Improving Hydrological Process Representations in GWF Models

John Pomeroy, Kevin Shook, Al Pietroniro, Howard Wheater,

Centre for Hydrology & GIWS

University of Saskatchewan, Saskatoon

UNIVERSITY OF SASKATCHEWAN
Global Water Futures
GWF.USASK.CA

WHY MORE PROCESSES?

HYDROLOGICAL PROCESSES
Hydrol. Process. **12**, 2339–2367 (1998)

An evaluation of snow accumulation and ablation processes for land surface modelling

J. W. Pomeroy[1]*, D. M. Gray[2], K. R. Shook[2], B. Toth[2], R. L. H. Essery[2], A. Pietroniro[1] and N. Hedstrom[1]

[1] *National Hydrology Research Centre, 11 Innovation Blvd, Saskatoon, Saskatchewan S7N 3H5, Canada*
[2] *Division of Hydrology, University of Saskatchewan, Saskatoon,Saskatchewan S7N 0W0, Canada*

Abstract:

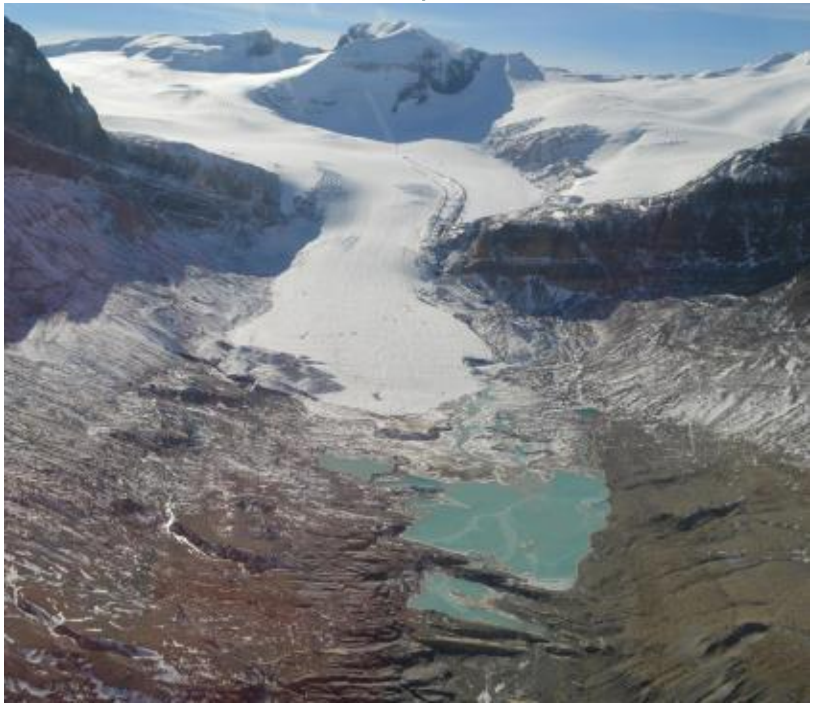
This paper discusses the development and testing of snow algorithms with specific reference to their use and application in land surface models. New algorithms, developed by the authors, for estimating snow interception in forest canopies, blowing snow transport and sublimation, snow cover depletion and open environment snowmelt are compared with field measurements. Existing algorithms are discussed and compared with field observations. Recommendations are made with respect to: (a) density of new and aged snow in open and forest environments; (b) interception of snow by evergreen canopies; (c) redistribution and sublimation of snow water equivalent by blowing snow; (d) depletion in snow-covered area during snowmelt; (e) albedo decay during snowmelt; (f) turbulent transfer during snowmelt; and (g) soil heat flux during meltwater infiltration into frozen soils.

Preliminary evidence is presented, suggesting that one relatively advanced land surface model, CLASS, significantly underestimates the timing of snowmelt and snowmelt rates in open environments despite overestimating radiation and turbulent contributions to melt. The cause(s) may be due to overestimation of ground heat loss and other factors. It is recommended that further studies of snow energetics and soil heat transfer in frozen soils be undertaken to provide improvements for land surface models such as CLASS, with particular attention paid to establishing the reliability of the models in invoking closure of the energy equation.

KEY WORDS snow hydrology; general circulation models; CLASS; land surface schemes; energy balance

Context:

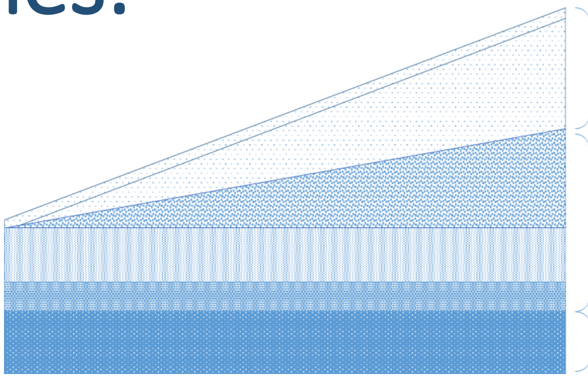
- Mountain glaciers and perennial snowpacks, and lowland (prairie/boreal/tundra) ponds are neglected components of Earth system models.
  - The mountain cryosphere can have important implications for sustaining river flows during droughts and delivering runoff in excess of precipitation in floods.
  - In lowland environments, ponds control the variable contributing area for streamflow generation through contributing area – surface storage relationships.



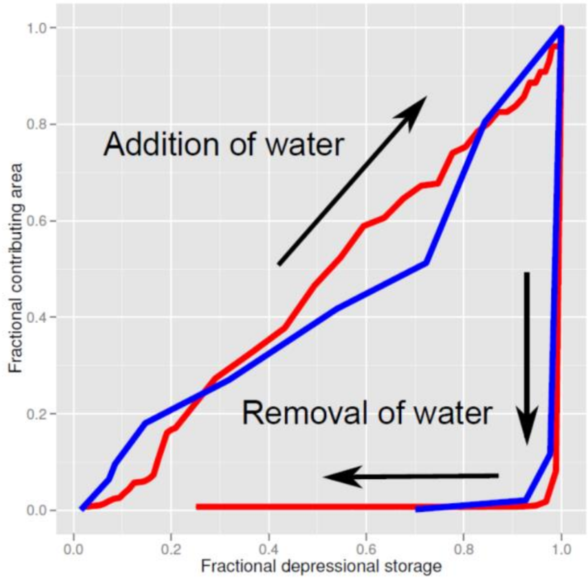
Objectives, Methods, Deliverables:

UNIVERSITY OF SASKATCHEWAN
Global Water Futures
GWF.USASK.CA

Develop a dynamical glacier component in MESH by porting algorithms from the Cold Regions Hydrological Model that modify current snowpack algorithms, accounting for topography and changes as perennial snow turns into firn and glacier ice.



Pond effects on runoff generation in lowland areas will be parameterised using a simplified algorithm that describes the non-linear network behaviour of large numbers of ponds that fill by blowing snow and overland flow and spill by overland flow



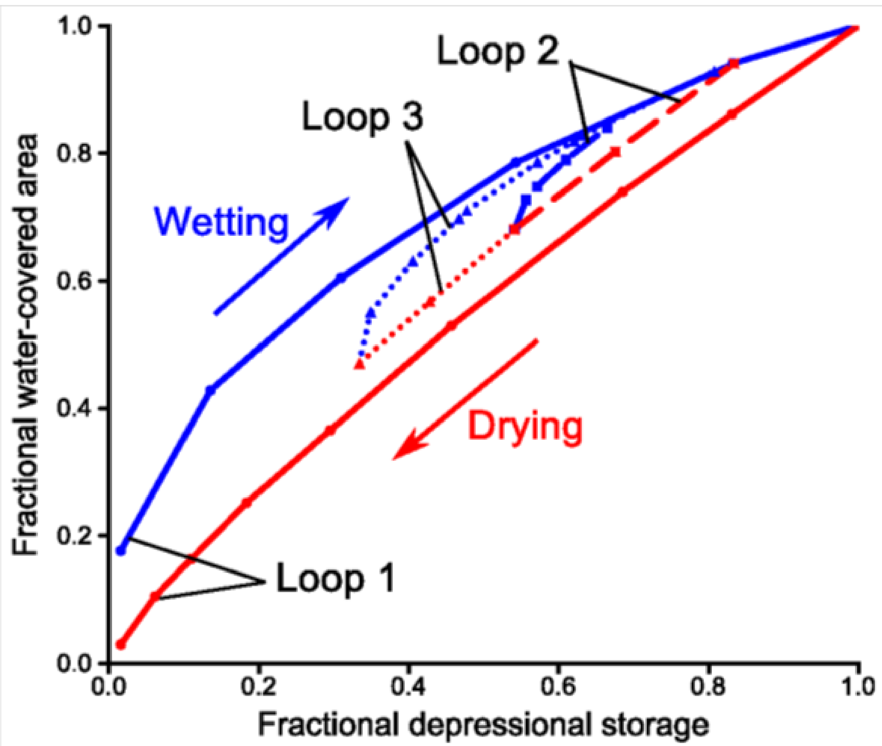
Parameterize in CRHM => Port to MESH

Deliverables: Glacier, perennial snow and lowland pond components added to MESH. Impacts of glaciers on runoff and depressional storage on runoff under climate change.

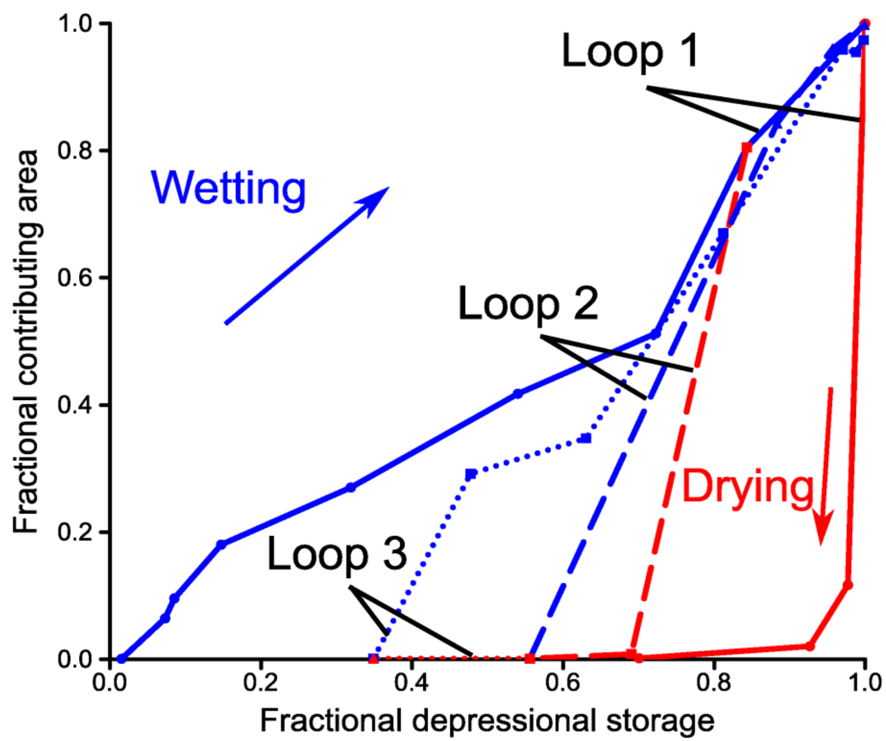
Prairie Runoff Generation

Wetland Network Hydrology

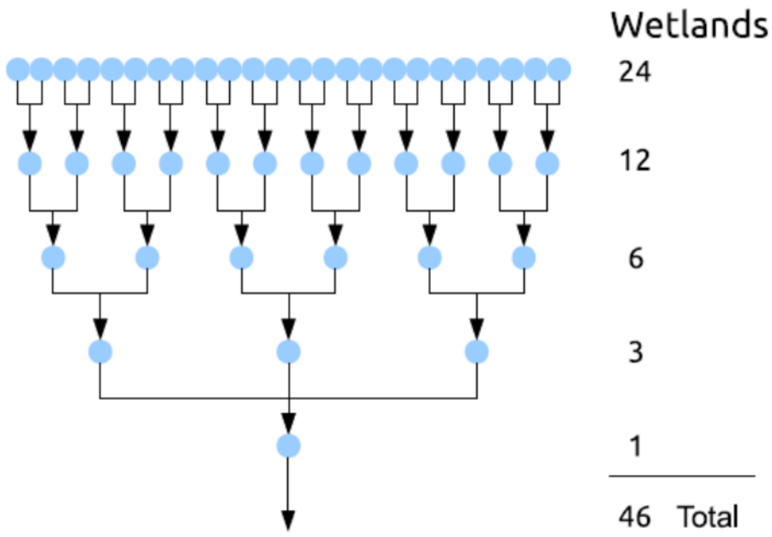
Depressional Storage vs Ponded Area

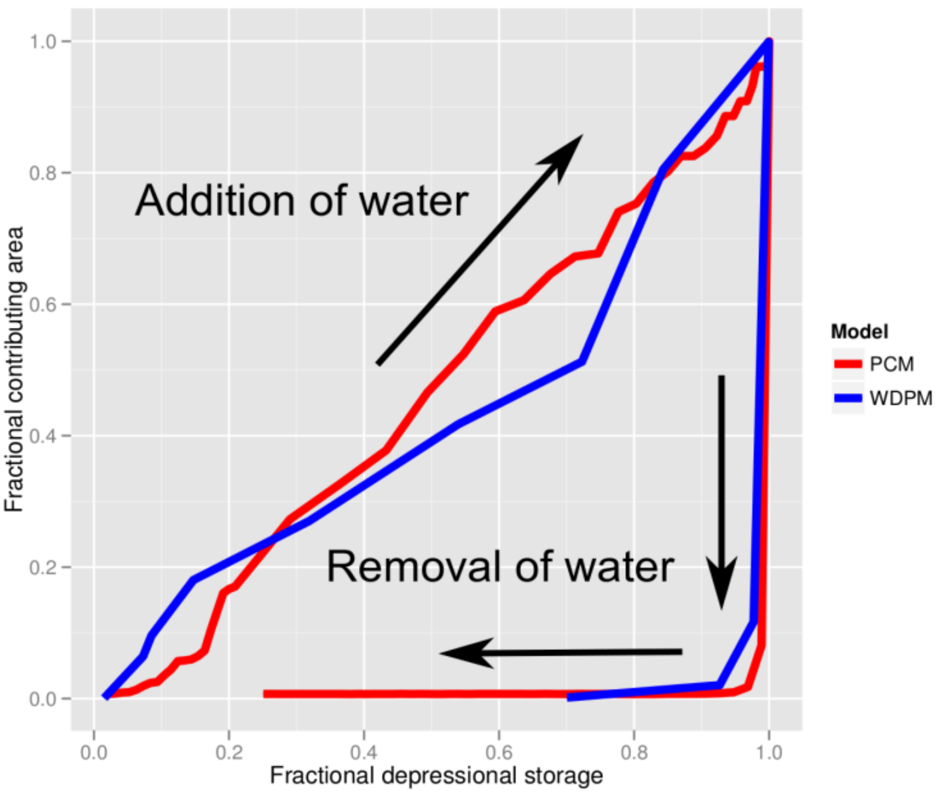


Depressional Storage vs Contributing Area

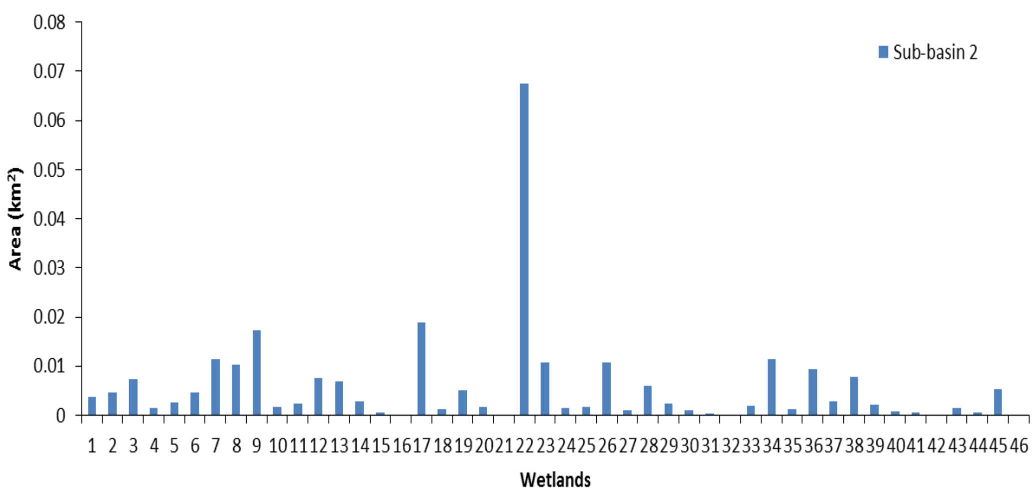


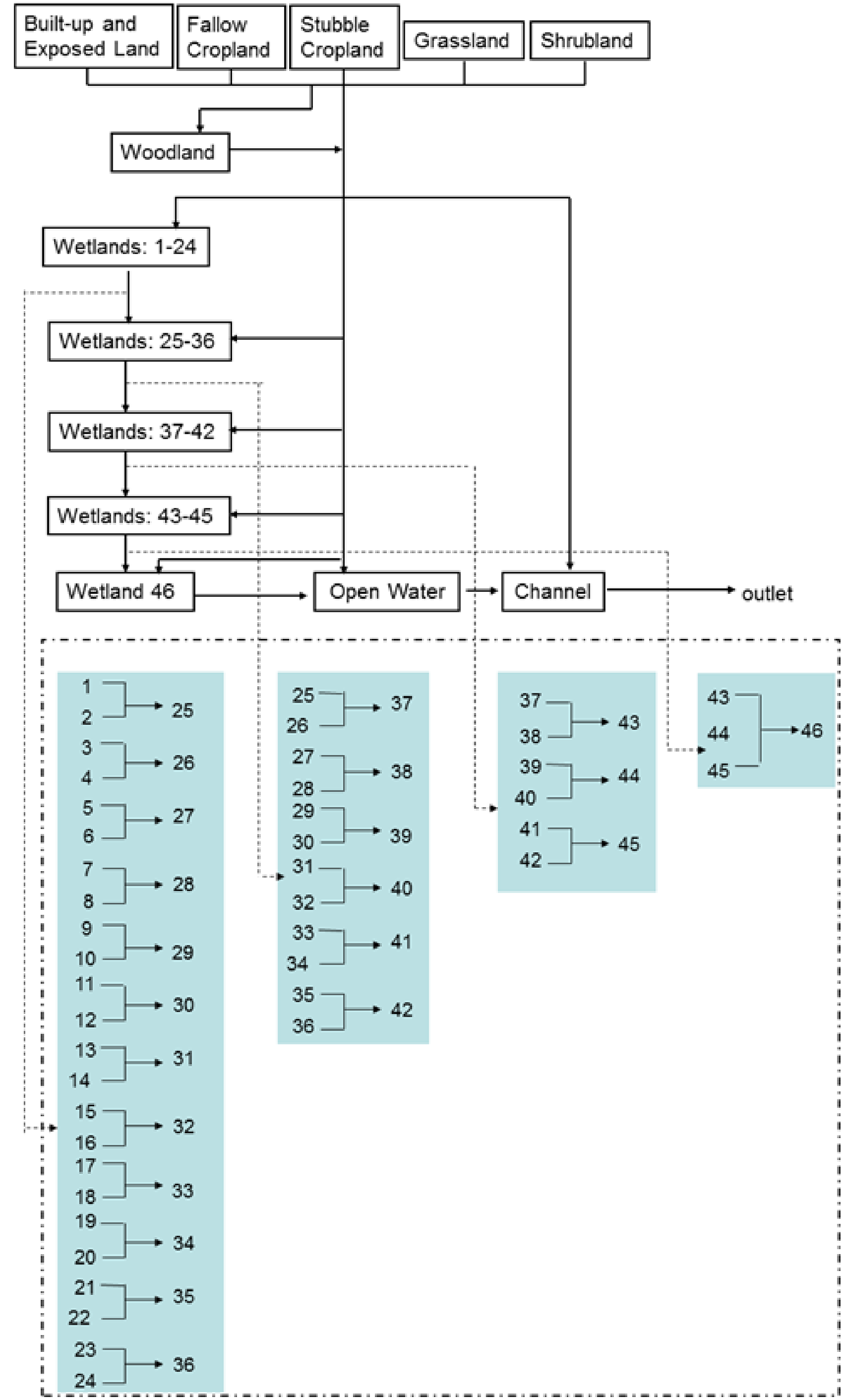
Wetland Representation in CRHM



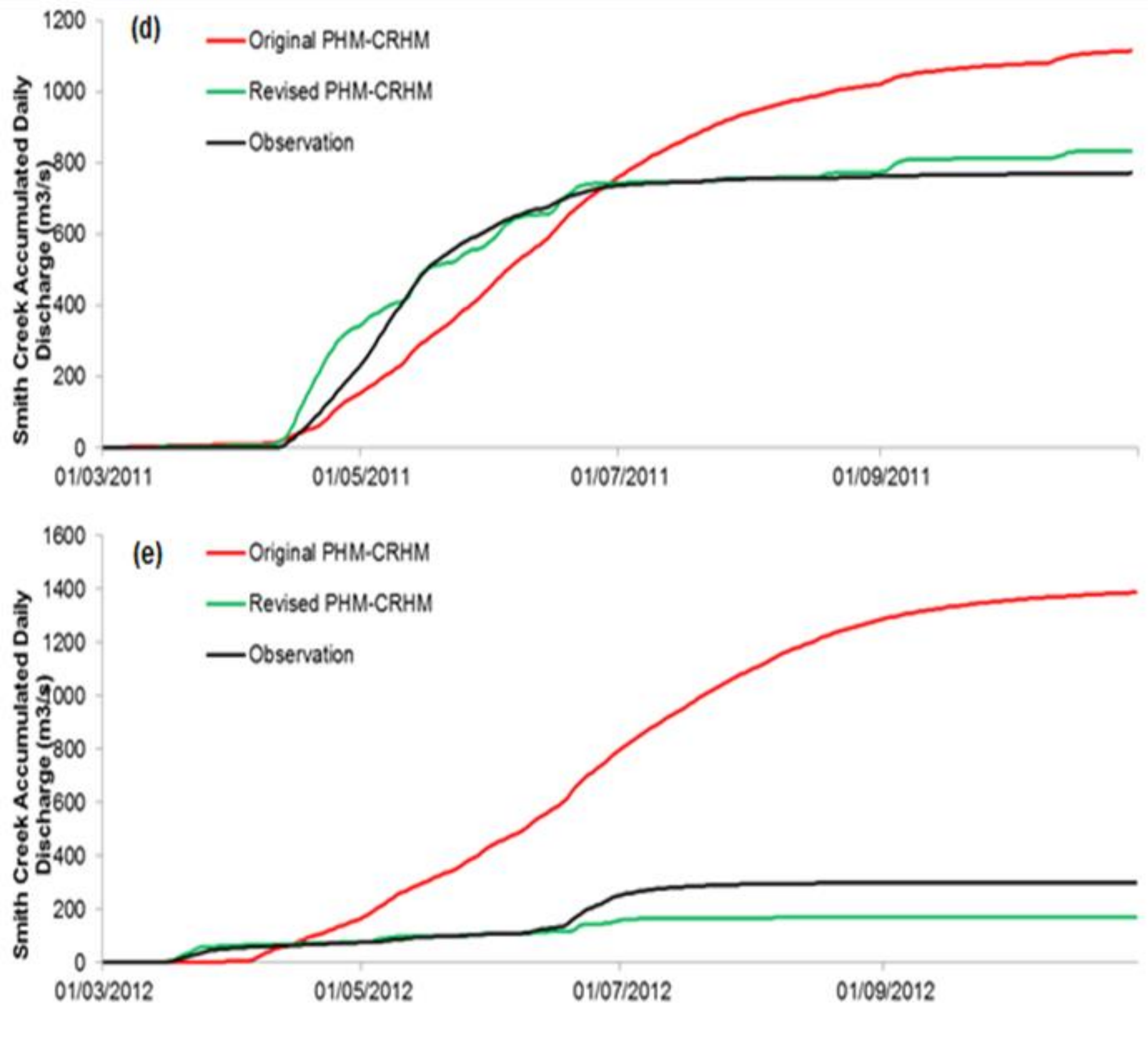


Hydrological Response Unit Routing and Wetland Network Representation





Representing explicit networks of wetlands improved CRHM simulations from those using a single wetland and a depressional storage parameterisation



Development of a generic model of Prairie basin response

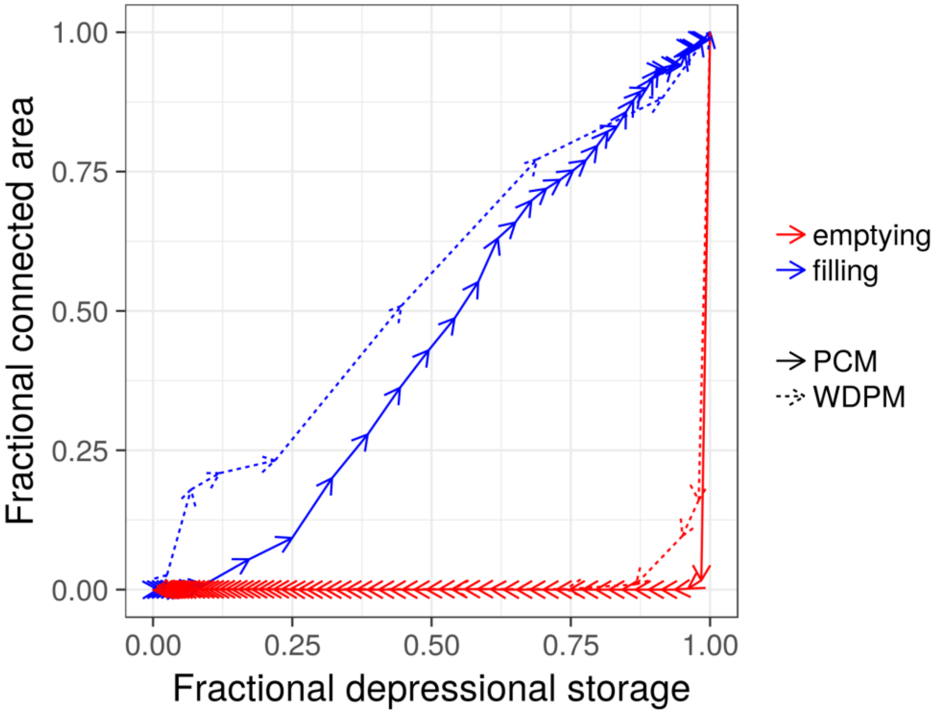
- Existing models have been slow (Wetland DEM Ponding Model), or very difficult to implement (Pothole Cascade Model)
- Need a model which is
  - Fast
  - Simple
    - few additional state variables
  - Generic
    - must work on any basin
    - must work in any modelling program
  - Easily parameterised
    - must be able to deal with effects of drainage

Small depression effects

- Gatekeeping not a big factor when maximum pond areas approximate a Generalized Pareto Distribution

- Results in a triangular hysteresis loop between connected fraction and water storage

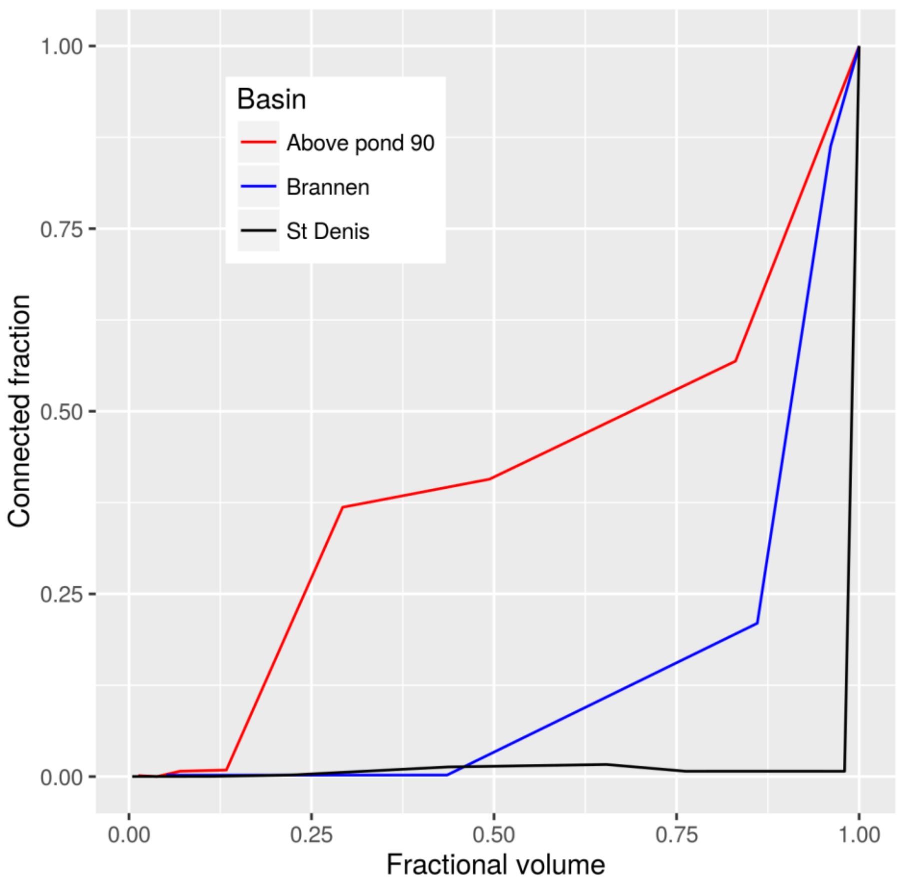
Smith Creek sub-basin 5



Large depression effects

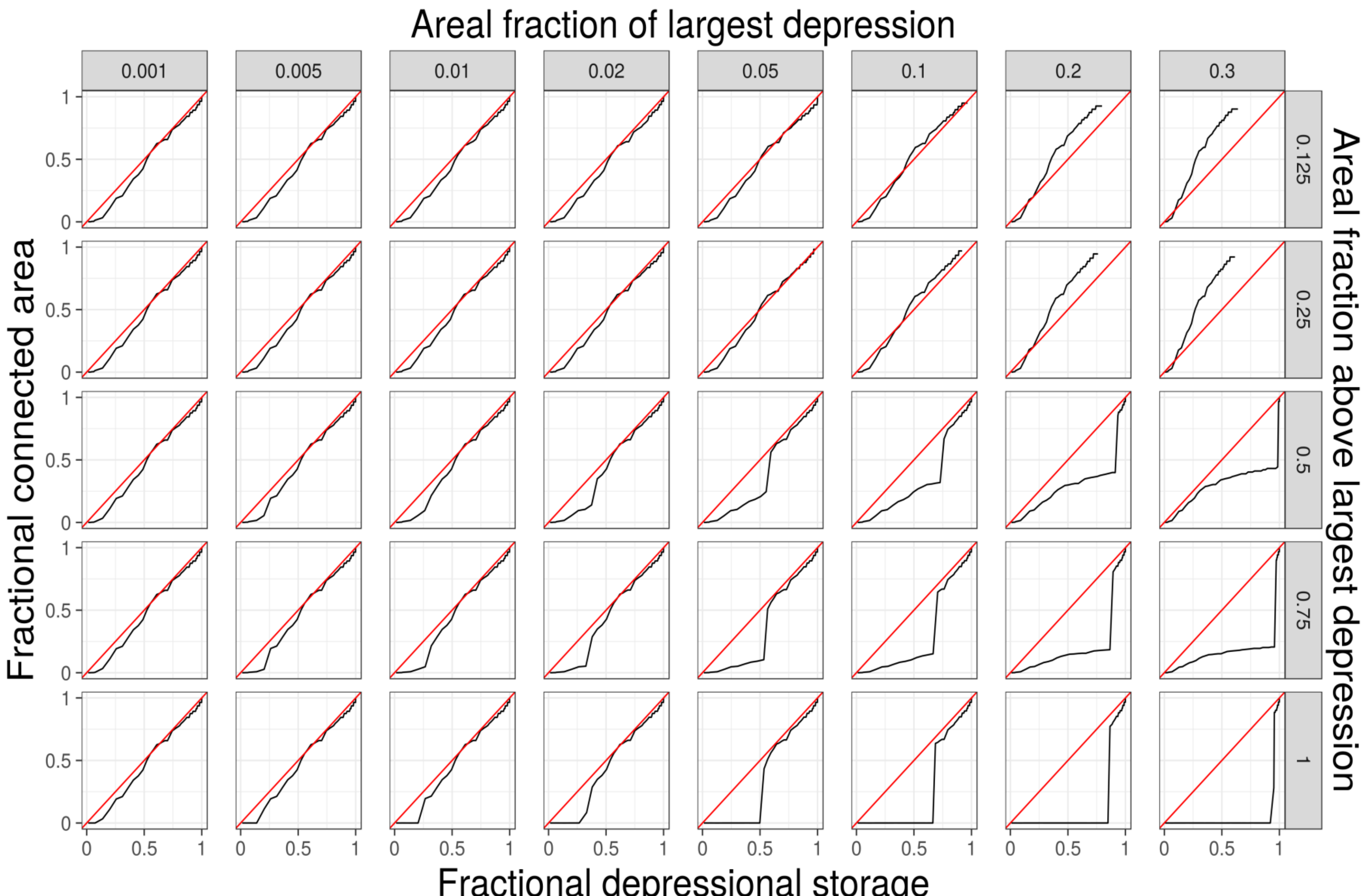
- Large depressions gatekeep drainage areas above them
- Large depressions require water from the drainage area above them, in order to fill
- Gatekeeping effect depends on the size of the largest depression and its location within the basin drainage network

St. Denis sub-basins



Numerical experiment

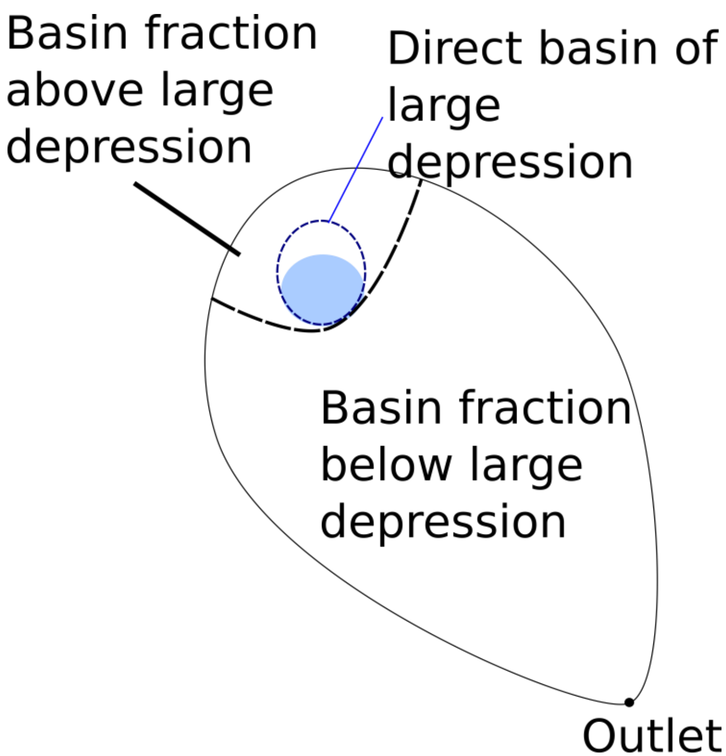
2944 Smith Creek ponds + 1 large pond

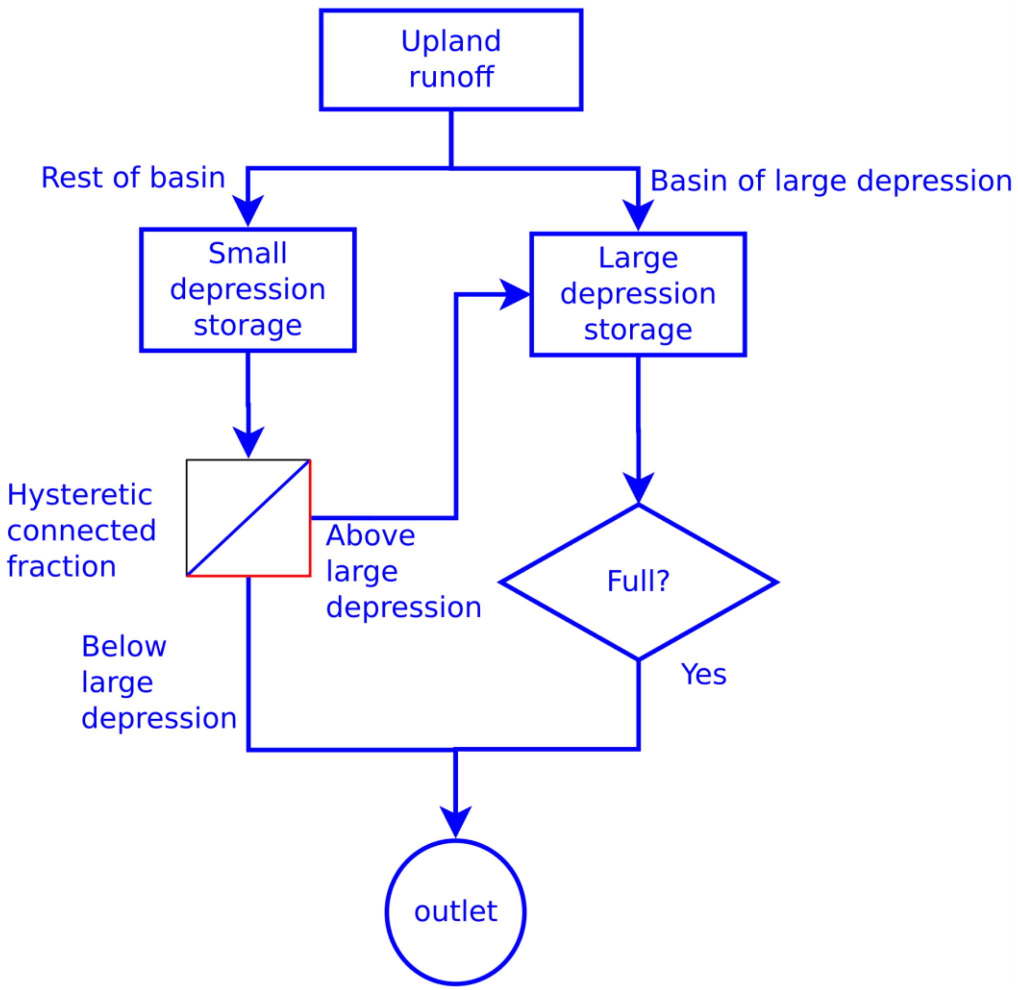


Parallel model proposal

- Gatekeeping only important when a depression is > ~1% of total depressional area
- Concept is to separate the small depressions with weak gatekeeping from the large gatekeeping depressions in the model
- Run parallel simulations of both types of regions
- Outputs are then combined

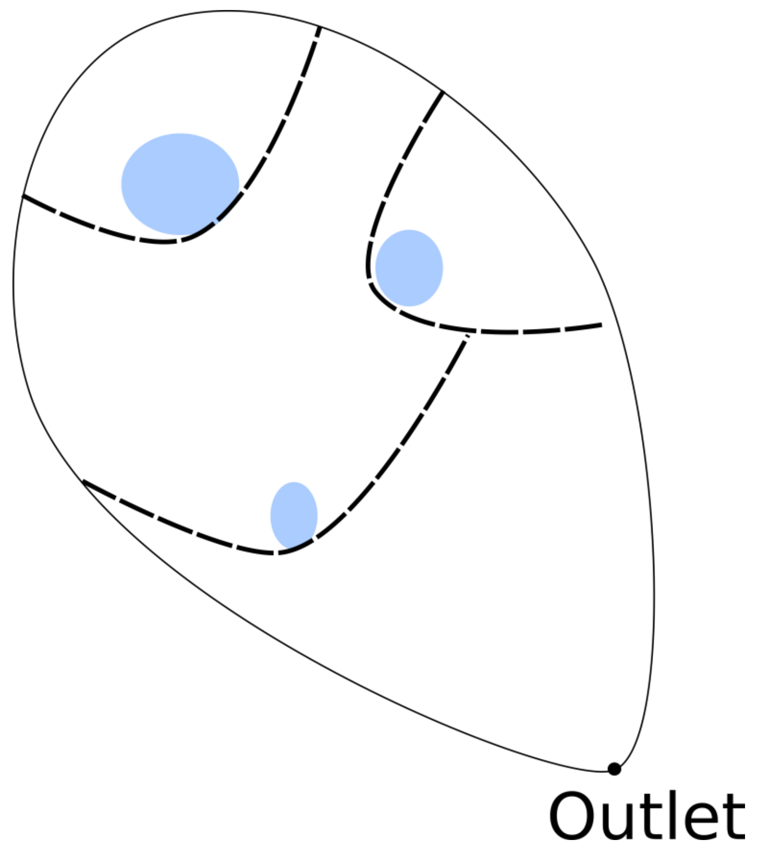
Parallel model





Model flexibility

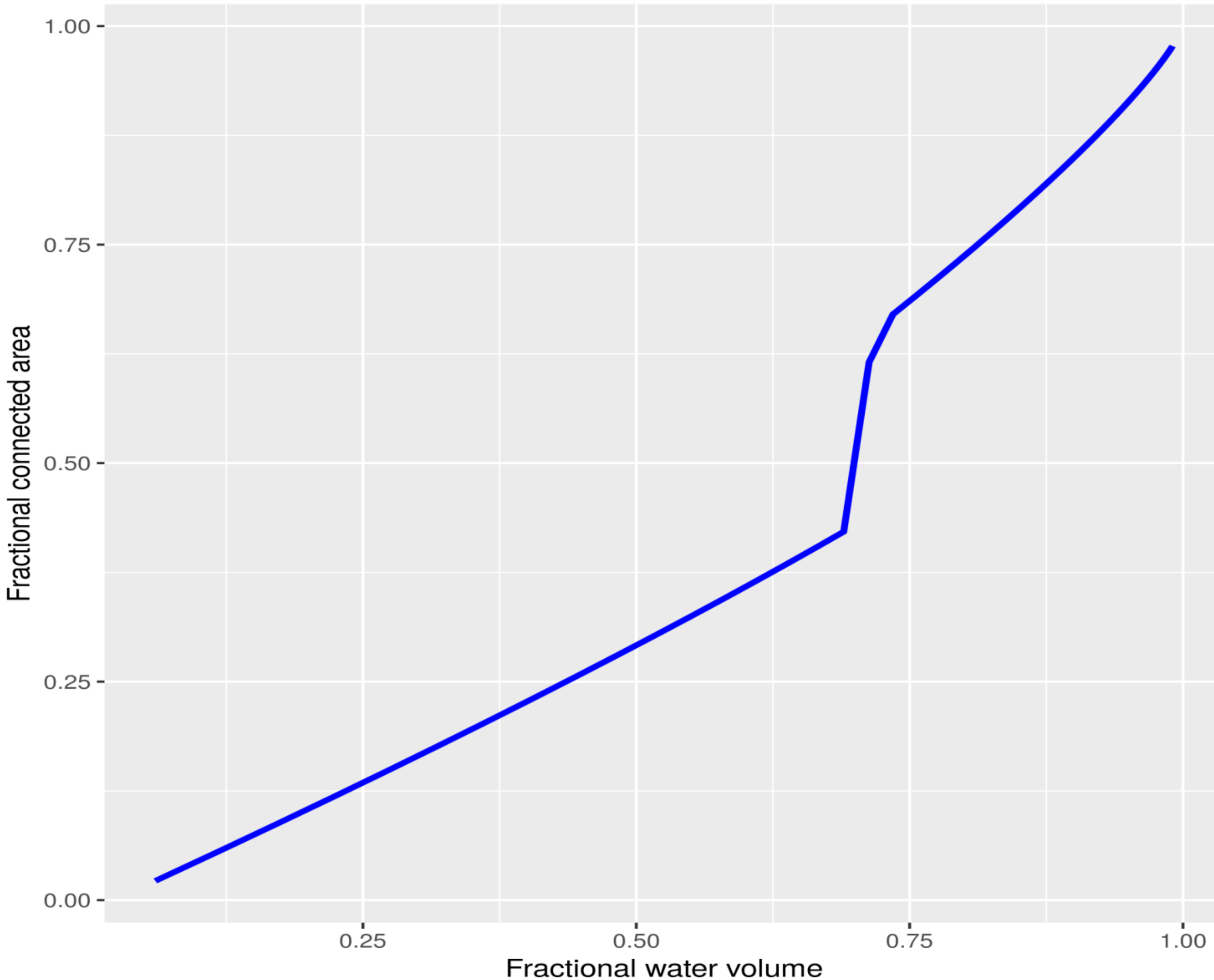
- Model could easily be extended to add more large ponds
  - All ponds would use the same outflow depths from the non-gatekeeping region
- Would also work with the fraction of basin which is not affected by depressional storage
  - Only limitation is the configurability of the modelling program



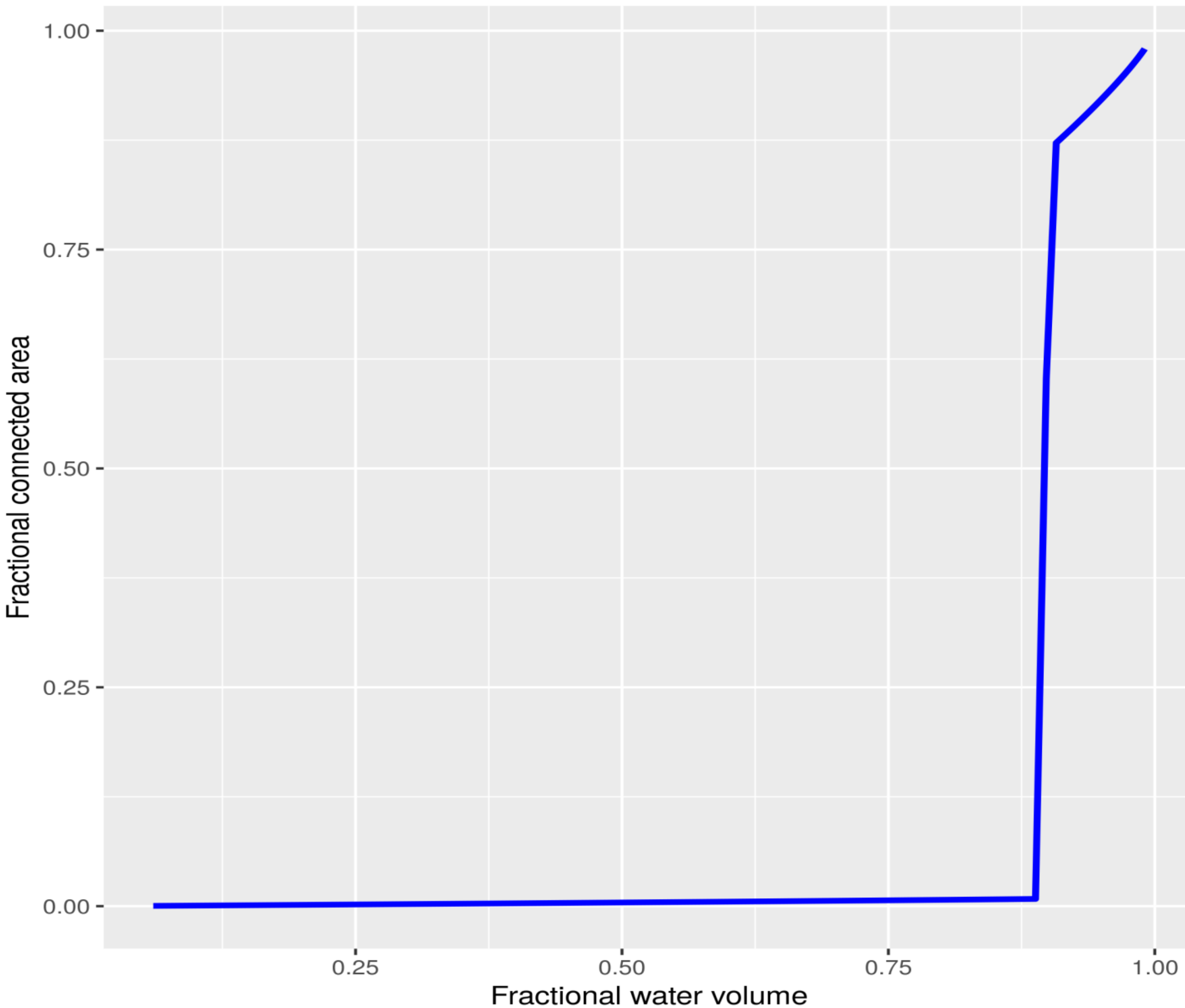
Model parameters

- Few new parameters are required
- Parameters (areas, storages) have physical meanings
  - can be estimated from GIS and DEMs
  - can also use simple pond scaling relationships
- Doesn't need calibration
  - can work at sub-basin scales
  - storage volumes can be adjusted for effects of drainage

Initial Model Test – Upper Pond. Pond with 10% of the pond area and 30% of the basin above.



Initial Model Test: Low Pond. Pond with 30% of the pond area and 99% of the basin above it.



Conclusions

- Capabilities in modelling depressional storage (ponds) in prairies and other environments that have been used in WDPM, PCM and CRHM have been difficult to implement in a large scale model such as MESH
- New parallel ponding model provides a capability for large scale models that is efficient and simple to parameterize.