# Summary Large Scale Hydrology Modeling in a Prairie Environment

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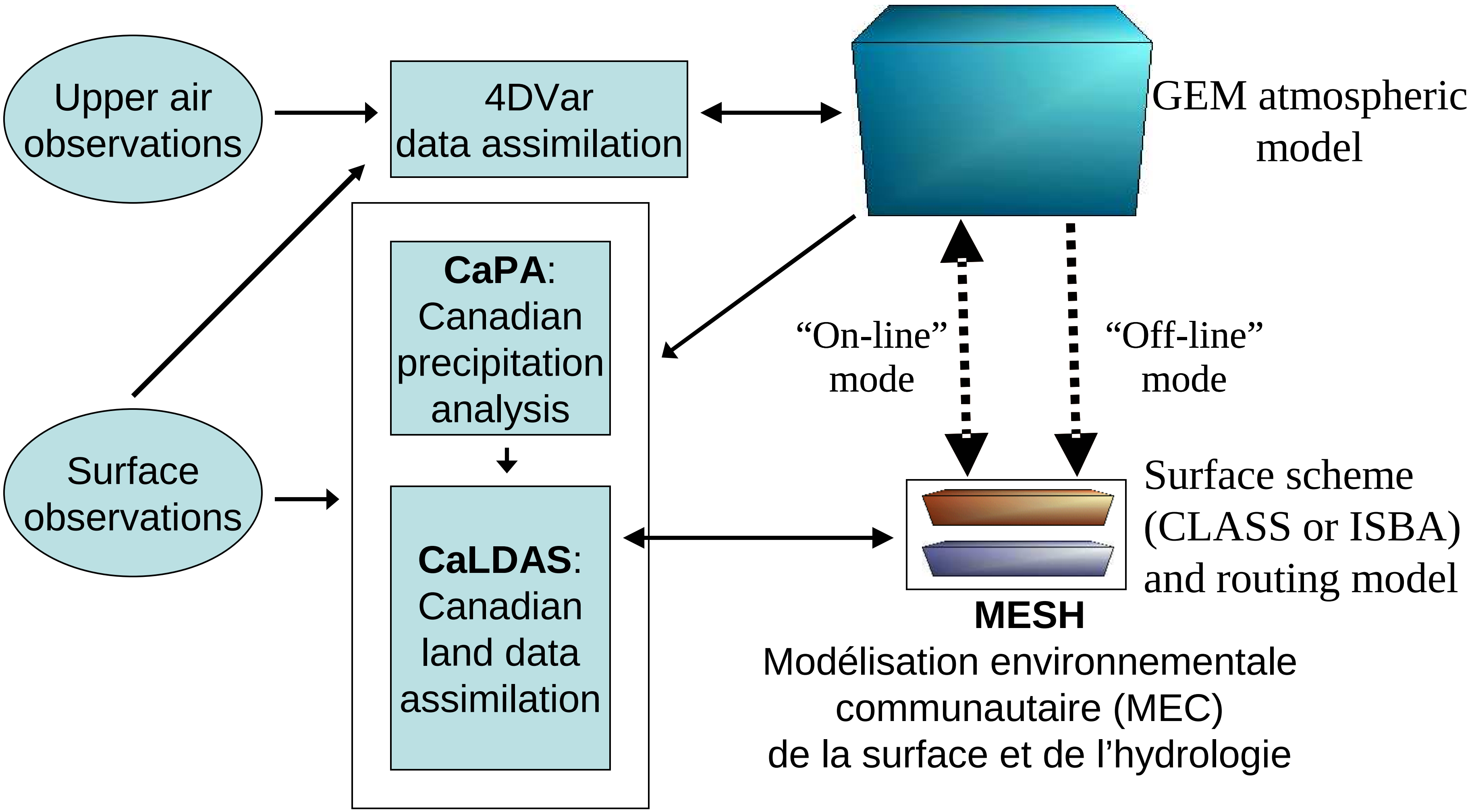
# Discussion

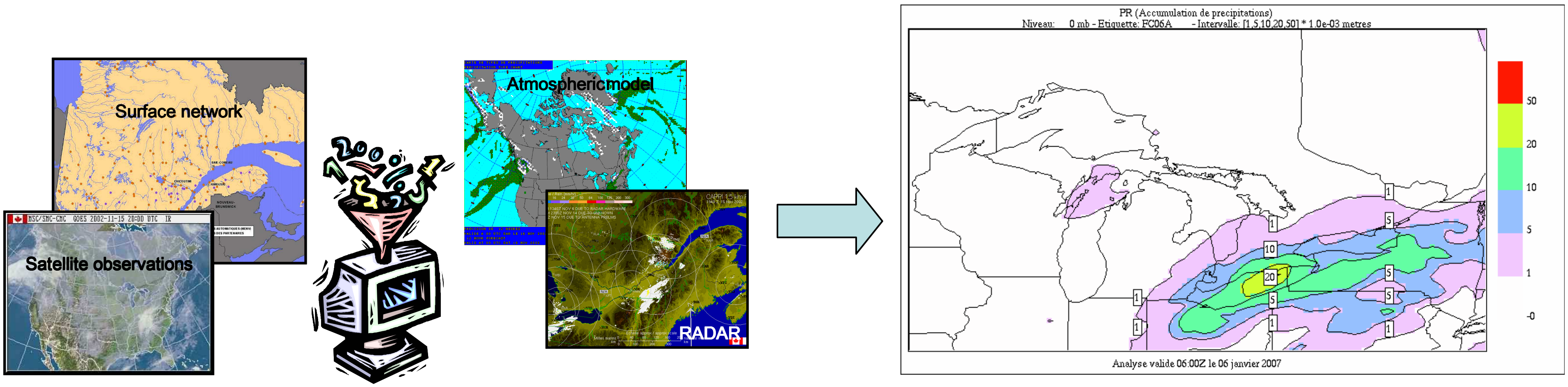
- Background
  - EC Modelling System
- Current Projects
  - Model Validation
    - Groundwater storage and weighing lysimeters
  - Coupled Model Application
    - EC MESH model on SSRB
  - Dealing with non-contributing areas.

# Environmental Prediction Framework



# CaPA: Analyse de précipitation
# CalDAS : Analyse du surface

- Assimilation combines different sources of available information (model, observations, remote sensing)
  – CaPA currently makes use of observed precipitation,  6h-12h ou 12h-18h precipitation forecasts from 15 km GEM

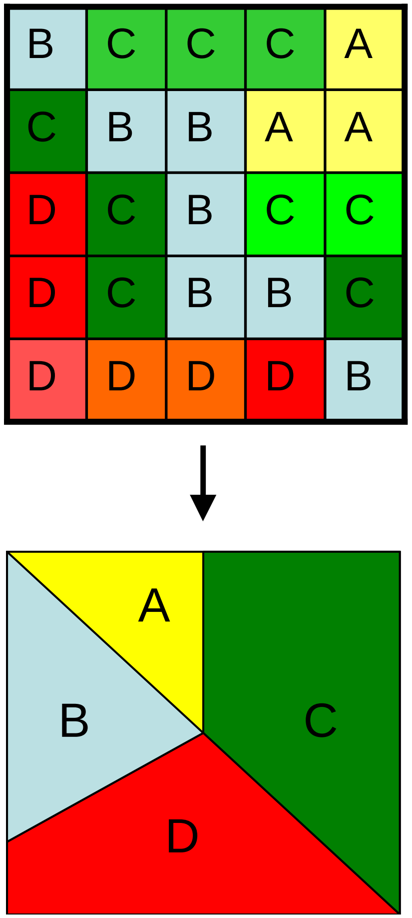


# MESH: A MEC surface/hydrology configuration designed for regional hydrological modeling

- Designed for a regular grid at a 1-15 km resolution
- Each grid divided into grouped response units (GRU or tiles) to deal with subgrid hetereogeneity
  - based on WATFLOOD

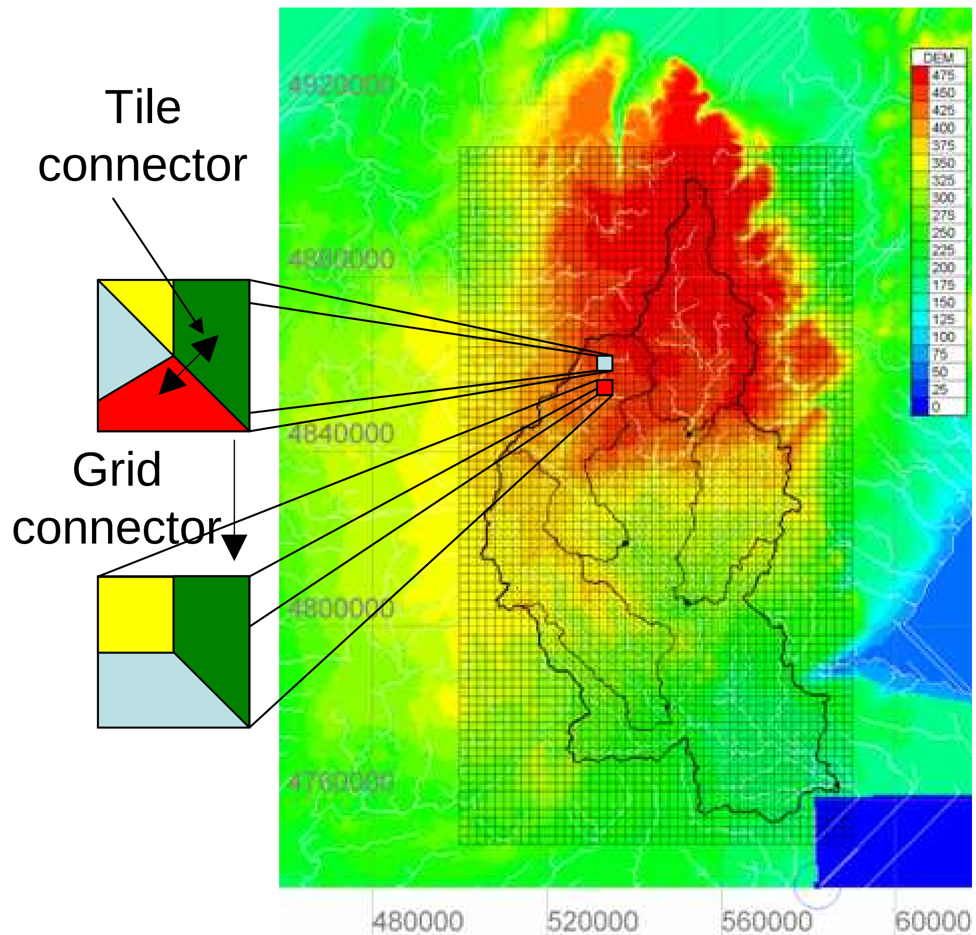
Sub-grid Hetereogeneity (land cover, soil type, slope, aspect, altitude)

A relatively small number of classes are kept, only the % of coverage for each class is kept



## MESH: A MEC surface/hydrology configuration designed for regional hydrological modeling

- The tile connector (1D, scalable) redistributes mass and energy between tiles in a grid cell
  - e.g. snow drift
- The grid connector (2D) is responsible for routing runoff
  - can still be parallelized by grouping grid cells by subwatershed



# WATFLOOD results

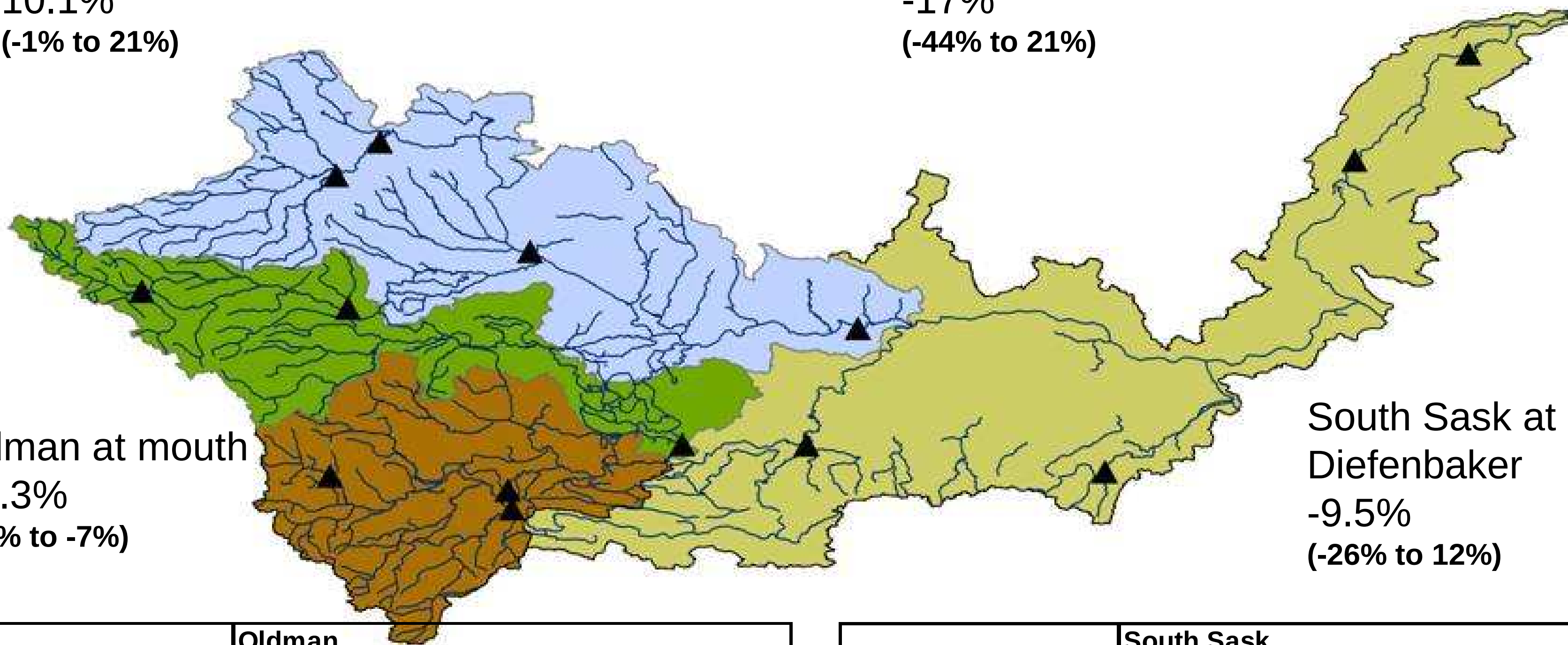
# GCM scenario results 2039 – 2070 cumulative flows – Debits cumulatif

| | Bow | | | |
|---|---|---|---|---|
| | current | echa21 | hada21 | ncara21 |
| Snow accum (mm) | 120.8 | 105.0 | 134.5 | 111.0 |
| Precip - ET (mm) | 162.9 | 75.0 | 118.7 | 157.9 |
| AET/PET | 1.00 | 0.93 | 0.98 | 1.00 |

| | Red Deer | | | |
|---|---|---|---|---|
| | current | echa21 | hada21 | ncara21 |
| Snow accum (mm) | 12.4 | 5.4 | 9.4 | 6.5 |
| Precip - ET (mm) | 106.6 | 59.3 | 90.0 | 123.2 |
| AET/PET | 0.76 | 0.66 | 0.70 | 0.75 |

Bow River at mouth
10.1%
**(-1% to 21%)**

Red Deer at Bindloss
-17%
**(-44% to 21%)**



Oldman at mouth
-23.3%
**(-37% to -7%)**

South Sask at Diefenbaker
-9.5%
**(-26% to 12%)**

| | Oldman | | | |
|---|---|---|---|---|
| | current | echa21 | hada21 | ncara21 |
| Snow accum (mm) | 4.2 | 1.8 | 5.4 | 2.3 |
| Precip - ET (mm) | 74.8 | 52.6 | 73.0 | 79.1 |
| AET/PET | 0.52 | 0.45 | 0.48 | 0.52 |

| | South Sask | | | |
|---|---|---|---|---|
| | current | echa21 | hada21 | ncara21 |
| Snow accum (mm) | 16.7 | 5.9 | 15.7 | 10.2 |
| Precip - ET (mm) | 31.7 | 26.5 | 34.1 | 31.3 |
| AET/PET | 0.46 | 0.38 | 0.41 | 0.47 |

# Glacier Contribution Downstream

Edmonton and Calgary 1975 to 1998

Bow River, Calgary

North Saskatchewan River, Edmonton

- Wastage (Volume-Area relationship)
- NSRB at N.Sask at Edmonton = 4 000 x$10^6$ $m^3$
  2.6% annually
- SSRB at Bow River at Calgary = 1 800 x$10^6$ $m^3$
  2.8% annually

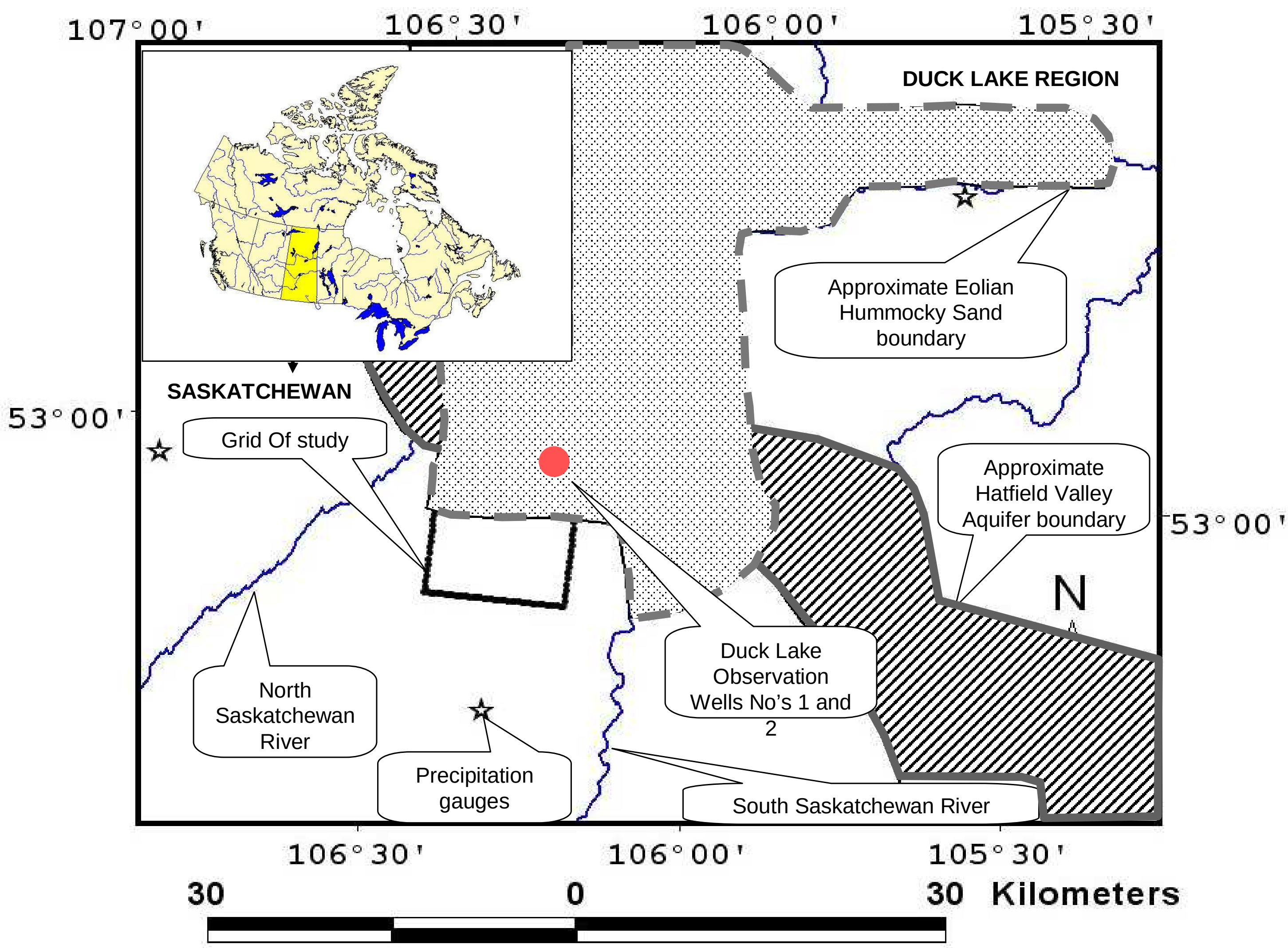
- Melt (WATFLOOD/MESH and Volume-Area difference)
- NSRB at N.Sask at Edmonton = 14 000 x$10^6$ $m^3$
- SSRB at Bow River at Calgary = 4 000 x$10^6$ $m^3$
  - Melt is over double the volume of wastage
  - Regulated streamflow
  - Main direct impact of glacier decline will be the advance of Melt volume towards the spring snowmelt peak timing
  - (Result of climate change is that the volume of Melt will decrease)

# Validation

- Traditionally we compare to observed hydrographs

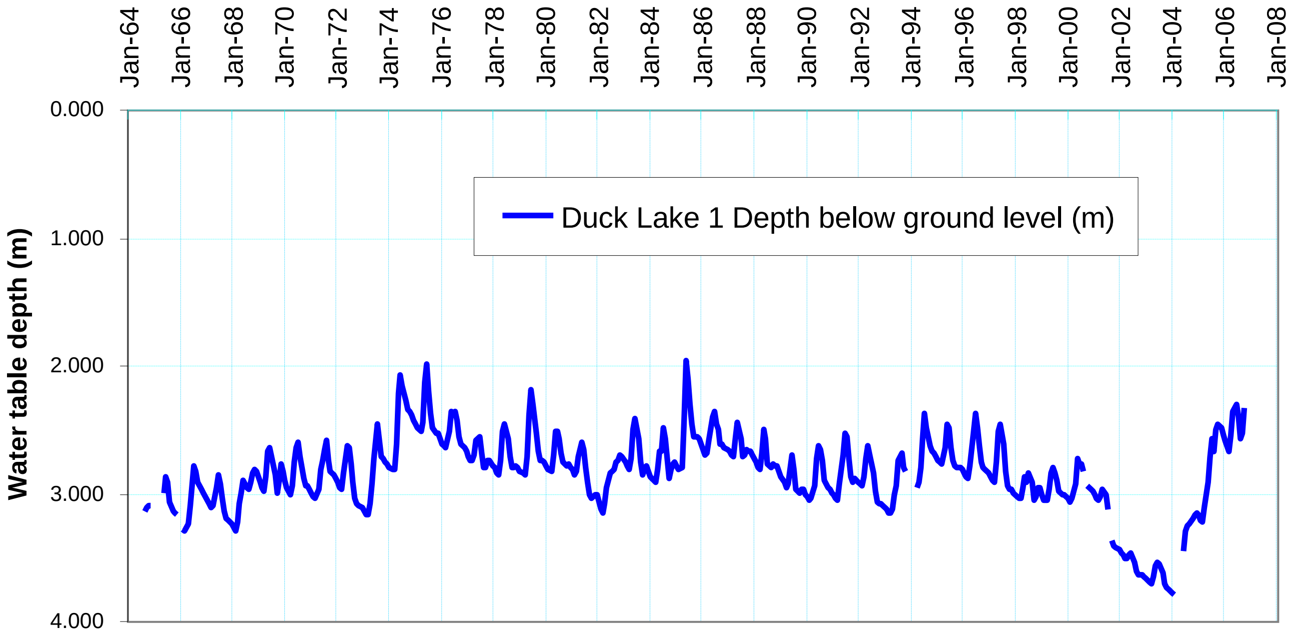
- Are we getting the right answer for the wrong reasons ?

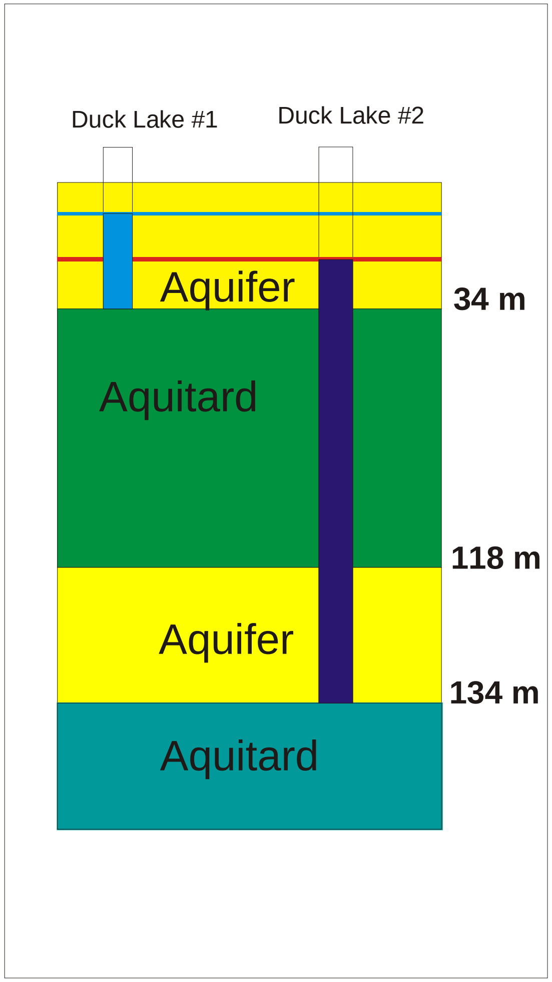
# Location of Duck Lake observations wells and Watflood grid cell *[Marin et al. 2009.]*

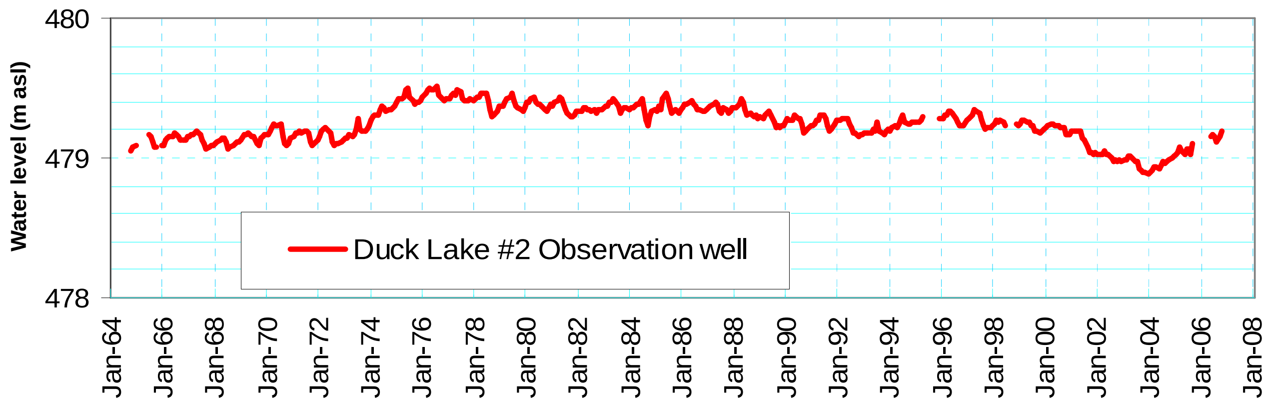


# Duck Lake SK Observation wells: water levels, 1964-2006

[Source: SK Watershed Authority, www.swa.ca]

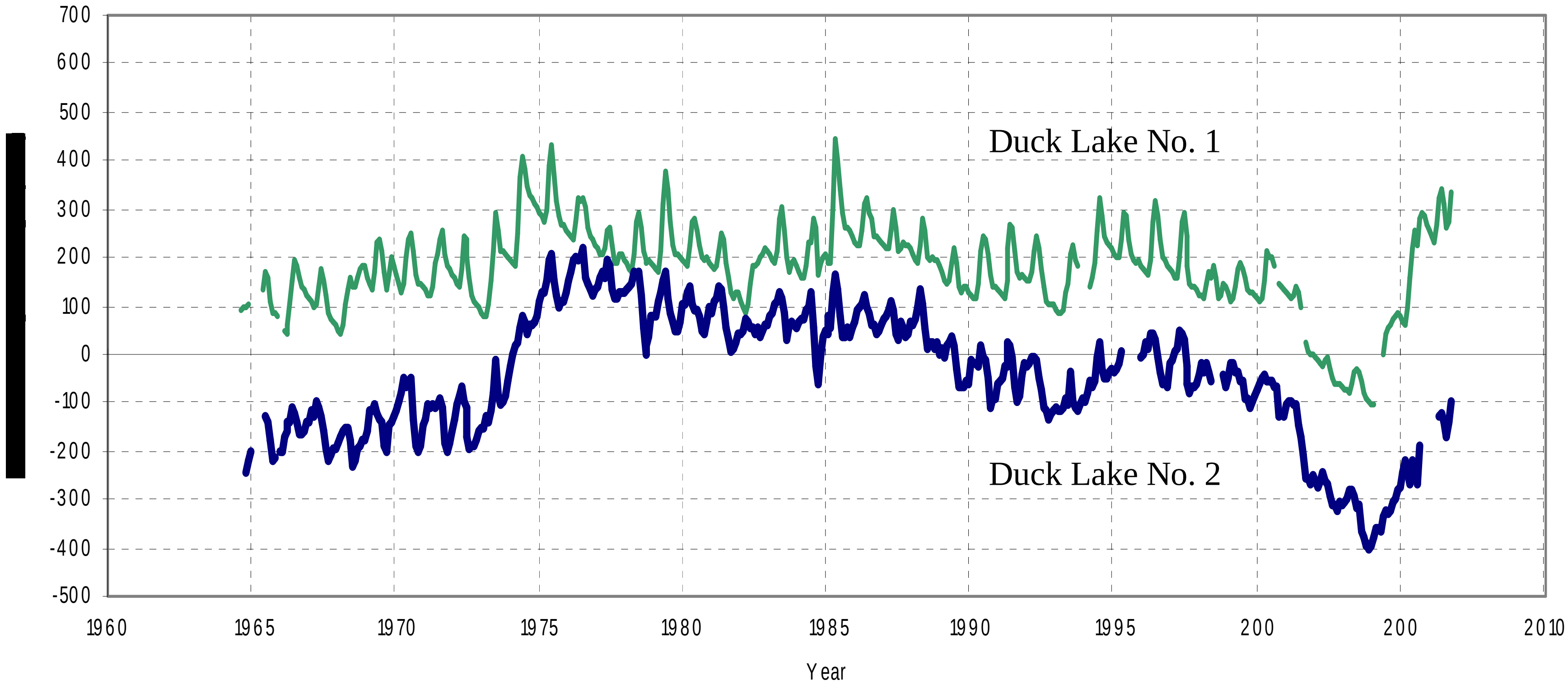


**Water storage changes observed for Duck Lake SK observation wells 1965-2007:**

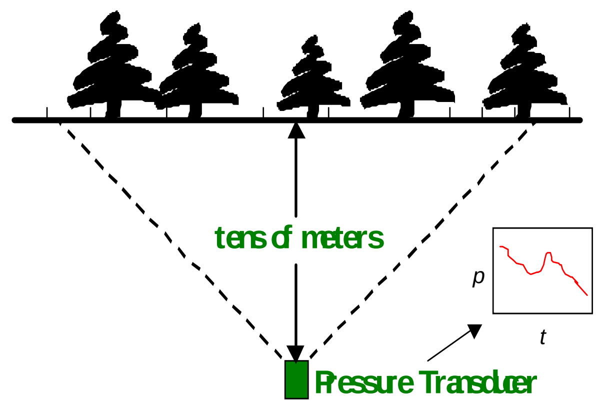
Duck Lake No. 1 – Shallow water table well with specific yield = 0.30
Duck Lake No. 2 – Deep well in confined aquifer (geological weighing lysimeter)



# Overview of the Weighing Lysimeter Instrumentation

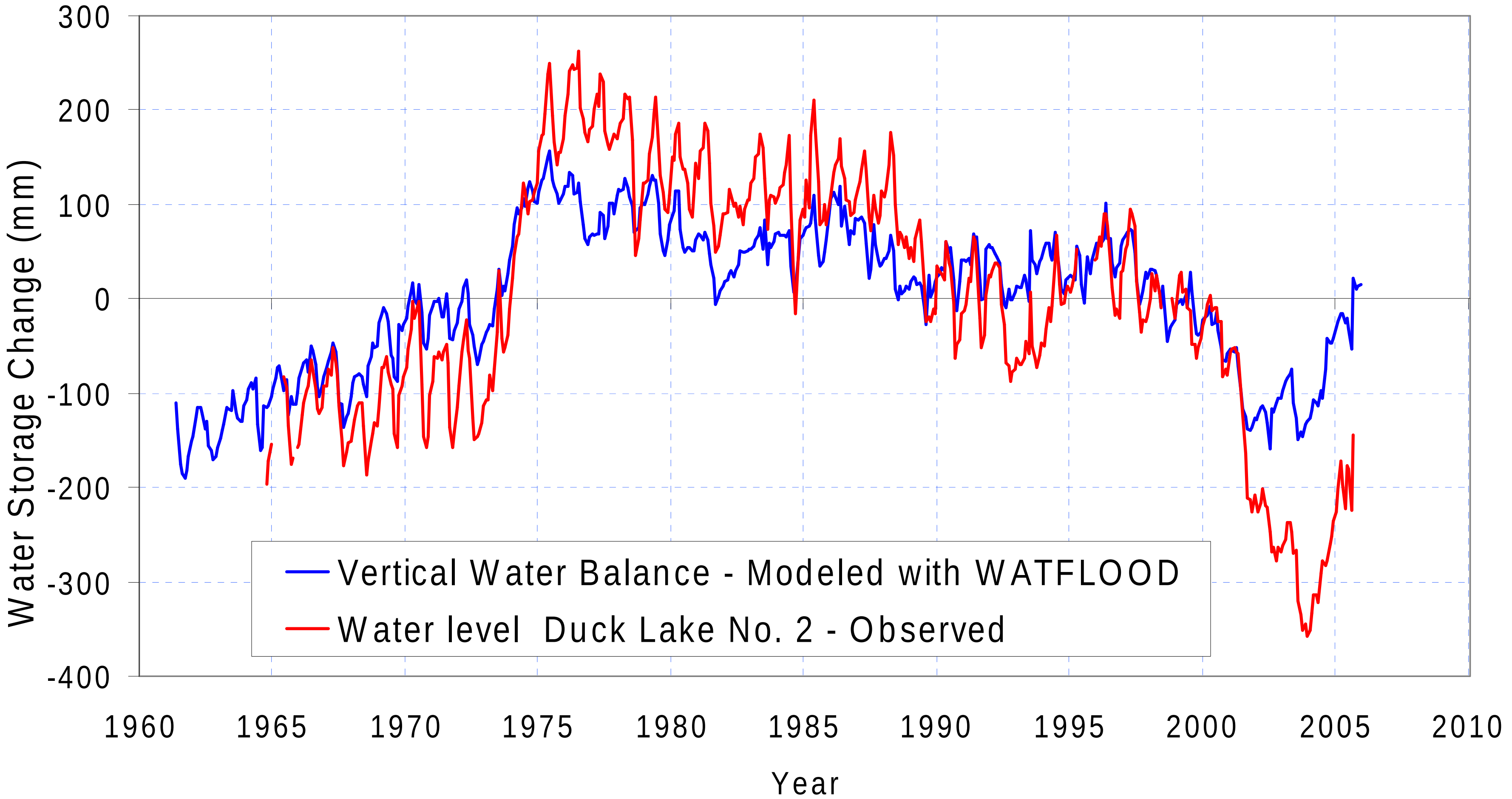
- **Fundamentals**
  - Change of mechanical surface loading is instantaneously transmitted to deep saturated formations resulting in change of pore water pressure;
  - Piezometers in saturated formations can therefore detect pore pressure changes due to hydrological processes such as:
    - ✓ Snow accumulation;
    - ✓ Rainfall;
    - ✓ Evapotranspiration

***Conceptual Sketch of Piezometric Weighing Lysimeter Installation***

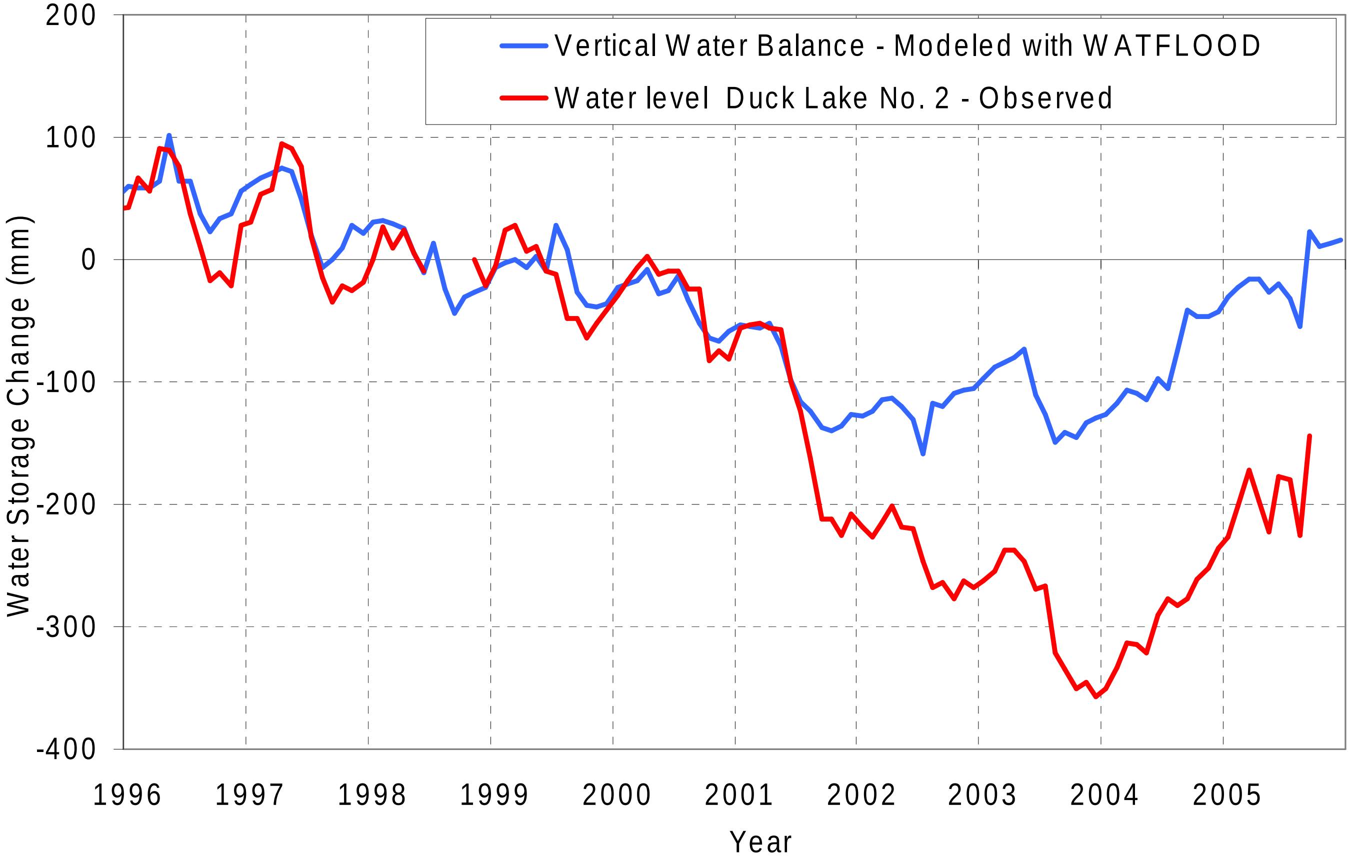



Van der Kamp et al, 2003

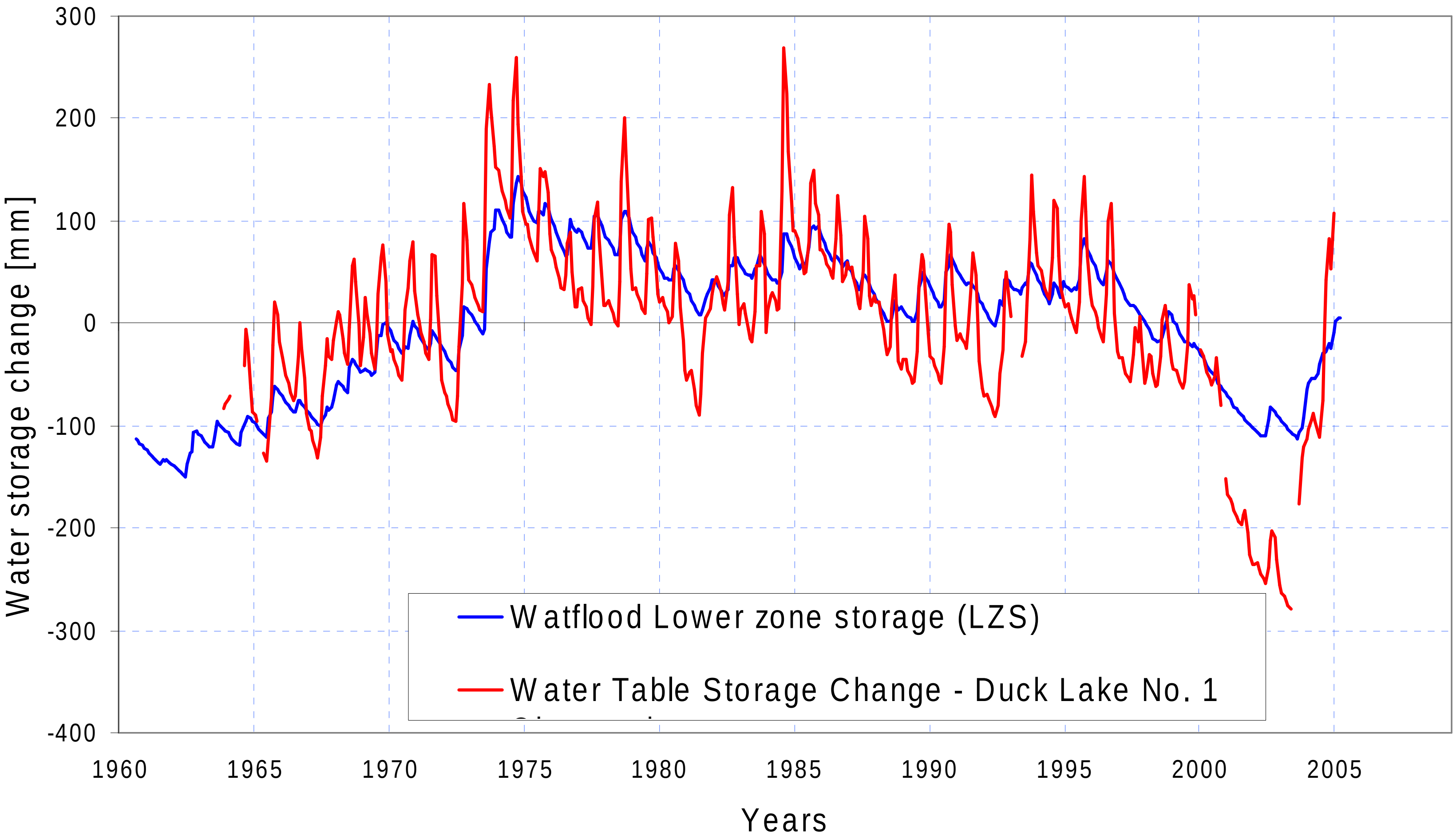
Comparison of Duck Lake No. 2 (geological weighing lysimeter) water level record with Watflood simulation of the vertical water balance



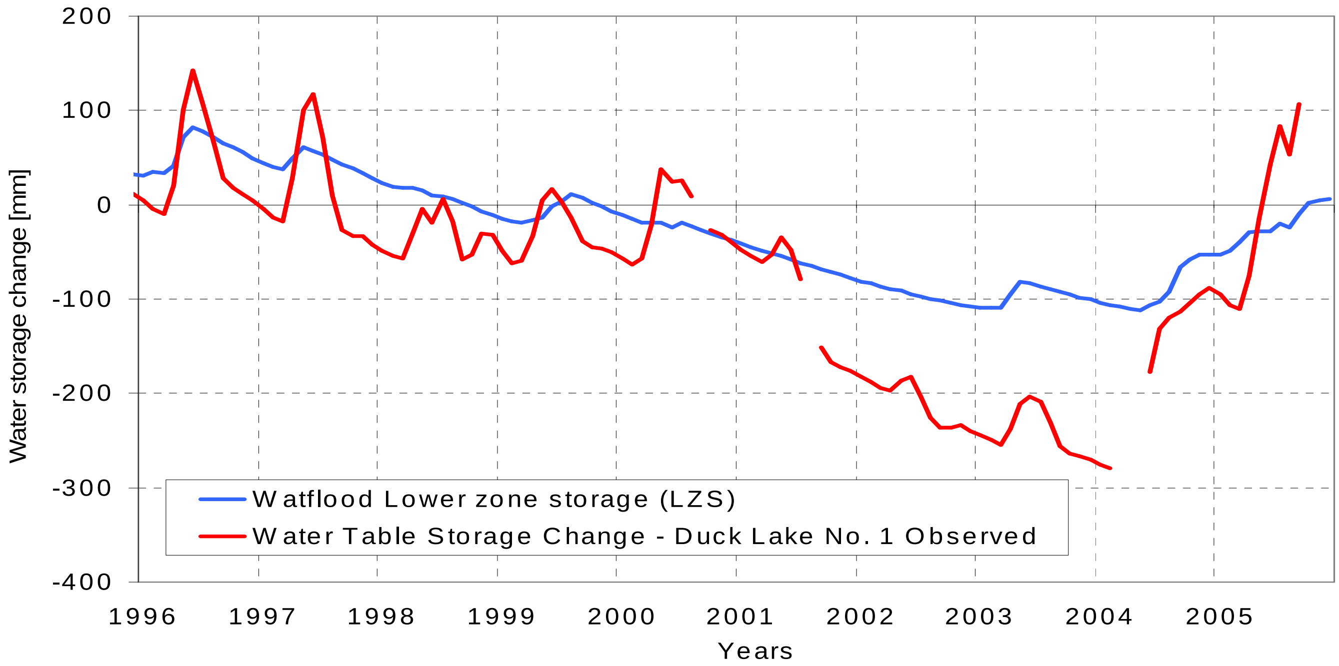
# Comparison of Watflood output with Duck Lake geological weighing lysimeter, 1996-2005



# Comparison of Duck Lake No. 1 (water table storage change) with Watflood simulation of the changes of groundwater storage



Comparison of Watflood simulation of groundwater storage with the record for the water table well at Duck Lake. Note that Watflood does not capture the rapid drawdown of the water table during the growing season.

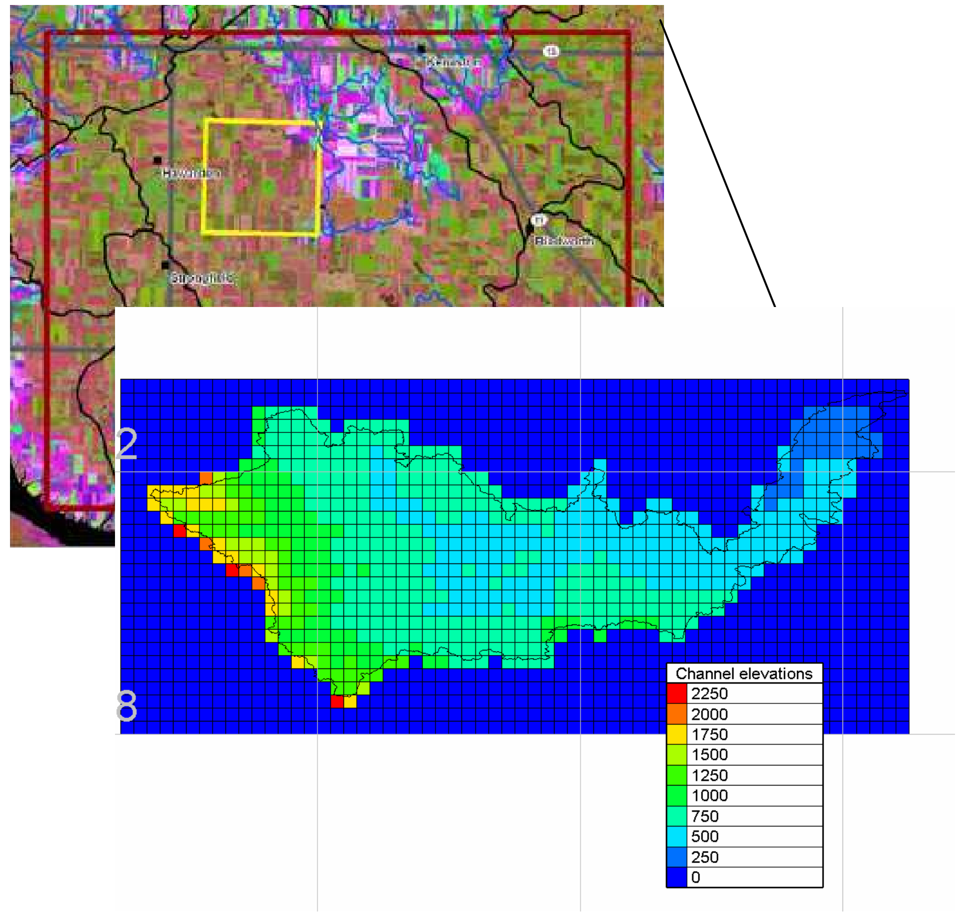


# Moving Towards Coupled Model

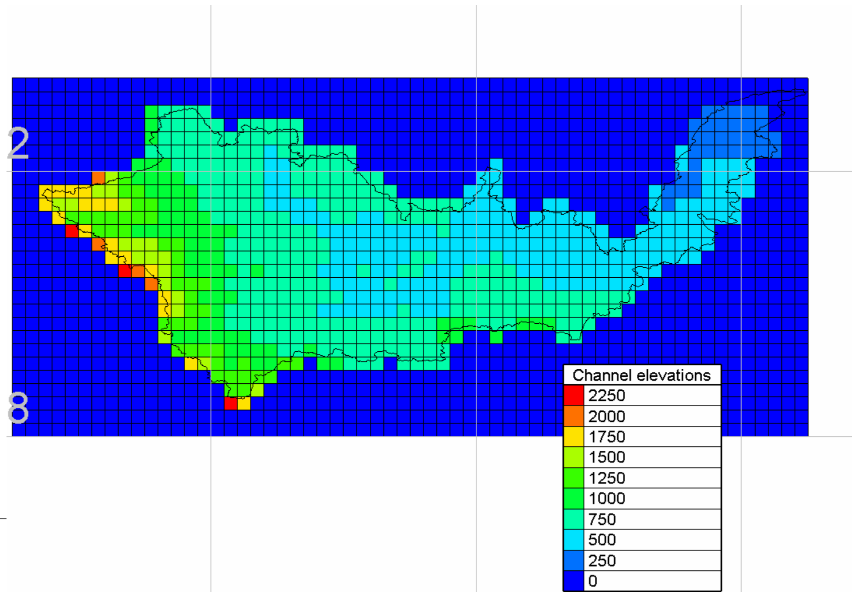
# NAESI: Water Balance Indicators

- **Objective**
- **To showcase our capacity required indicators of the hydrological assessment which are useful for the development of standards using a coupled system of environmental modeling**
- **Precipitation (CaPA)**
- **Soil moisture and snow on the ground (CaLDAS)**
- **Discharge (MESH)**
- **Evapotranspiration**

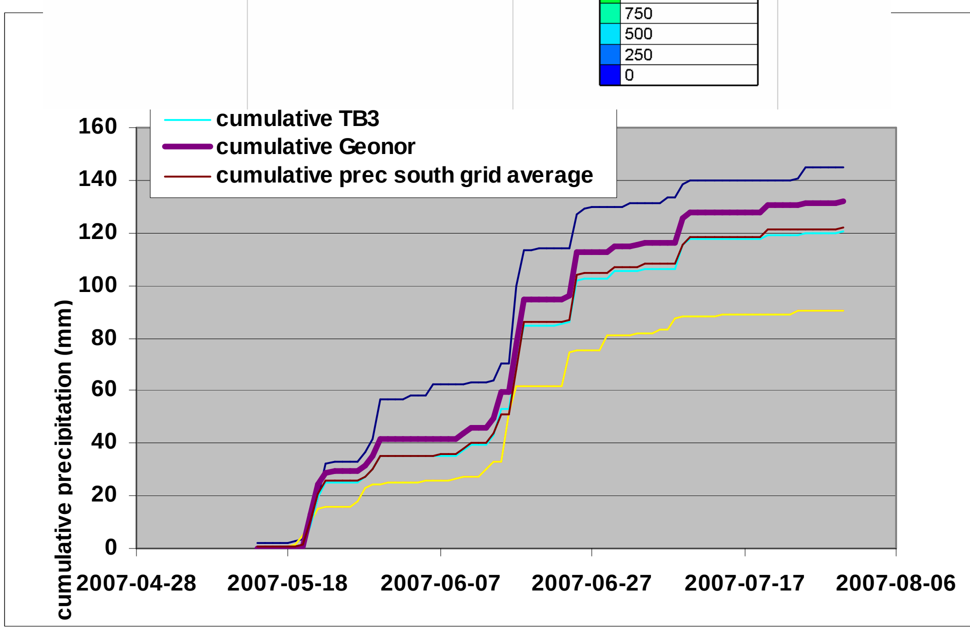
- **August 1,2006 to July 31,2007**

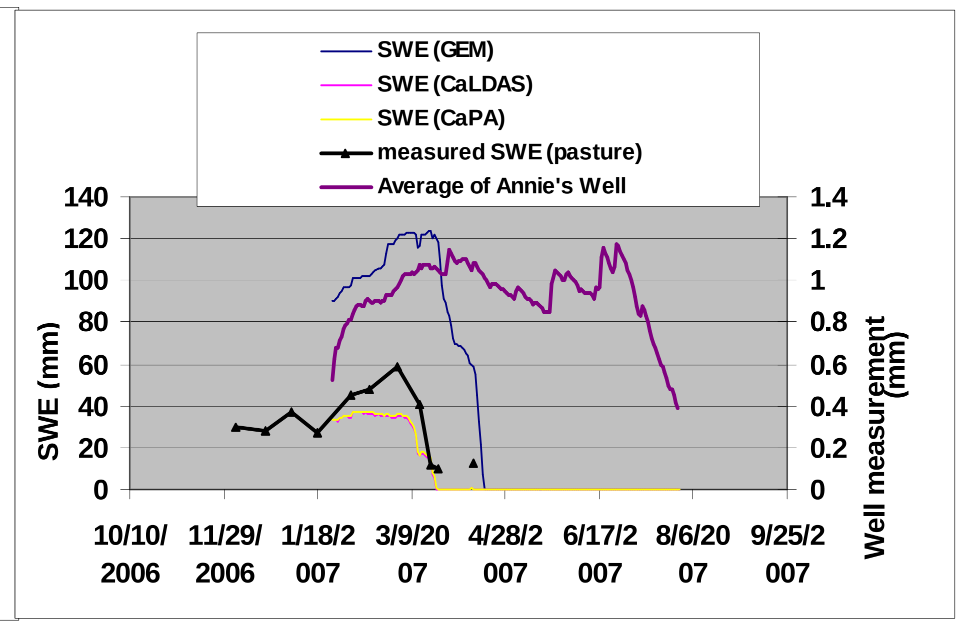


# CaPa and Assimilation

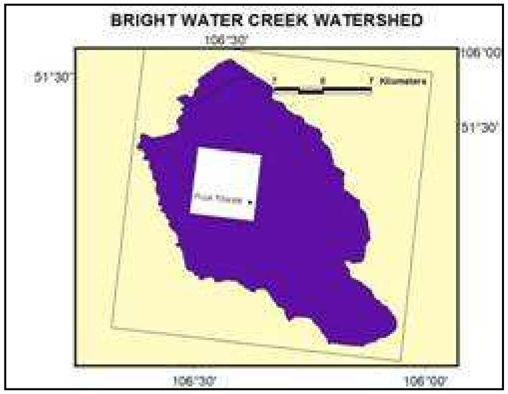



- MESH model physics (ISBA LSS, migrating to CLASS LSS in future)
  – with added routing based on Watroute
- Model forcing is archived GEM model output conditioned by precipitation reanalysis (CaPA) and land data assimilation (CaLDAS)
- August 1, 2006 to July 31, 2007

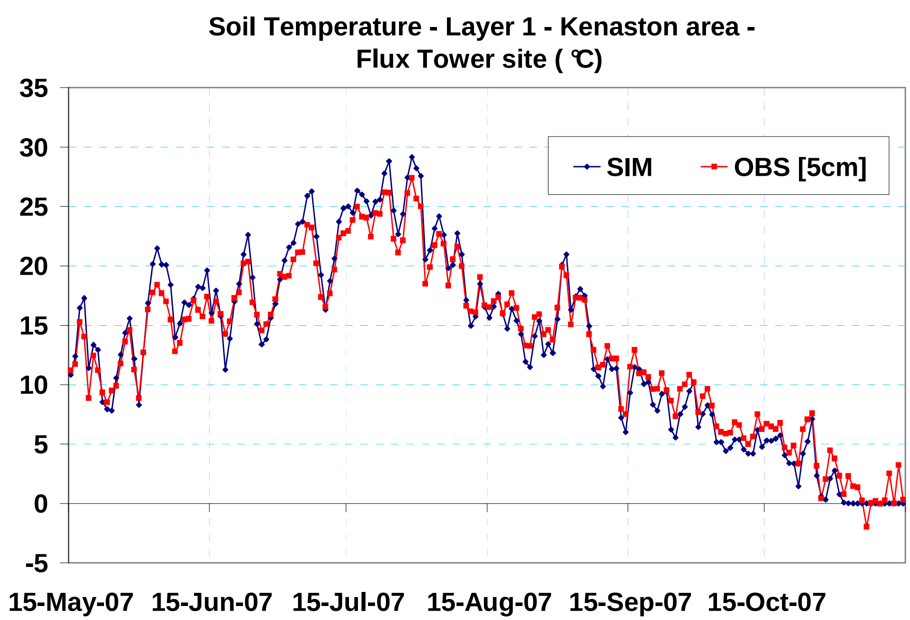


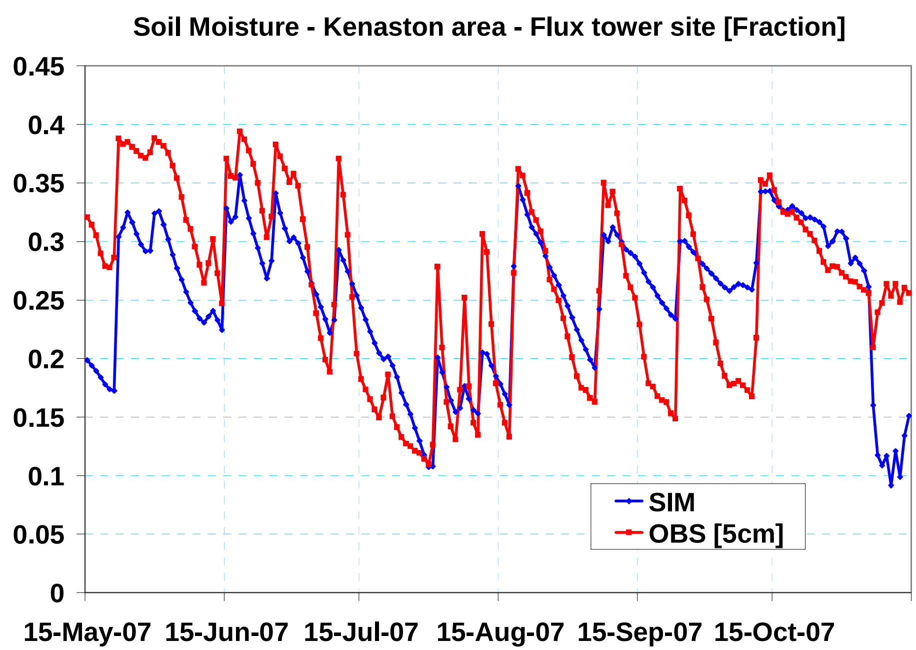



# Stand alone MESH




- MESH model physics (CLASS LSS)
  - with added routing based on Watroute
- Forcing with met tower data
  - Temp, precip, station pressure, specific humidty, wind, lw and sw radiation
- May 15 to November, 2007, half hourly



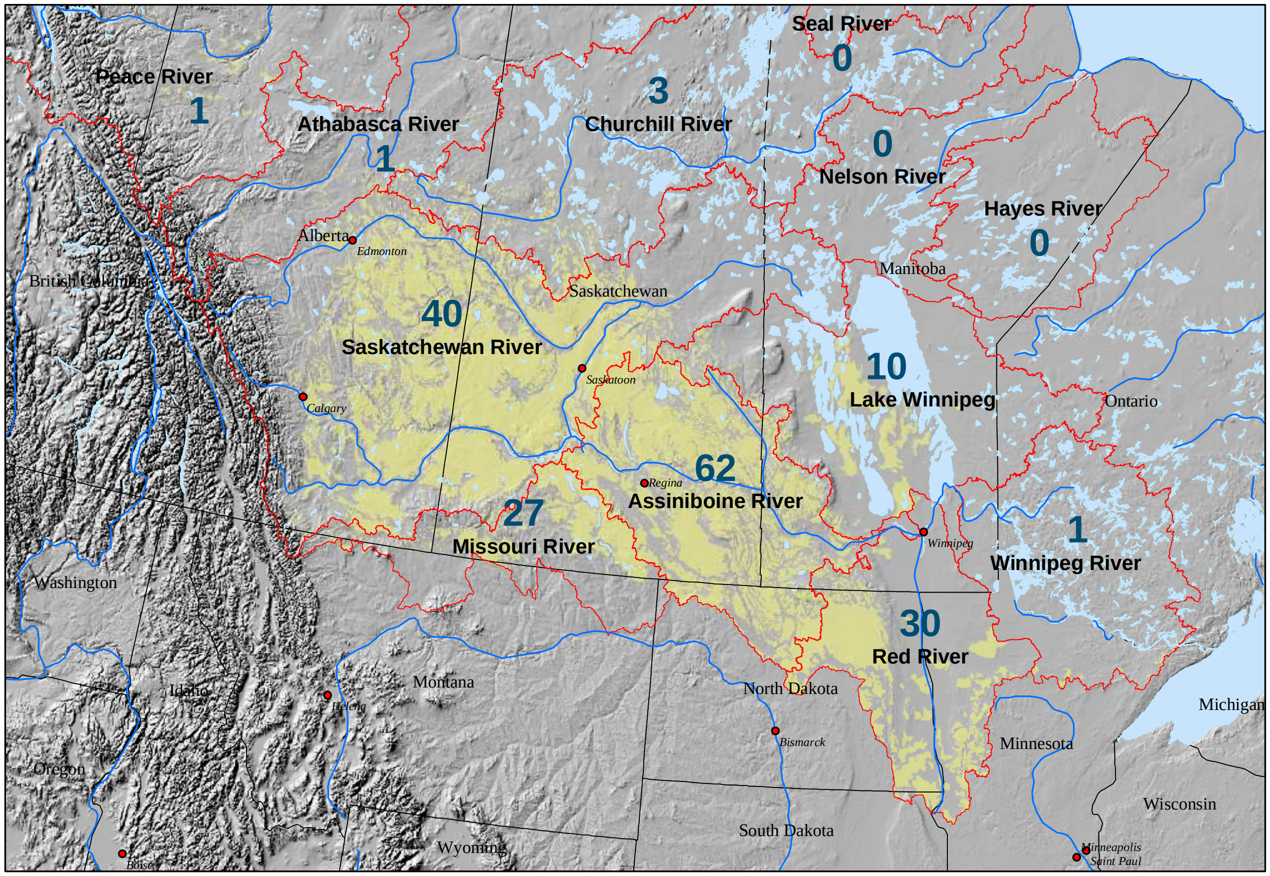



# Potholes ……….

- Hydrological models do not currently incorporate the influence of dynamic potential surface storage and the effect this dynamic storage has on contributing area in prairie pothole basins.
- Many models simply assume that 100% of the basin contributes to the outlet.
- TOPAZ and other landscape analysis tools can determine a storage threshold volume that allows 100% of the basin to contribute.
- However, due to the semi-arid environment, such a *threshold* runoff event may occur infrequently in the prairie pothole region(Leibowitz and Vining, 2003).
- To improve hydrological models for the prairie pothole region, a methodology for quantifying contributing areas for runoff events that only partially satisfy the potential surface storage of a basin (*pre-threshold* runoff events) is required.

# Non-contributing areas

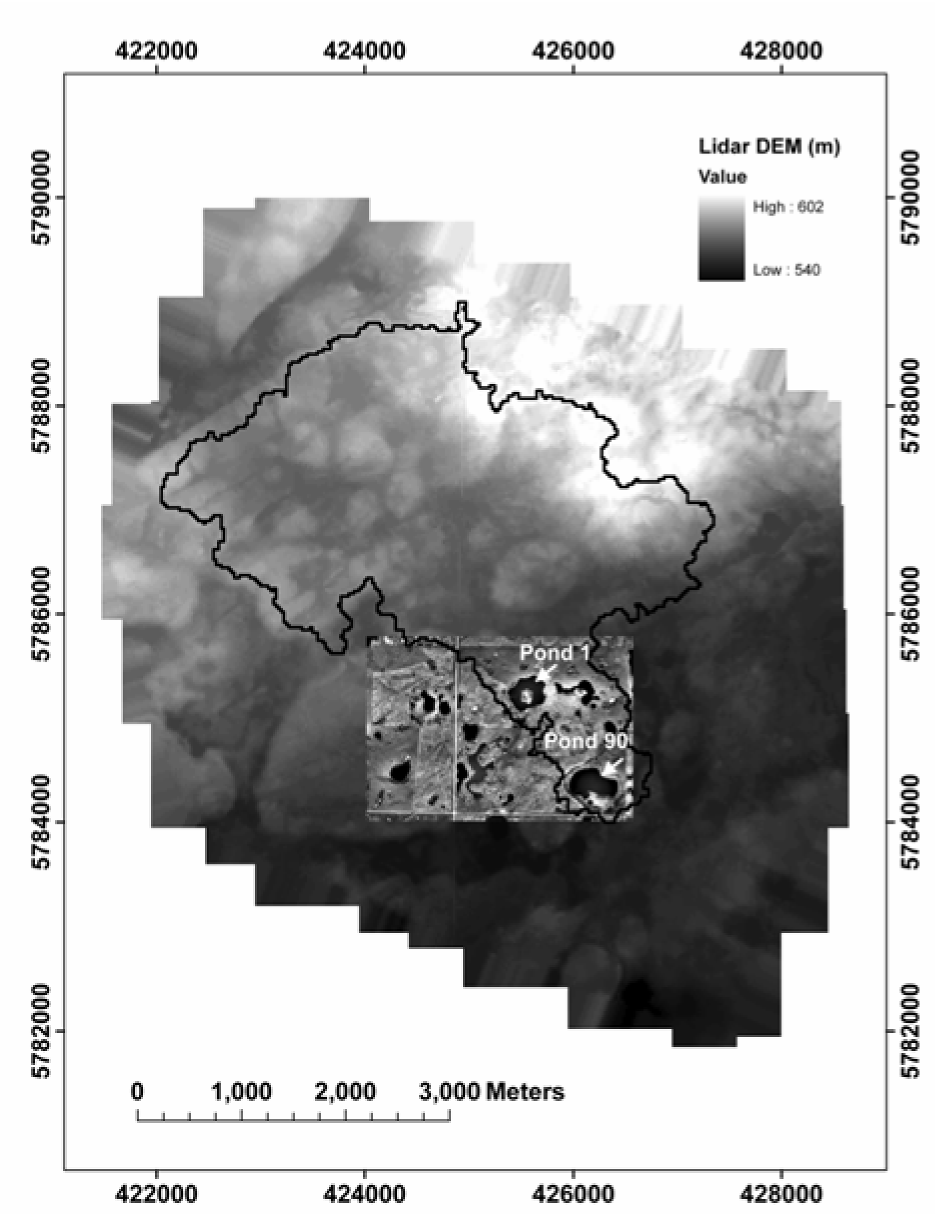
## - mean annual runoff -

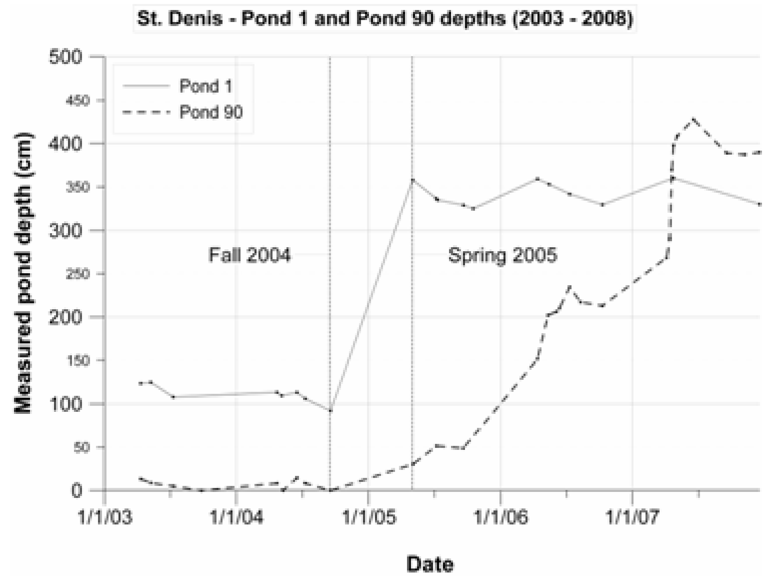


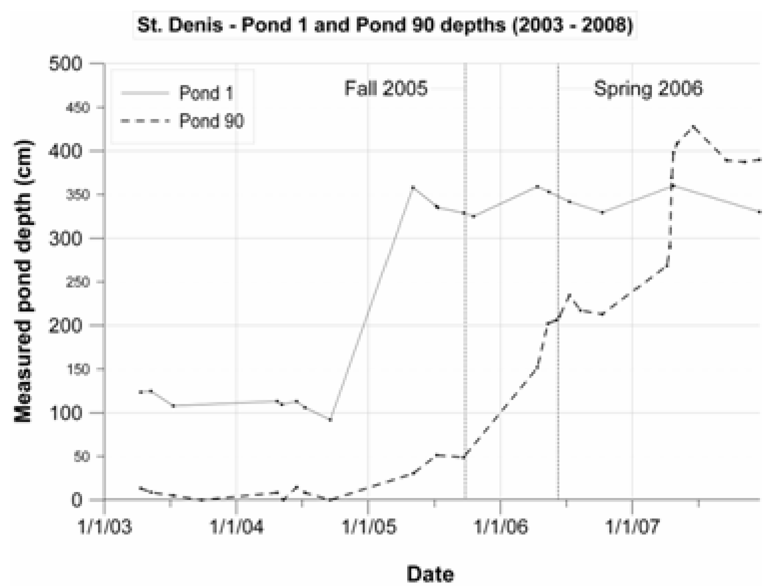

Prairie pothole region encompasses approximately 775,000 km$^2$ of the north-central United States and south-central Canada.

Contributing area within this landscape varies by seasons and year

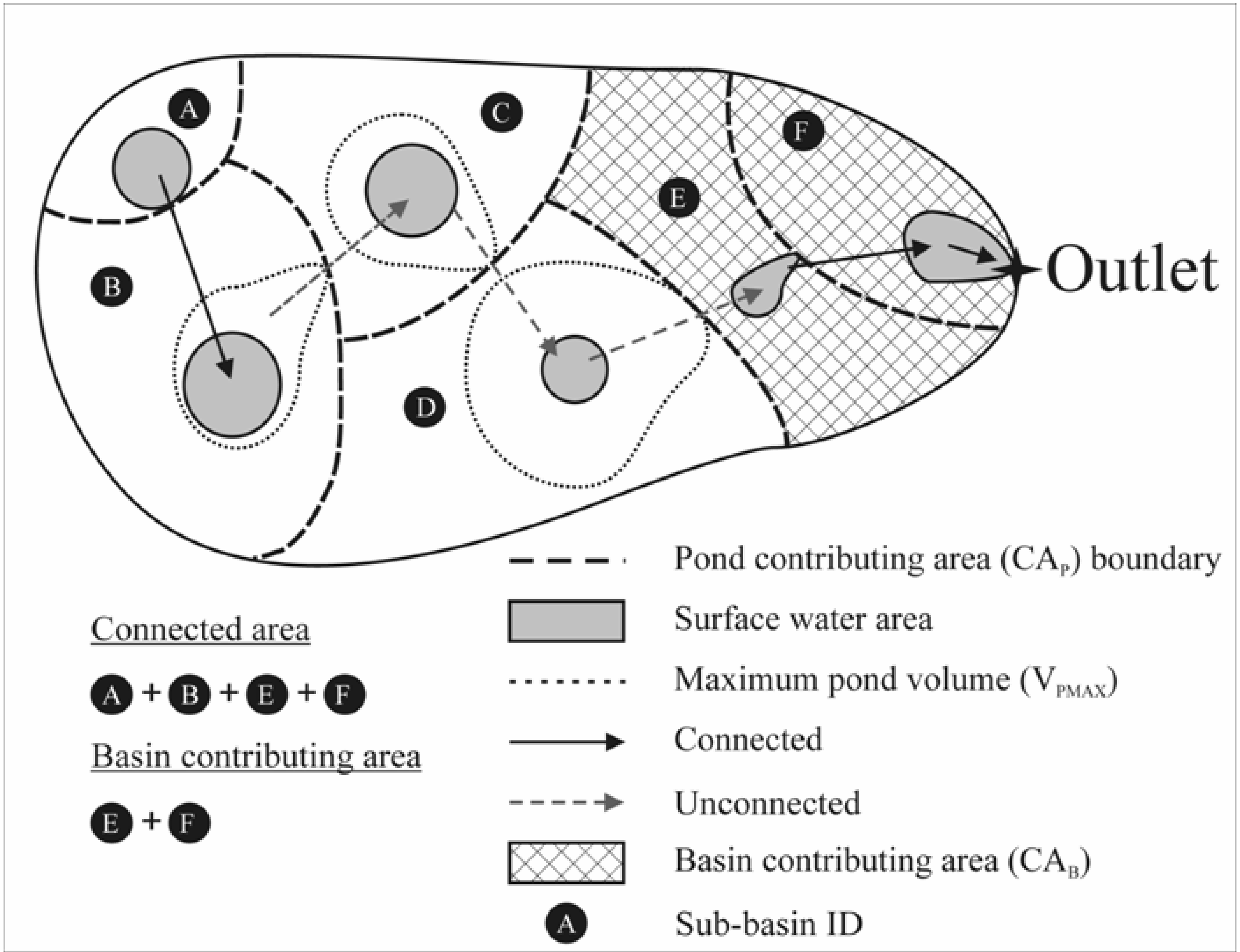
# Importance of Connectivity



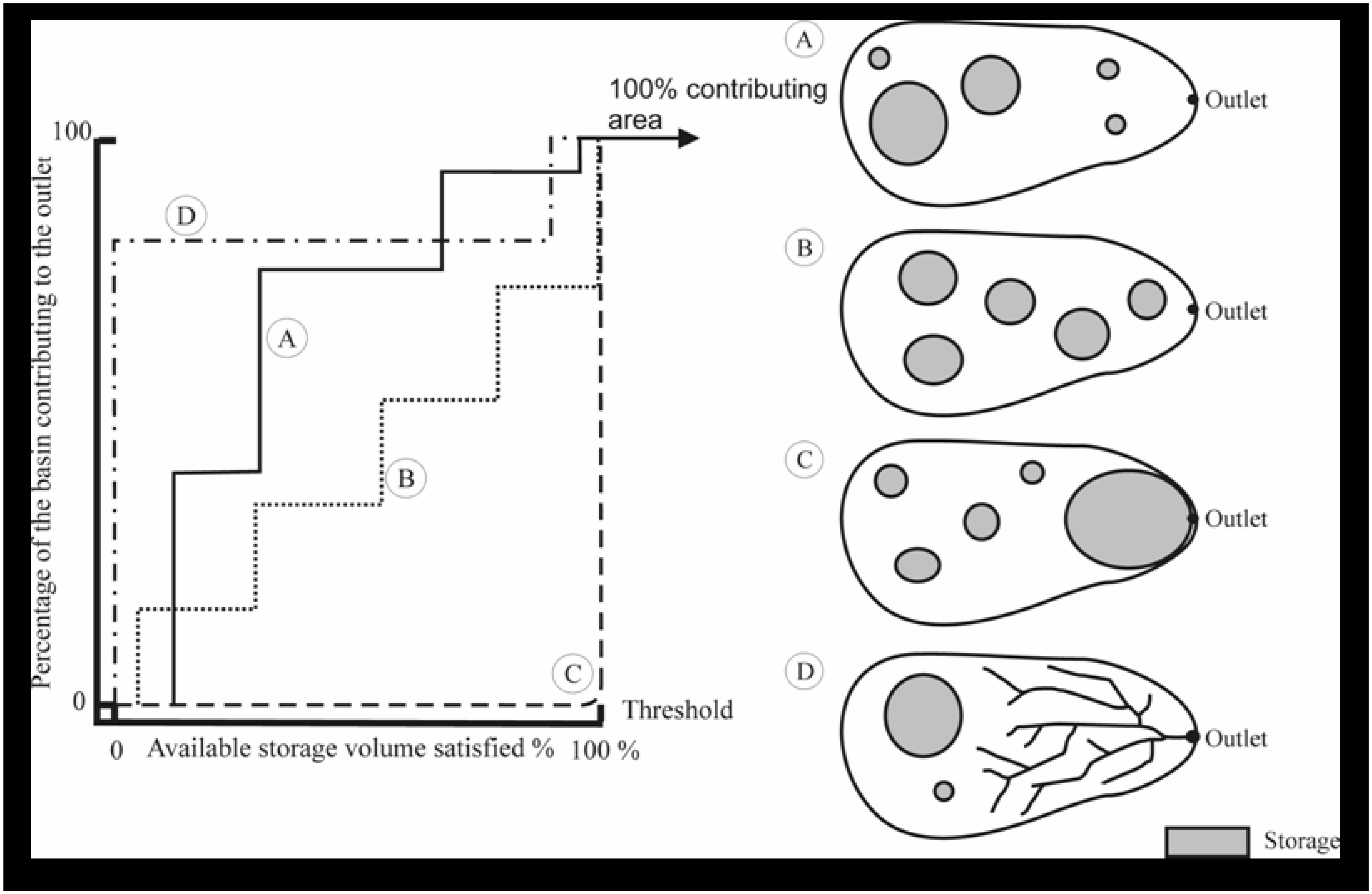



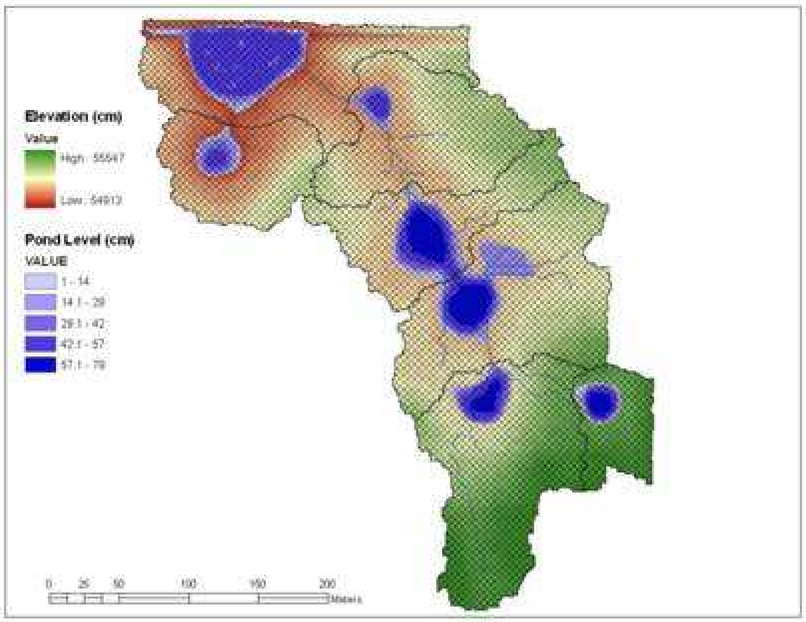
# Key Concepts

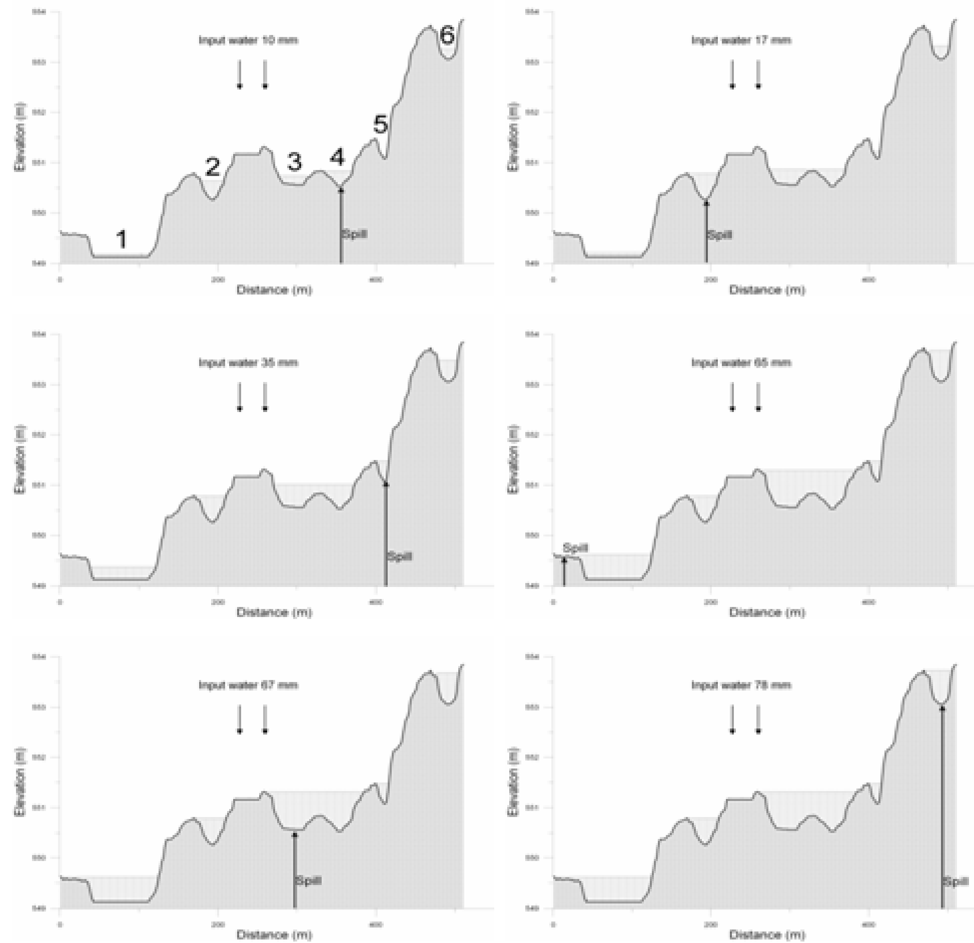


# Conceptual landscapes



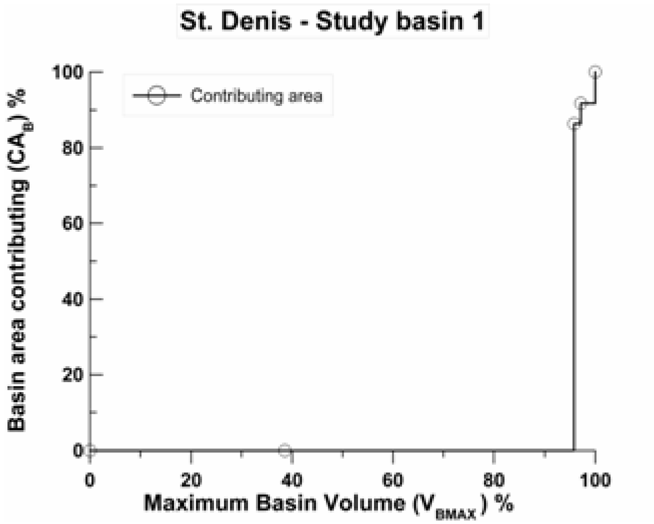
# Prairie pothole algorithm

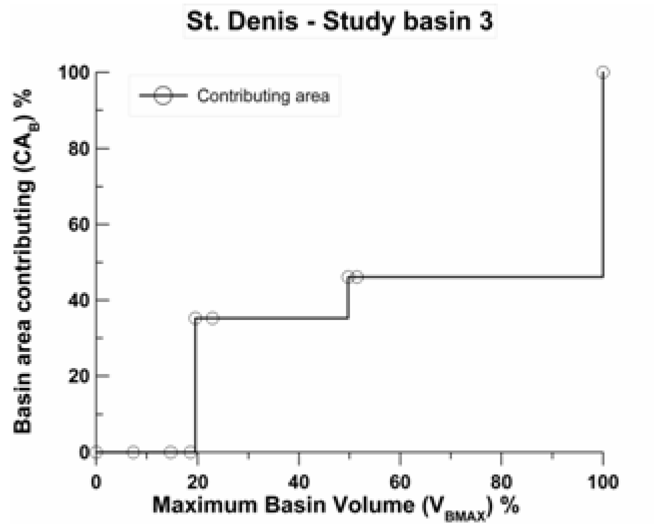


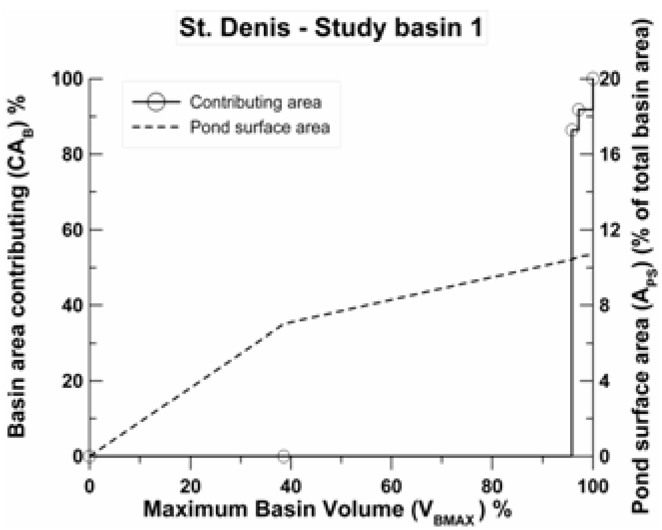
# SPILL Results

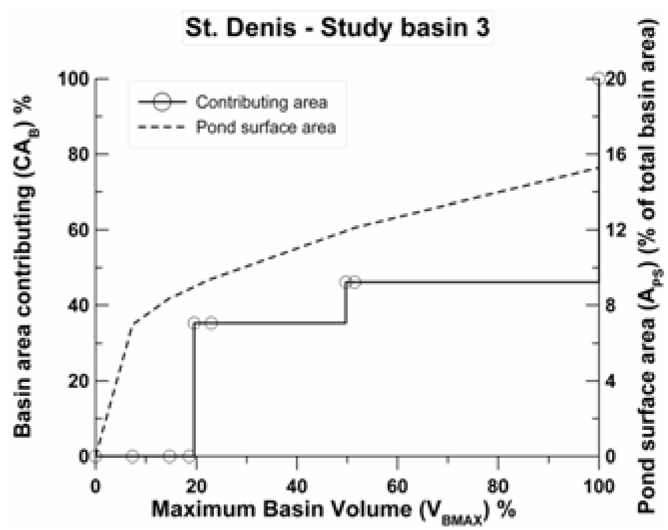
## Contributing area/Potential storage volume relationship



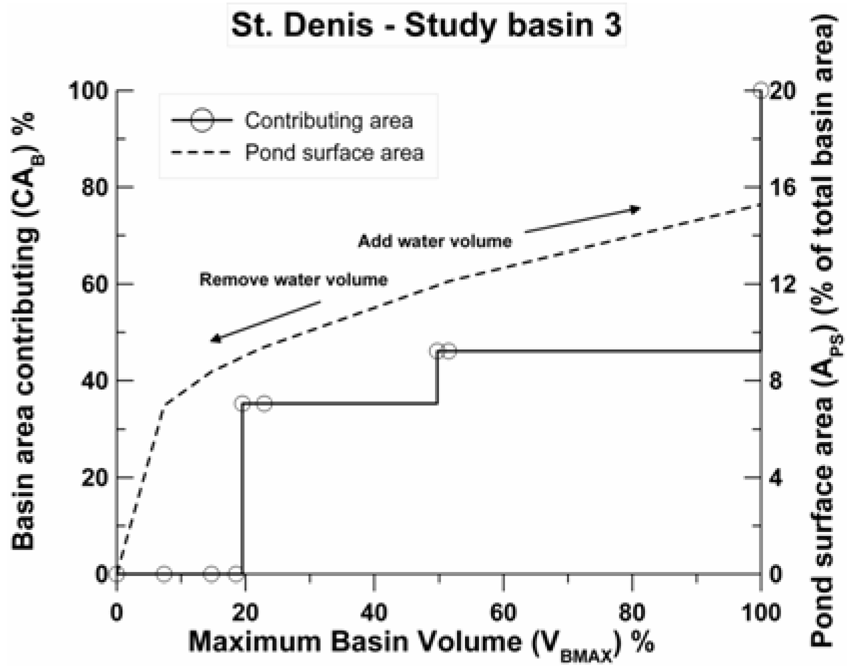



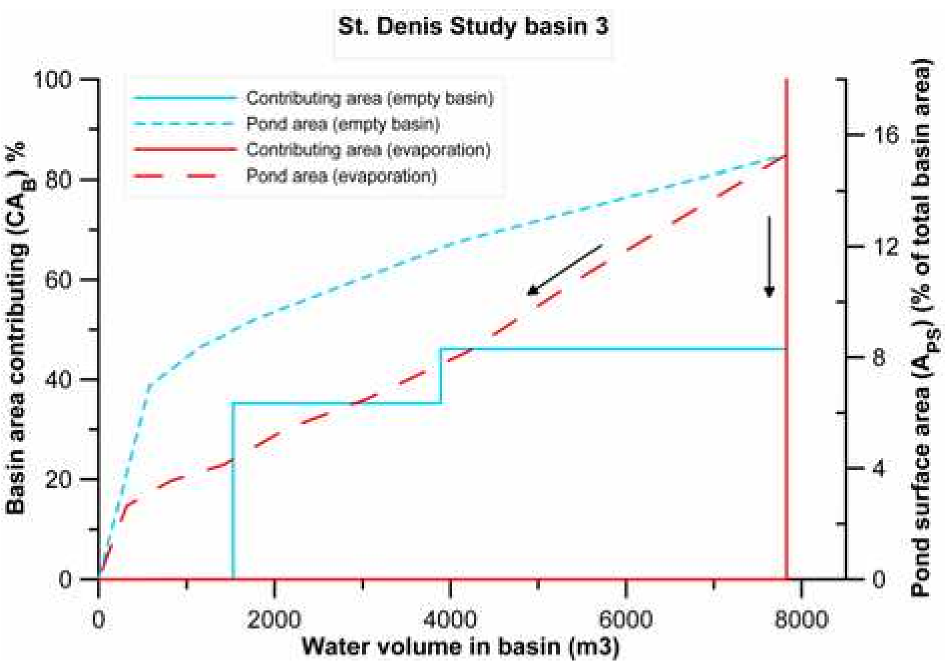

## Contributing area/Pond surface area relationship

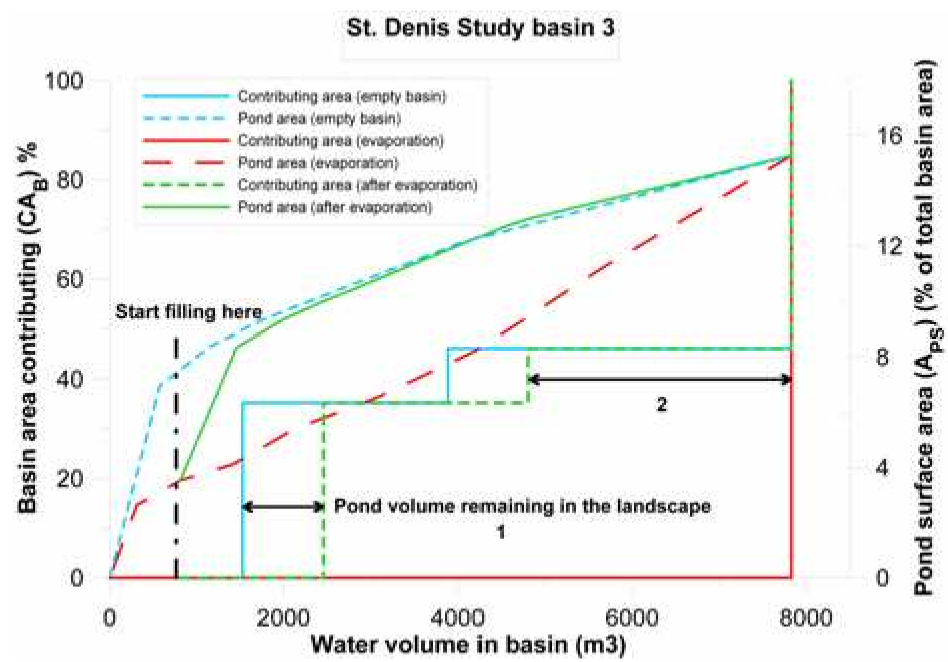


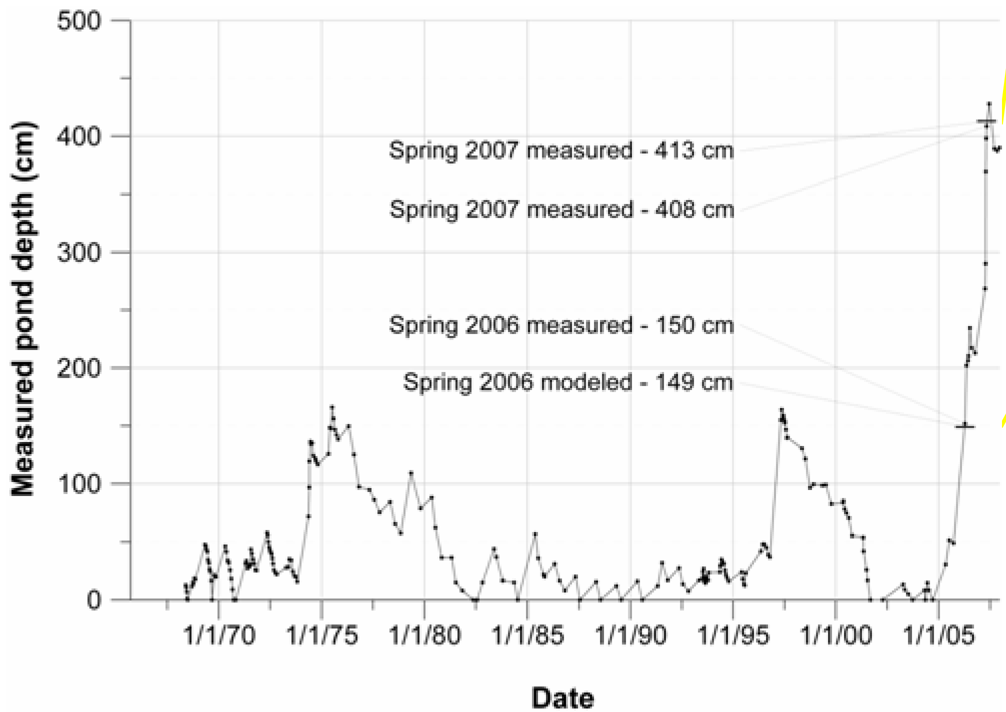
# Hysteresis

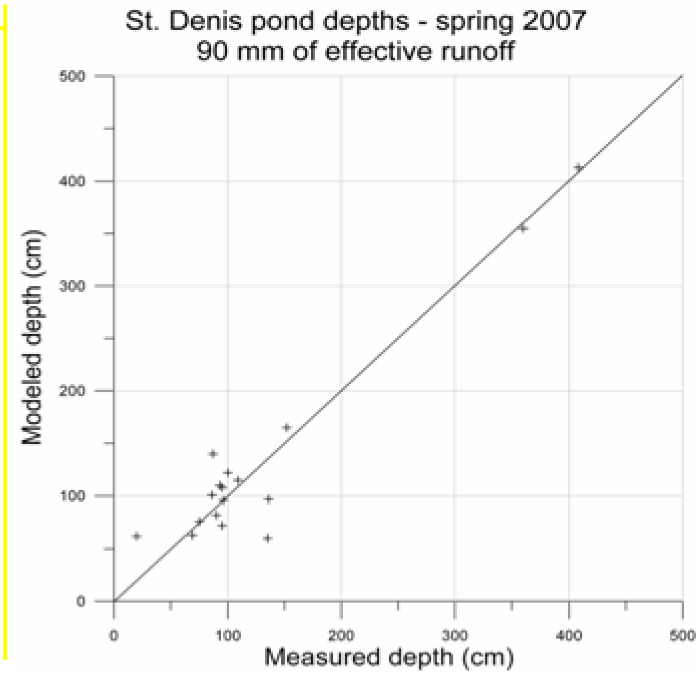

St. Denis - Study basin 3
Contributing area
Pond surface area
Add water volume
Remove water volume
Basin area contributing ($CA_B$) %
Pond surface area ($A_{PS}$) (% of total basin area)
Maximum Basin Volume ($V_{BMAX}$) %
0
20
40
60
80
100
0
4
8
12
16
20

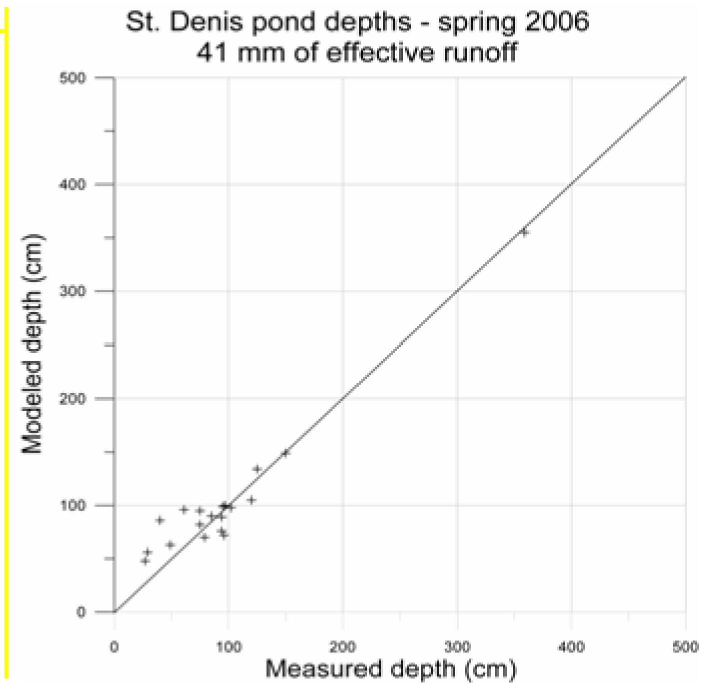

St. Denis Study basin 3
Contributing area (empty basin)
Pond area (empty basin)
Contributing area (evaporation)
Pond area (evaporation)
Basin area contributing ($CA_B$) %
Pond surface area ($A_{PS}$) (% of total basin area)
Water volume in basin (m3)
0
2000
4000
6000
8000
0
20
40
60
80
100
0
4
8
12
16


St. Denis Study basin 3
Contributing area (empty basin)
Pond area (empty basin)
Contributing area (evaporation)
Pond area (evaporation)
Contributing area (after evaporation)
Pond area (after evaporation)
Start filling here
Pond volume remaining in the landscape
1
2
Basin area contributing ($CA_B$) %
Pond surface area ($A_{PS}$) (% of total basin area)
Water volume in basin (m3)
0
2000
4000
6000
8000
0
20
40
60
80
100
0
4
8
12
16

# Modeled vs. Actual pond depths



# Summary and future considerations

- Early runs of WATFLOOD allow for basin understanding and large-scale simulations on the SSRB domain.

- Groundwater observations wells provide unique opportunity to understand the groundwater system, lower storages and assess vertical water budgets.
  - Weighing lysimeter concept allows a relatively simple methodology to look at the overall water balance on a footprint well aligned with the WATFLOOD/MESH modeling system
  - Validation show some deficiencies
- MESH coupled system tested on SSRB
  - Validation of surface soil moisture using TDR seems reasonable
  - Further validation is required
- Systematic treatment of no-contributing area is important.
  - Detailed DEM provide insights into lateral flow mechanisms
  - Difficult problem to characterize in larger scale models
  - SPILL algorithm provides detailed histroy and conceptual curves
  - Application in Tile-based system still needs to be refined