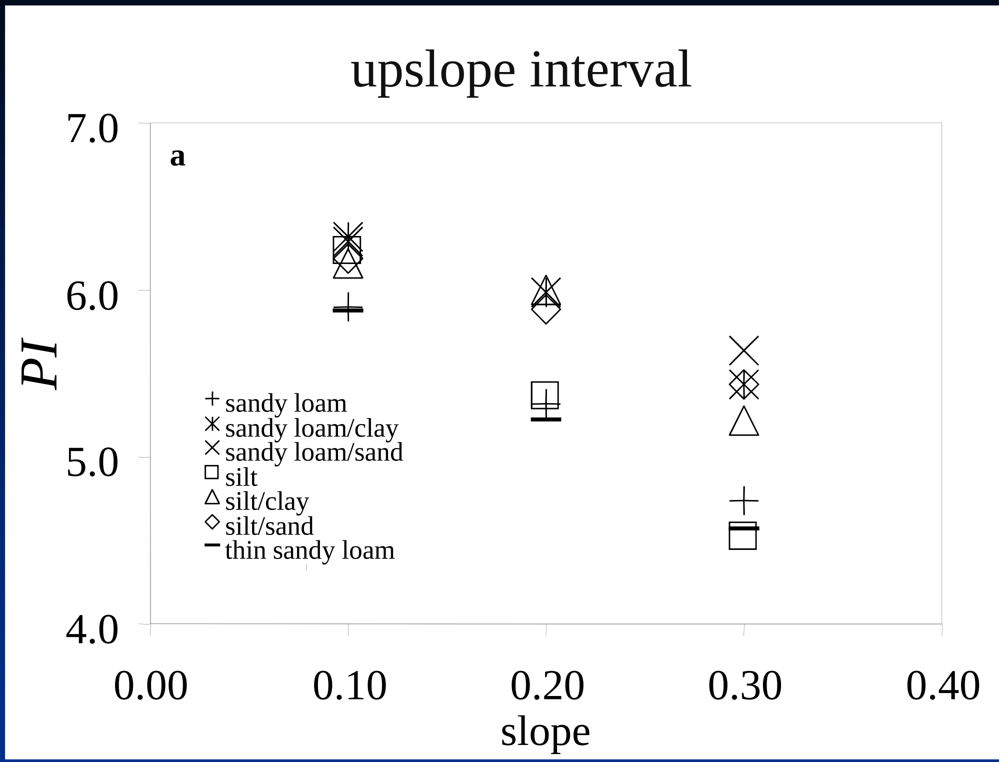
PI = percolation / interflow



Steady state simulations

Soil Characteristics

- Soil characteristics
  - type, thickness, layering
  - influence recharge mainly by controlloing downhill interflow and leading to soil saturations high enough to activate bedrock fractures.
  - percolation is always larger for double soil-cover slopes
    - bottom layer = clay or sand

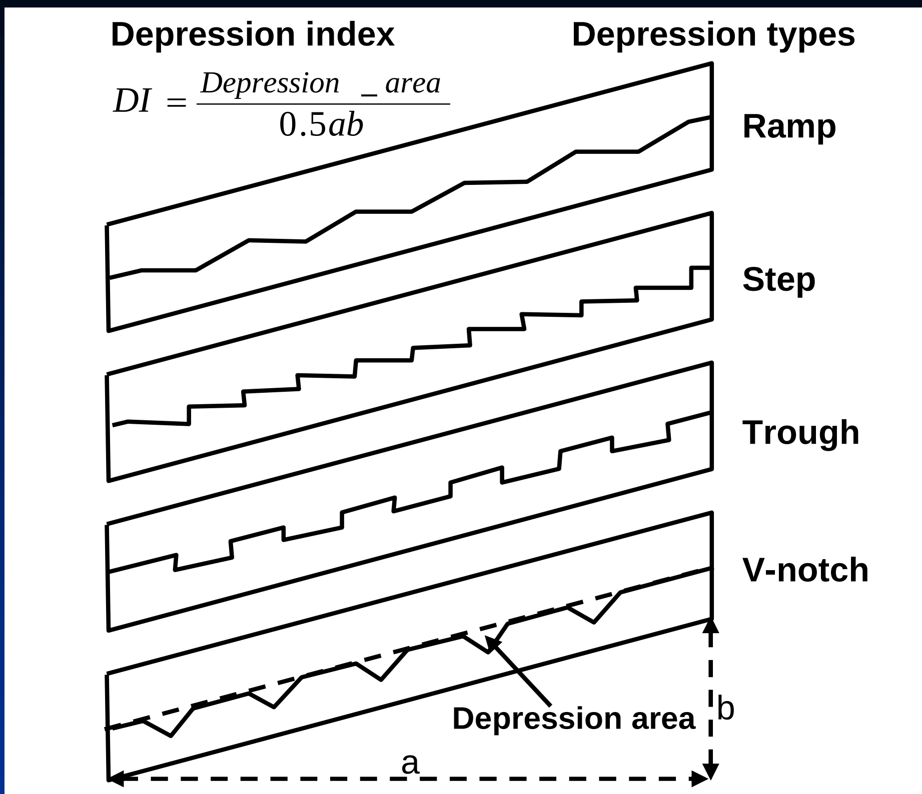


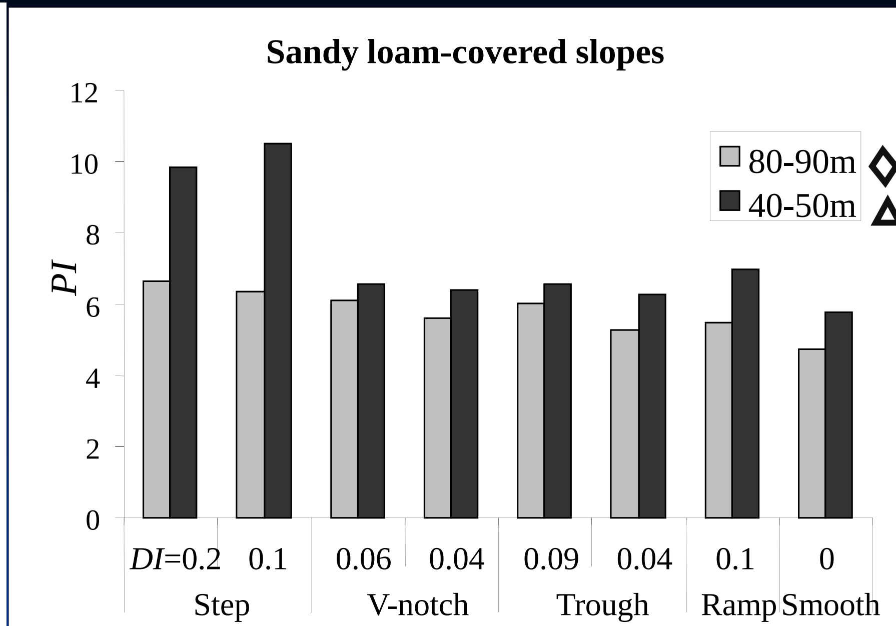
PI = percolation / interflow

Steady state simulations

Bedrock Topography

Is less important than hypothesized, at least for these steady-state 2D simulations.





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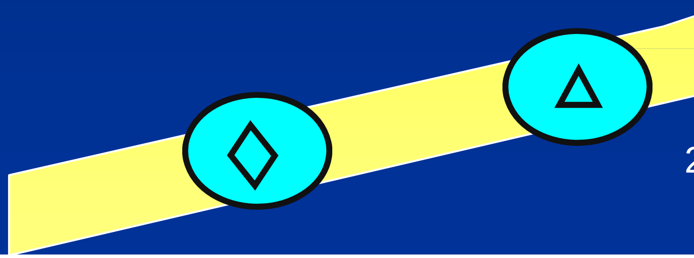


Steady state simulations

Limitations

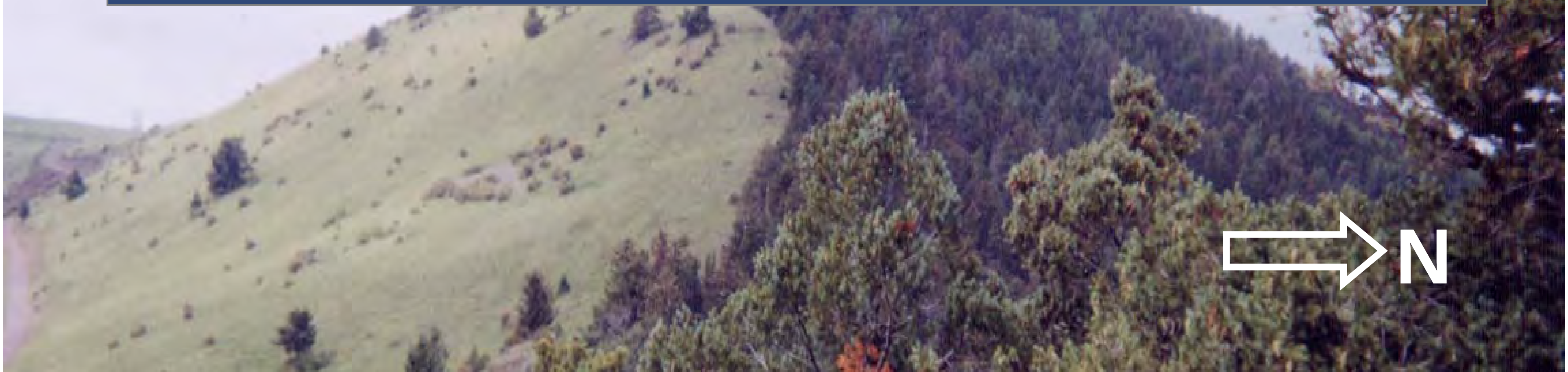
- Steady-state simulations with constant “net infiltration” inputs do not capture
  - temporal variation in rainfall or snowmelt
  - temporal concentration of high water saturations along the bedrock interface that cause episodic percolation.
  - seasonally or diurnally varied evapotranspiration
- Let’s examine these issues in at a site near Socorro, NM …

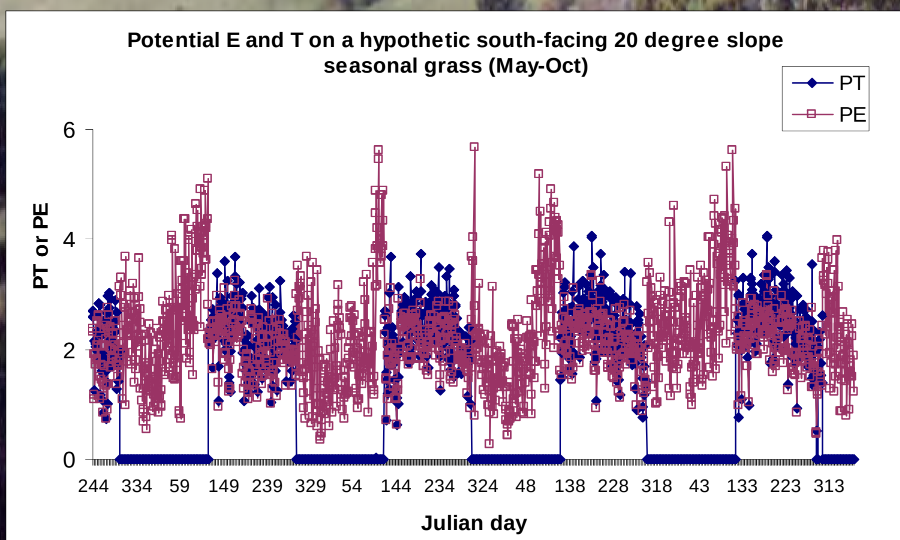
Magdalena Mountains

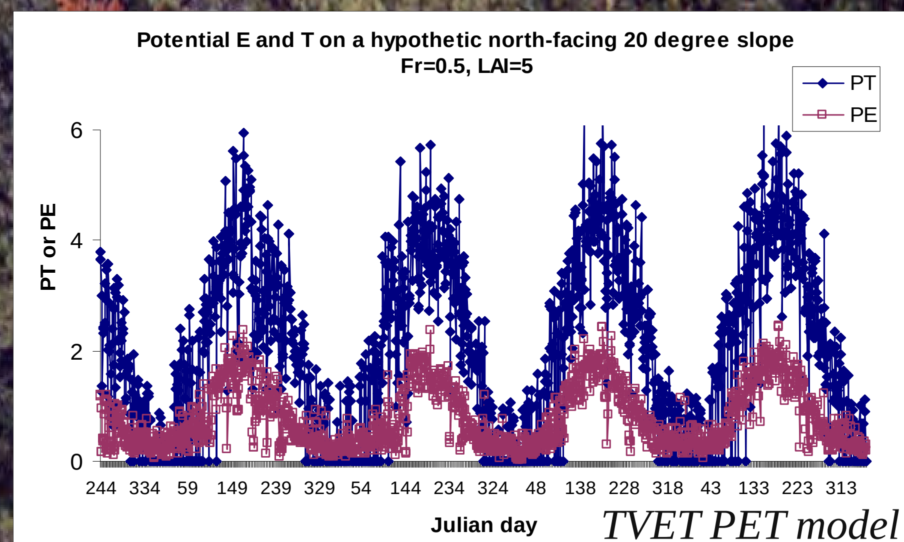
- 4 years of data
- Daily time steps
  - No RO
- Two different soil thicknesses
- Two different bedrocks
- Two exposures (aspects)
- Two vegetation types

Transient simulations

Annual potential ET (PET)
200 mm larger on the south-facing slope than the north-facing slope



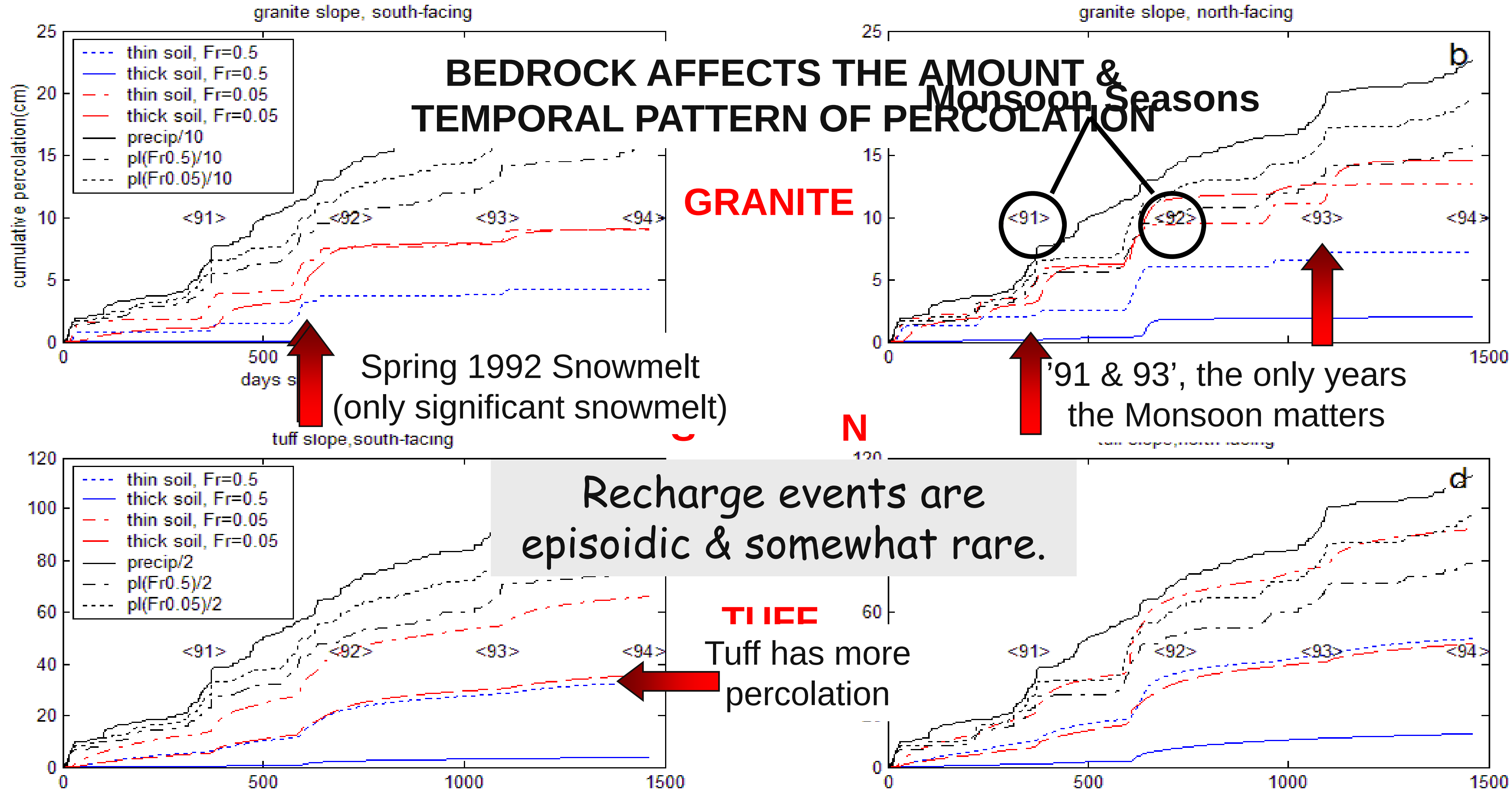


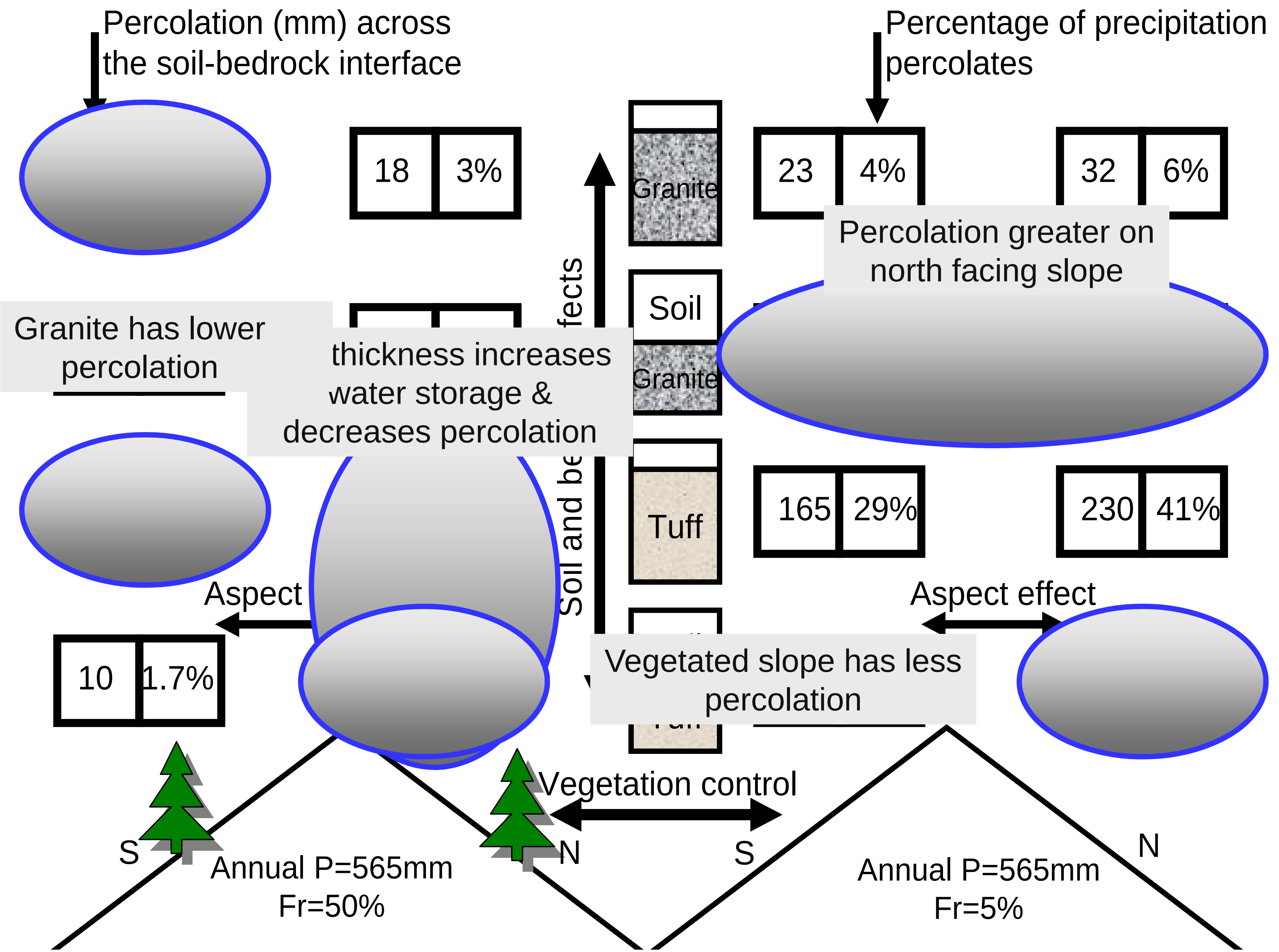


Cummulative deep percolation

on slopes with various conditions

Interception, snowmelt, aspect effect, vegetation coverage effect, captured by *TVET*




Percolation (mm) across the soil-bedrock interface
Percentage of precipitation percolates
18
3%
Granite
Soil
Granite
Tuff
23
4%
32
6%
Percolation greater on north facing slope
Granite has lower percolation
thickness increases water storage & decreases percolation
165
29%
230
41%
Aspect
Aspect effect
10
1.7%
Vegetated slope has less percolation
Vegetation control
S
N
S
N
Annual P=565mm
Fr=50%
Annual P=565mm
Fr=5%

What influences deep percolation into the bedrock?

Water availability at the soil-rock interface, which depends on

- the thickness and nature of the soil cover (e.g., pipes and barriers),
- the climate and vegetation

Bedrock permeability

- the type of bedrock and the nature of its fractures and faults.
- permeability in critical range important
  Hydraulic conductivity ~ Water availability

Also playing a role:

Slope steepness and aspect, which interact with

- vegetation and soil development, especially via PET
- affecting percolation rates by
  - adjusting moisture fluxes to and from the atmosphere
  - down-slope movement of moisture on the surface (runoff) and in the soil above the bedrock (interflow).