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Summary Large Scale Hydrology Modeling in a Prairie Environment

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RPN, Environment Canada, CMC

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Water Science and Technology
Environment Canada, NHRC

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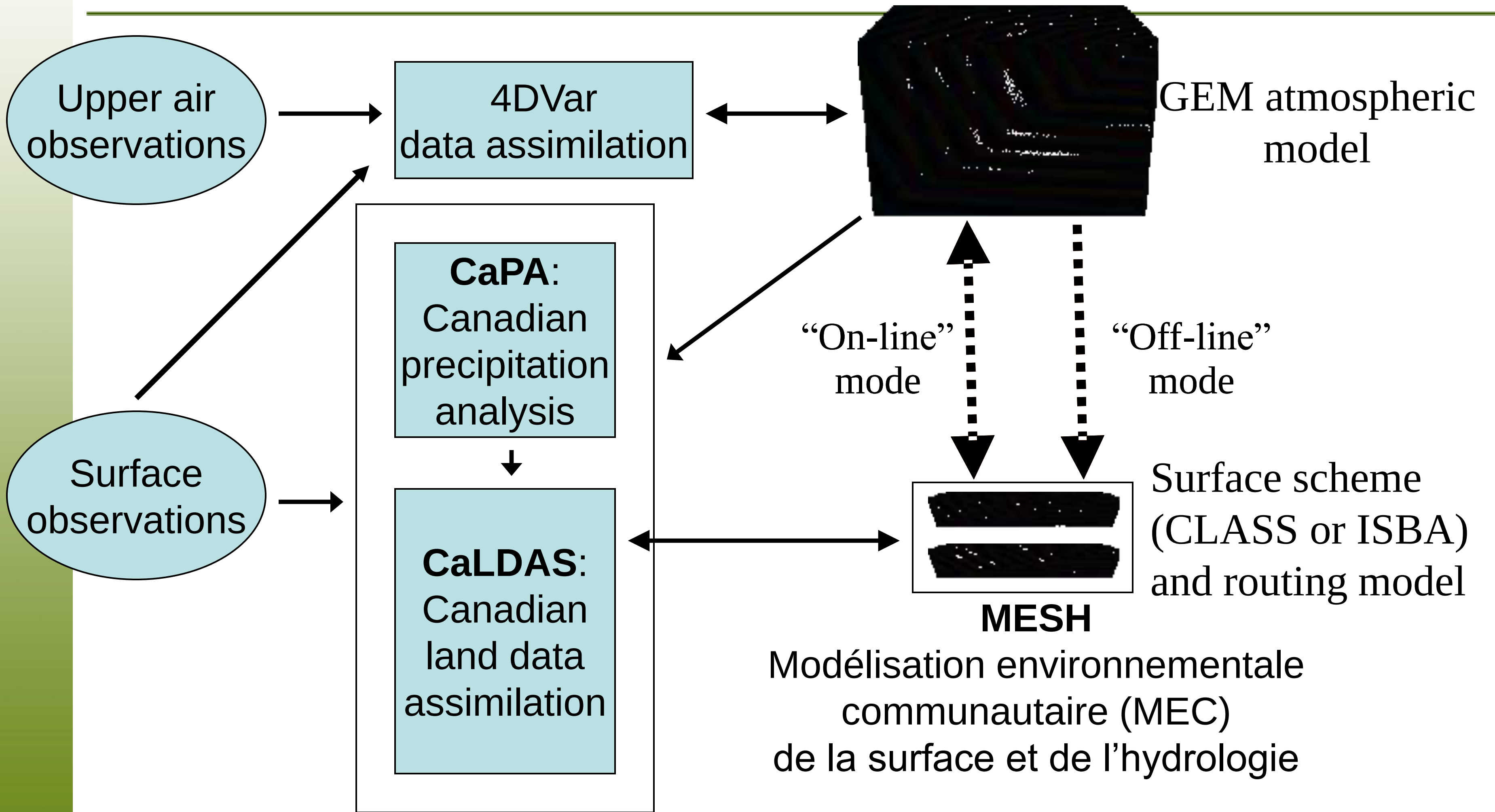
CRB, Environment Canada, NHRC

Discussion

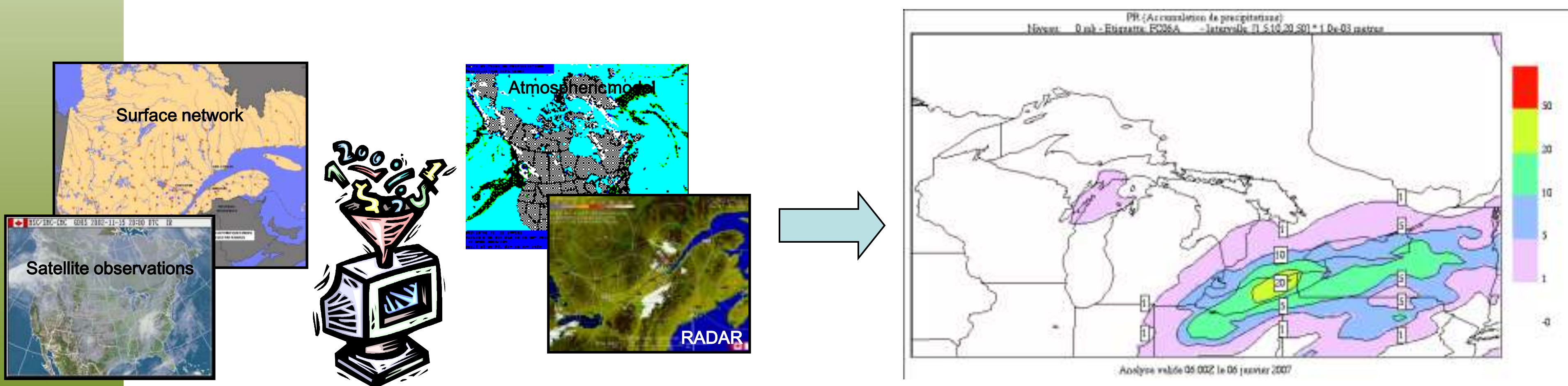
- Background
  - EC Modelling System
- Current Projects
  - Model Validation
    - Groundwater storage and weighing lysimeters
  - Coupled Model Application
    - EC MESH model on SSRB
  - Dealing with non-contributing areas.

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

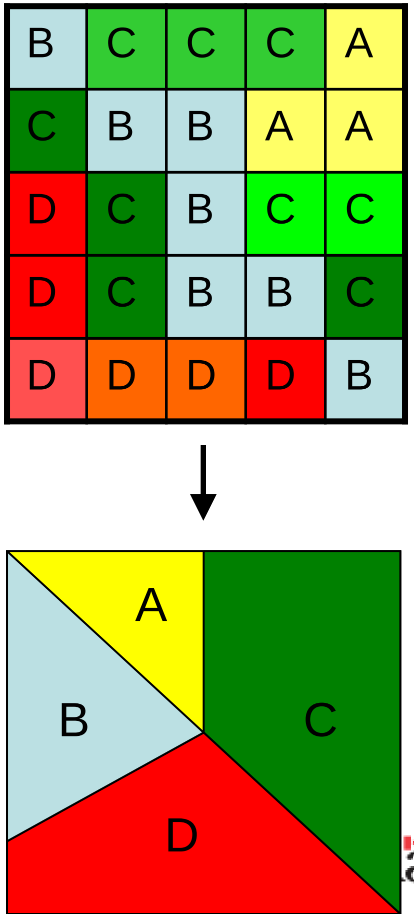


MESH: A MEC surface/hydrology configuration designed for regional hydrological modeling

- 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

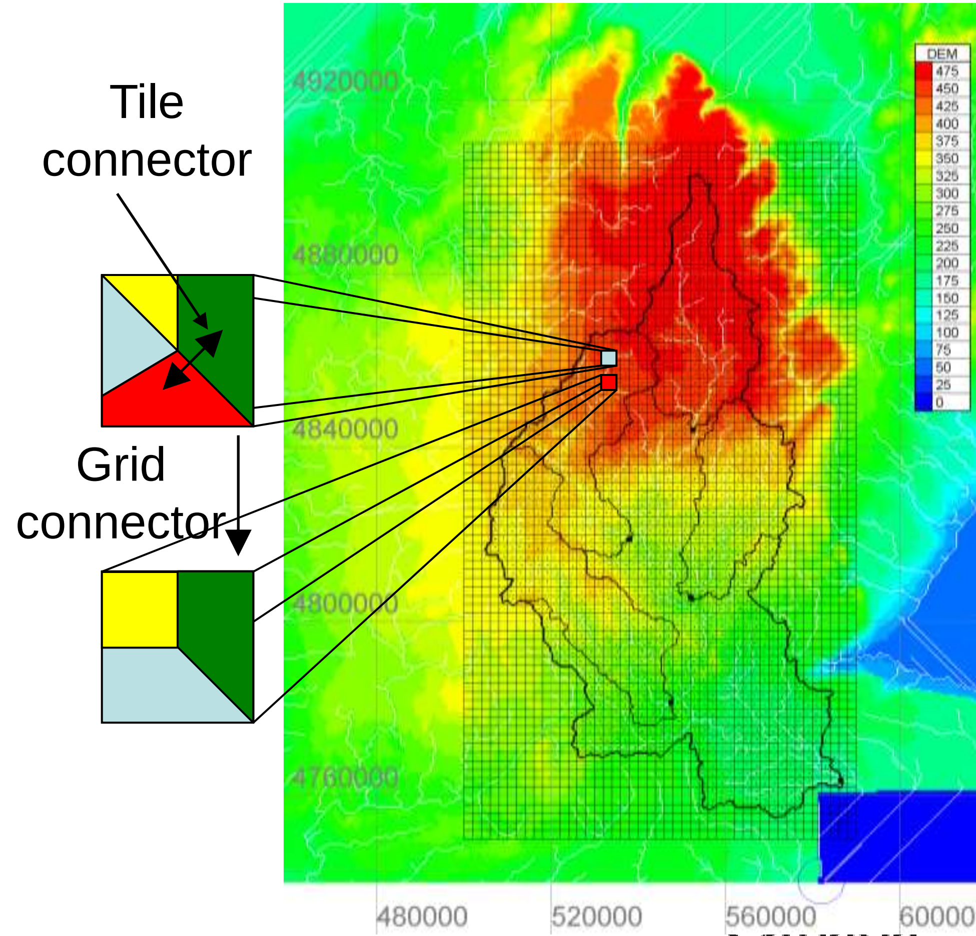
Sub-grid Hetereogeneity (land cover, soil type, slope, aspect, altitude)

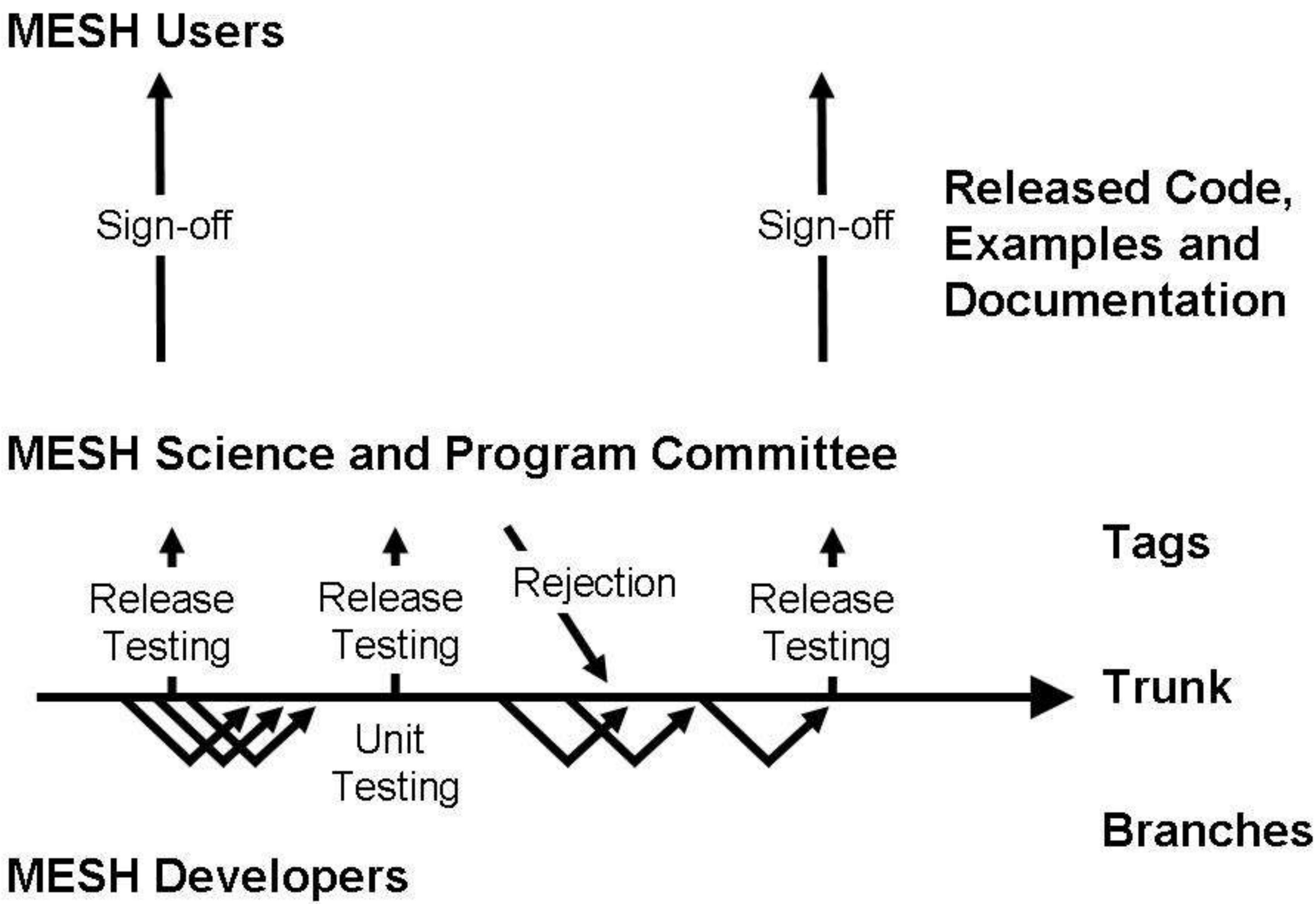
A relatively small number of classes are kept, only the % of coverage for each class is kept



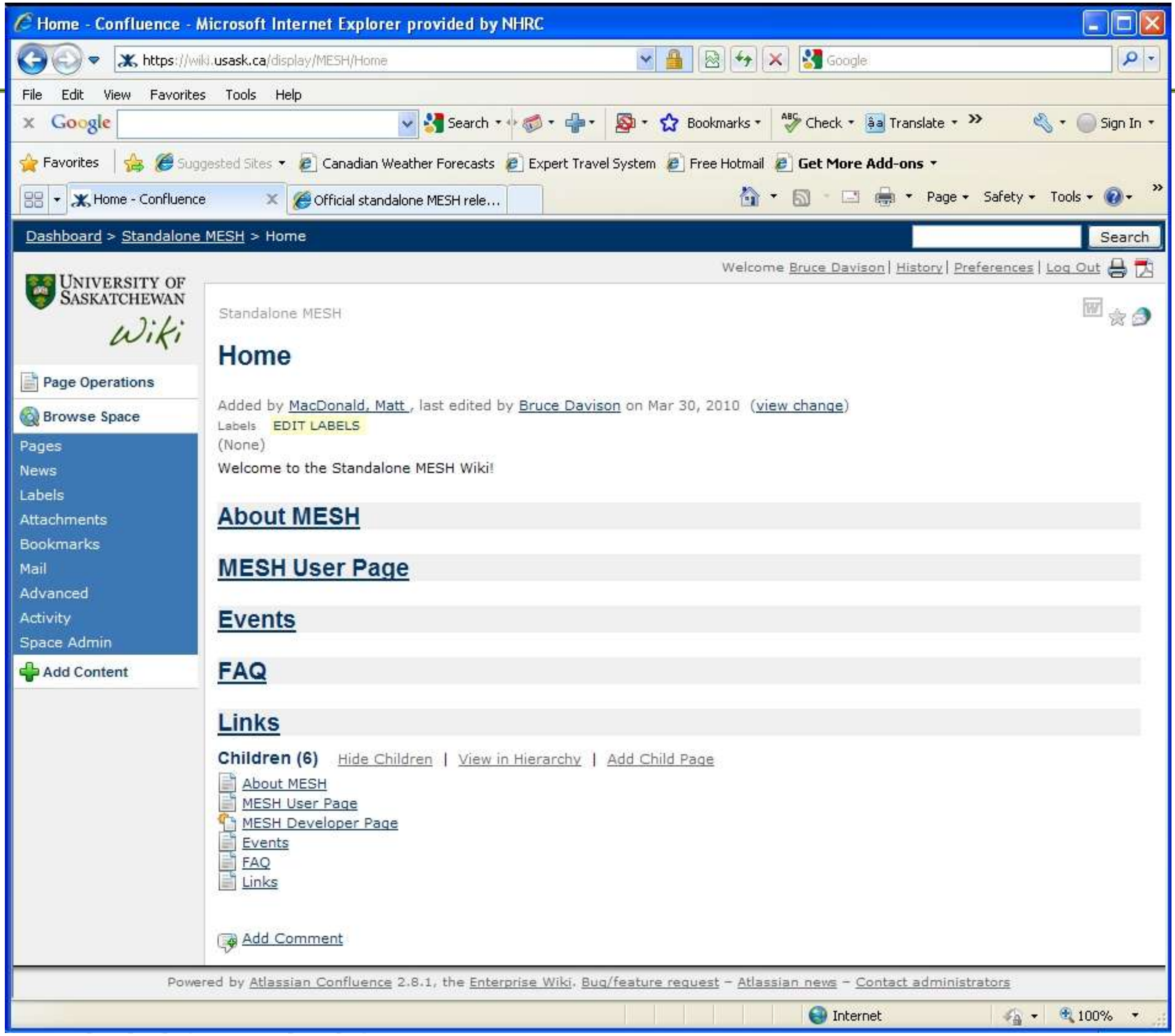
MESH: A MEC surface/hydrology configuration designed for regional hydrological modeling

- 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

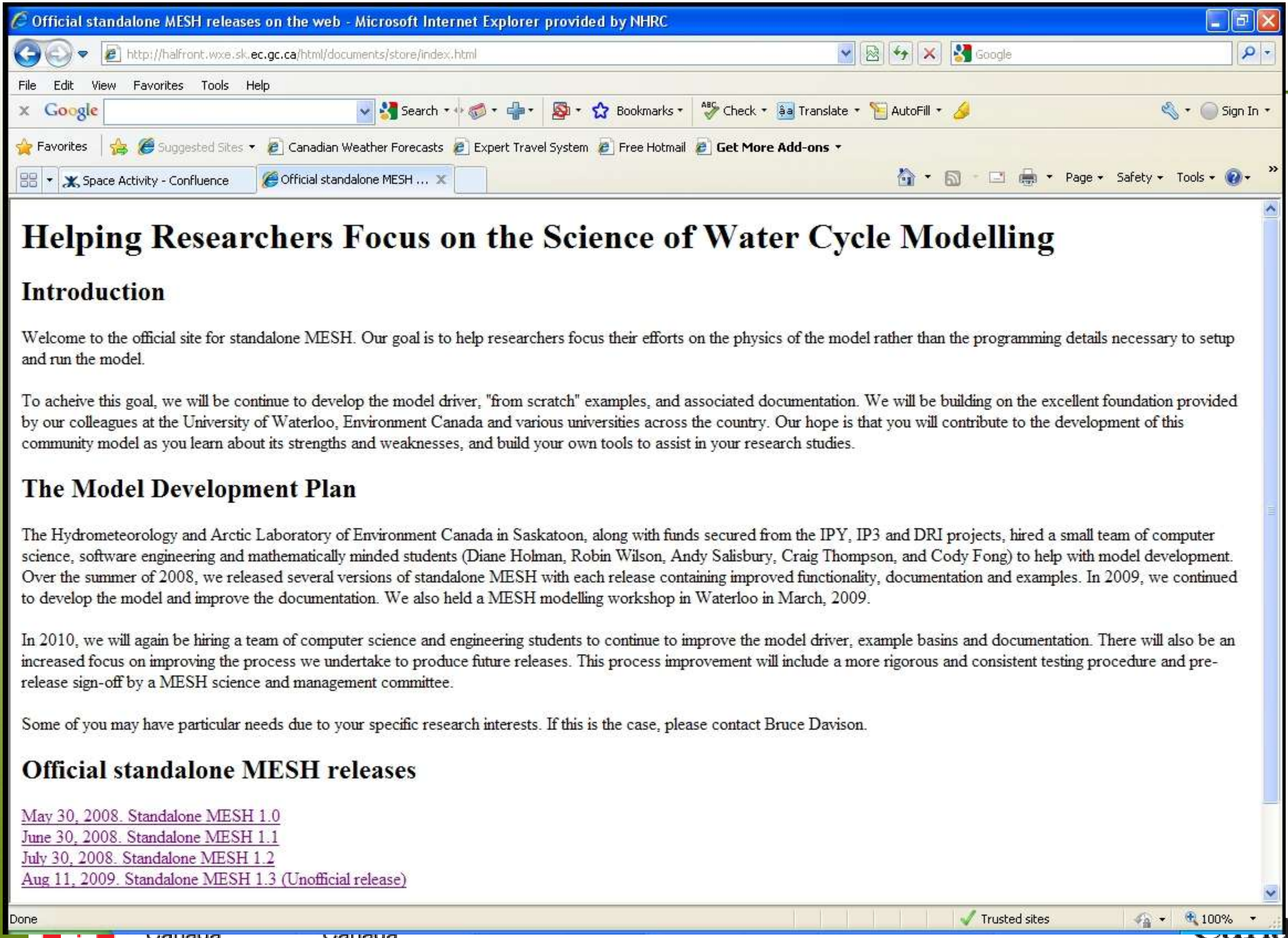



MESH Users
Sign-off
Sign-off
Released Code, Examples and Documentation
MESH Science and Program Committee
Tags
Release Testing
Release Testing
Rejection
Release Testing
Trunk
Unit Testing
Branches
MESH Developers

Wiki for "live" documentation



Static Website



Helping Researchers Focus on the Science of Water Cycle Modelling

Introduction

Welcome to the official site for standalone MESH. Our goal is to help researchers focus their efforts on the physics of the model rather than the programming details necessary to setup and run the model.

To acheive this goal, we will be continue to develop the model driver, "from scratch" examples, and associated documentation. We will be building on the excellent foundation provided by our colleagues at the University of Waterloo, Environment Canada and various universities across the country. Our hope is that you will contribute to the development of this community model as you learn about its strengths and weaknesses, and build your own tools to assist in your research studies.

The Model Development Plan

The Hydrometeorology and Arctic Laboratory of Environment Canada in Saskatoon, along with funds secured from the IPY, IP3 and DRI projects, hired a small team of computer science, software engineering and mathematically minded students (Diane Holman, Robin Wilson, Andy Salisbury, Craig Thompson, and Cody Fong) to help with model development. Over the summer of 2008, we released several versions of standalone MESH with each release containing improved functionality, documentation and examples. In 2009, we continued to develop the model and improve the documentation. We also held a MESH modelling workshop in Waterloo in March, 2009.

In 2010, we will again be hiring a team of computer science and engineering students to continue to improve the model driver, example basins and documentation. There will also be an increased focus on improving the process we undertake to produce future releases. This process improvement will include a more rigorous and consistent testing procedure and pre-release sign-off by a MESH science and management committee.

Some of you may have particular needs due to your specific research interests. If this is the case, please contact Bruce Davison.

Official standalone MESH releases

May 30, 2008. Standalone MESH 1.0
June 30, 2008. Standalone MESH 1.1
July 30, 2008. Standalone MESH 1.2
Aug 11, 2009. Standalone MESH 1.3 (Unofficial release)

Repository for Code and Small Model Run Files

- MESH_Code_Repository
  - .svn
  - Branches
  - Tags
    - .svn
    - CLASS
      - .svn
      - CLASS_3.3
      - CLASS_3.4
      - CLASS_3.5
    - Documentation
    - SA_MESH
      - .svn
      - SA_MESH_1.0
      - SA_MESH_1.1
      - SA_MESH_1.2
      - SA_MESH_1.2.01
      - SA_MESH_1.3_unofficial
  - TRUNK
    - .svn
    - Driver
    - LSS_Model
    - Model_run_files
    - Modules
    - Post_Process
    - Pre_Process
    - Routing_Model
    - Tile_Connector

Continuous Improvement

The following list shows where we are focusing our efforts to continuously improve the way in which we develop the community model.

- **Software requirements – improving user feedback**
- **Software design – documenting designs**
- **Software construction – code reviews and documentation**
- **Software testing – more rigorous standards**
- **Software maintenance – ongoing support**
- **Software configuration management (SCM) – new, systematic approach**
- **Software engineering management – in support of SCM**
- **Software engineering process – continuous improvement**
- **Software engineering tools and methods – svn for SCM, bug tracking**
- **Software quality – continuous improvement**

WATFLOOD results

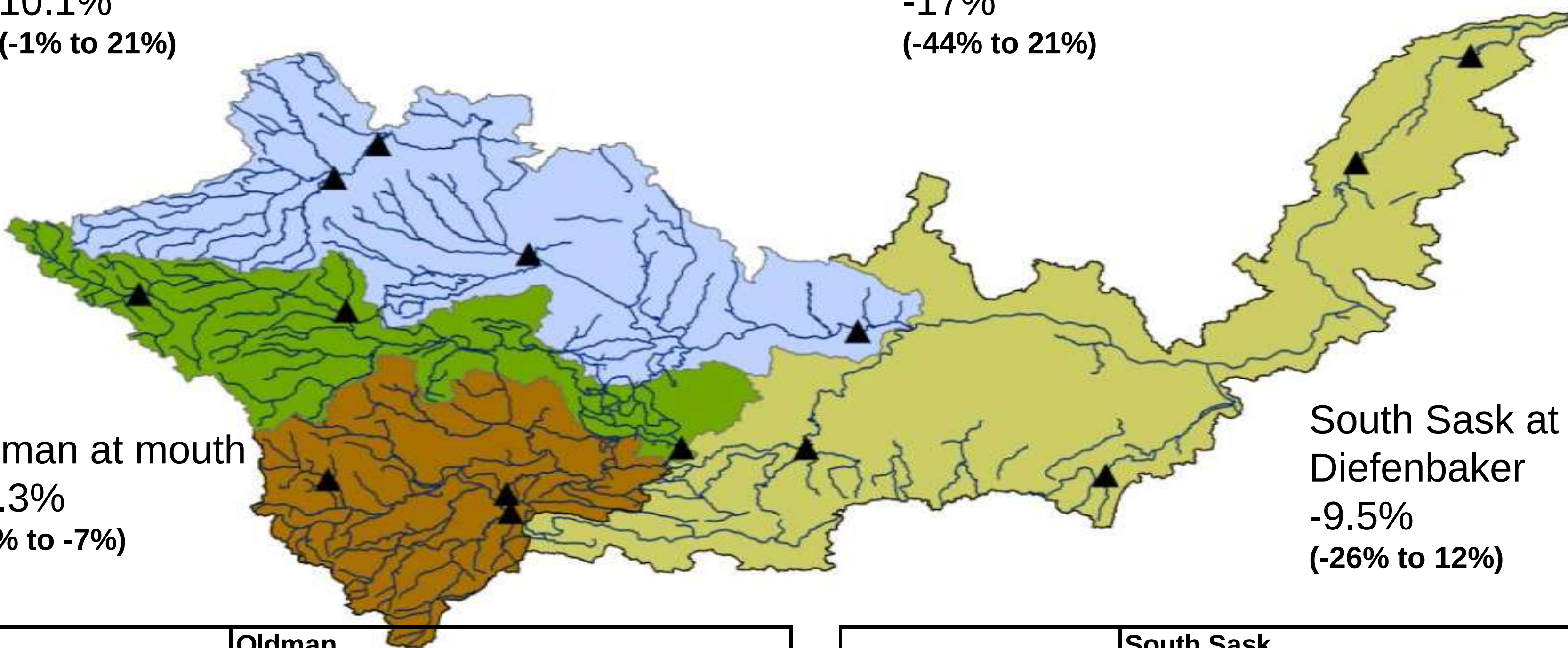
GCM scenario results 2039 – 2070 cumulative flows – Debits cumulatif

	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

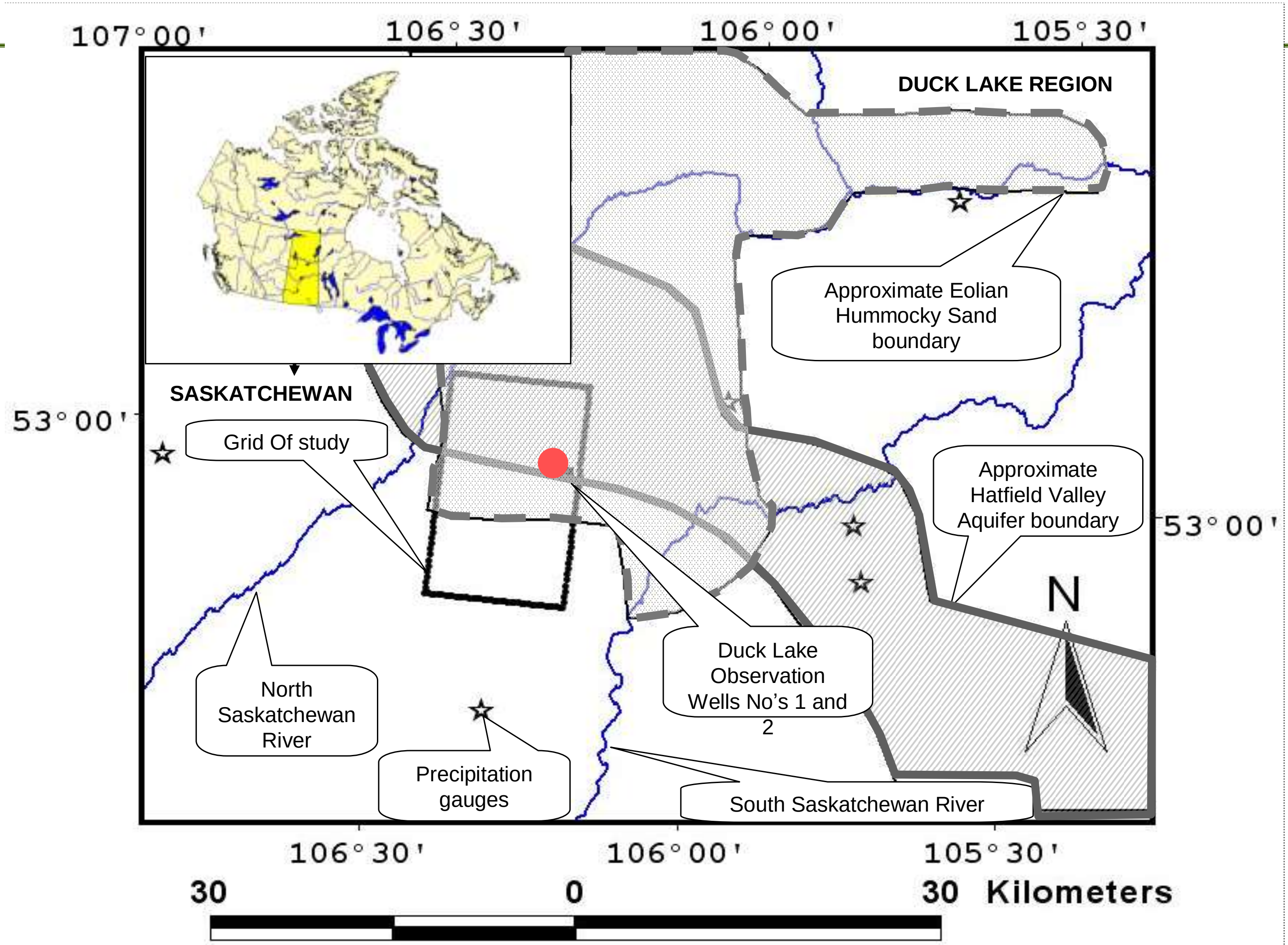
- Wastage (Volume-Area relationship)
- NSRB at N.Sask at Edmonton = 4 000 x10^6 m^3
  2.6% annually
- SSRB at Bow River at Calgary = 1 800 x10^6 m^3
  2.8% annually

- Melt (WATFLOOD/MESH and Volume-Area difference)
- NSRB at N.Sask at Edmonton = 14 000 x10^6 m^3
- SSRB at Bow River at Calgary = 4 000 x10^6 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

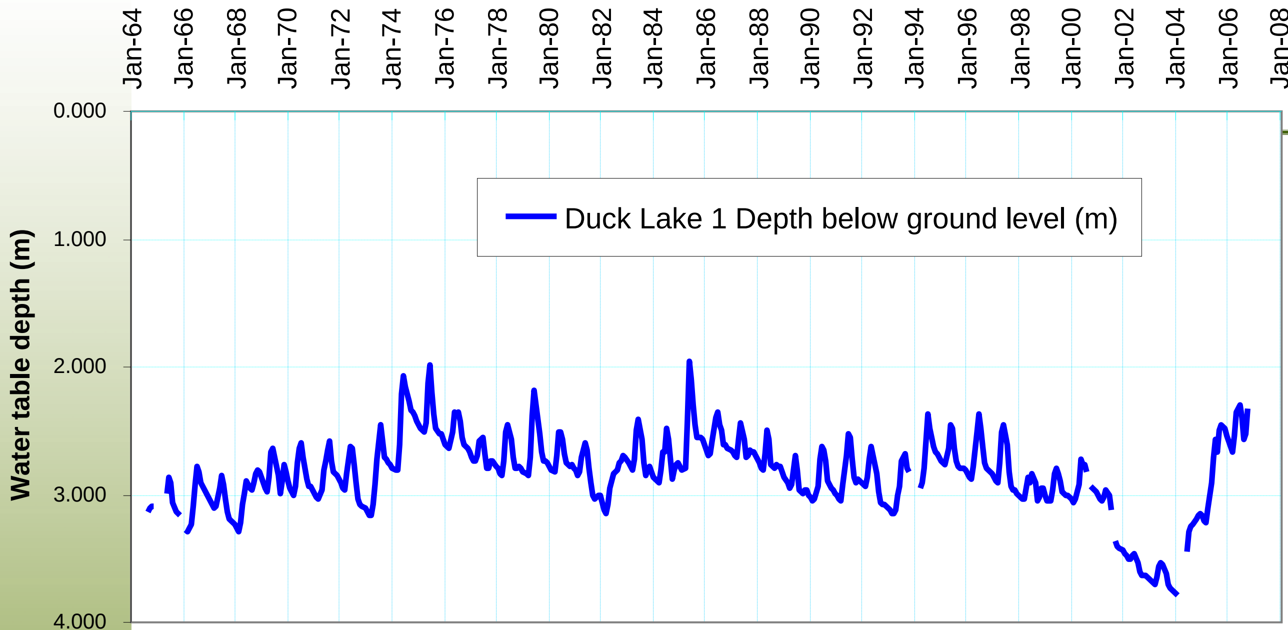
- Traditionally we compare to observed hydrographs
- Are we getting the right answer for the wrong reasons ?

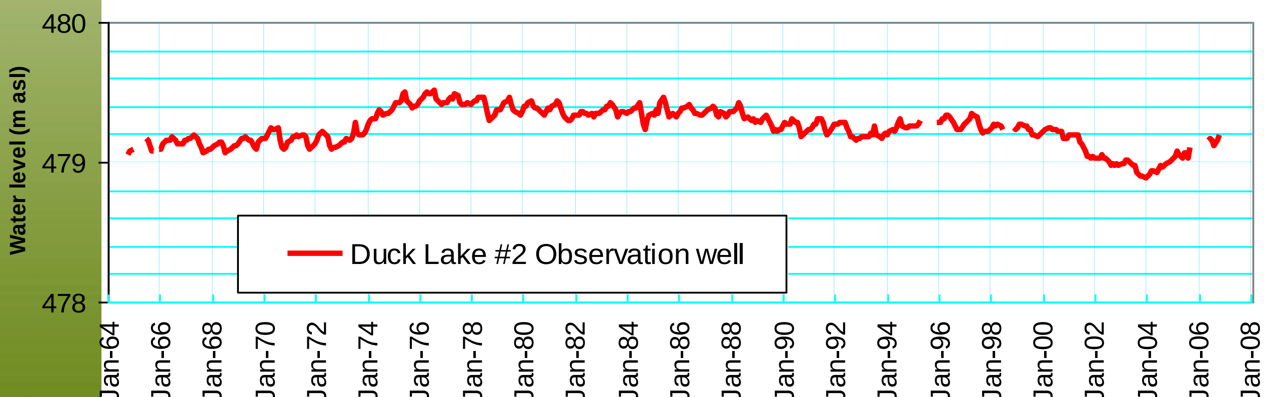
Location of Duck Lake observations wells and Watflood grid cell *[Marin et al. 2009.]*

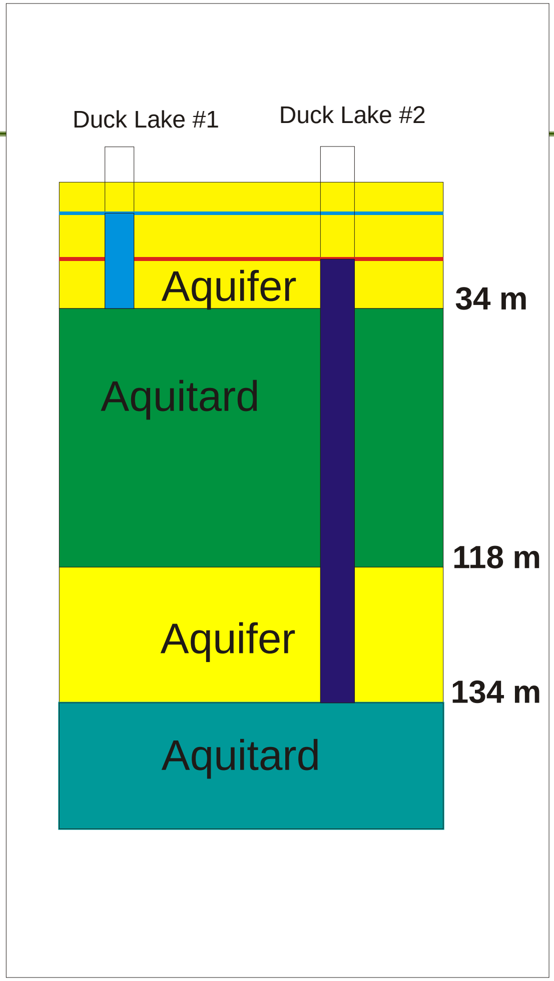


Duck Lake SK Observation wells: water levels, 1964-2006

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







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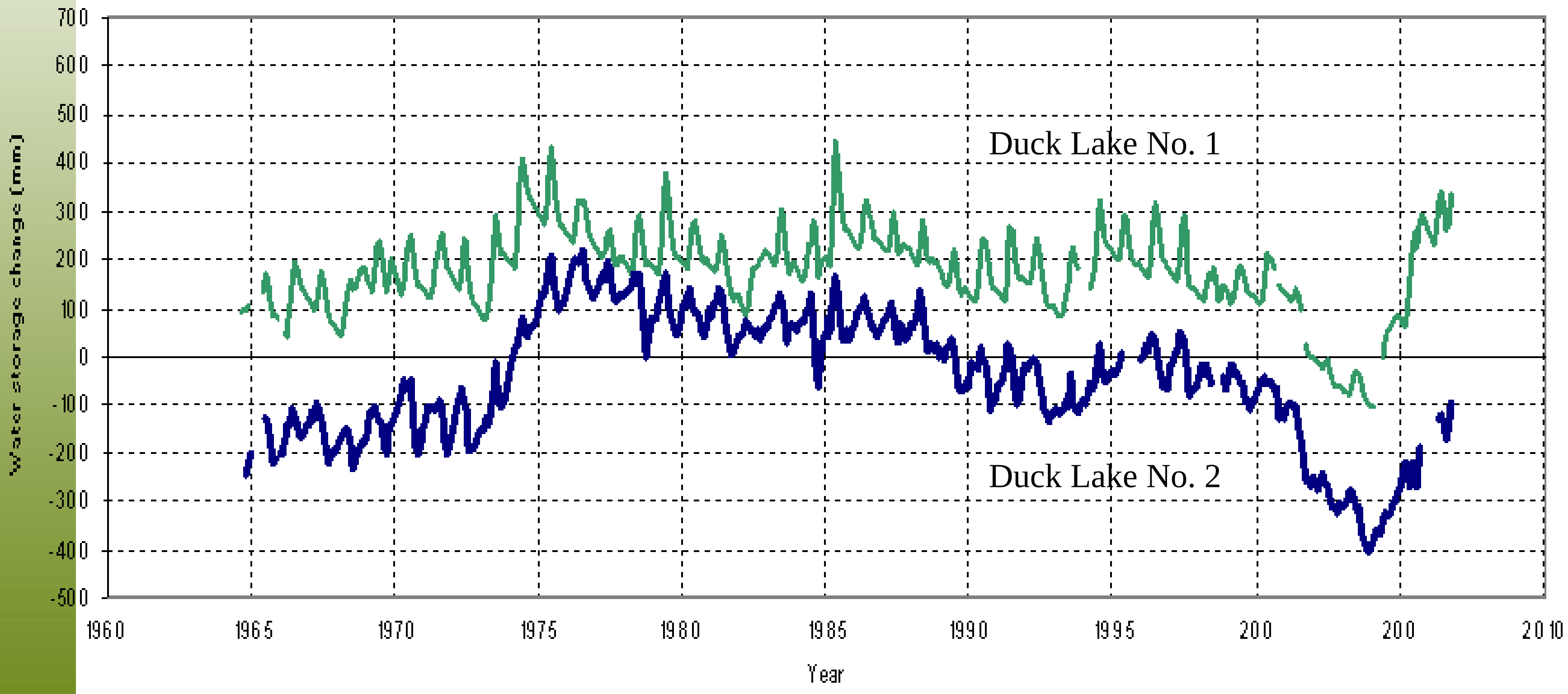
Water storage changes observed for Duck Lake SK observation wells 1965-2007:

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

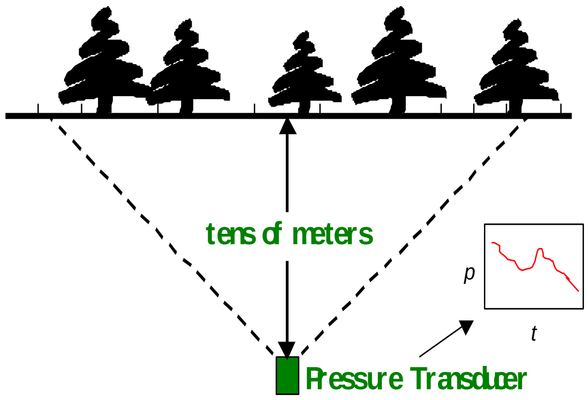
Fundamentals

- 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:

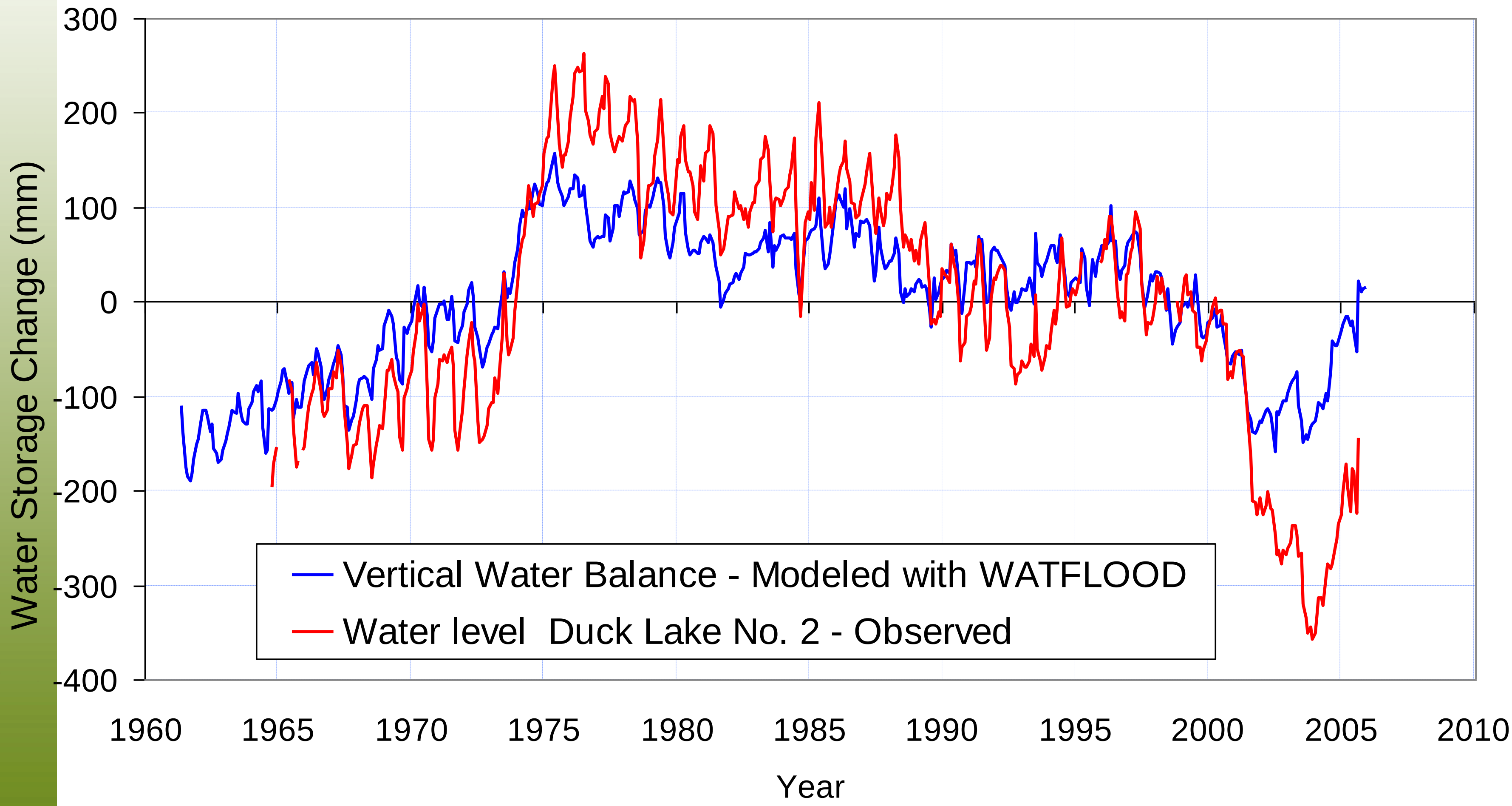
  - ✓ Snow accumulation;
  - ✓ Rainfall;
  - ✓ Evapotranspiration

Conceptual Sketch of Piezometric Weighing Lysimeter Installation

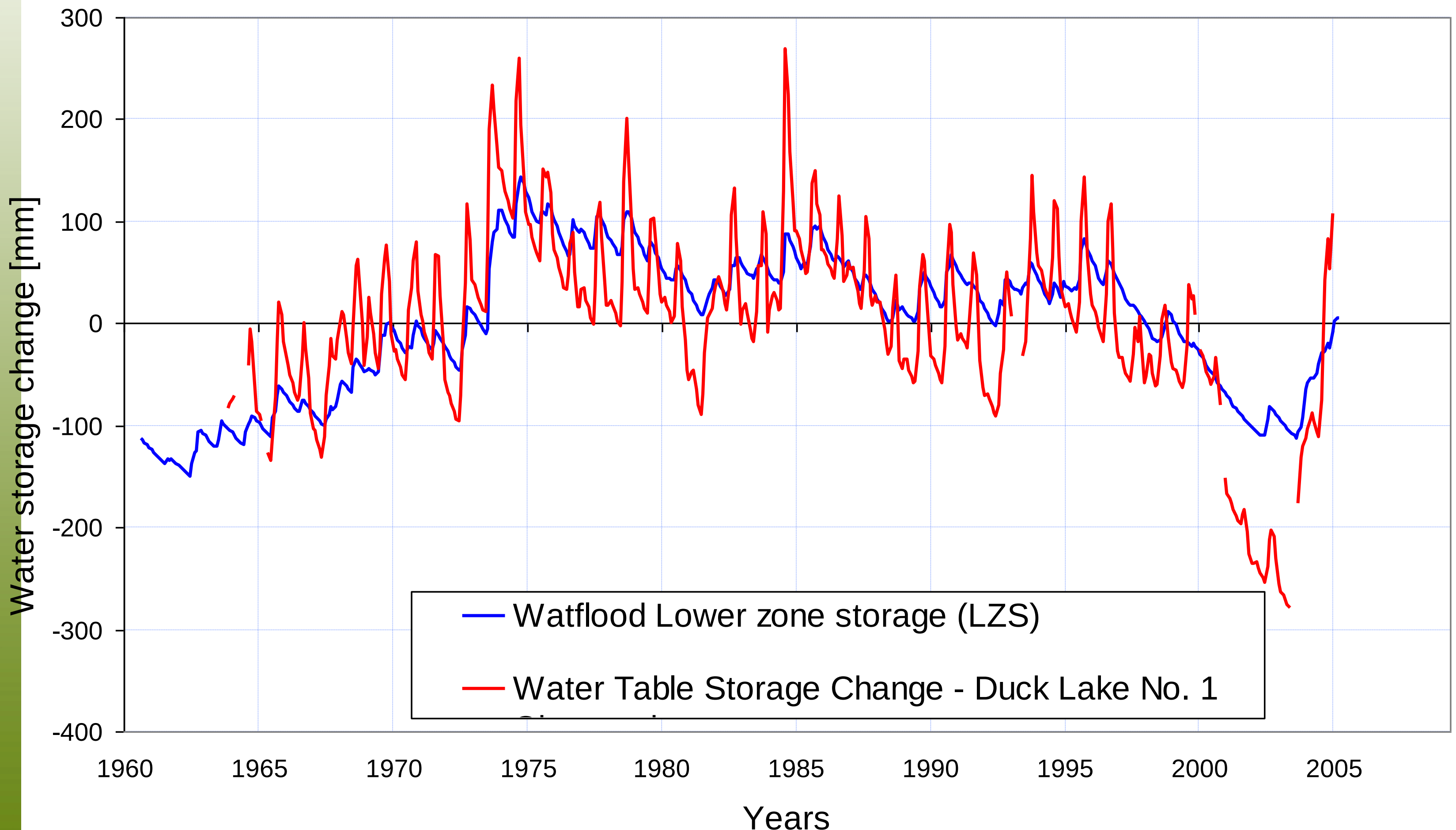


Van der Kamp et al, 2003

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



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



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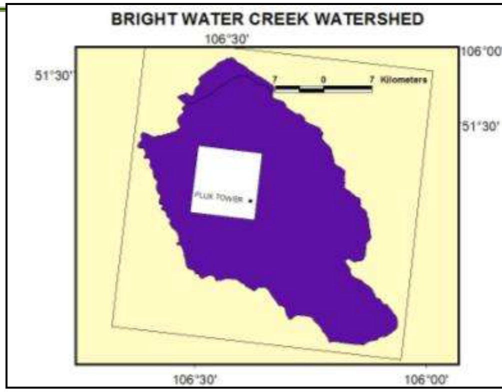
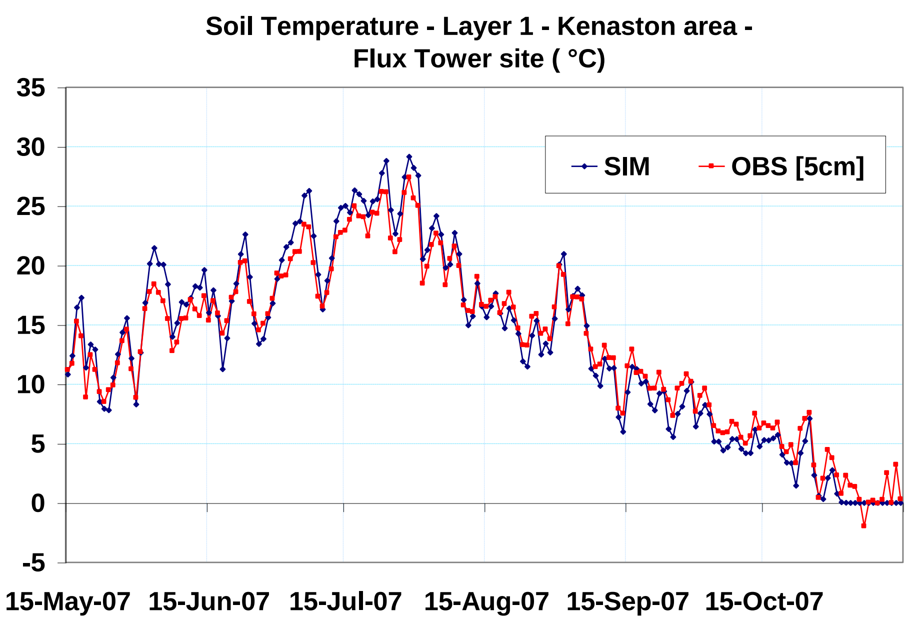
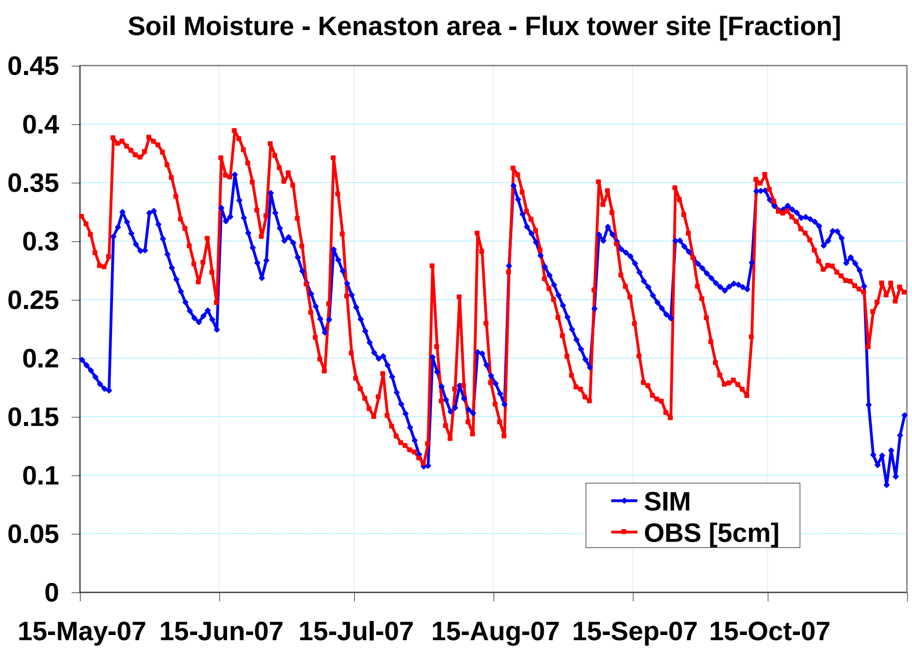
Moving Towards Coupled Model

Stand alone MESH

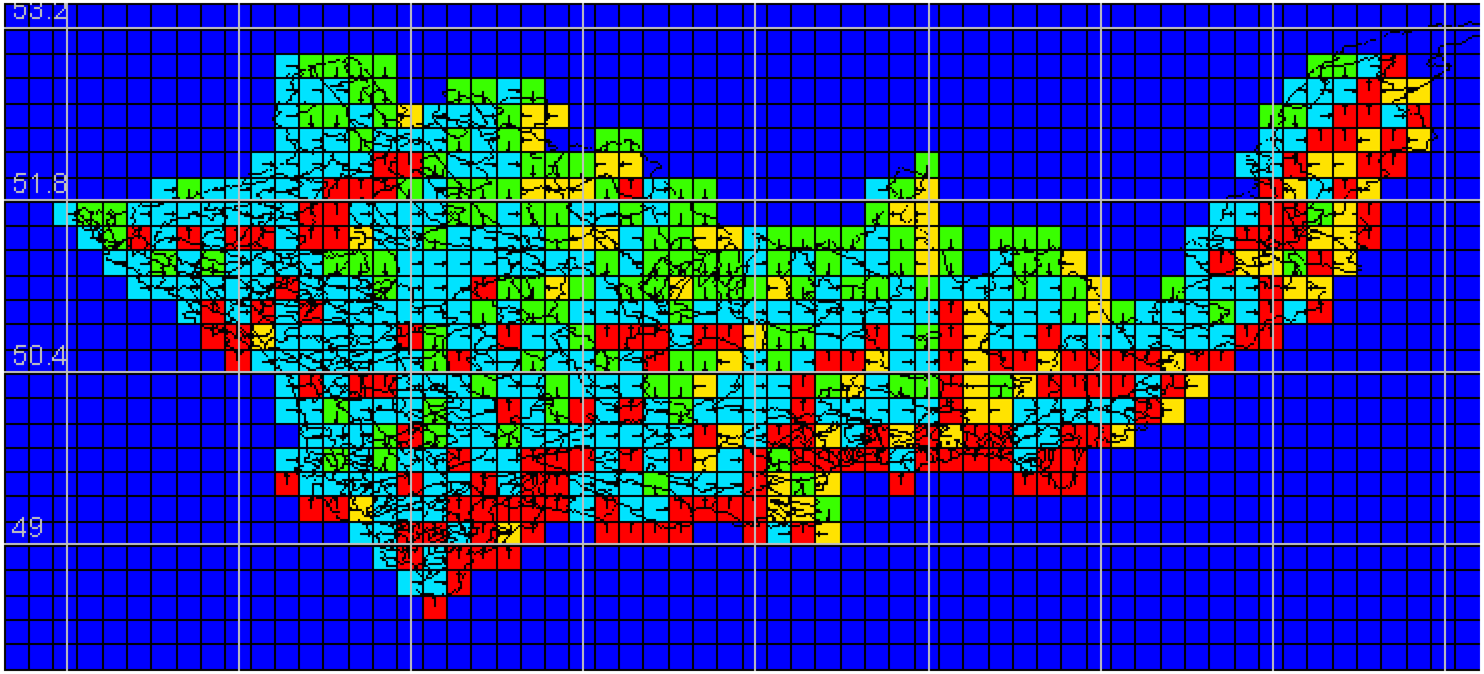


- MESH model physics (CLASS LSS)
  - with added routing based on Watroute
- Forcing with met tower data
  - Temp, precip, station pressure, specific humidty, wind, lw and sw radiation
- May 15 to November, 2007, half hourly

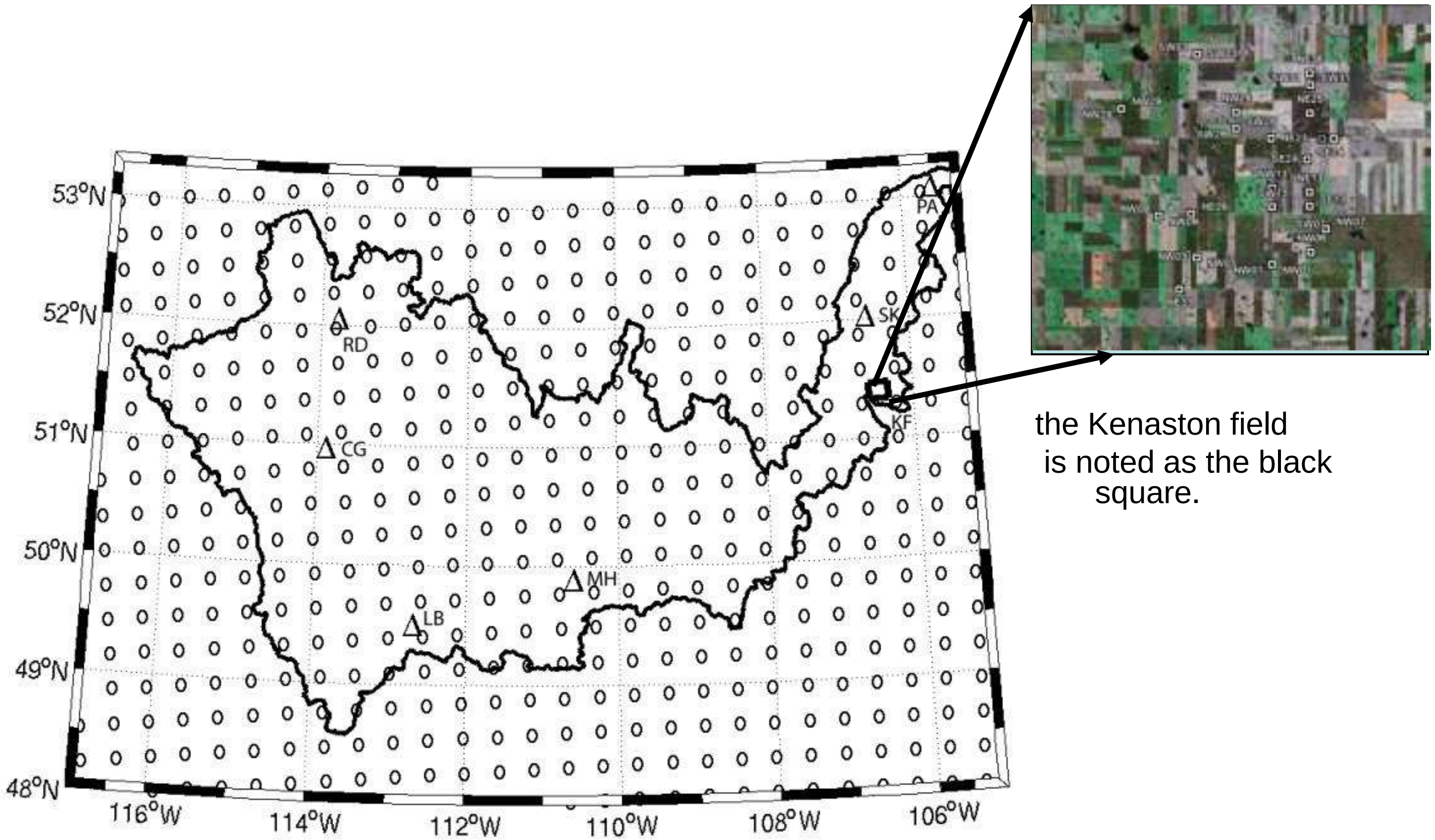




Setup of Sa-MESH simulation for SSRB

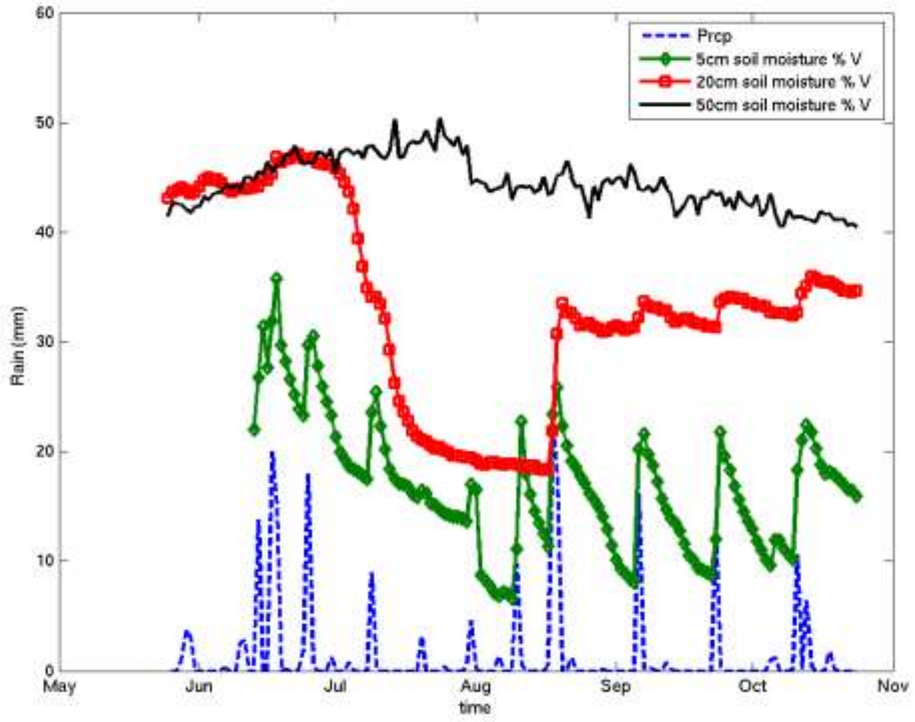


Distribution of NARR data grid and MSC weather stations

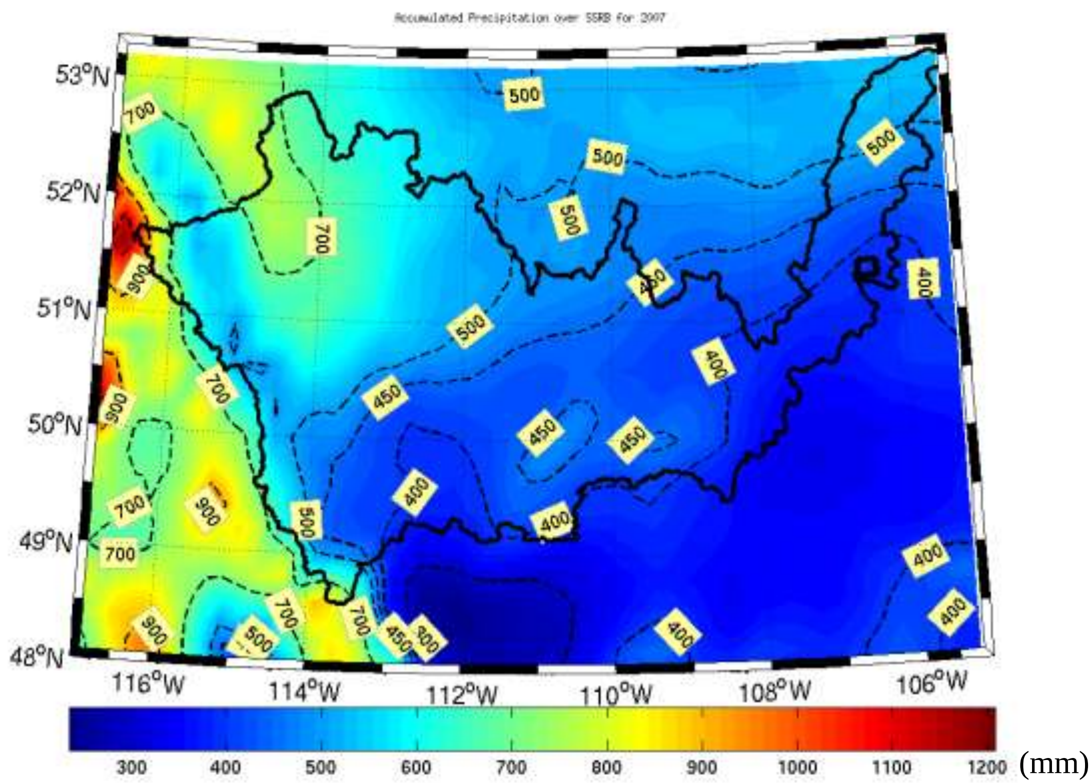


the Kenaston field is noted as the black square.

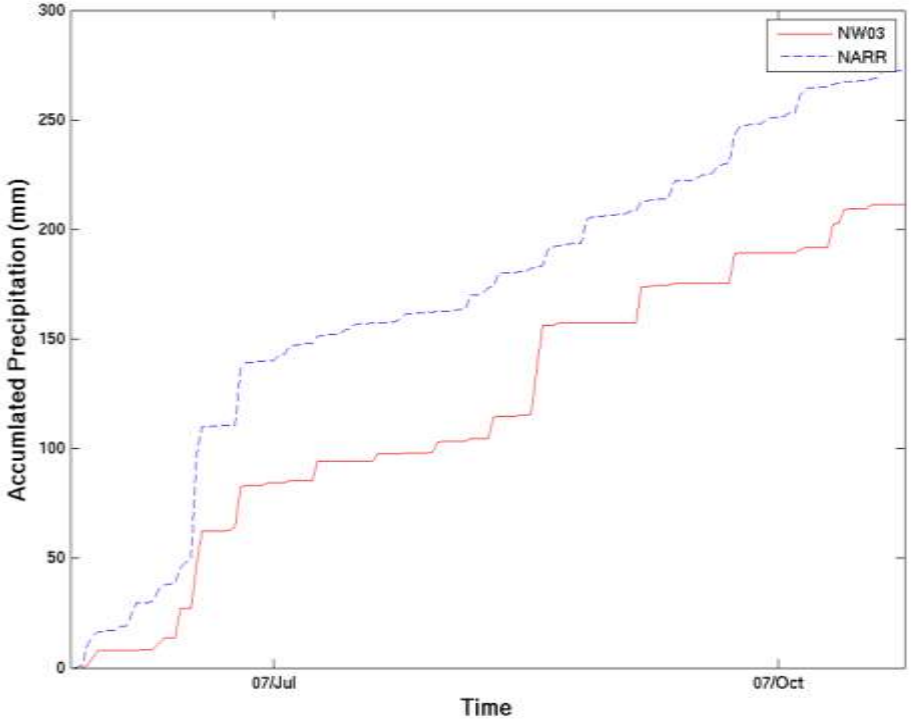
Observed precipitation and soil moisture at site NW03 for 2007



NARR accumulated precipitation over SSRB for 2007

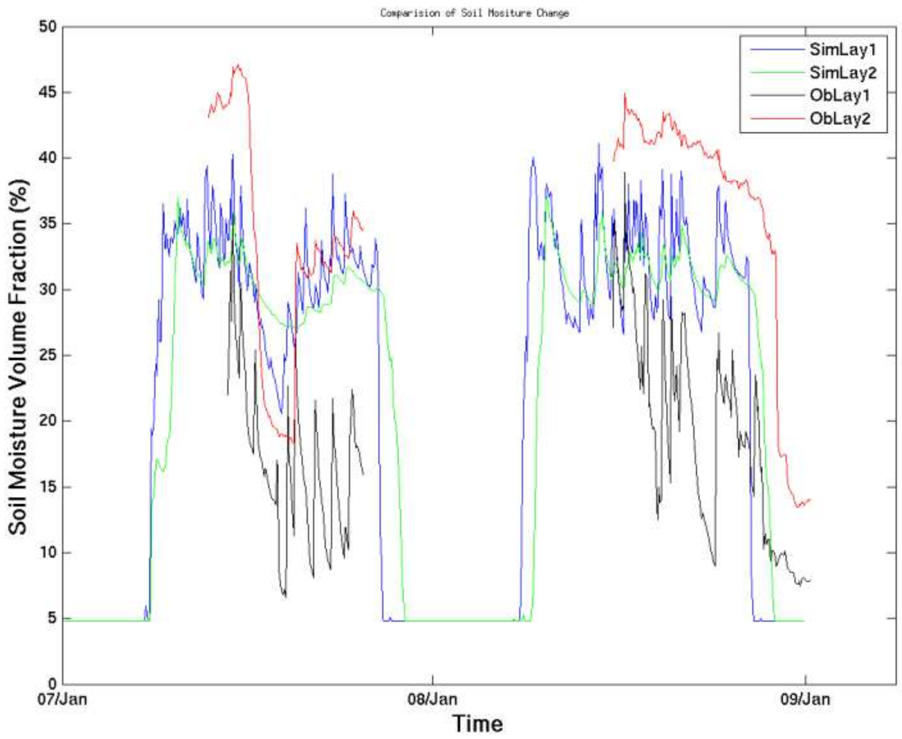


Comparison of accumulated precipitation



Comparison of accumulated precipitation between NARR dataset (blue) and field observation (red) at NW03 for 2007 summer .

Comparison of soil moisture



Comparison of measured to simulated soil moisture at

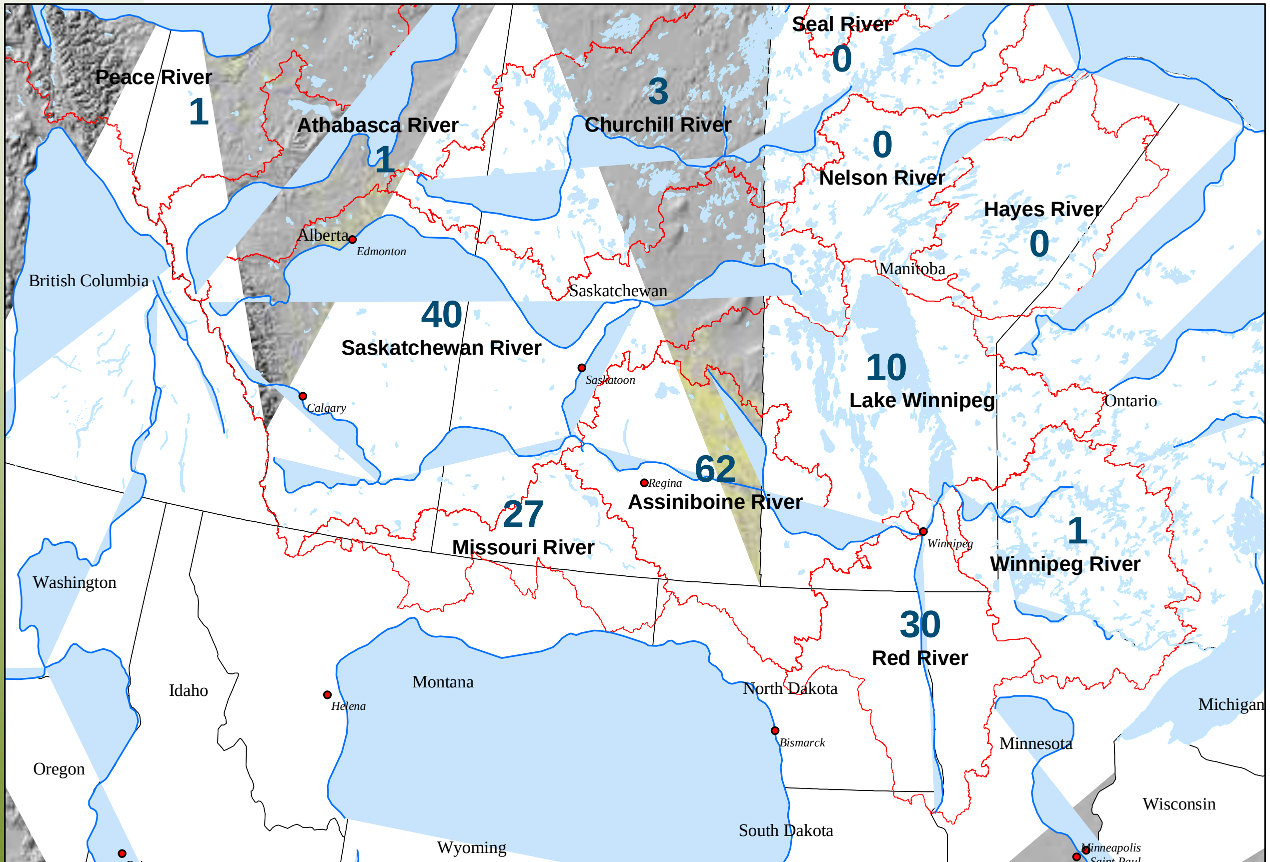
at NW03 for 2007 (layer 1 = 0-10cm; level 2=10-30 cm) .

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 -

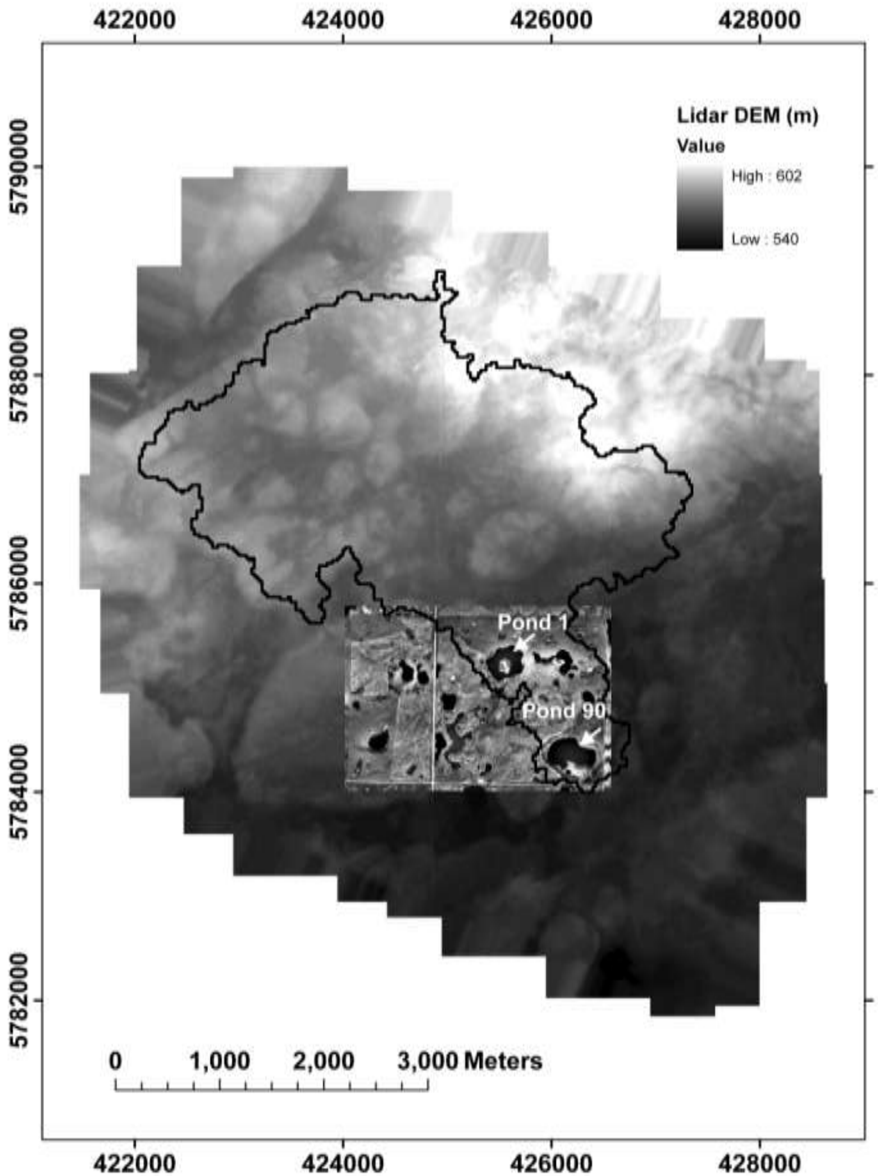


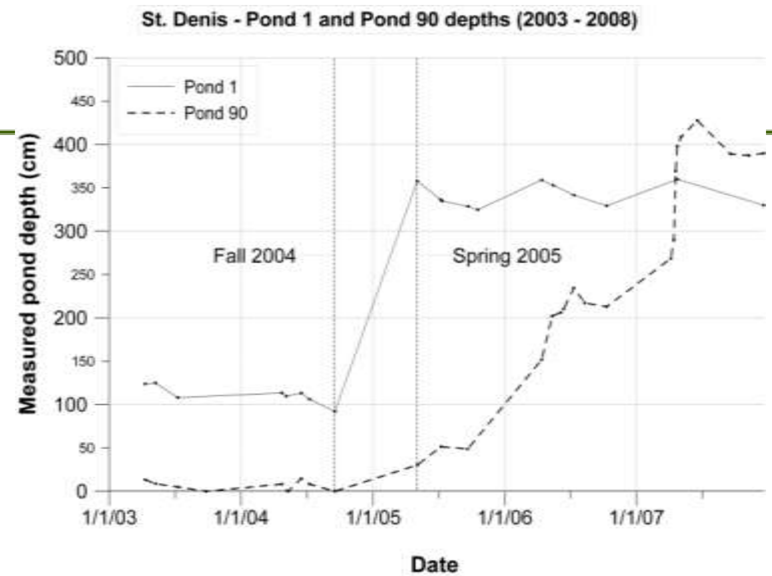
Source: Non-contrib
Elevation d

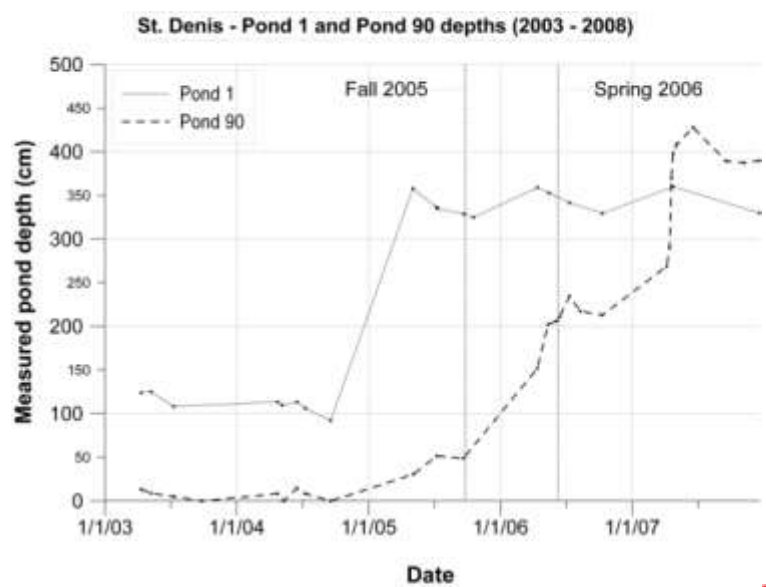
Prairie pothole region encompasses approximately 775,000 km^2 of the north-central United States and south-central Canada.

Contributing area within this landscape varies by seasons and year

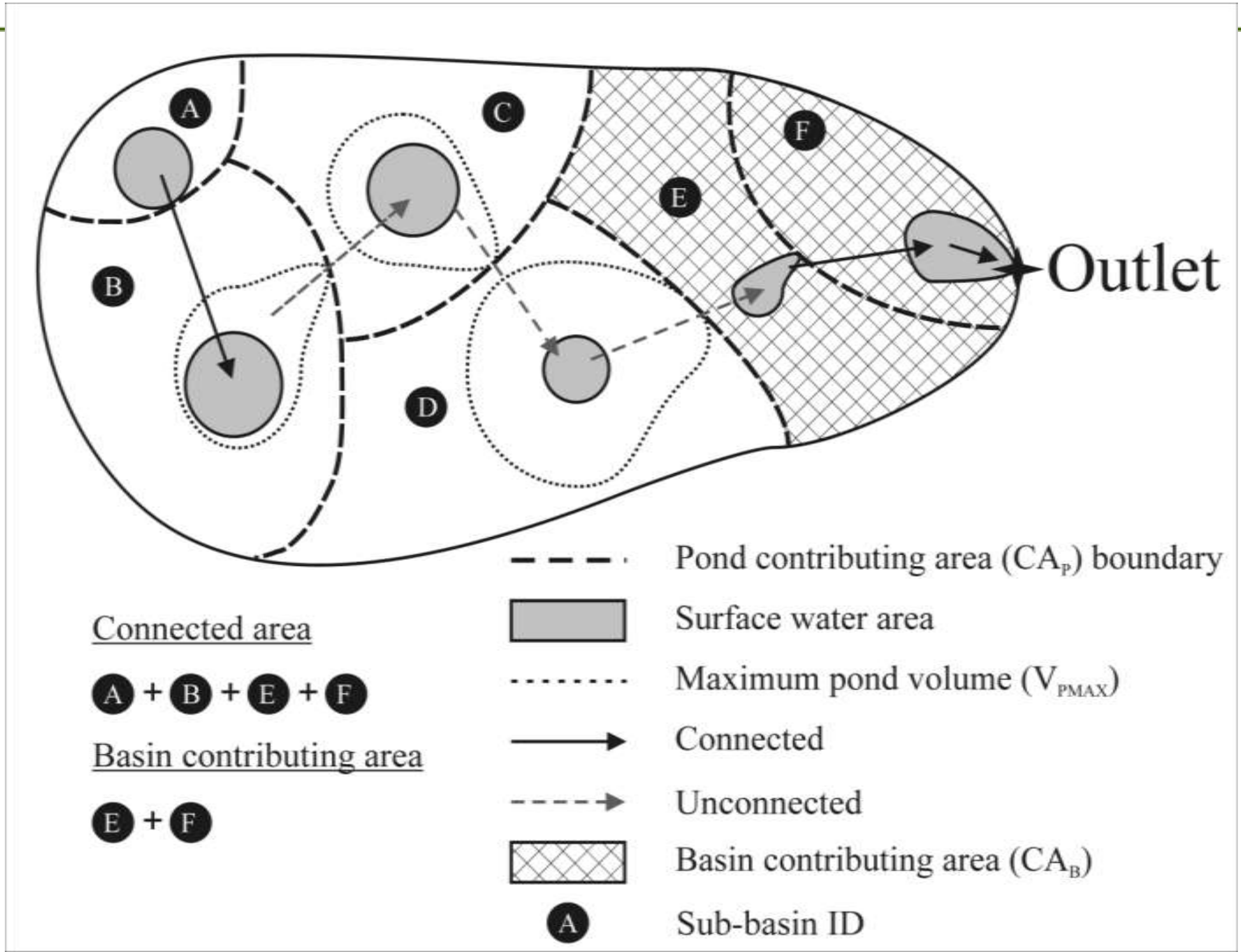
Importance of Connectivity



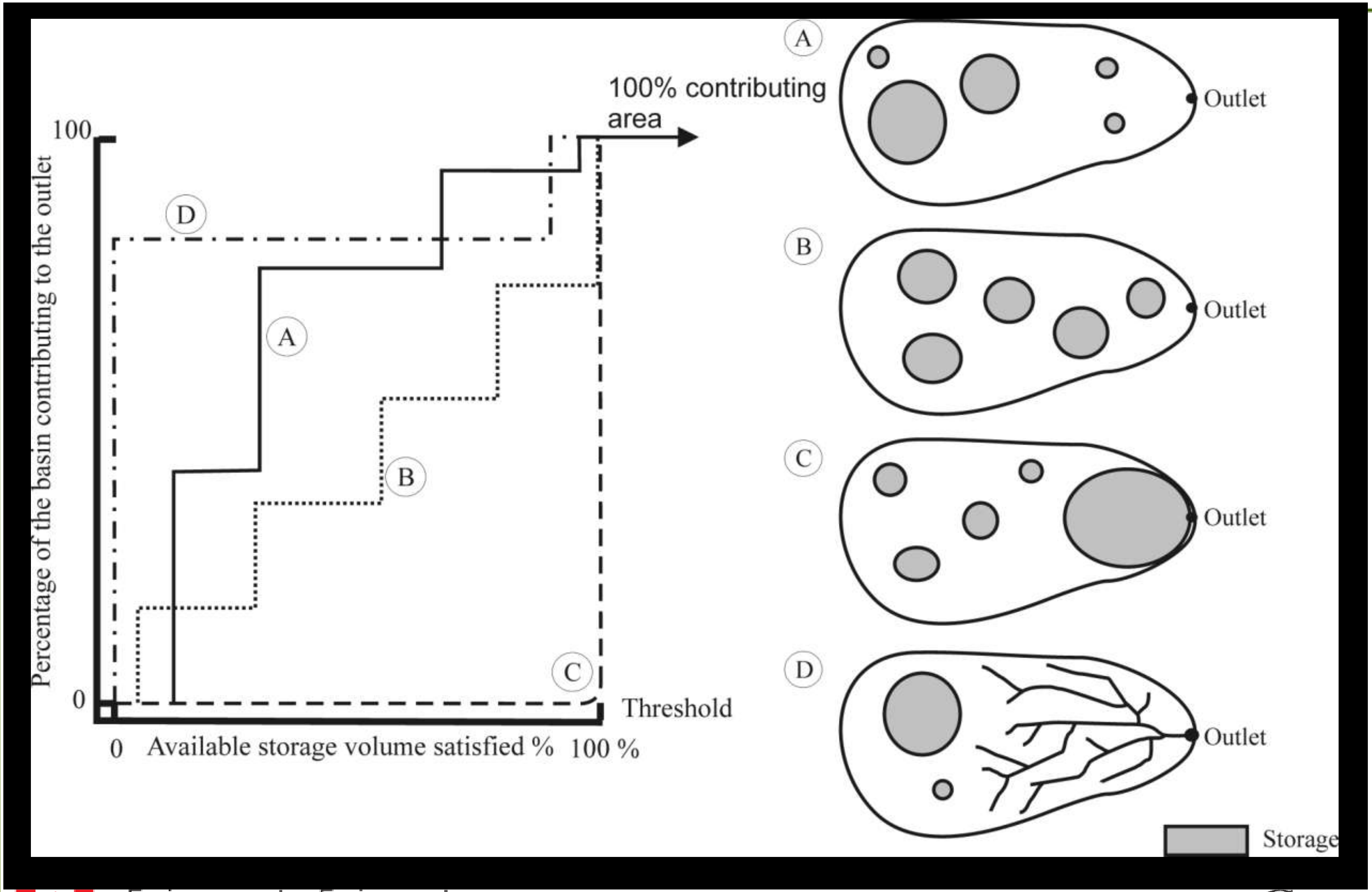




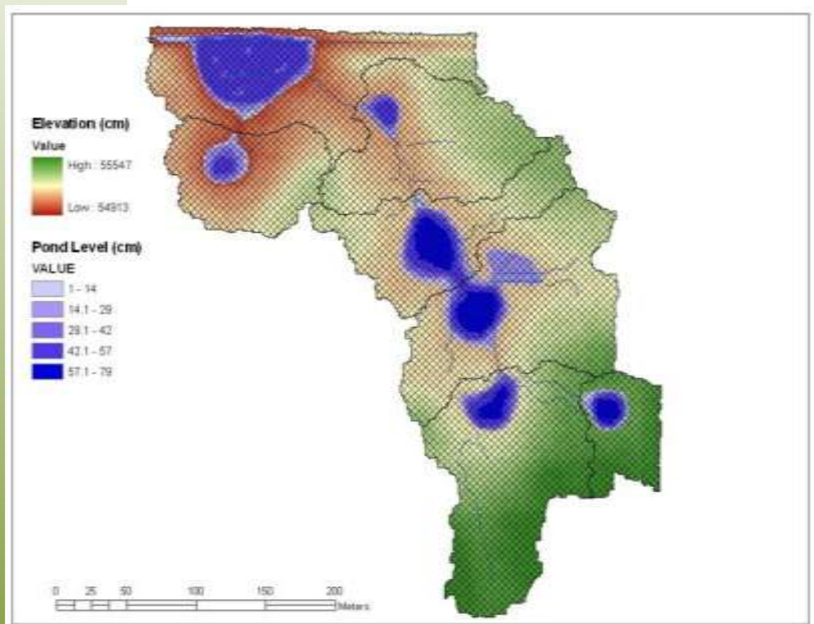
Key Concepts

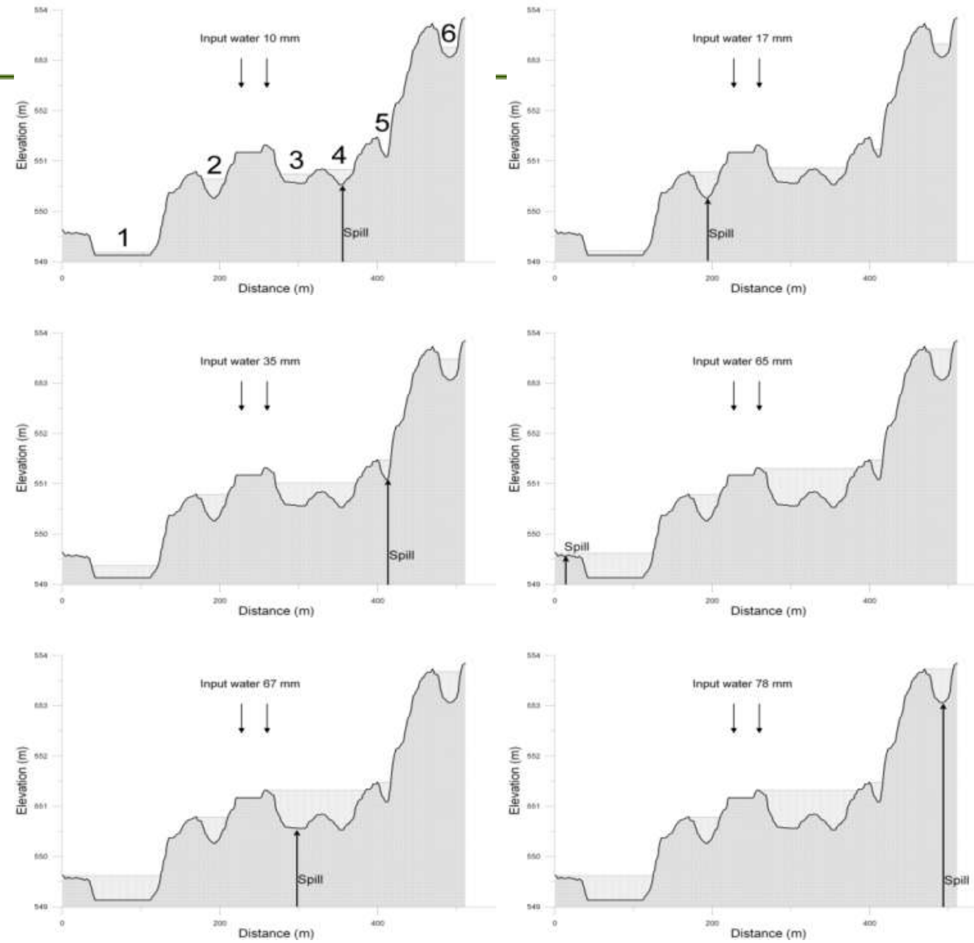


Conceptual landscapes



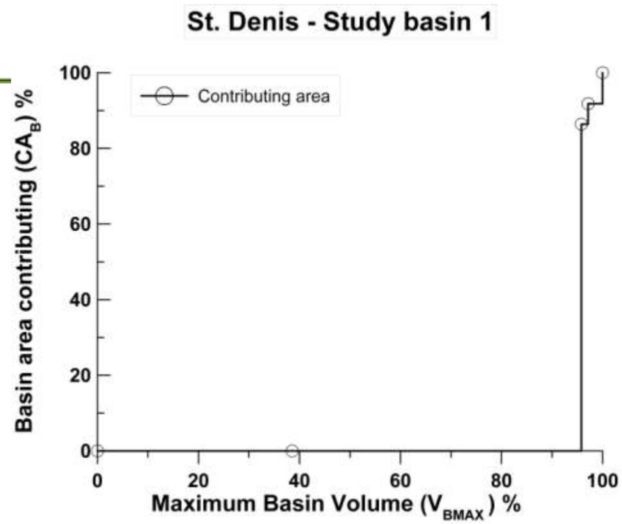
Prairie pothole algorithm

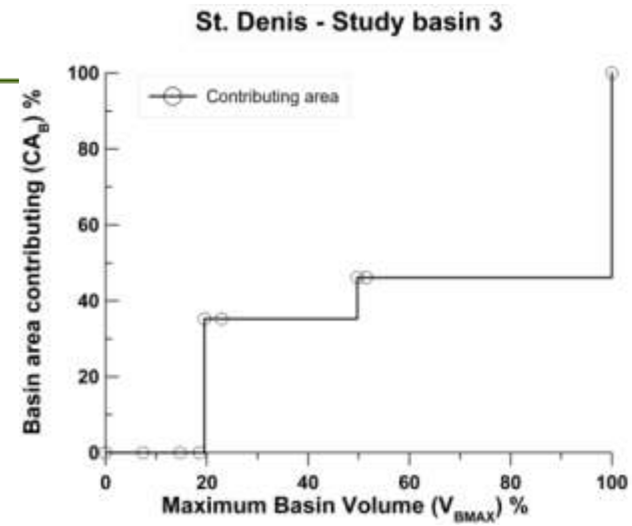




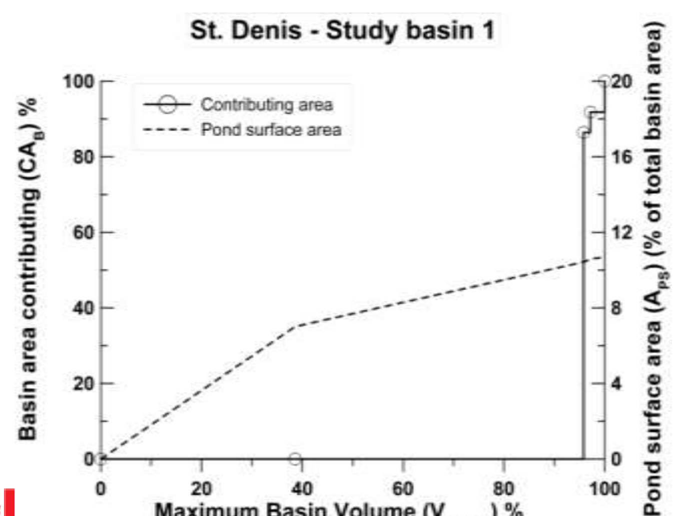
SPILL Results

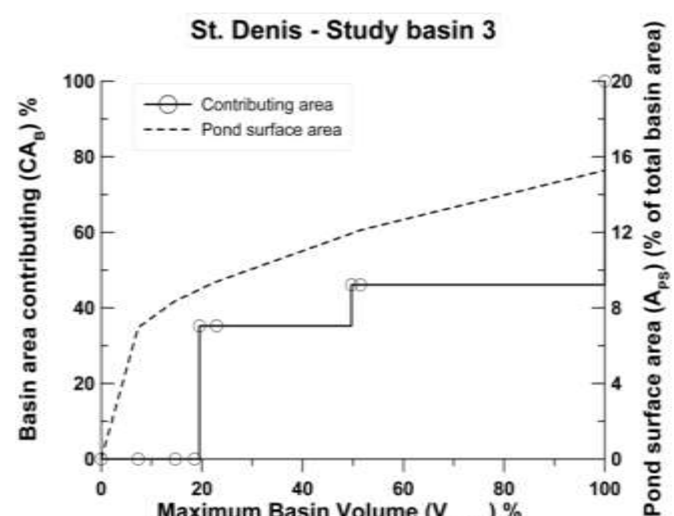
Contributing area/Potential storage volume relationship





Contributing area/Pond surface area relationship





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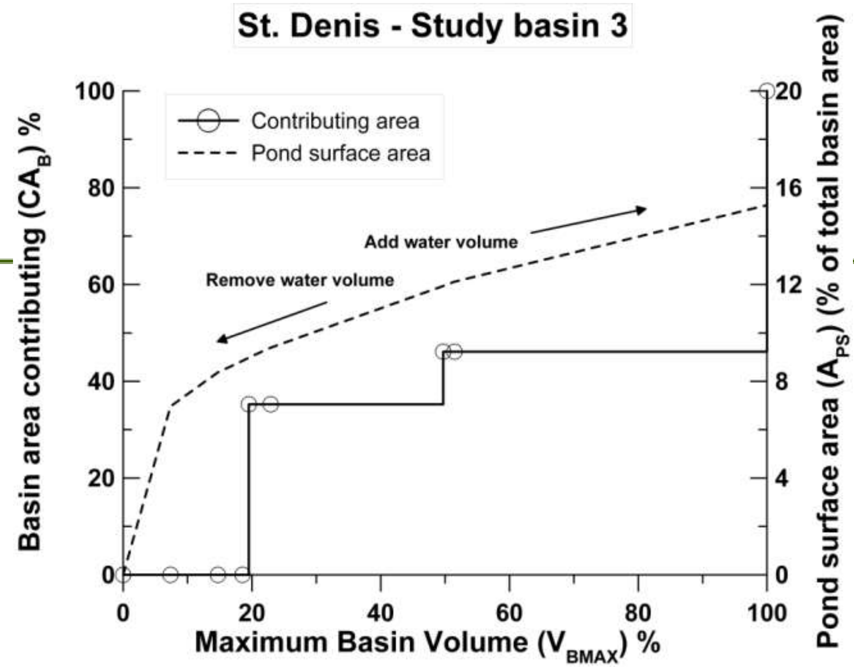
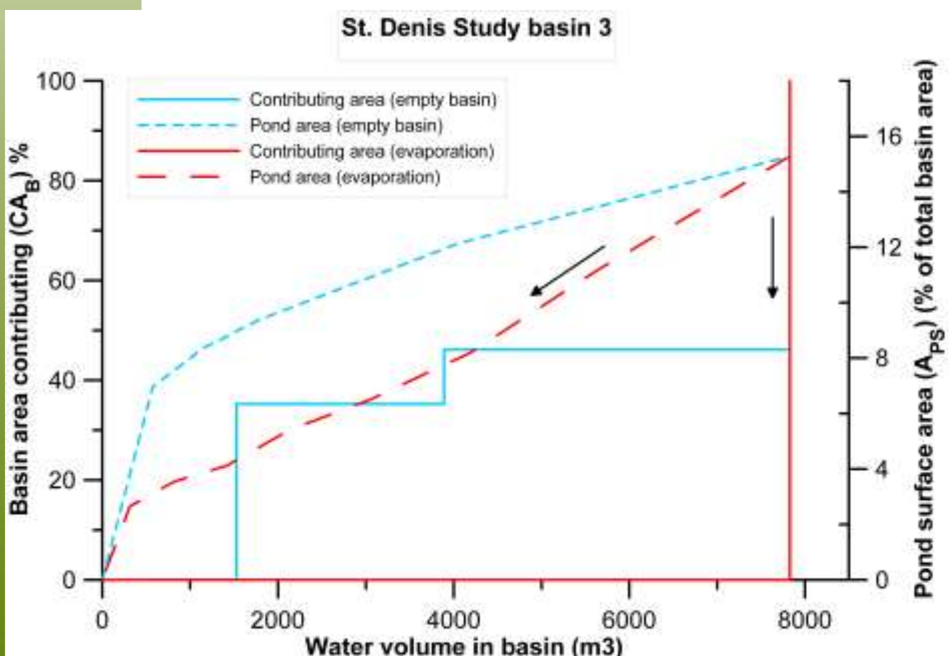
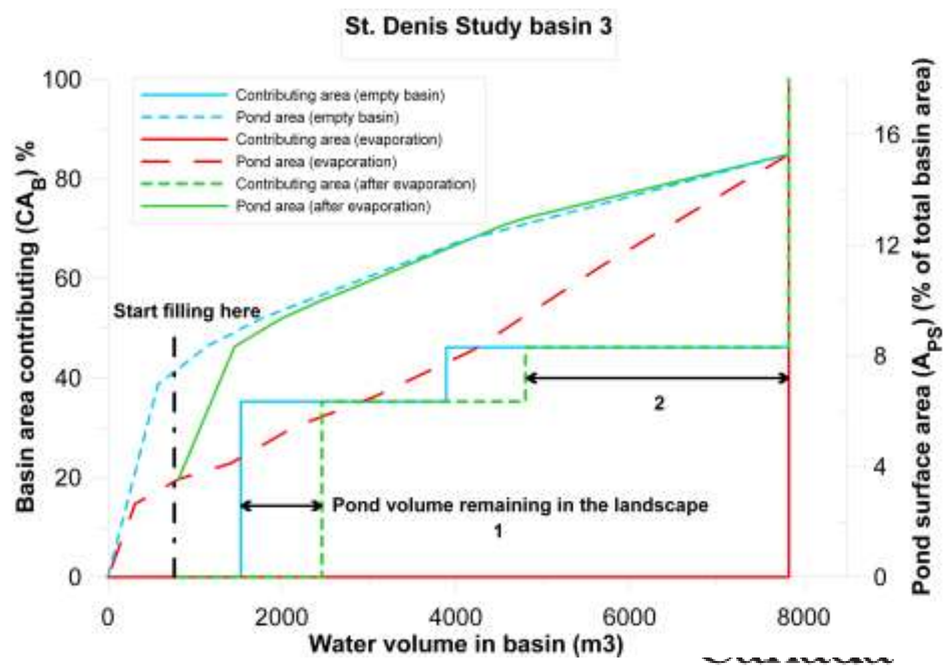
Hysteresis



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}) %

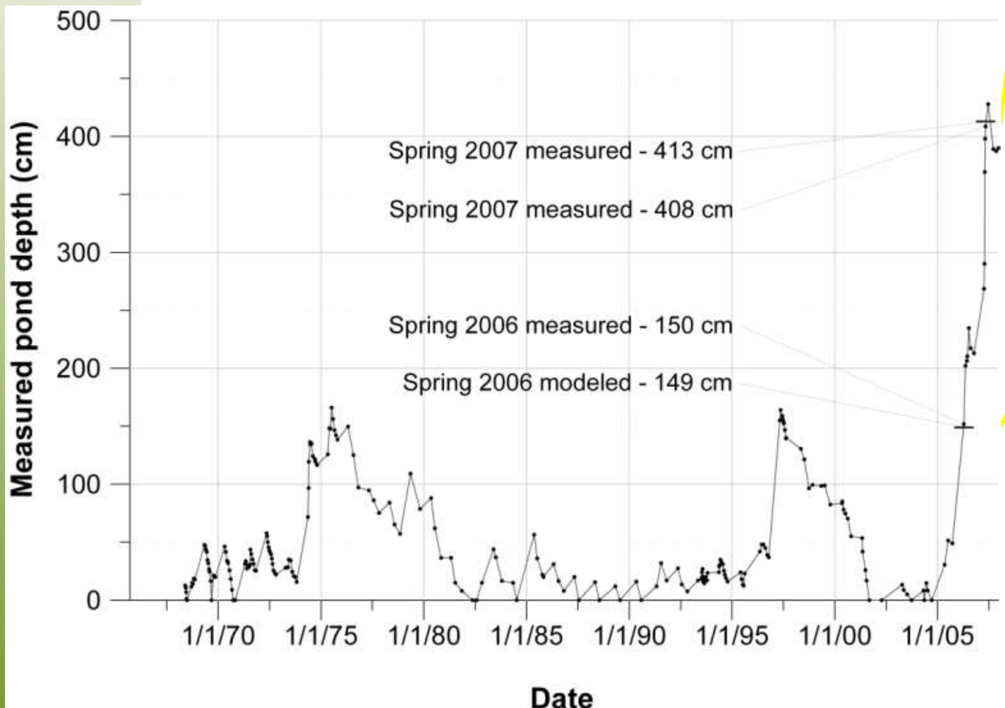


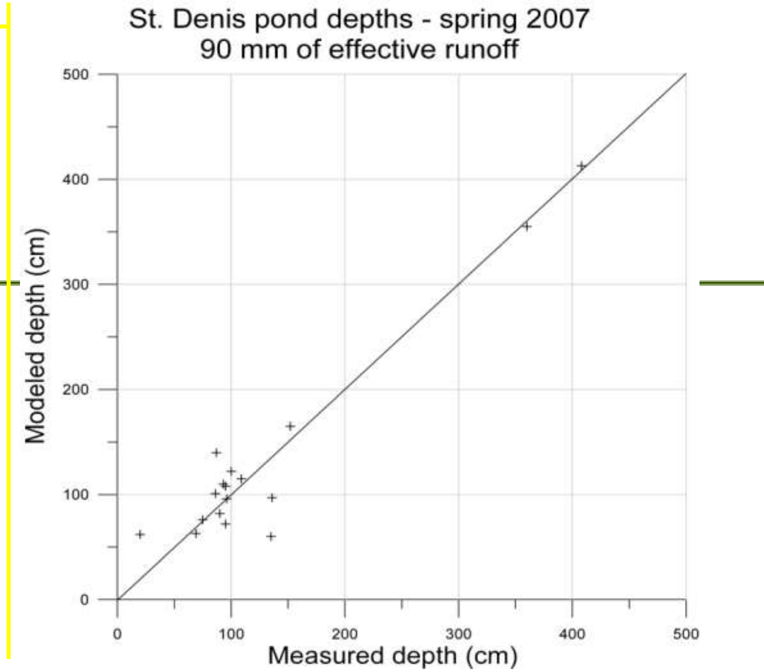
St. Denis Study basin 3
Contributing area (empty basin)
Pond area (empty basin)
Contributing area (evaporation)
Pond area (evaporation)
Basin area contributing (CA_B) %
Pond surface area (A_{PS}) (% of total basin area)
Water volume in basin (m3)

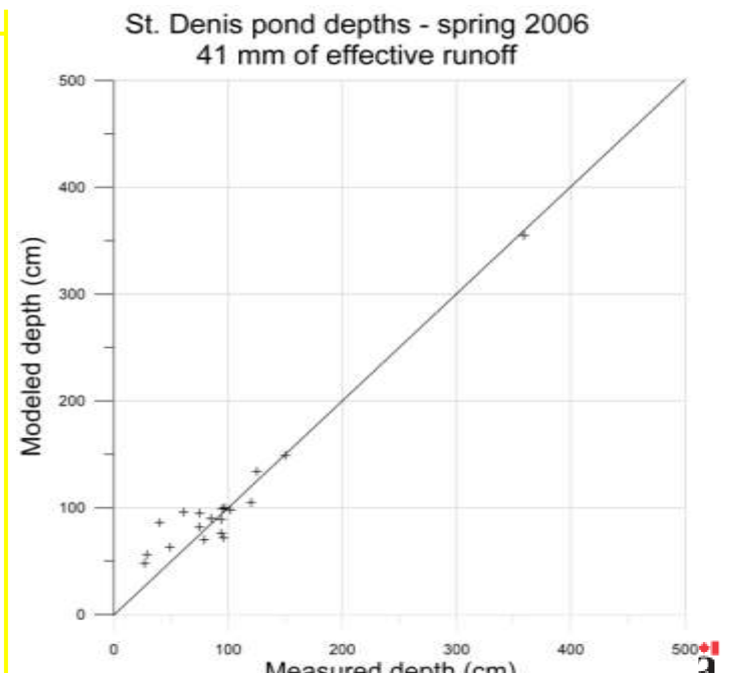


St. Denis Study basin 3
Contributing area (empty basin)
Pond area (empty basin)
Contributing area (evaporation)
Pond area (evaporation)
Contributing area (after evaporation)
Pond area (after evaporation)
Start filling here
Pond volume remaining in the landscape
1
2
Basin area contributing (CA_B) %
Pond surface area (A_{PS}) (% of total basin area)
Water volume in basin (m3)

Modeled vs. Actual pond depths







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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
  - MESH – SA validation for entire SSRB currnetly underway with focus on streamflow and Kenaston vertical water budget.
  - Soil Mositure Data Assimilation experimints this summer
- 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