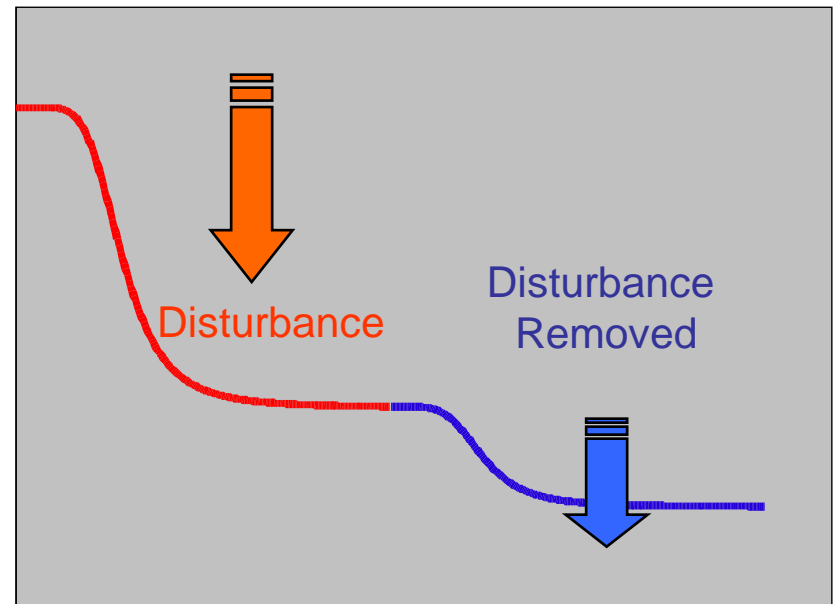
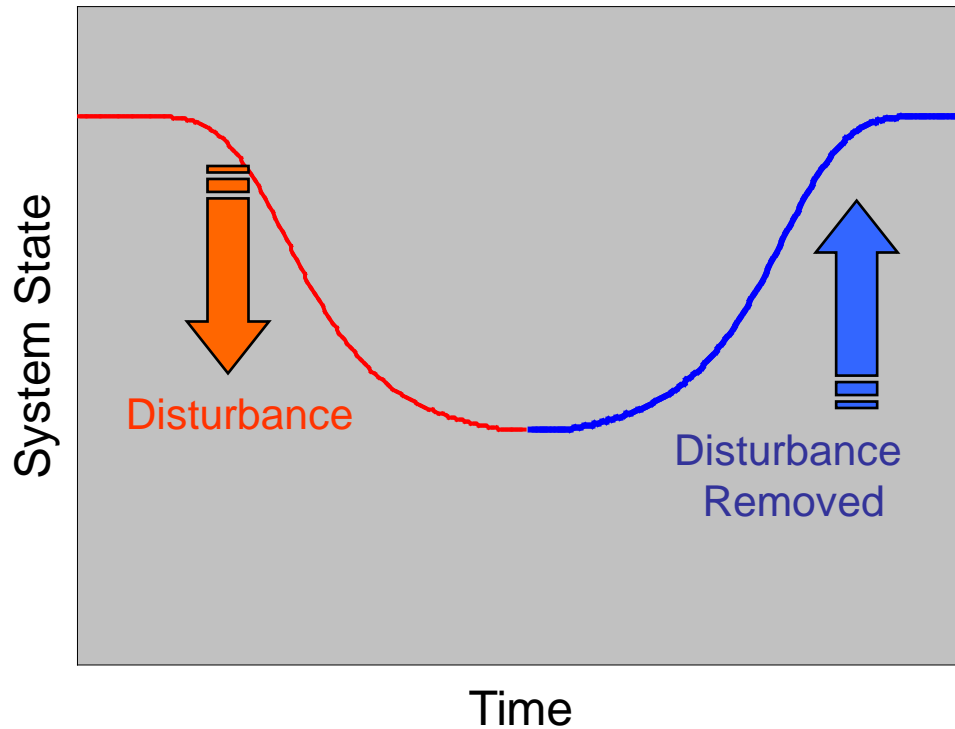


***Multiple Stable States within Dryland
Catchments:
Validity of theories, prevalence and impacts of
climate variability.***

Tim Peterson, Rob Argent, Andrew Western,
Francis Chiew

Some assumptions of water resource models...

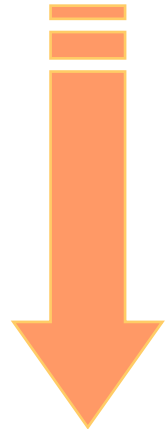


Background to PhD ...

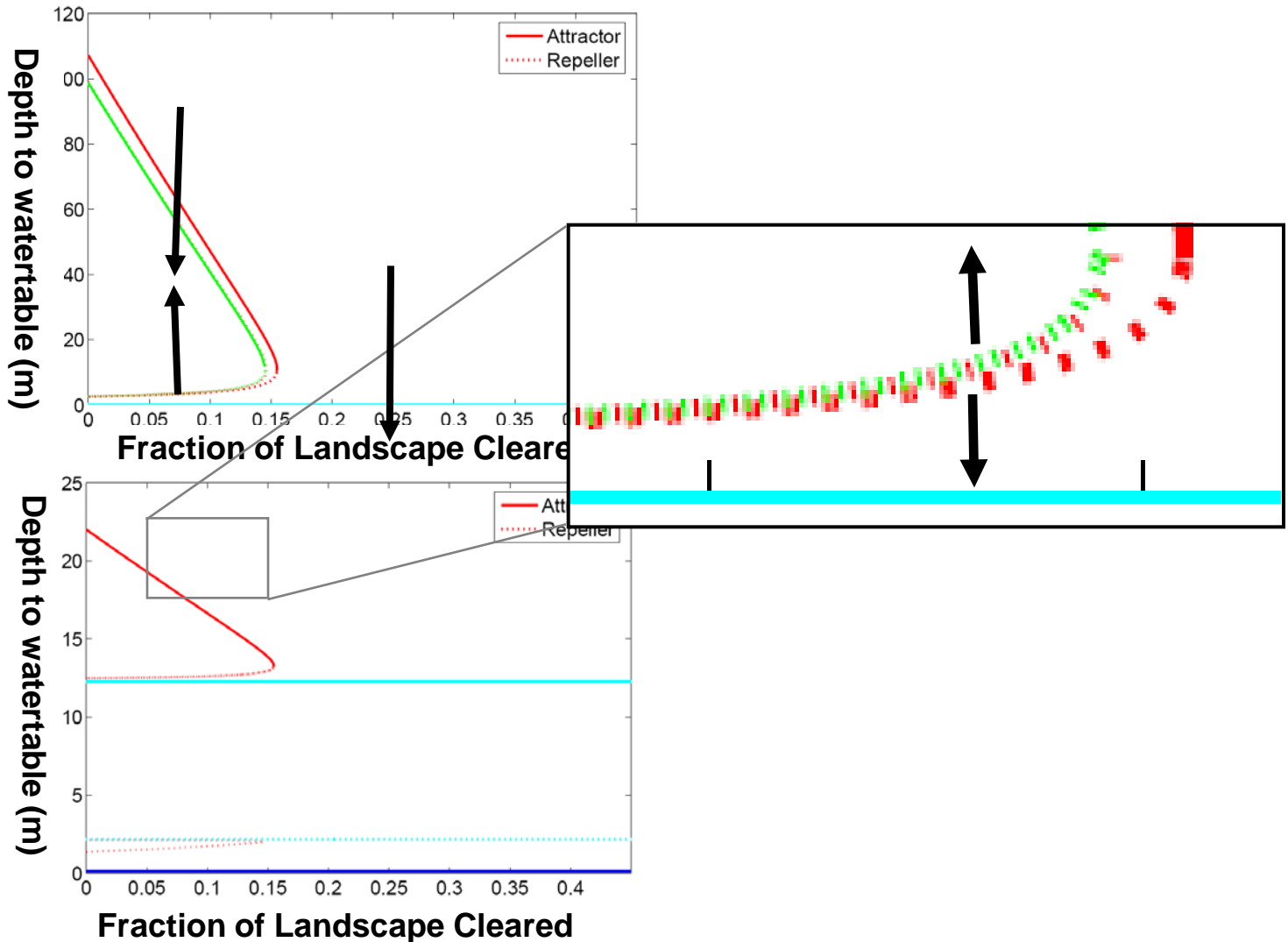
- Validity of Anderies 2005?
 - Spatial discretisation;
 - Shorter time-steps;
- Testing against observed data via calibration and evaluation.

An Existing catchment resilience model for Goulburn Catchment, Victoria (Anderies 2005)

Uplands



Lowland Plains

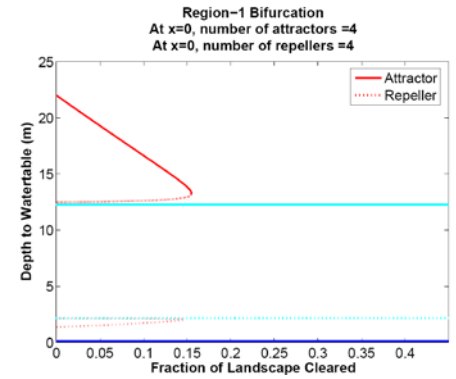
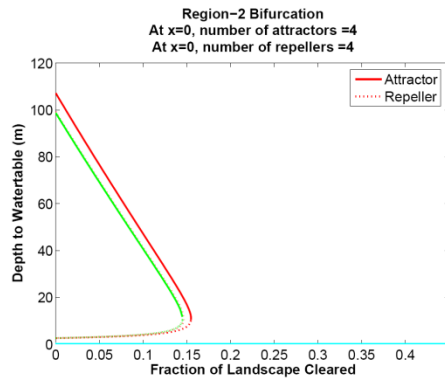


Validity of Lumped Model?

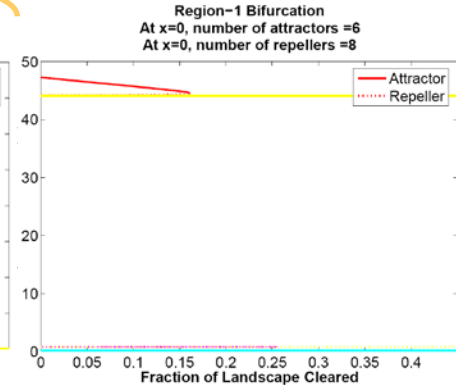
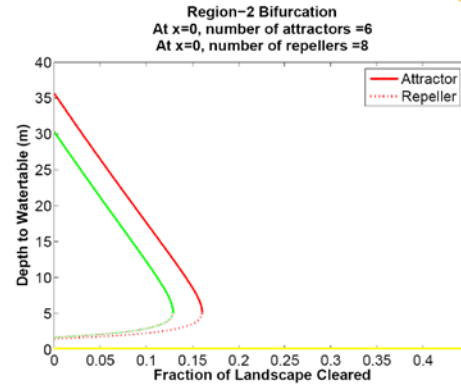
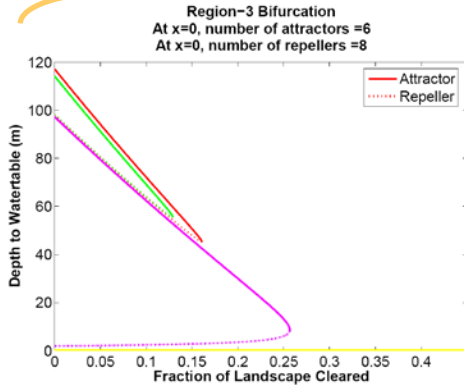


Water table remains deep in a large % of the area

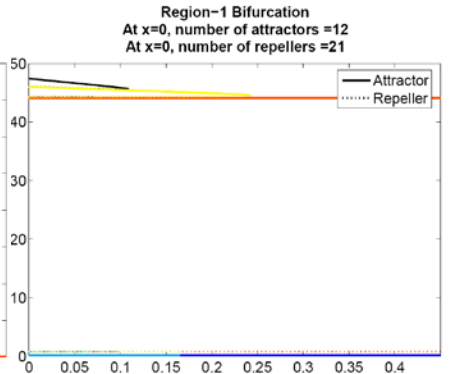
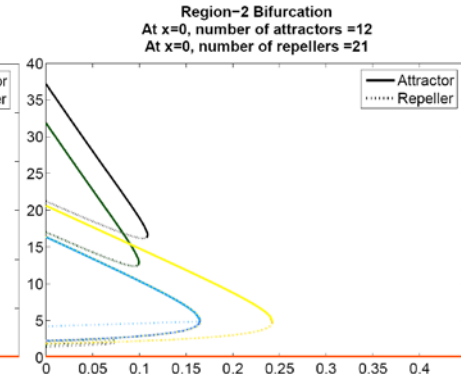
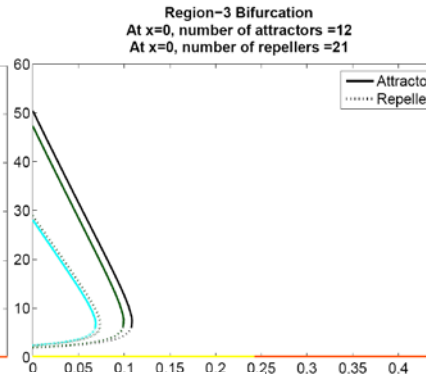
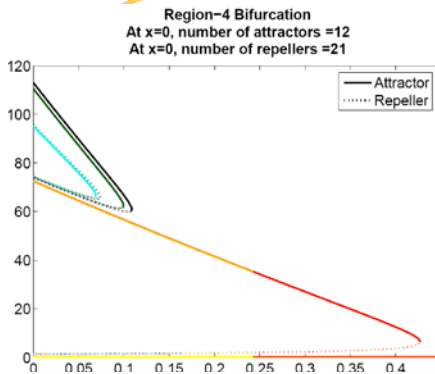
© CSIRO LAND AND WATER
PHOTOGRAPHY BY WILLEM VAN AKEN



Region Subdivided



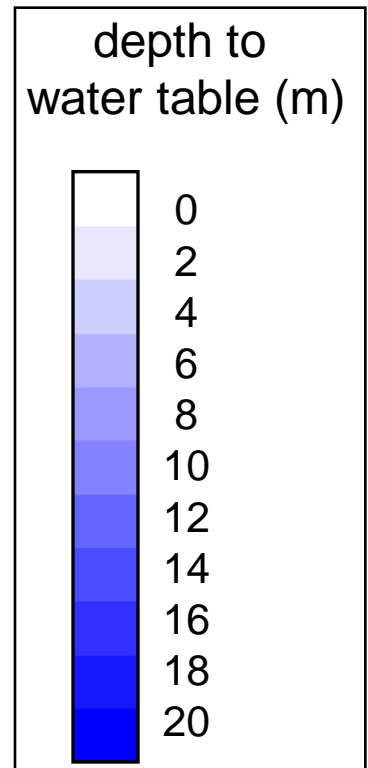
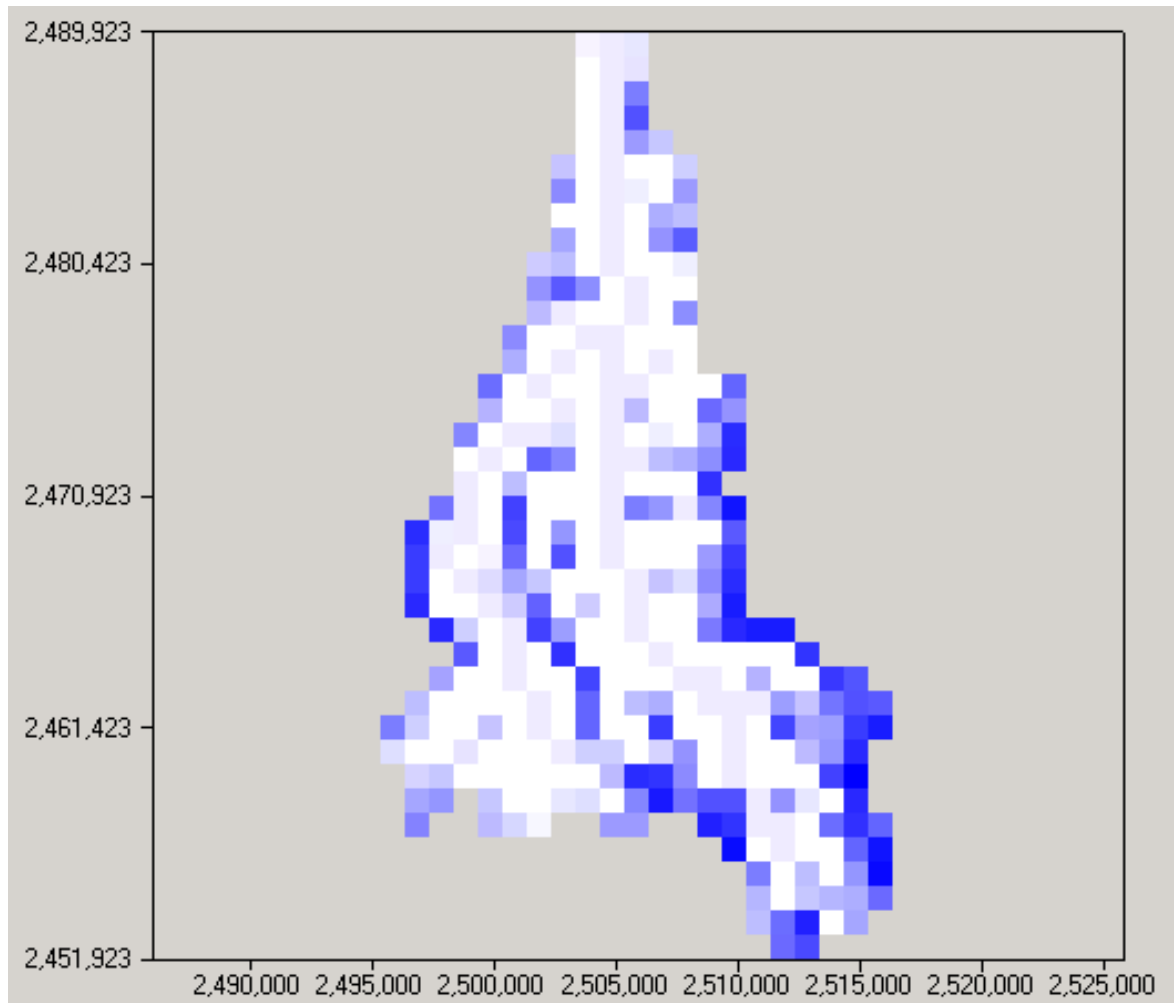
Region Subdivided



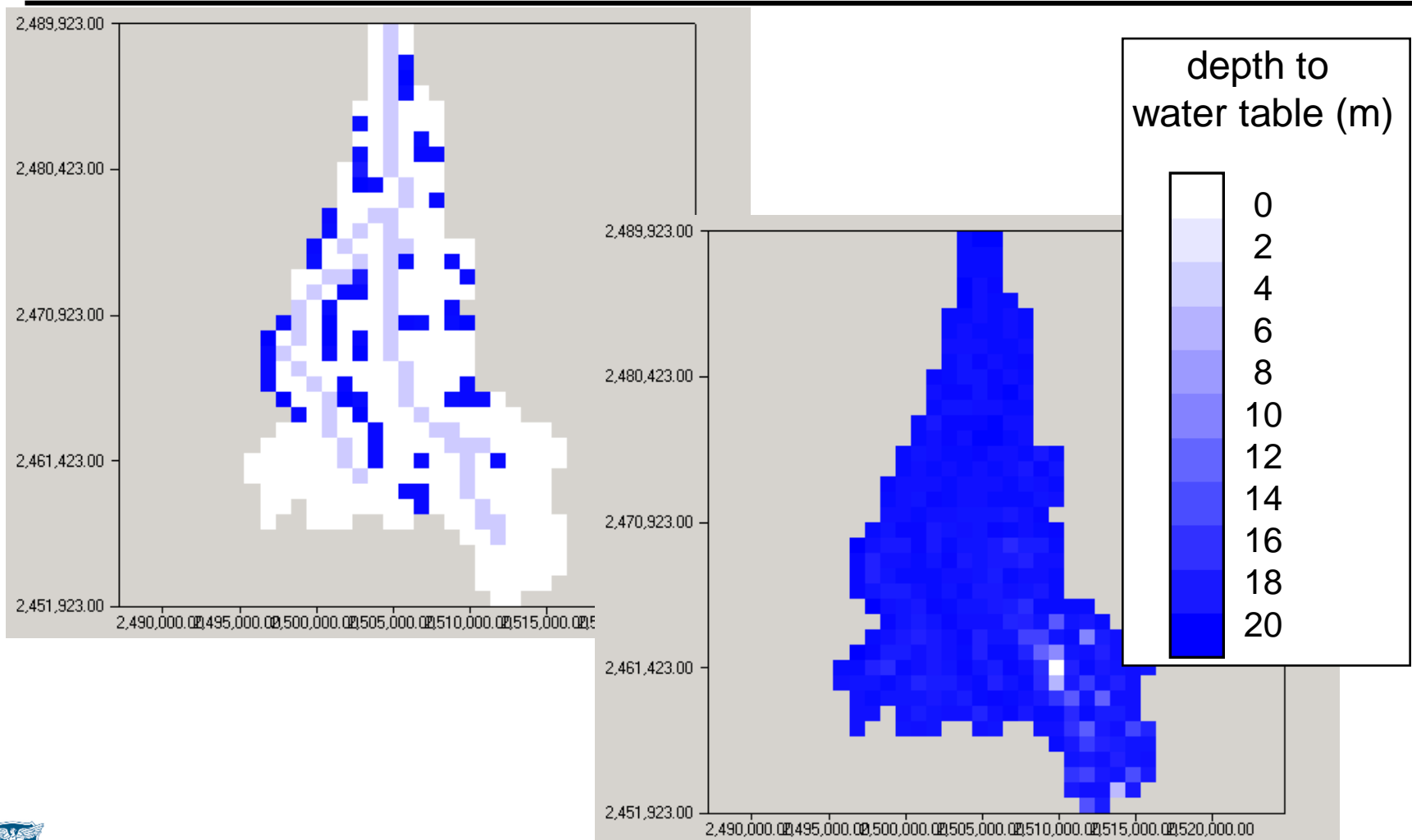
Fraction of Landscape Cleared

Depth to waterable (m)

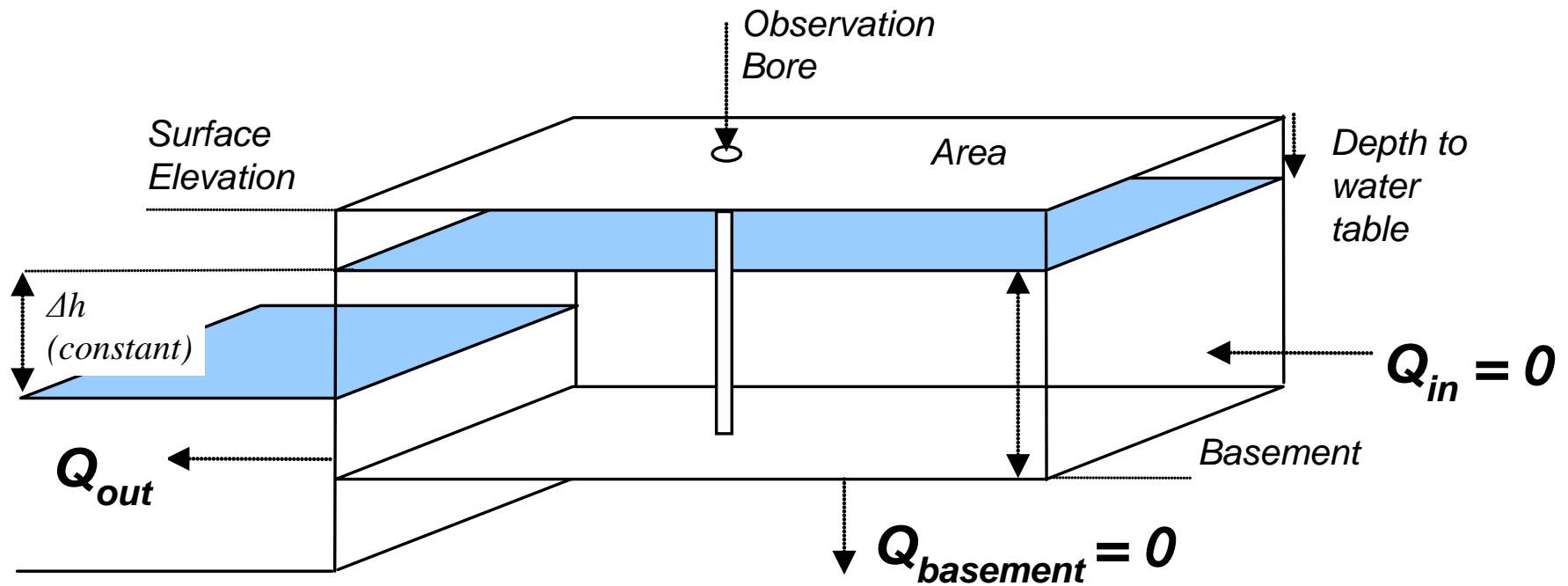
A distributed model for validation: Sunday Creek-SWG implementation.



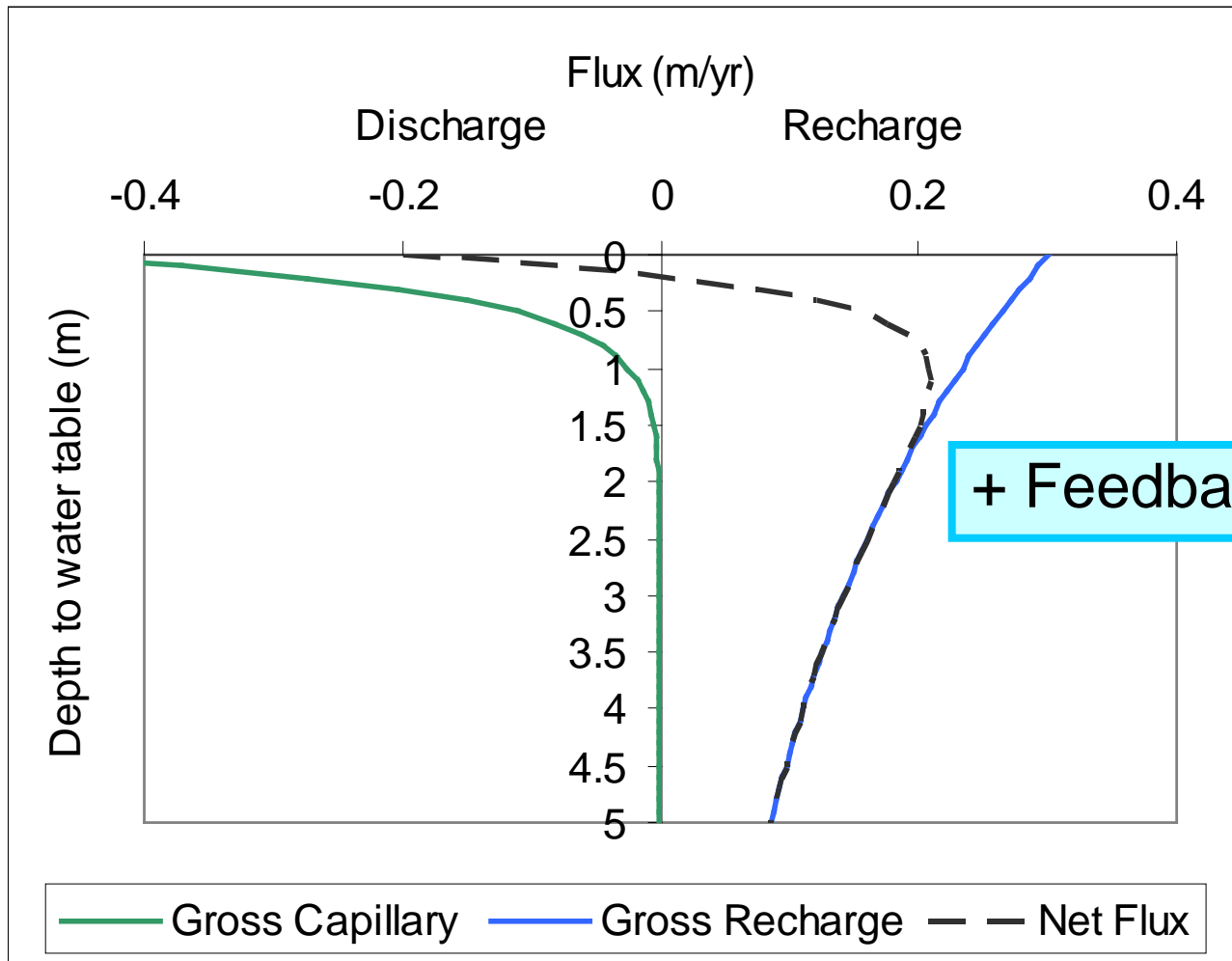
But, 2 states only at extreme parameter values.



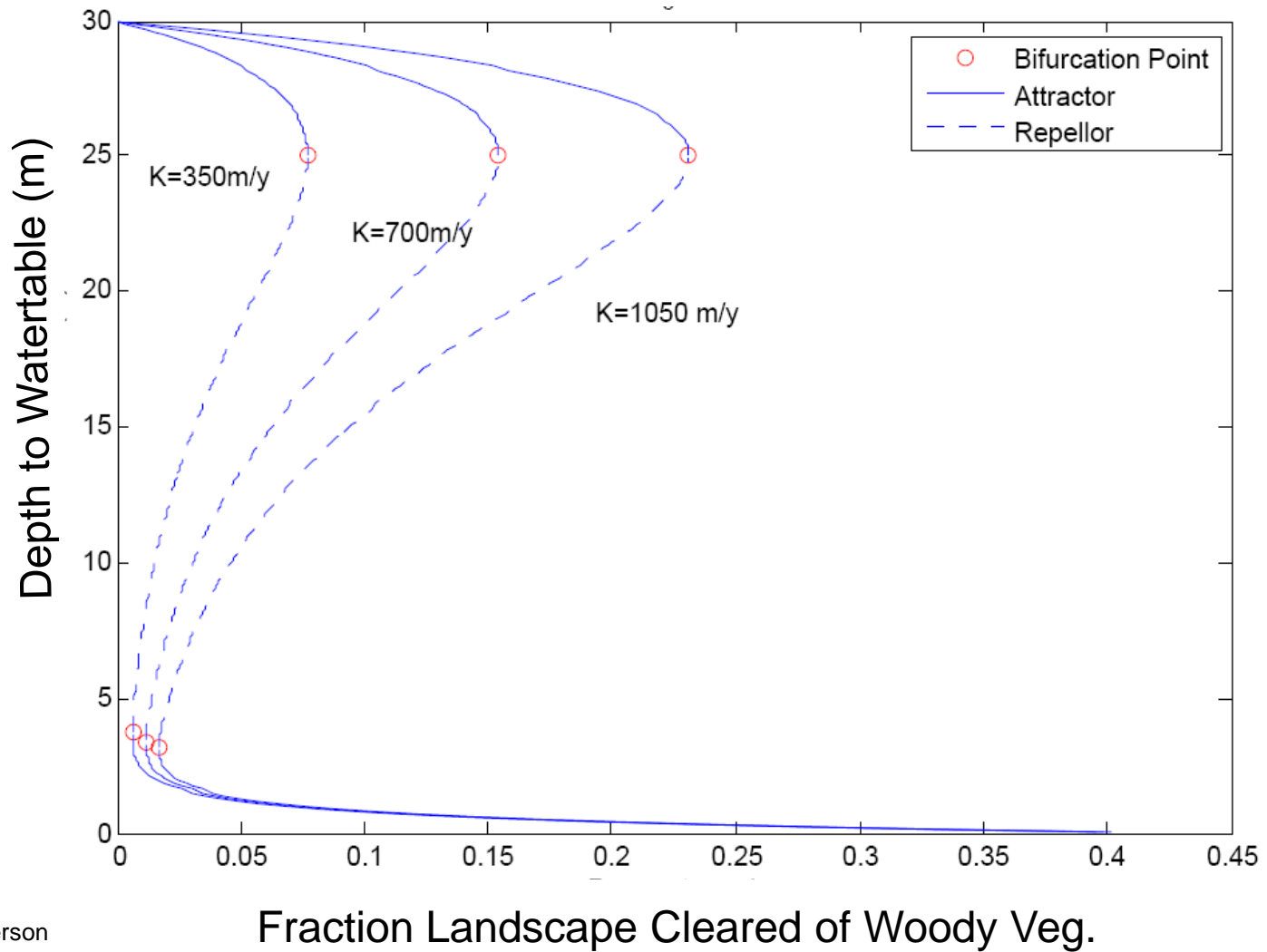
Back to Basics: A simple lumped model...



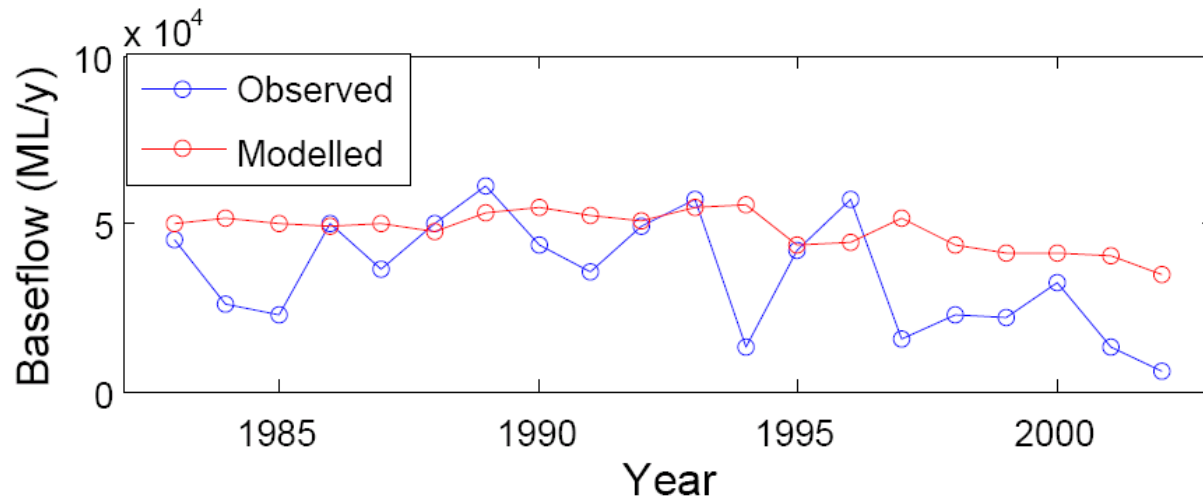
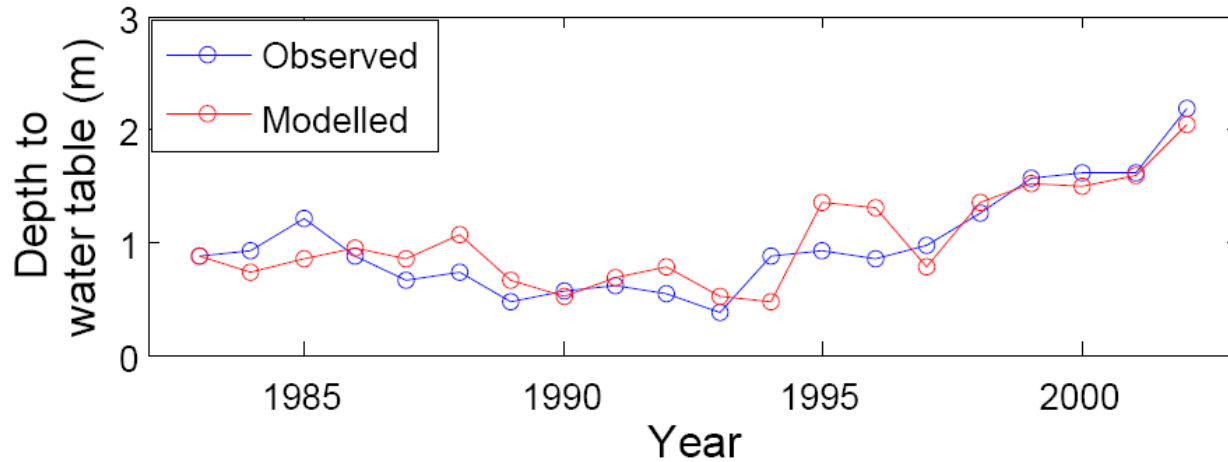
Back to Basics: Simple unsat. zone processes...



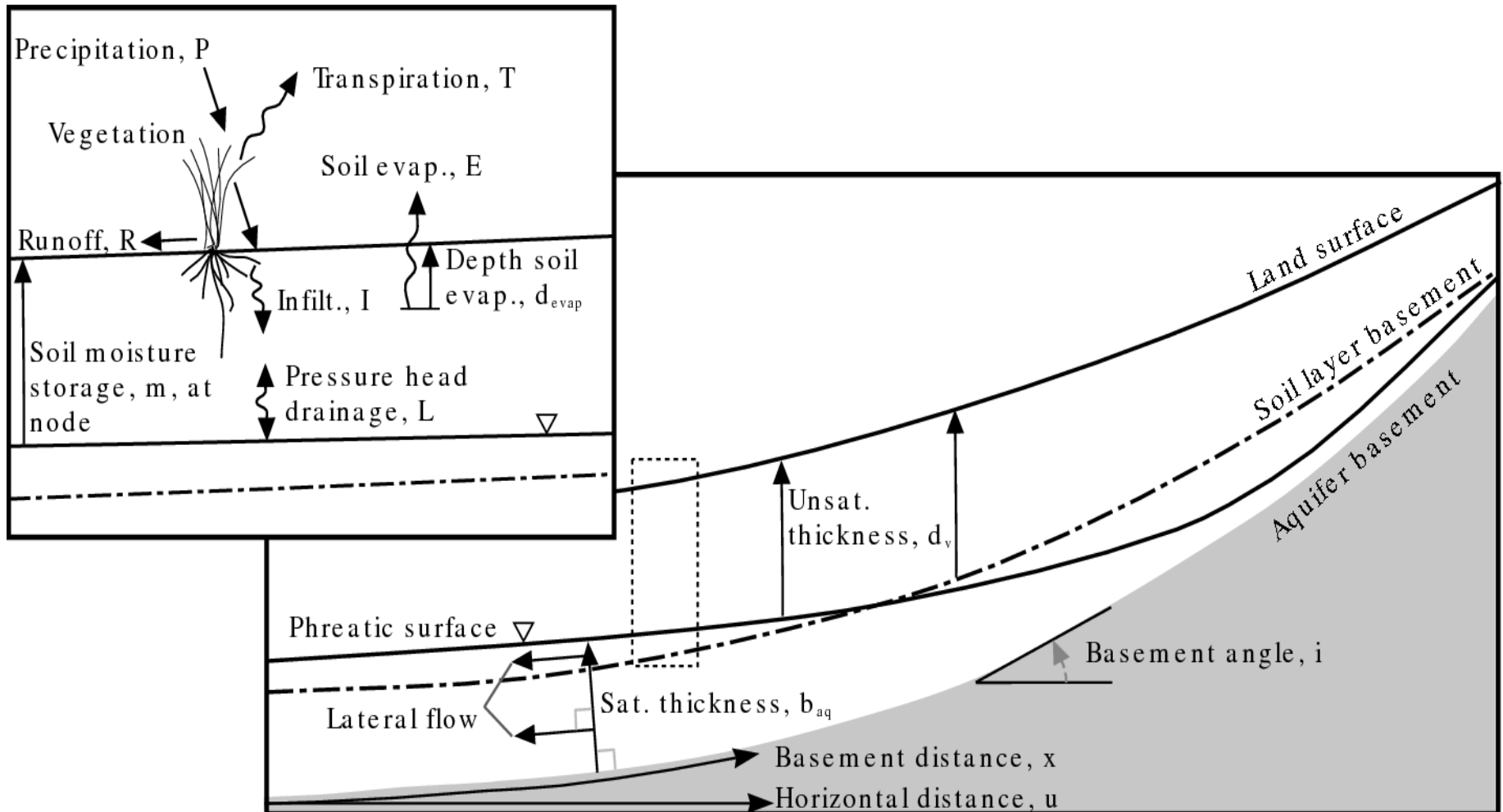
Two states still emerge...



Back to Basics: Some trials and calibrations ...

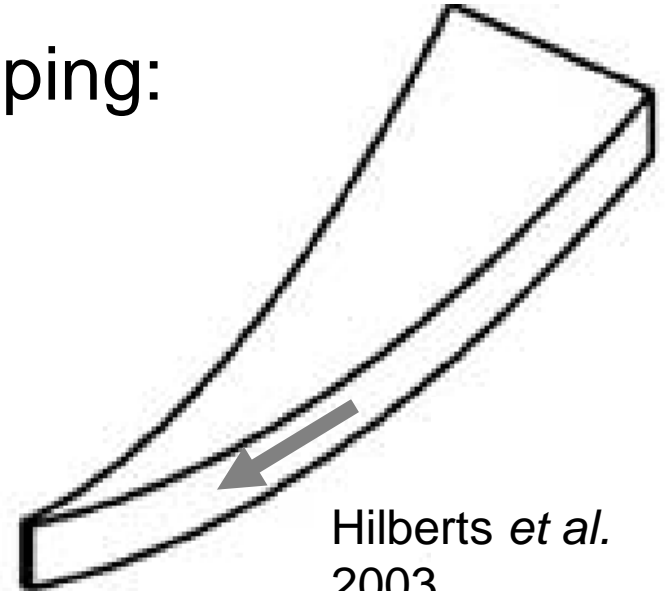


Away from Basics: Adding Lateral Flow Processes ...



An exploration of the model ...

- Supplied limited climate ($P/PET = 0.5$);
- Clay loam and pastures ($LAI_{\text{mean}} = 2.0$);
- Homogeneous isotropic unconfined aquifer;
- Geometry: convergent and sloping:

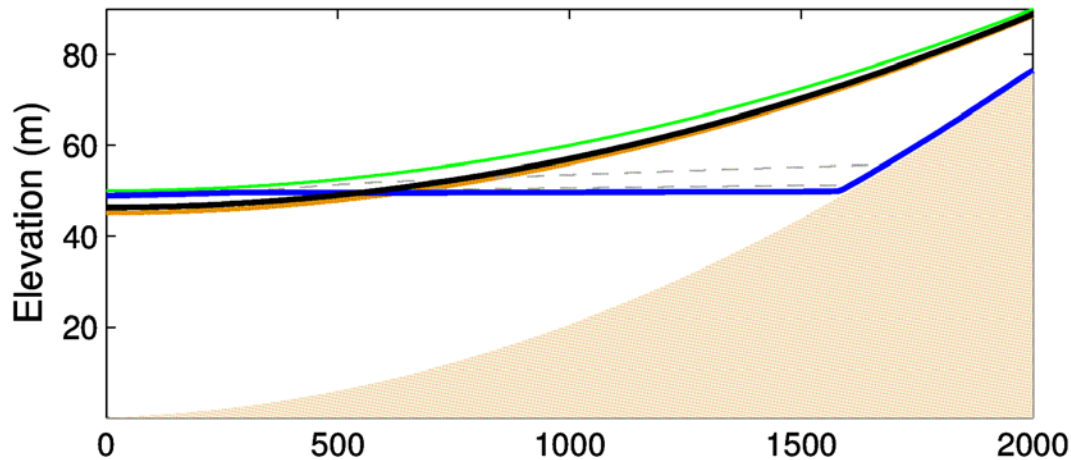


Hilberts *et al.*
2003

Transient solutions:

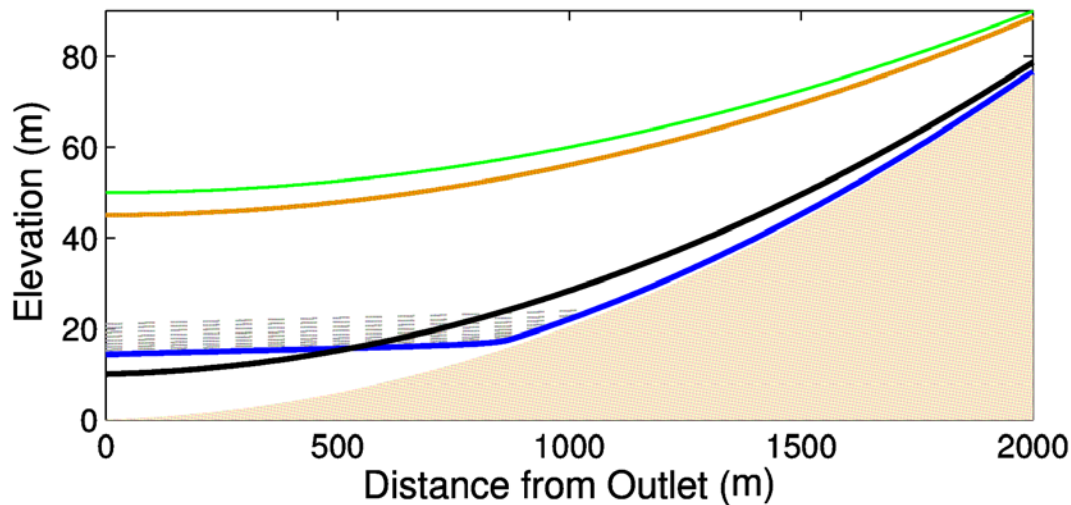
Saturated lateral conductivity = 0.5 m/day

Shallow
Initial
Head



⇒ Shallow
Equilibria

Deep
Initial
Head

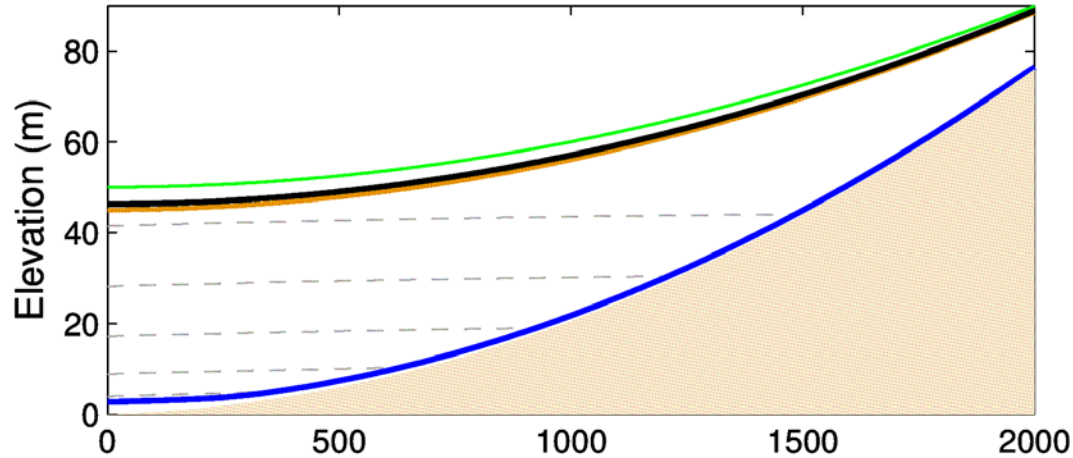


⇒ Deep
Equilibria

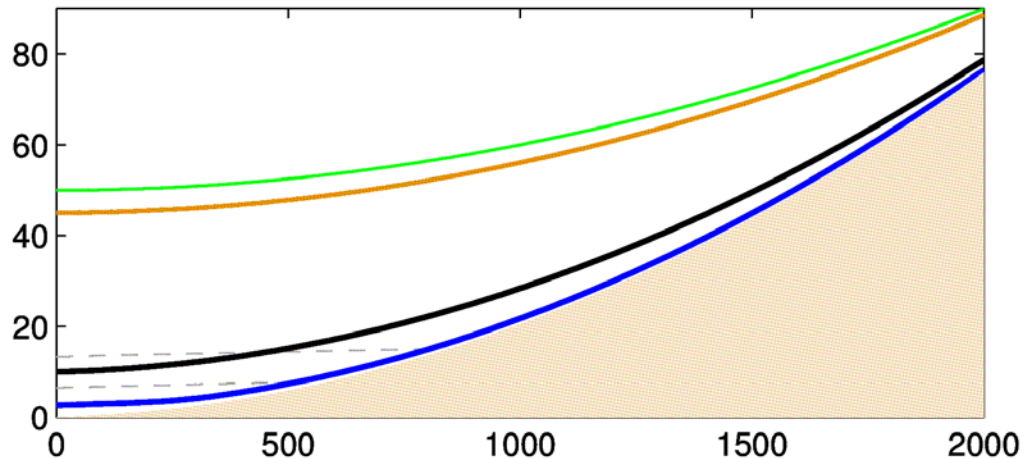
Transient solutions:

High saturated lateral conductivity ($k_{sat} = 1.3 \text{ m/day}$)

Shallow
Initial
Head



Deep
Initial
Head

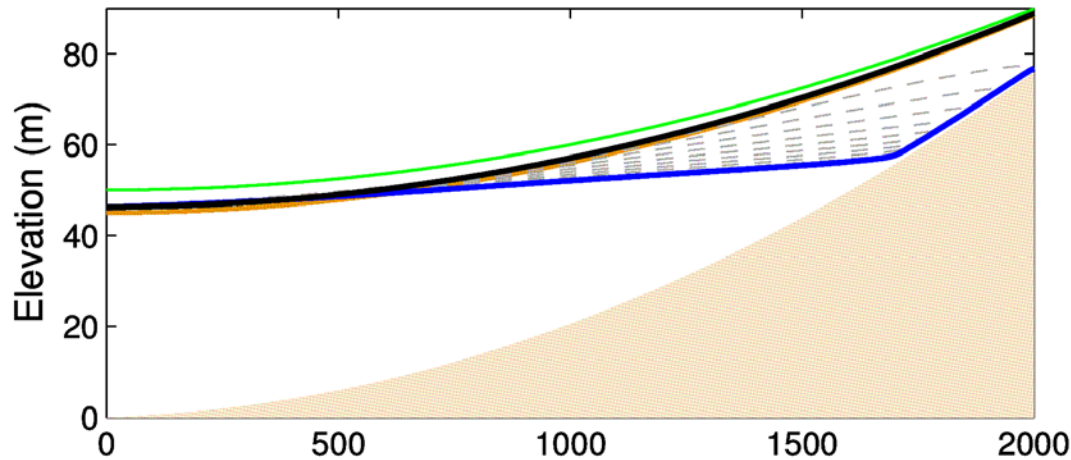


➡ Deep
Equilibria

Not all catchments have two attractors:

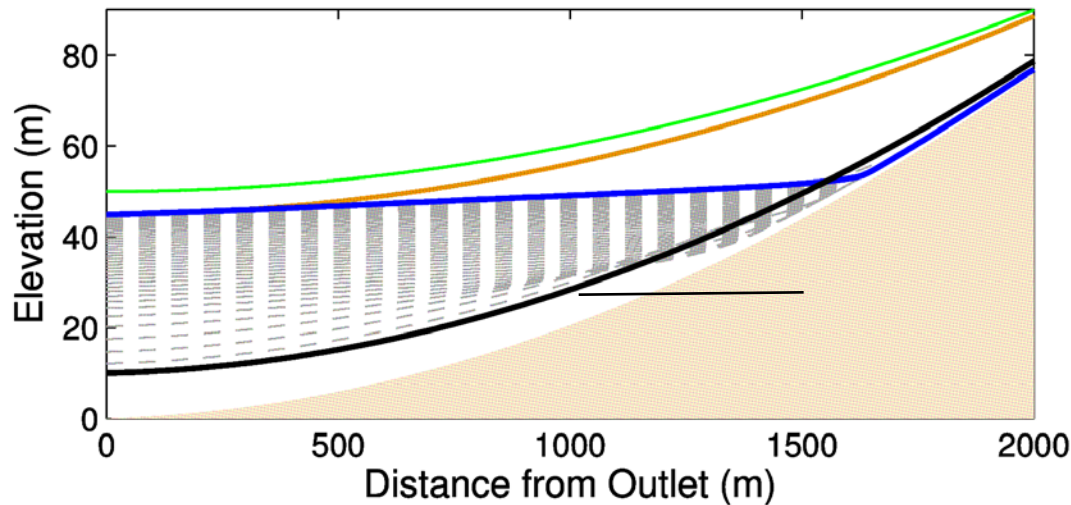
Low saturated lateral conductivity ($k_{sat} = 0.01$ m/day)

Shallow
Initial
Head



➔ Shallow
Equilibria

Deep
Initial
Head



Positive feedbacks and model changes

- Transpiration declines as water table approaches the surface*:

$$T = \text{PET} \left(1 - e^{-k_{\text{light}} \text{LAI}} \right) \frac{\theta - \theta_{wp}}{\theta - \theta_{wp}}$$

$$\text{LAI} = \text{LAI}_{\text{avg}} \left(\frac{P_t}{P_{\text{avg}}} \right)^{\beta} \left(\frac{d_v^{\alpha}}{d_v^{\alpha} + d_{\text{LAI}/2}^{\alpha}} \right)$$

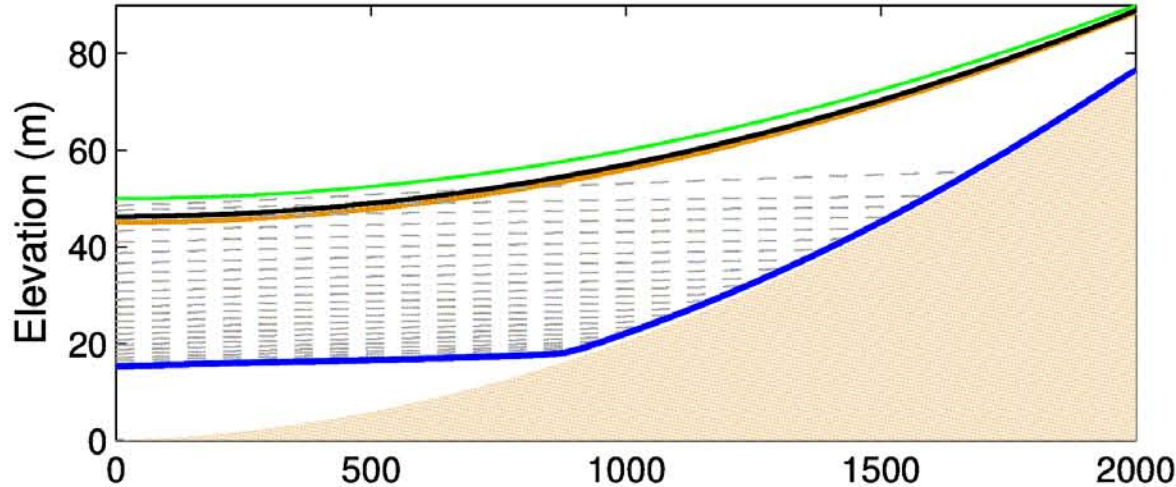
- **Logistic Function (0->1)**
- **LAI \propto 1 / Depth to water table**

- Simulations repeated **without** logistic function.

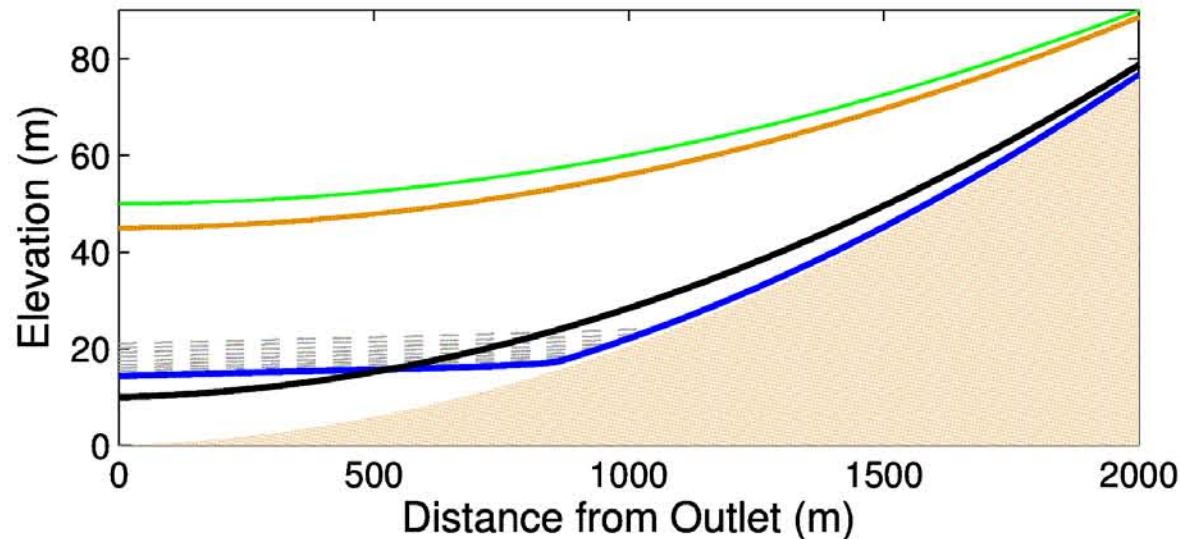
Transient solutions without transpiration feedback

Saturated lateral conductivity = 0.5 m/day

Shallow
Initial
Head



Deep
Initial
Head

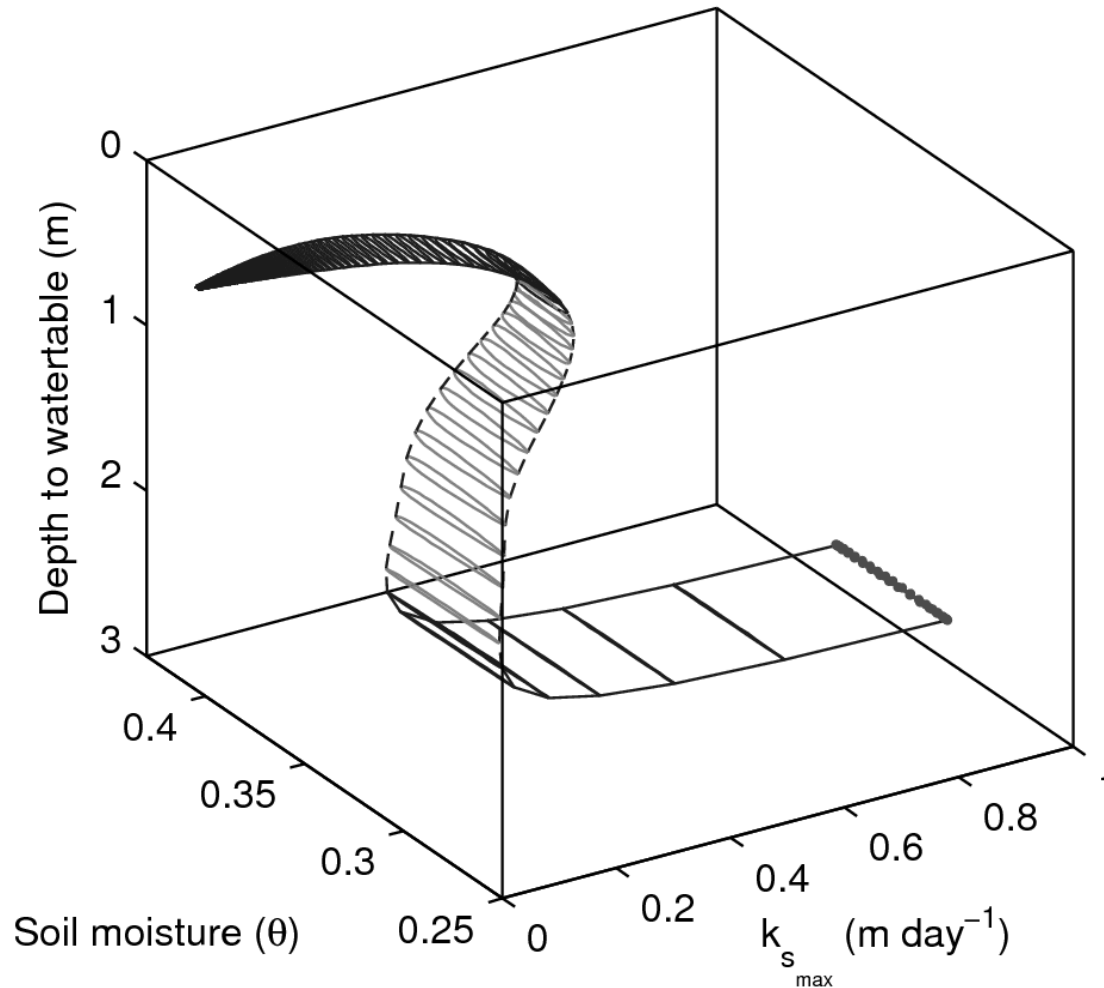


Only
Deep
Equilibria

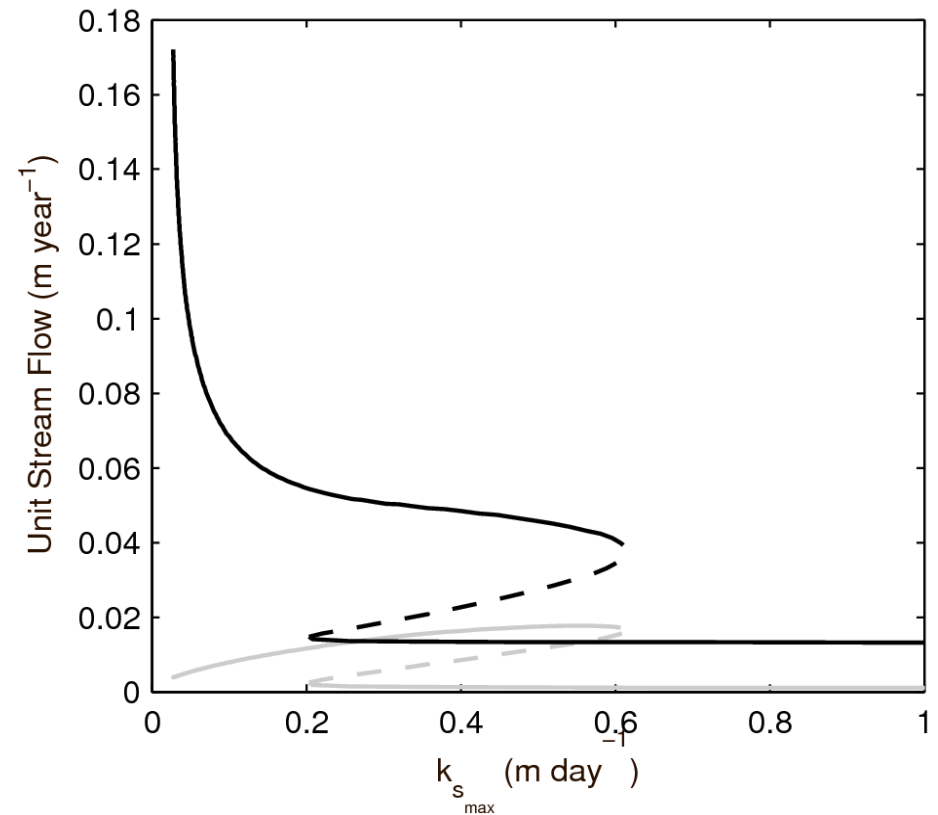
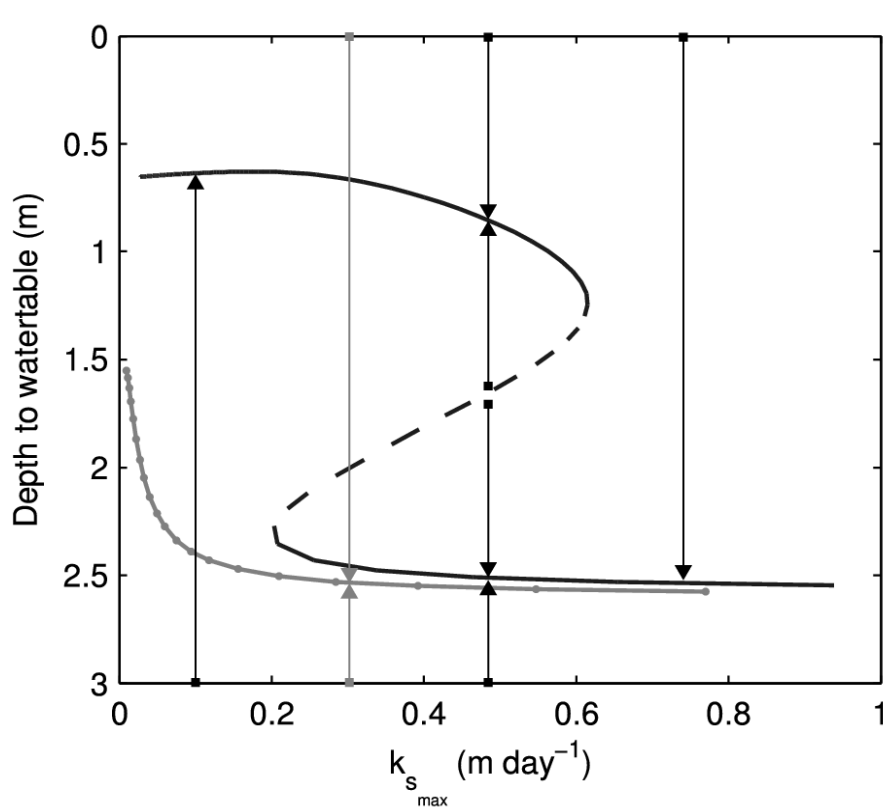
Some Findings...

- Only some catchments have two states;
 - Saturated conductivity, Areal convergence / outlet constriction, slope, ...
- Parameters independently observable.
- Climate time step significantly affects estimated range of two states.
- Transparent and tractable processes for two states.

Limit Cycle Continuation (i.e. stability analysis): General head boundary condition.



Limit Cycle Continuation 2-D View: General head boundary condition.

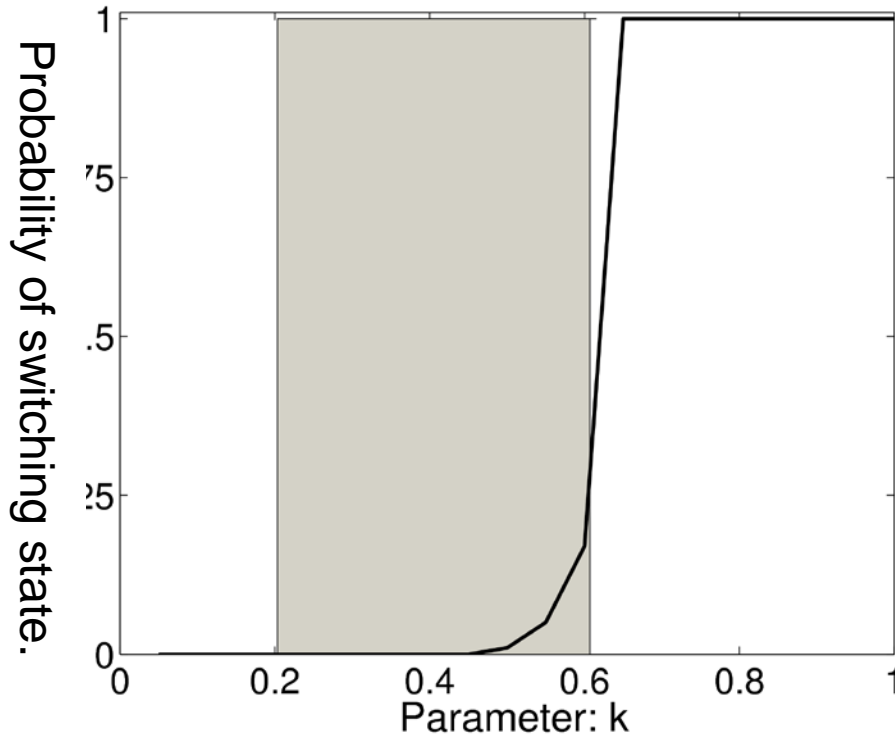


Some Findings...

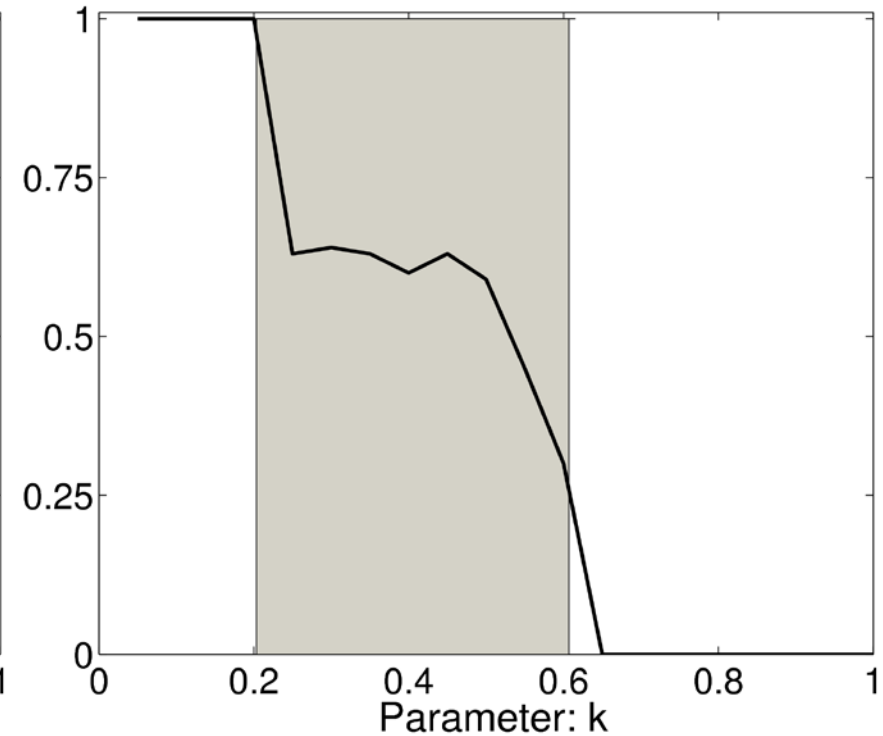
- Boundary conditions are very significant in defining which catchments have 2 states;
- 72% reduction in streamflow!
- But, recharge is very event driven.
 - Do two states occur with observed data?


Climate Variability: Do two states still emerge?

Shallow watertable initially



Deep watertable initially



 : Saturated lateral conductivity (k_{sat}) range of 2 stable states.

Some Implications ...

- Identify catchments >1 stable state:
 - where existing models are applicable;
 - prioritising actions to >1 catchments.
- Major hysteresis when state change occurs:
 - asymmetric vulnerability of the 2 states;
 - existing measures of resilience are incomplete.

What's Next?

- Repeat with probability simulations with daily data.
- Implementation to paired catchments in Wimmera.
- Post-Doctorate at Uni Melb with DPI (Cheng), DSE (McAuley), BoM (Frost-Daamen).
 - Mid-2009 to mid-2011.