Simulating the Impact of Land Use Change on Watershed Hydrologic Characteristics

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Canadian Forage and Grassland Association
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Hydrologic Simulation

HOURS
DAYS
WEEKS
MONTHS
YEARS
..
1000s YEARS

Future Prediction

High Performance Computer

HGS™ SIMULATION

Weather - Climate Forecast

What If Scenarios

Calibrate to Historic Data

Add / Alter Data Parameters

Create / Alter Digital Model

Real Life Domain

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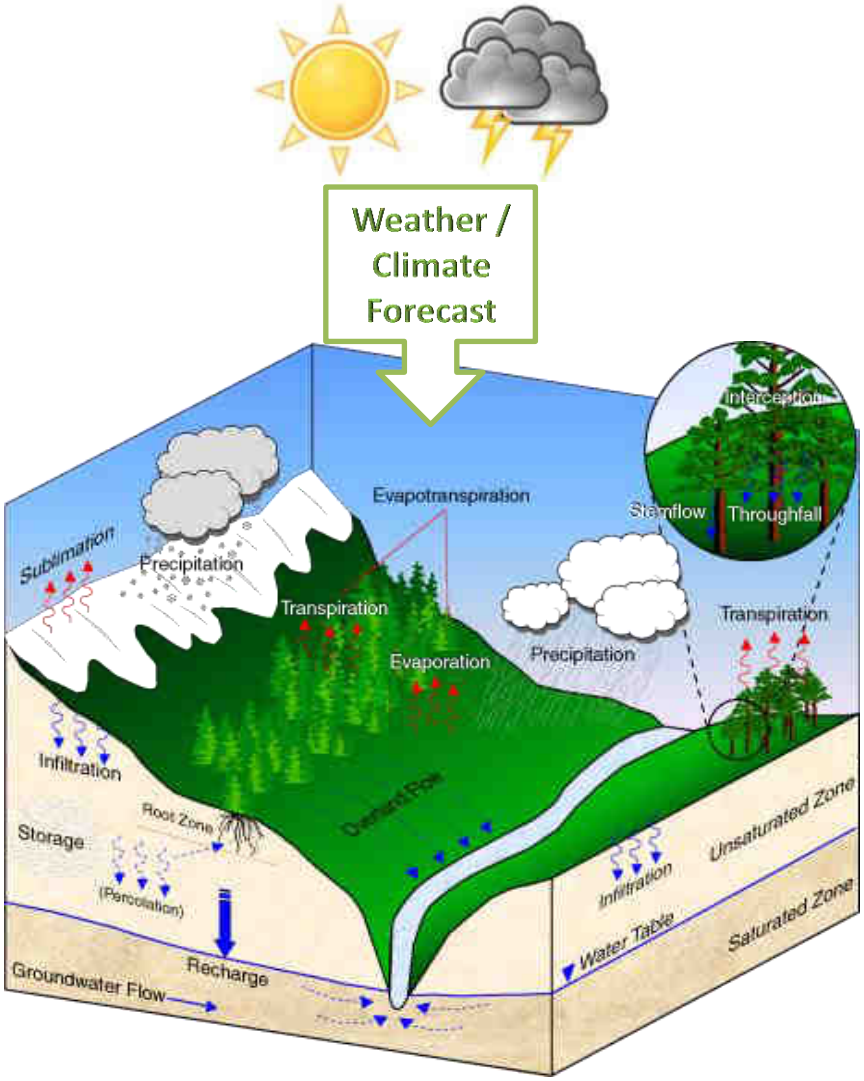
The HydroGeoSphere Model



HGS Simulation™

- Class leading 3D hydrologic simulation software
- Simulation of the entire terrestrial water cycle
- Utilizes state of the art HPC
- Emphasis on physics
- Minimal use of empirical relations

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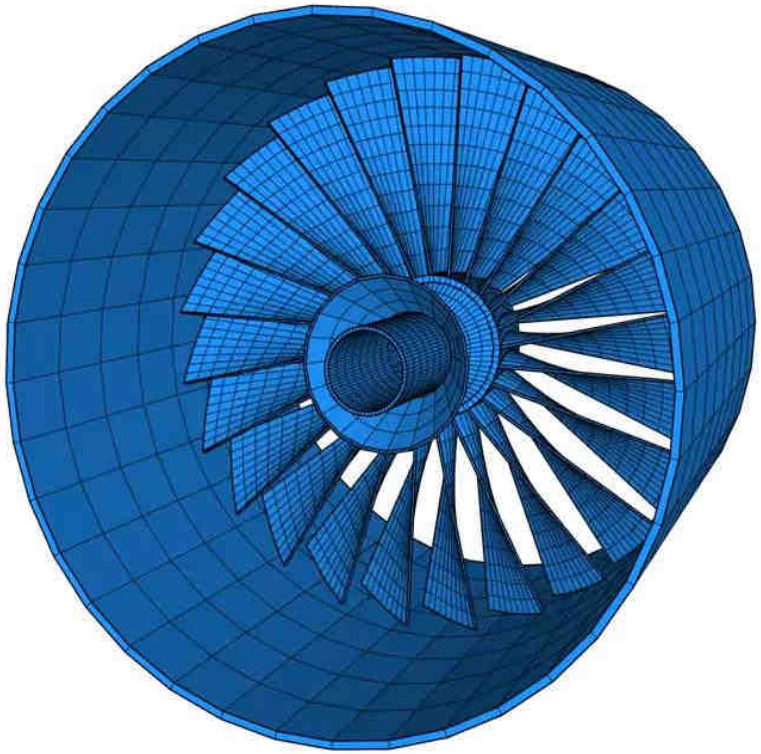
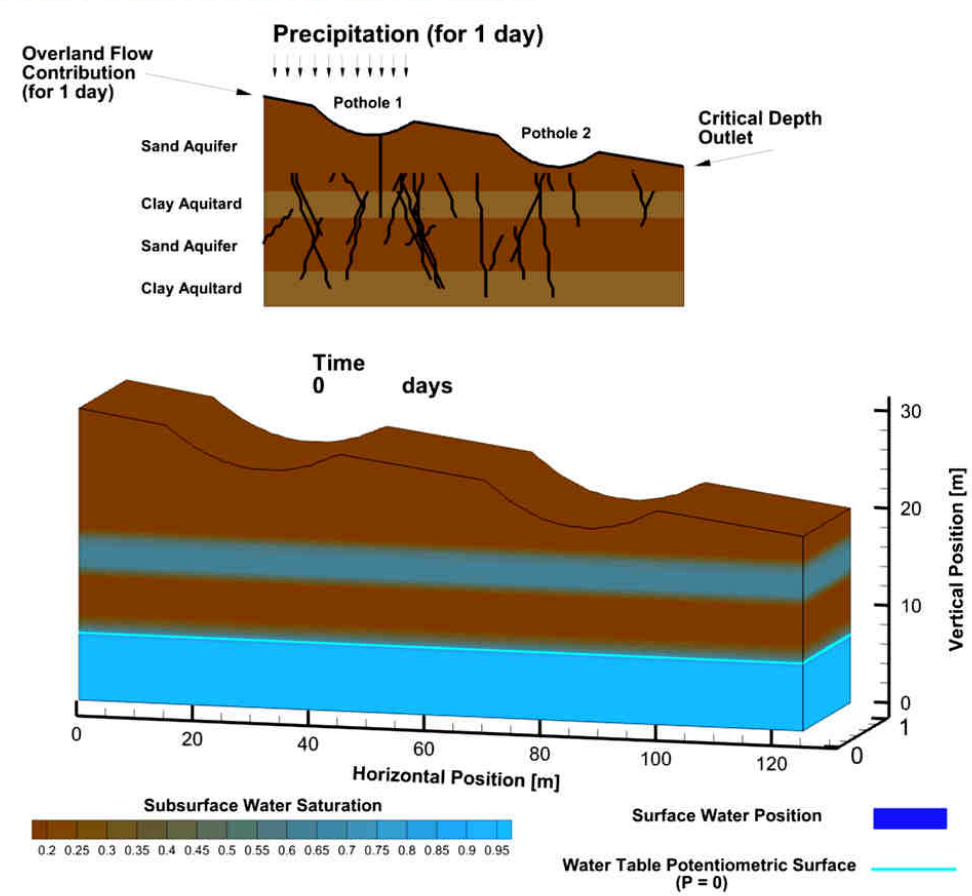
3

FE Solution Concept

Finite Element Analysis



HGS Simulation



Motivation for an Integrated Hydrology Model

- Surface water models commonly lack rigor in the treatment of 3D subsurface variably-saturated flow and solute transport processes, especially in complex geologic settings
- Groundwater models typically ignore dynamics of overland/stream/wetland flow processes & surface water quality issues
- Coupling between surface/subsurface models commonly performed via sources/sinks without feedback or weakly through simple iteration

MFGA roots run deep

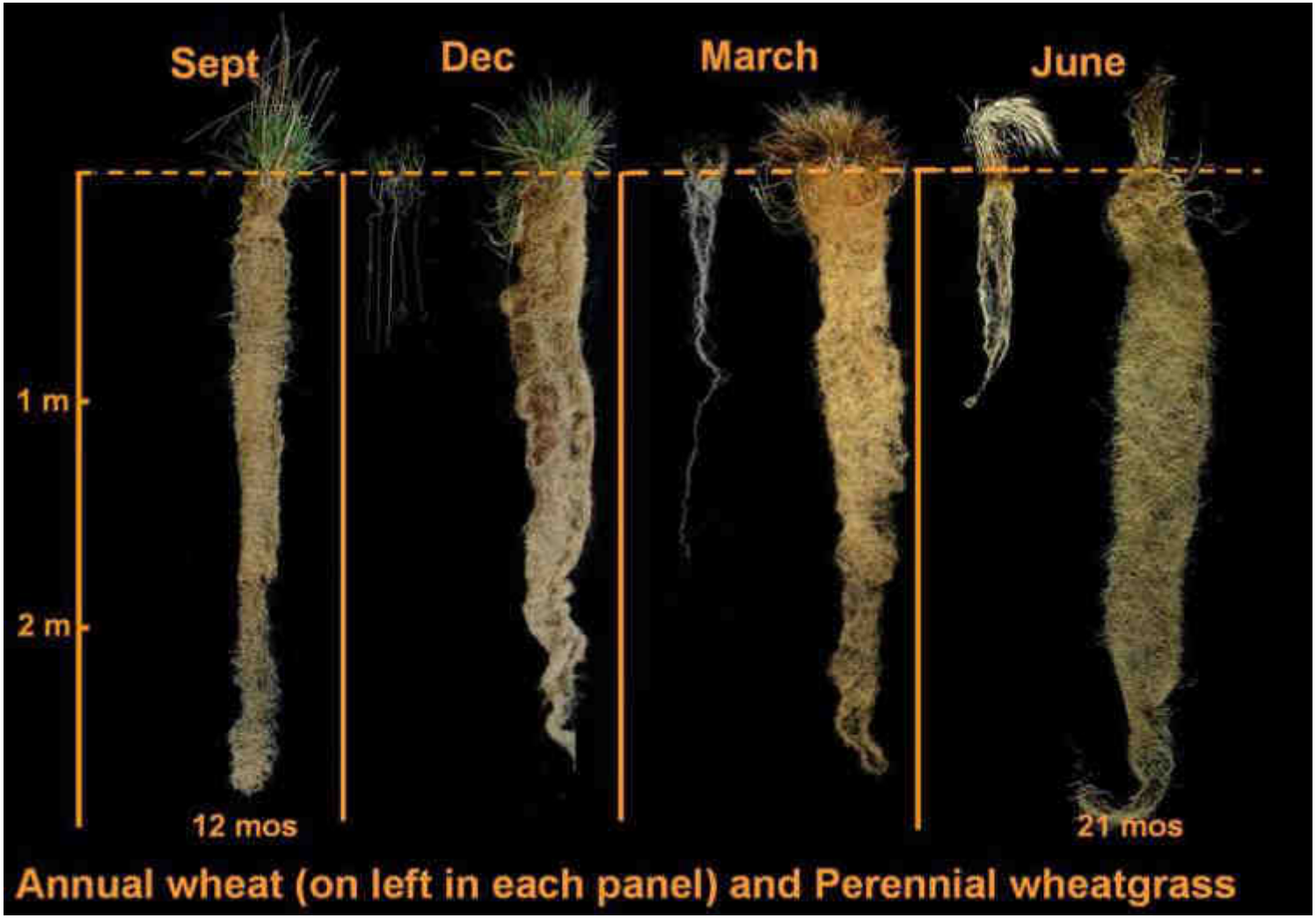


Image from landinstitute.org

Preliminary Landcover Sensitivity Tests

1. **Scenario 1 (flow_out_woodlands)**

Irregular channel with meanders and dense growth woody debris (logs),

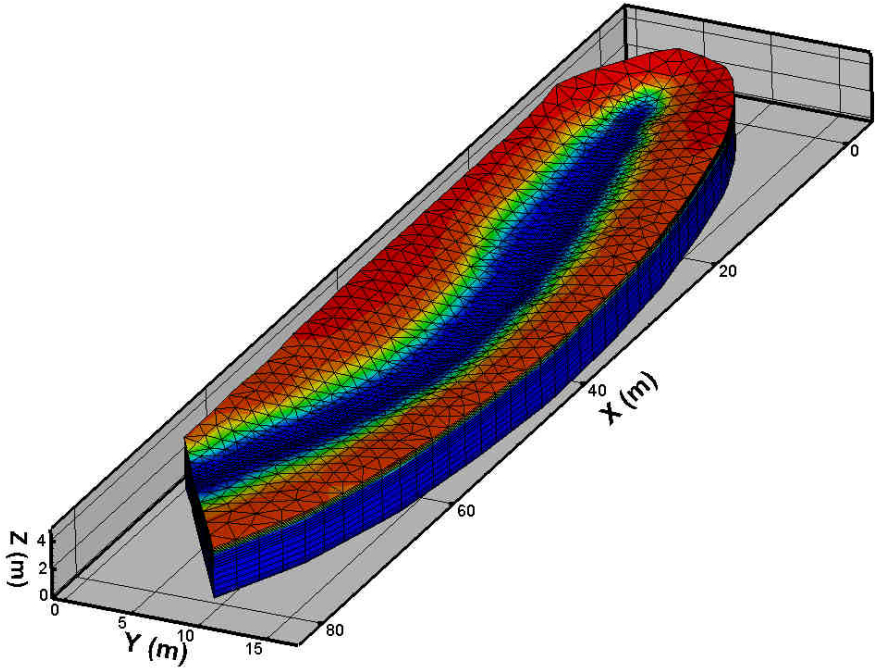
Overbank with n=0.5 and stream channel n = 0.06

2. **Scenarios 2 (flow_out_grasslands):**

Short grass Prairie with overbank n = 0.1 and stream channel n = 0.05

3. **Scenario 3: (flow_out_original):**

Minimal cover with overbank n=0.3 and stream channel = 0.03



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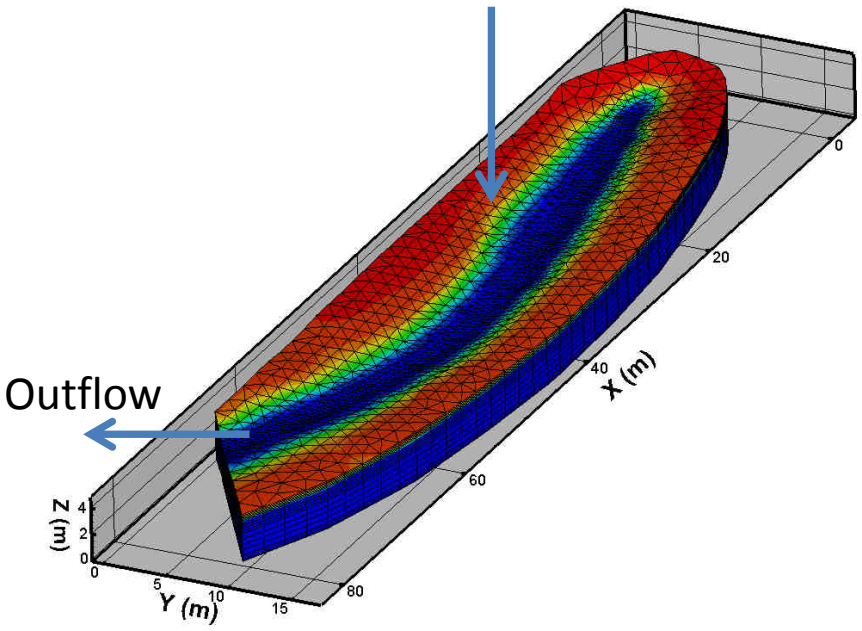
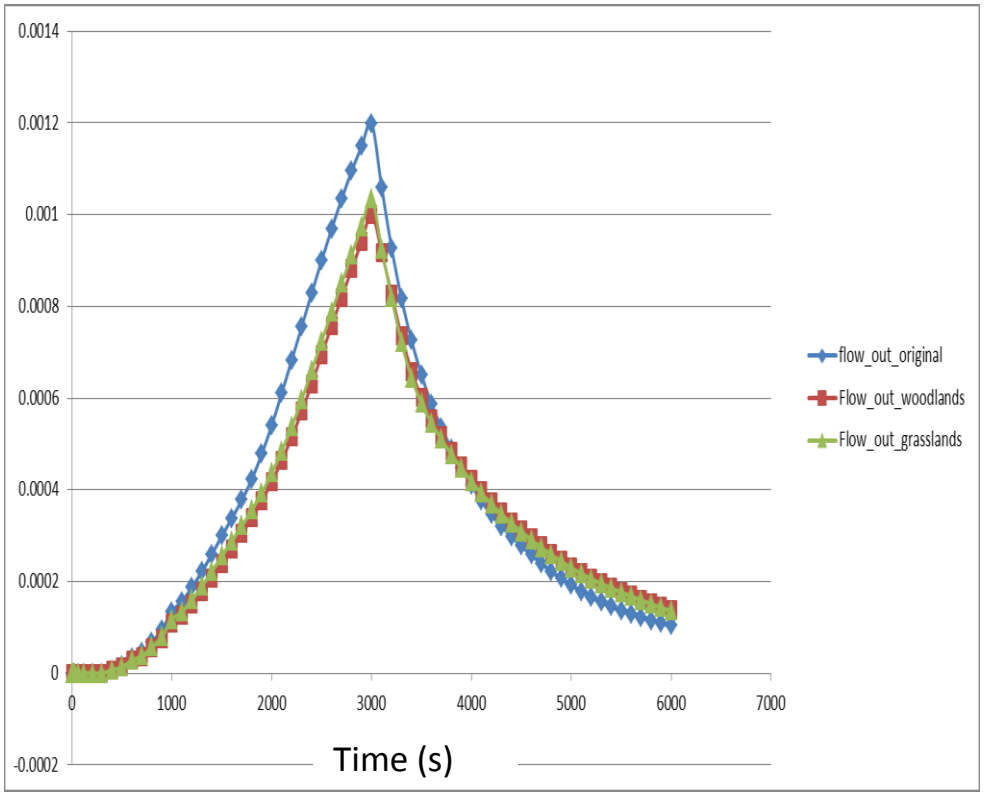
Preliminary Test Results

2 cm/hour of precipitation
for 50 minutes (3000 sec)



Watershed Outflow (m^3/s)

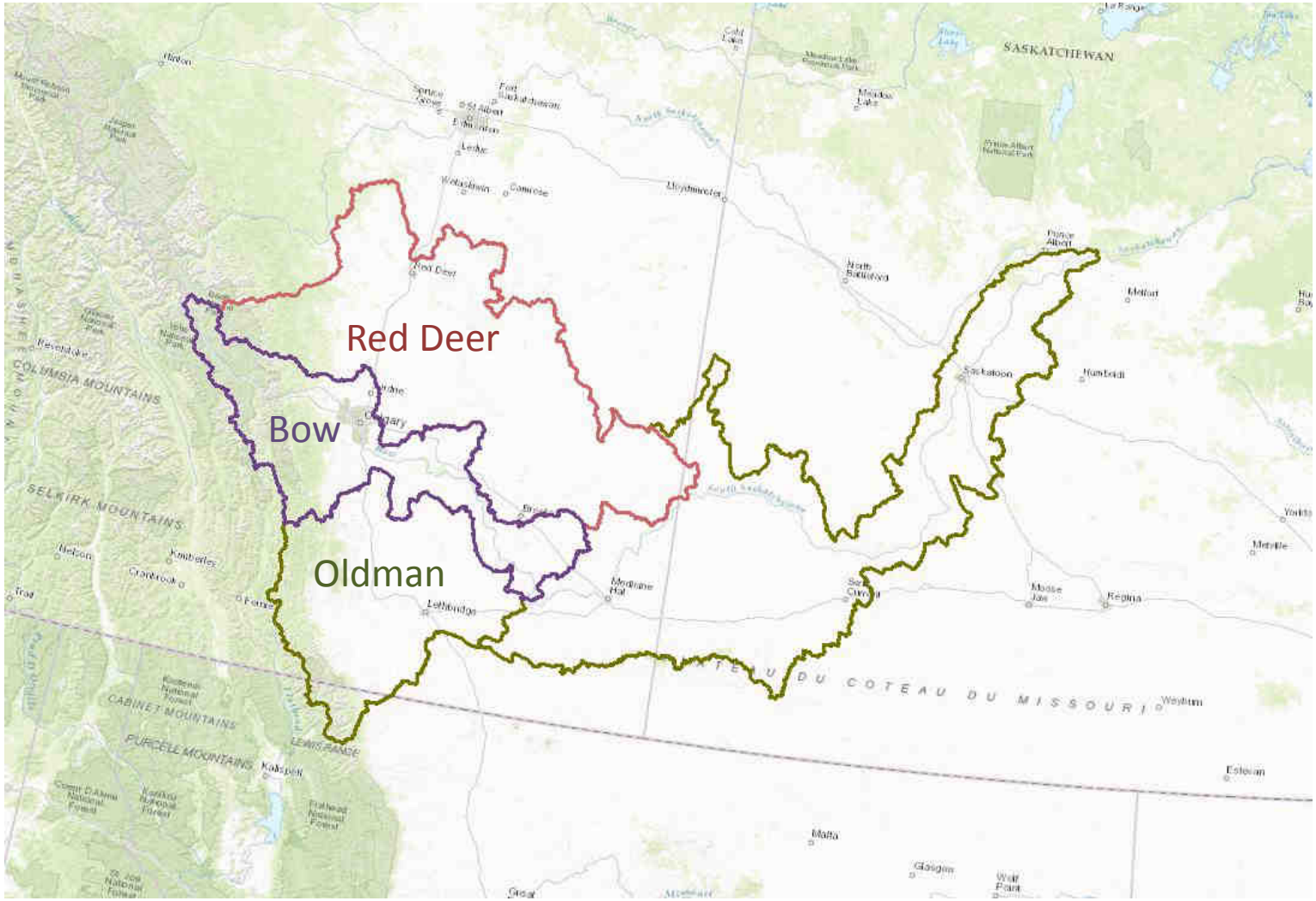


South Saskatchewan River Basin (SSRB) Project

Alberta Federation of Agriculture

DYMAC Risk Management Solutions Ltd.

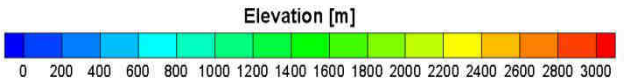
South Saskatchewan River Basin (SSRB)



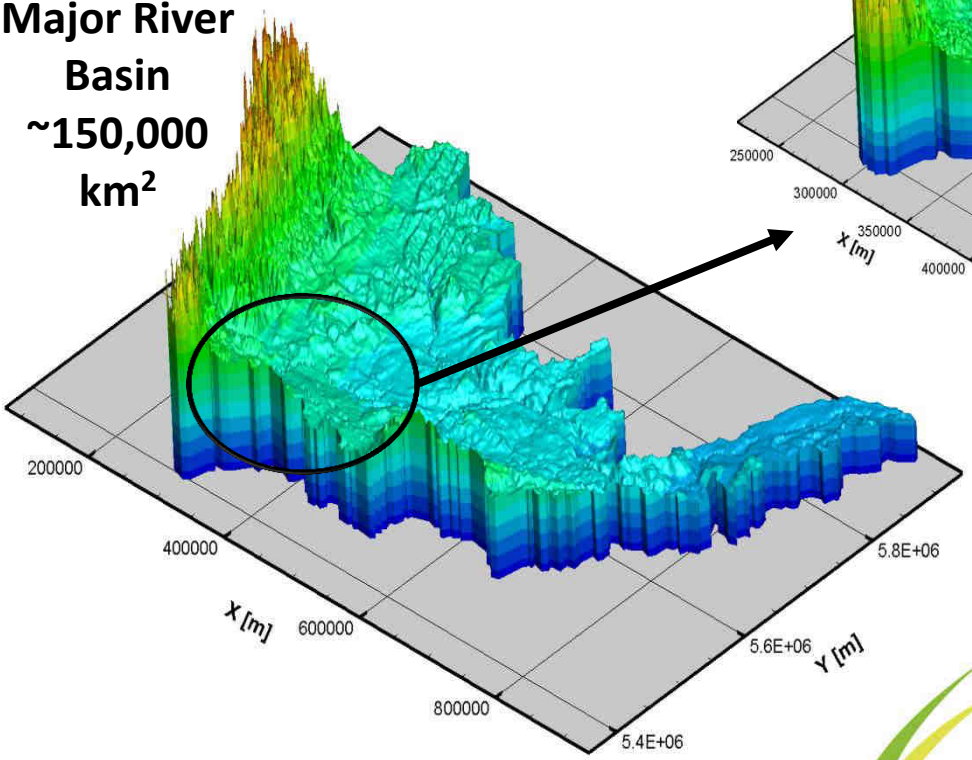
Modelling Across Scales in the SSRB

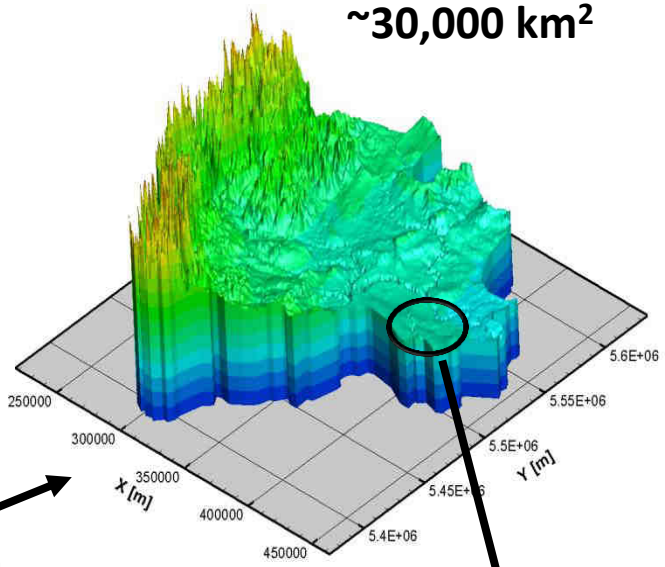
Sub Basin
~30,000 km²

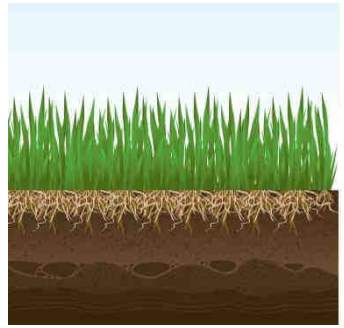
Field – Soil Column Scale
~1 km²

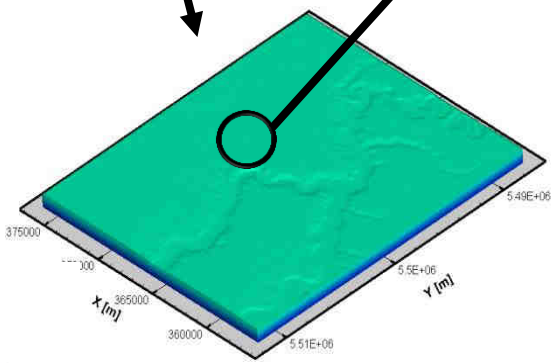


Major River Basin
~150,000 km²









Regional Scale
~500 km²

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Alberta Federation of Agriculture

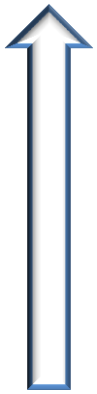
DYMAC Risk Management Solutions Ltd.

Project Objectives

- **Major River Basin**
  - Capture broad hydrologic response to weather events and climate variability
  - Provide boundary conditions for smaller scale and higher resolution simulations
- **Sub Basin**
  - Assess broad scale overland flood risk, and soil moisture variability throughout the South Saskatchewan R. Basin
- **Regional Scale**
  - Assess local impacts and effects of flood mitigation strategies
- **Field Scale**
  - Provide a high resolution, physics based analysis of water cycling in the root zone and shallow soil profile in the regions where hay and pasture risk rating functions are to be developed

SSRB Model Construction

Soils



Bedrock Geology

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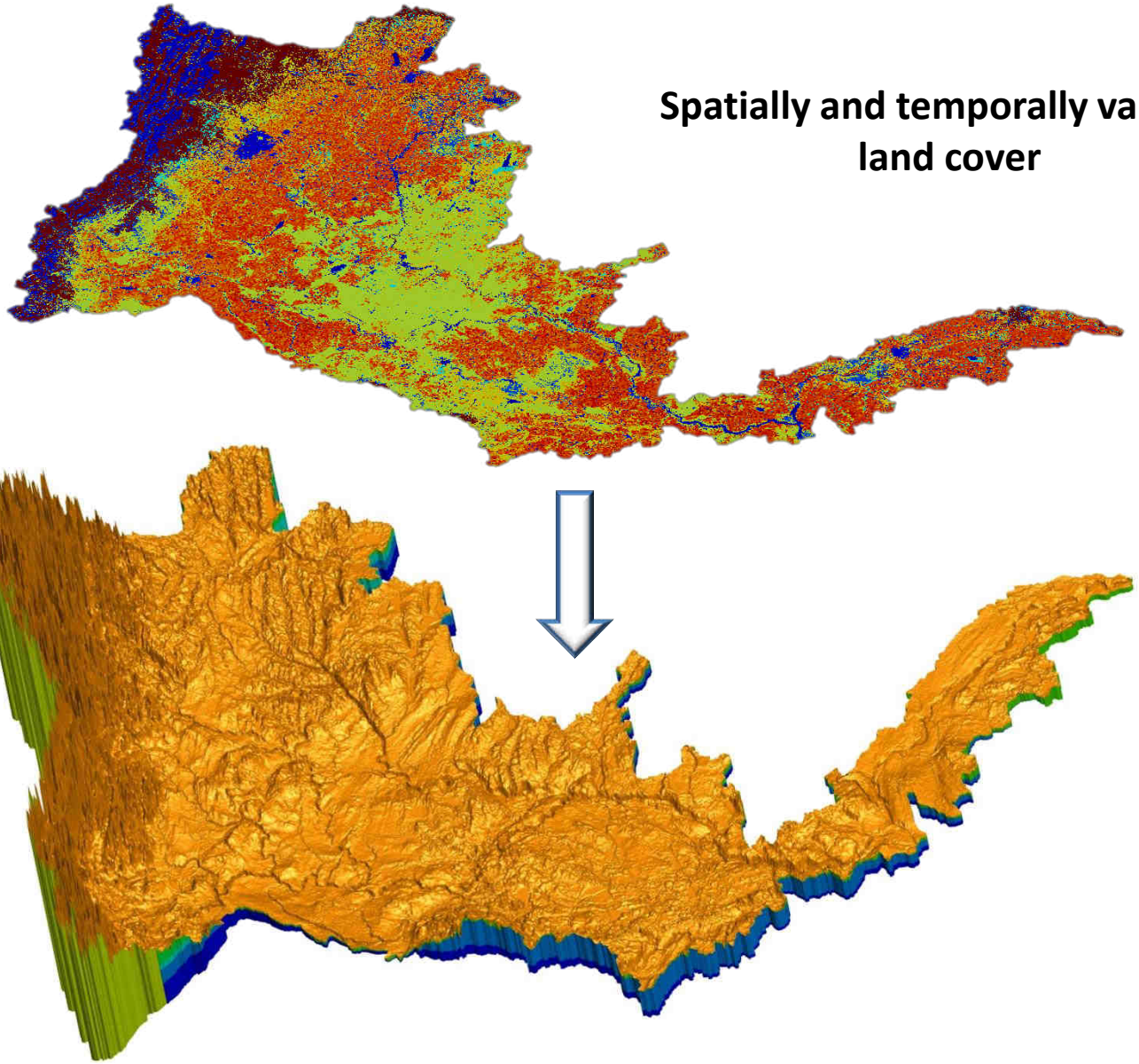
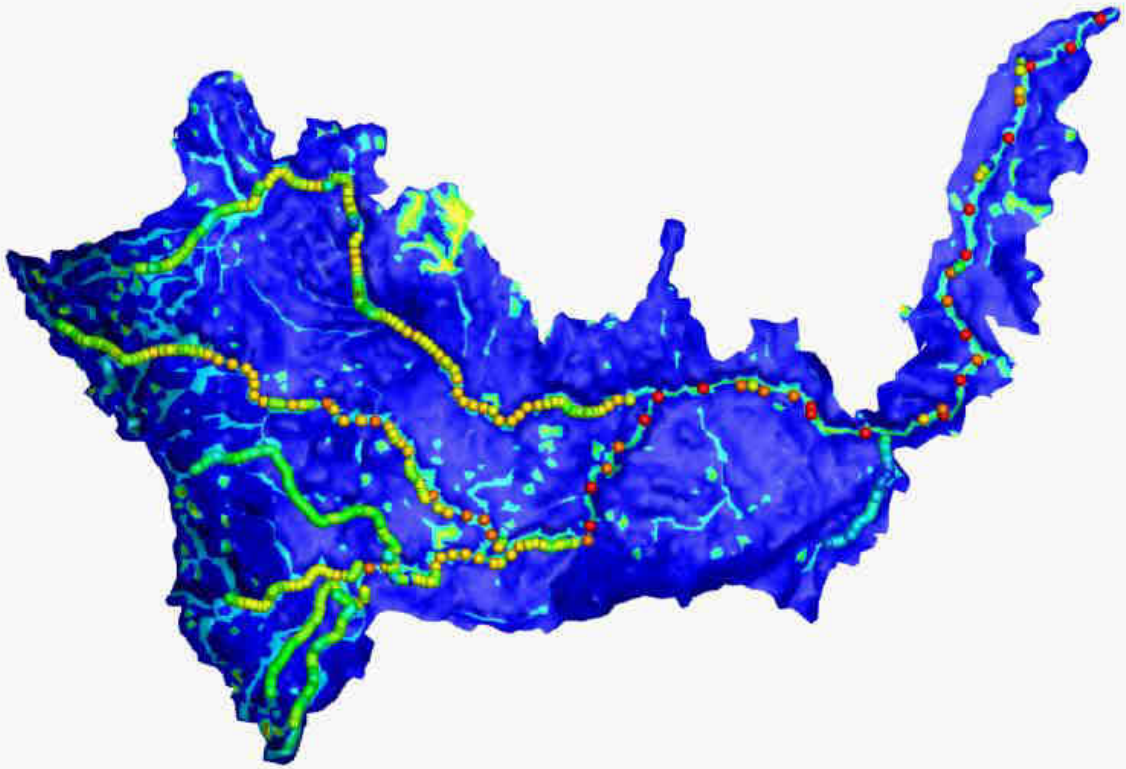
SSRB Model Construction



Spatially and temporally variable land cover

Basin Scale Surface Water Flows

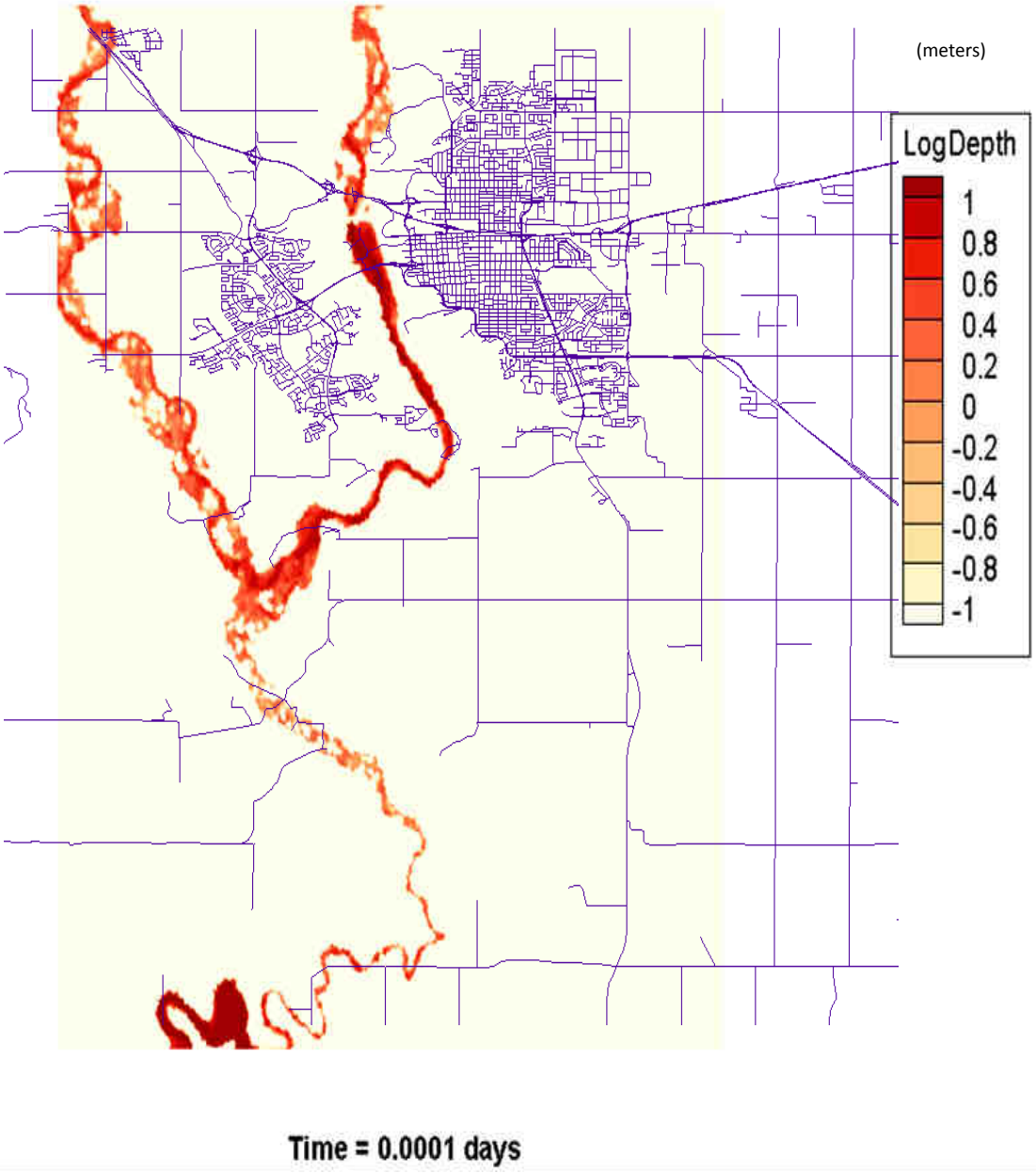


Regional Flood Risk - Lethbridge

Dynamic representation of flood event across broad land area

Rain 20 cm/day
for 2 days
+ basin flood wave propagation

650 km²



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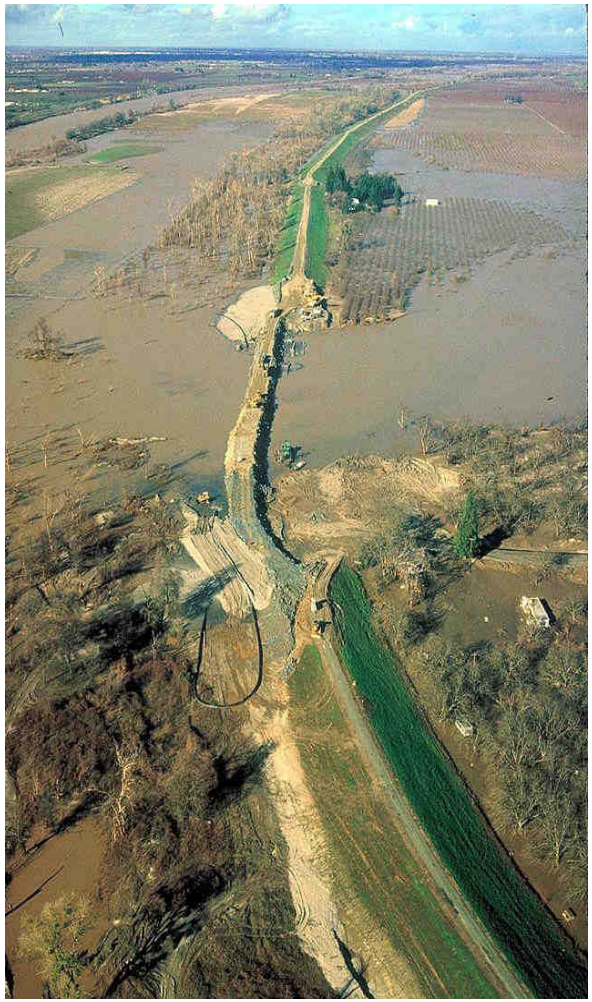
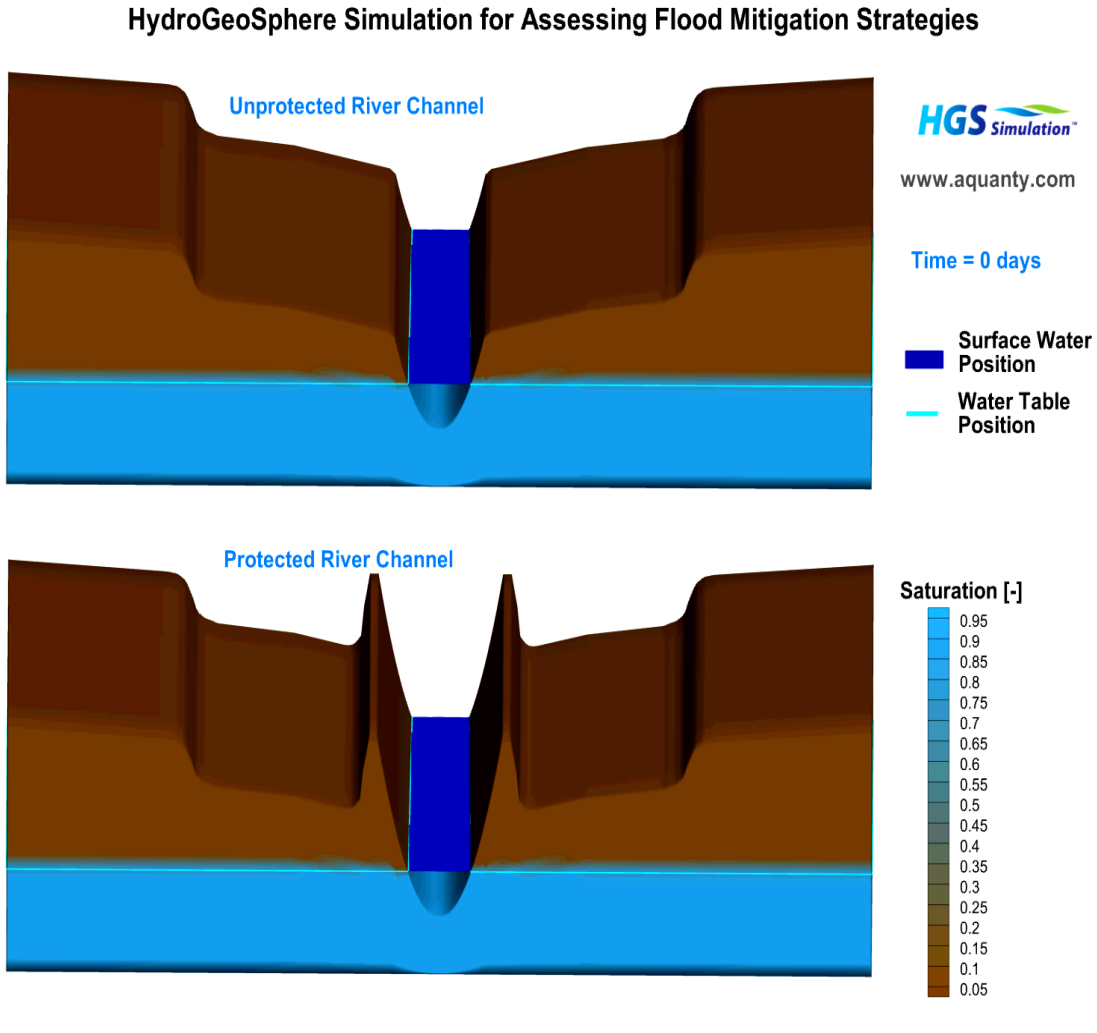
Municipal Flood Simulation – Medicine Hat

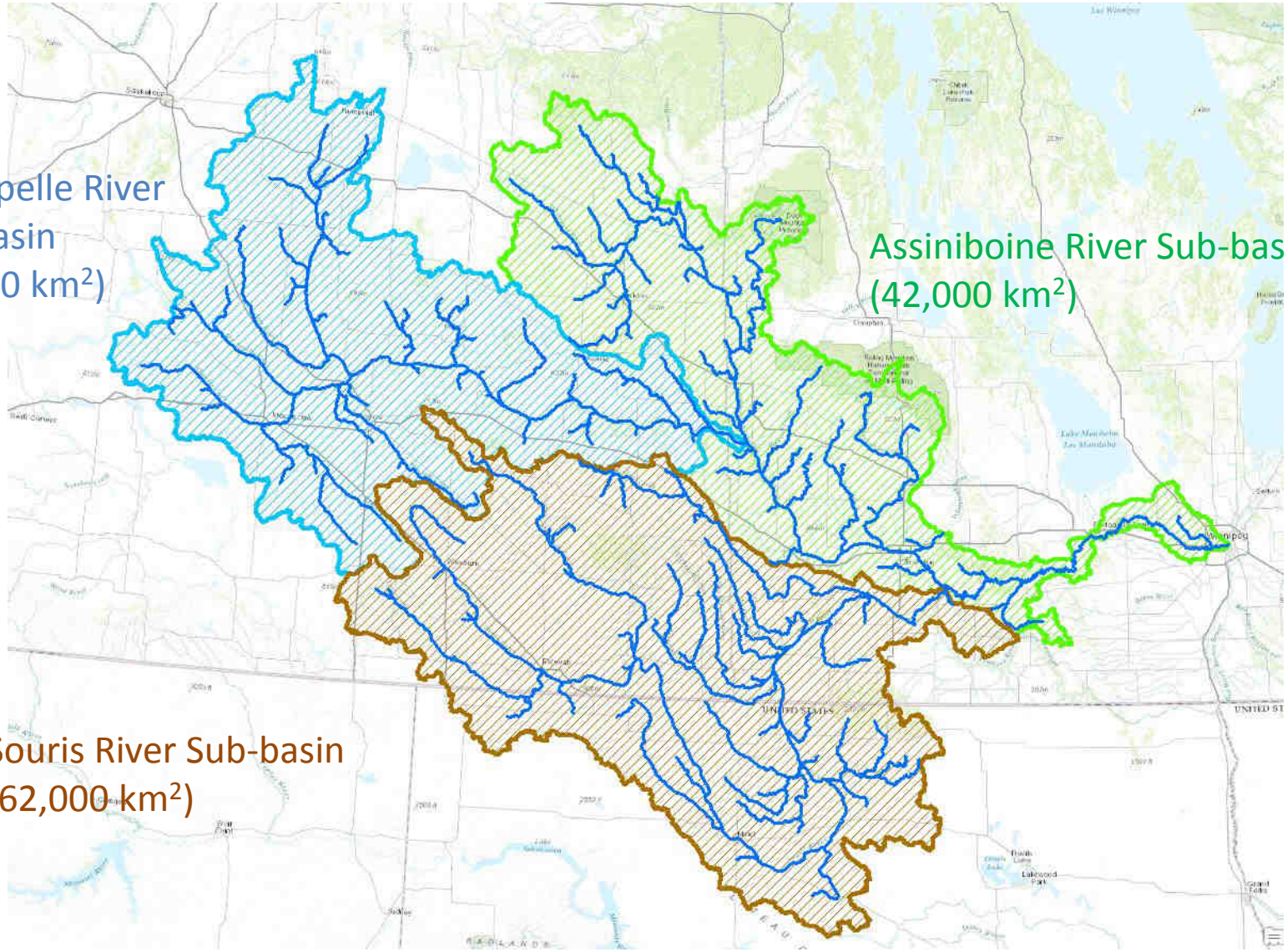
Simulation of Mitigation Strategies



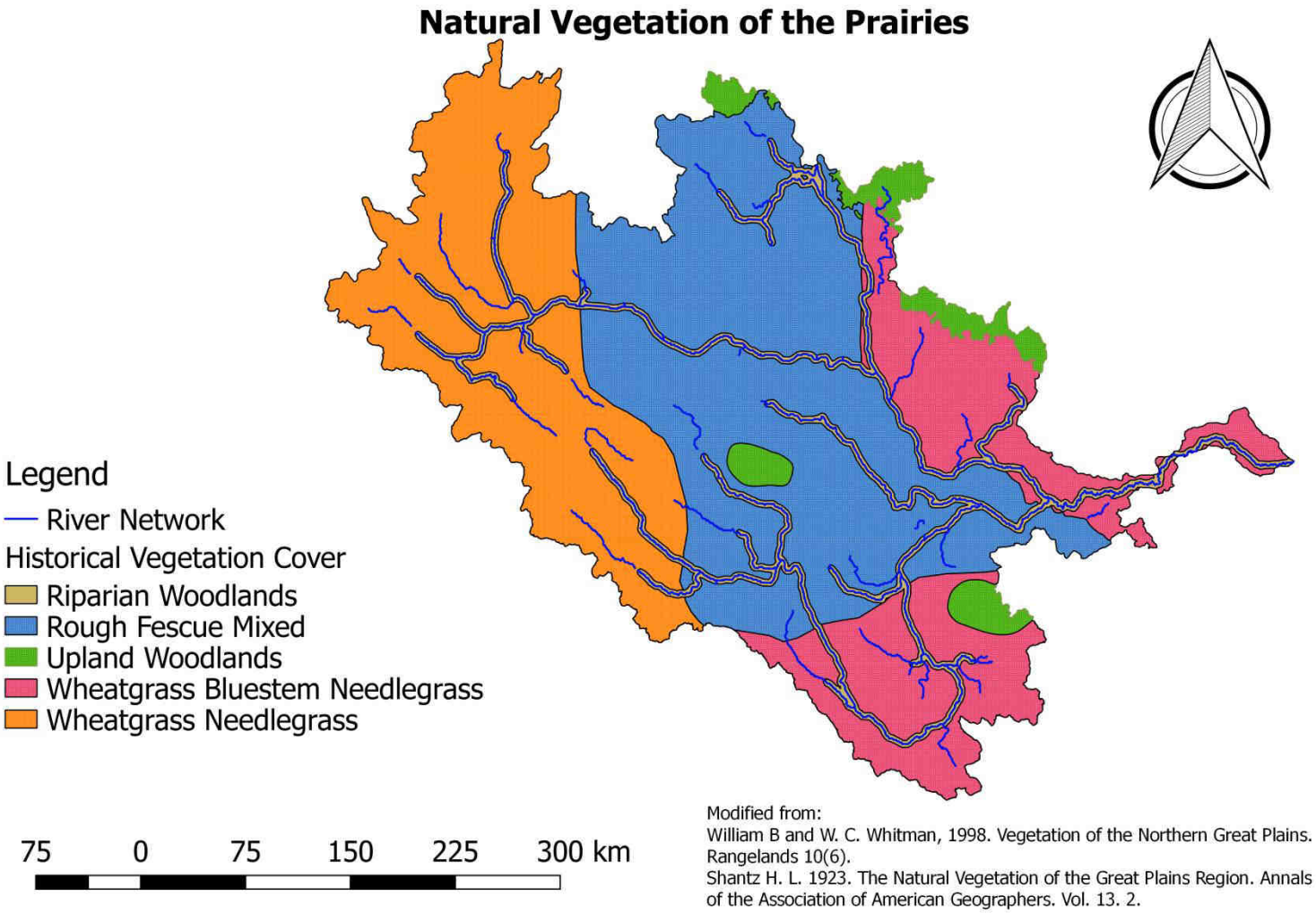


Assiniboine River Basin (ARB) Project

Assiniboine River Basin (~154,000 km^2)

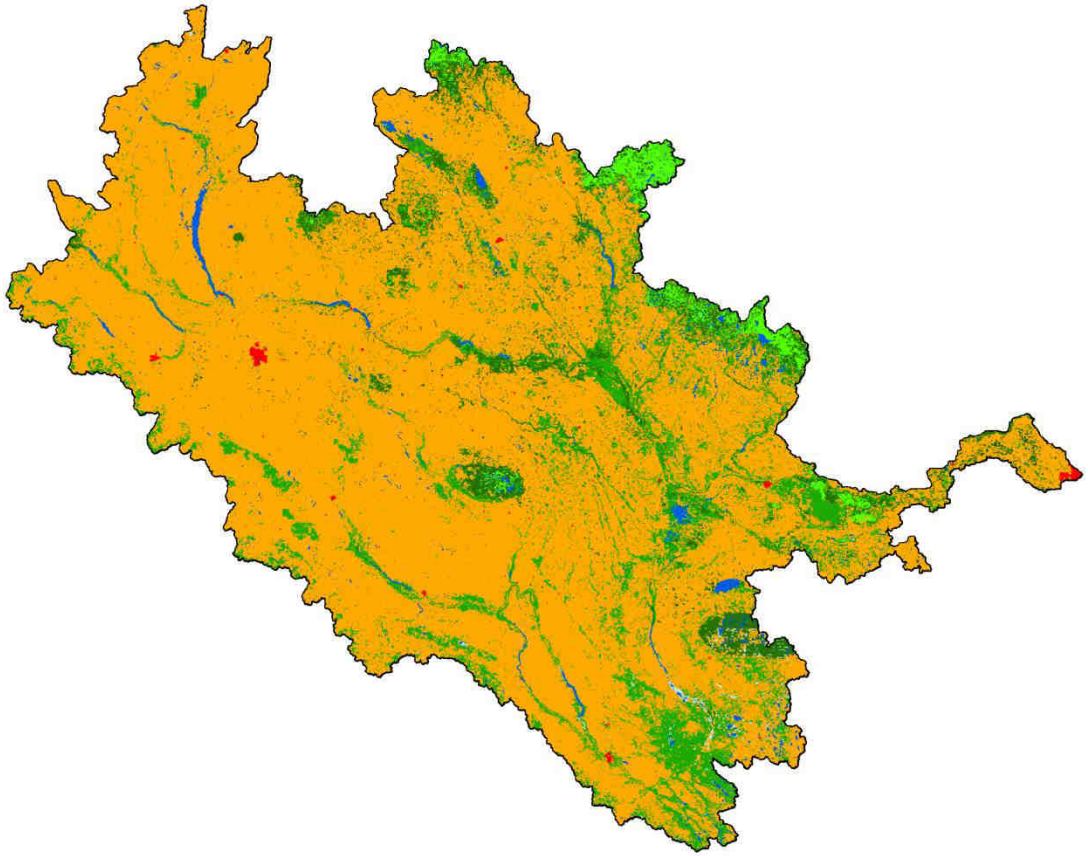


Pre-Settlement Landcover



Modified from:
William B and W. C. Whitman, 1998. Vegetation of the Northern Great Plains. Rangelands 10(6).
Shantz H. L. 1923. The Natural Vegetation of the Great Plains Region. Annals of the Association of American Geographers. Vol. 13. 2.

Present Day Landcover



- Wetland
- Water
- Urban and built-up
- Temperate or sub-polar shrubland
- Temperate or sub-polar needleleaf forest
- Temperate or sub-polar grassland
- Temperate or sub-polar broadleaf deciduous forest
- Mixed forest
- Cropland
- Barren land

Assiniboine River Basin Project

IBM
Hardware

Power 7 Server with high clock speed

Nested Hydrolologic Models

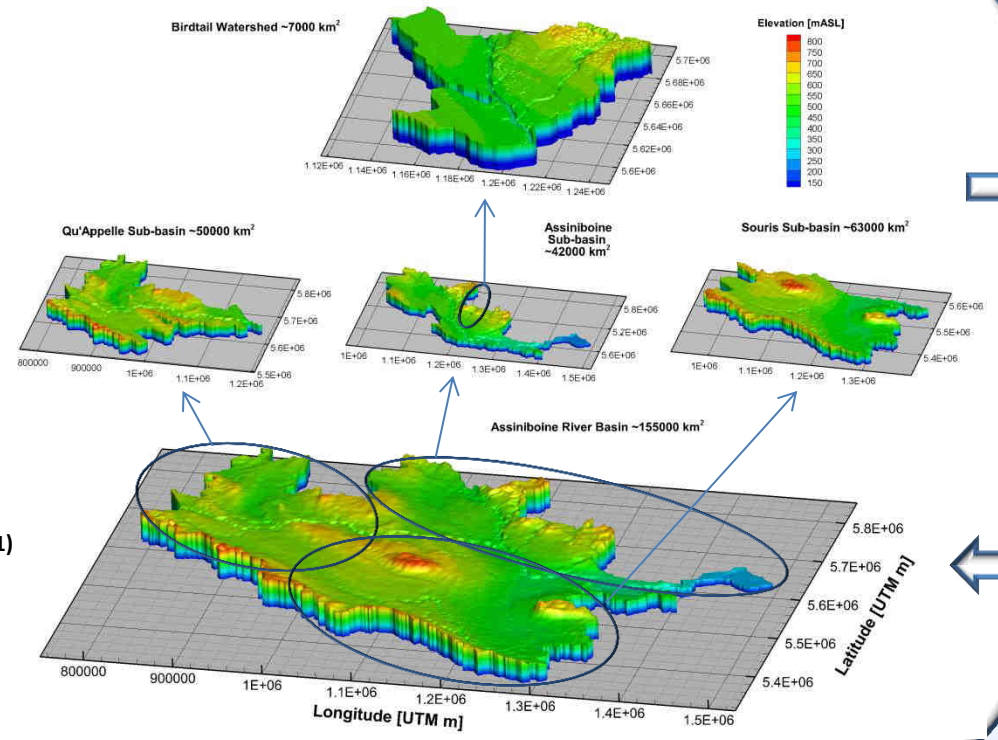
(+) Scale (-)

(-) Resolution (+)

Watershed (1)

Sub-basin (3)

Major basin (1)



HGS Simulation™

IBM
Analytics

Spatially Dependent Output Visualization and Storage
- River Flows
- Soil Moisture
- Groundwater levels

Model Driving Data
- Climate
- Observational Information

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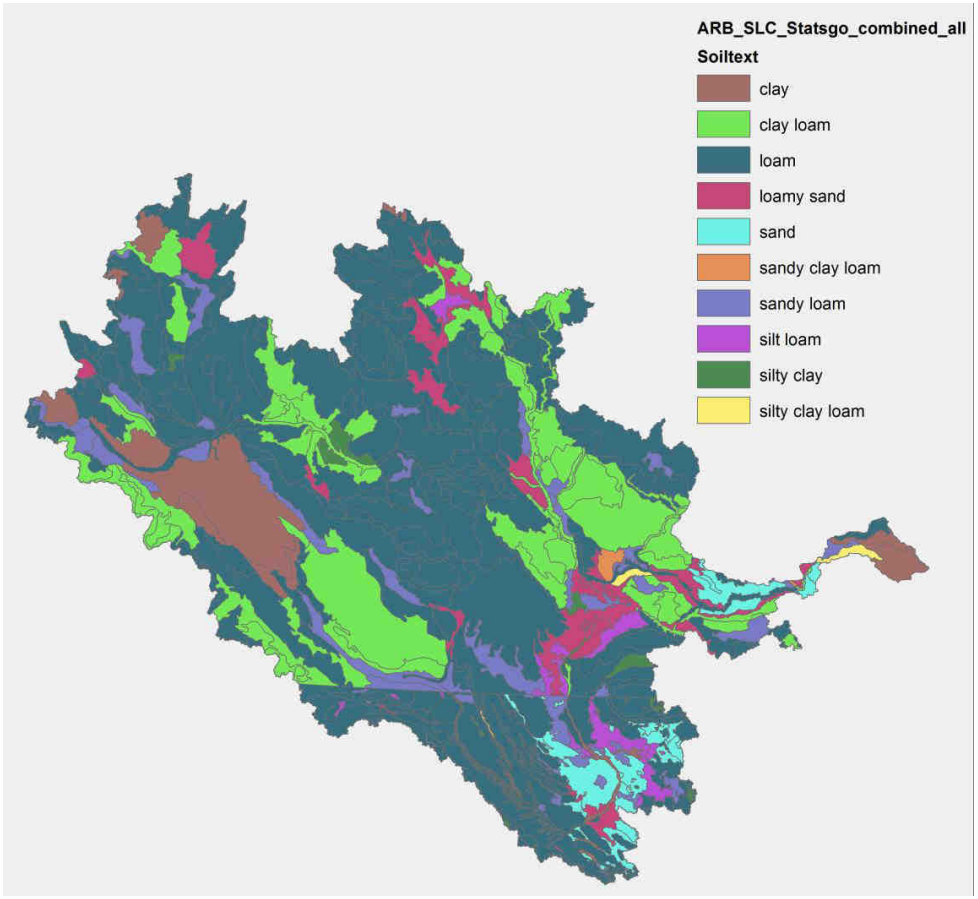
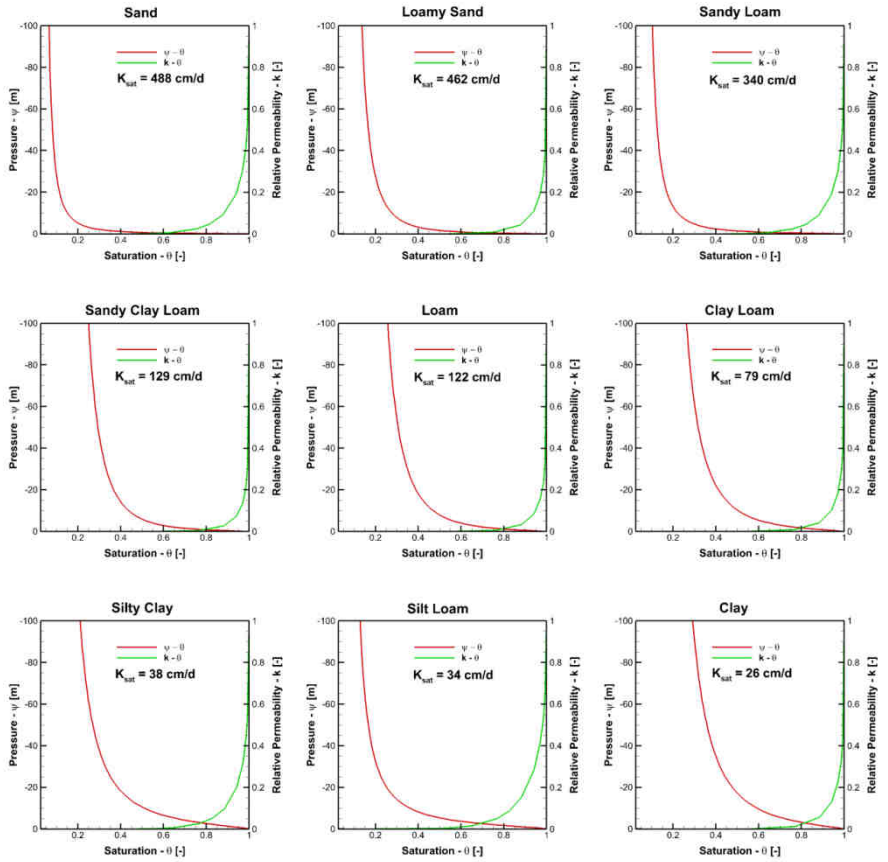
Basin Scale Soil Layer





US and Canadian soils data homogenized into 9 unique classes

0 – 1 m depth in model

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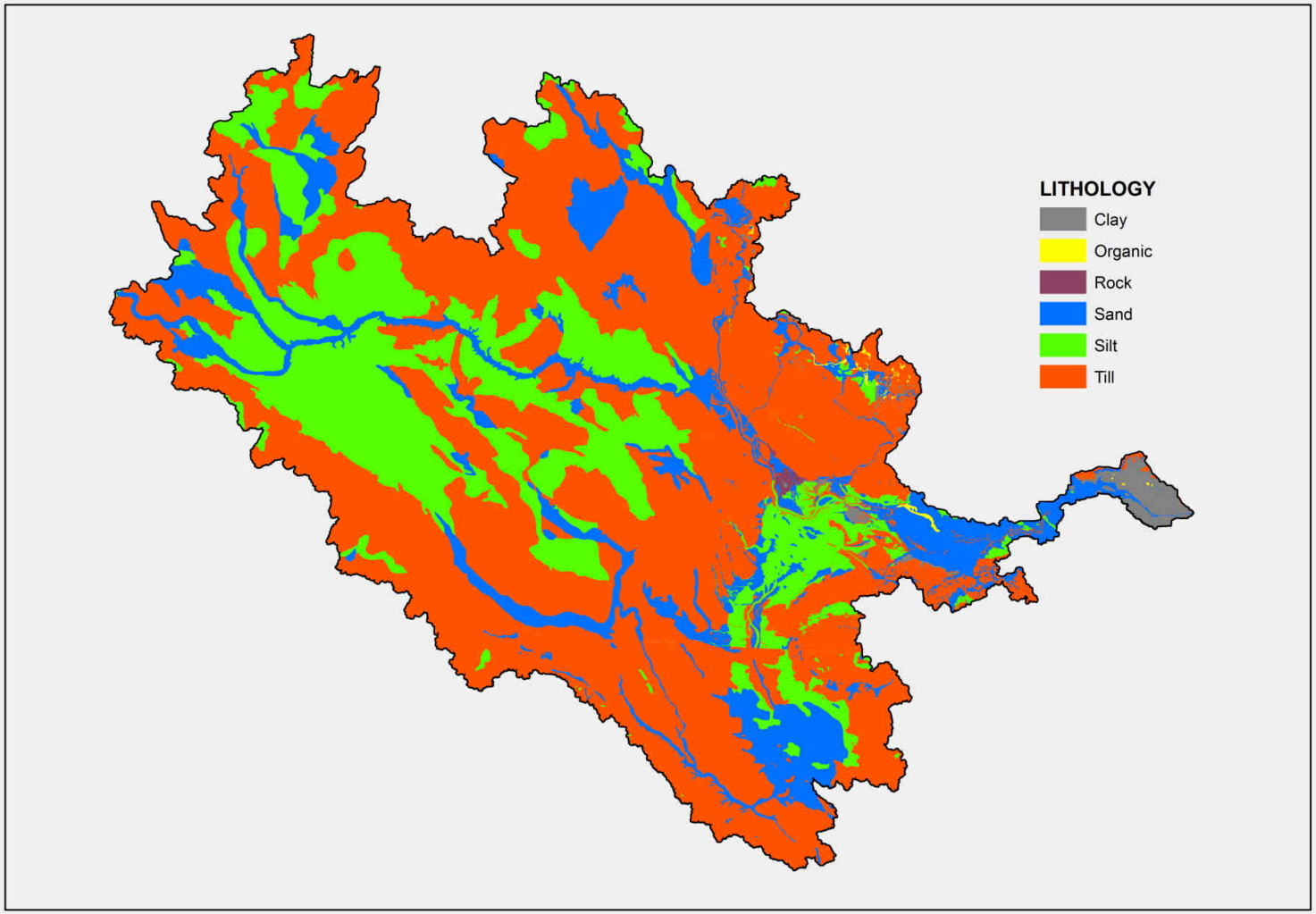
Surficial Geology Distribution



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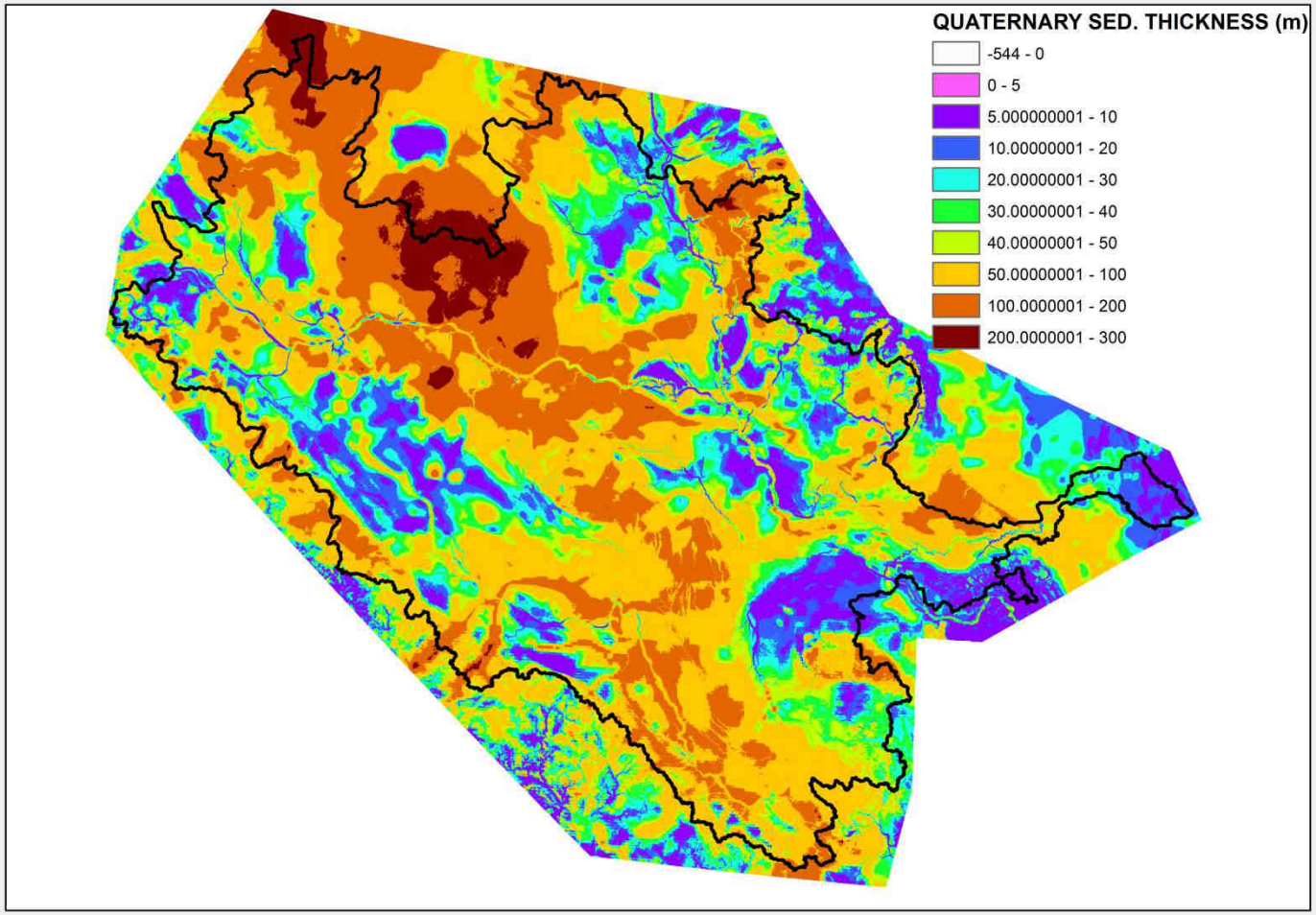
Surficial Sediment Thickness



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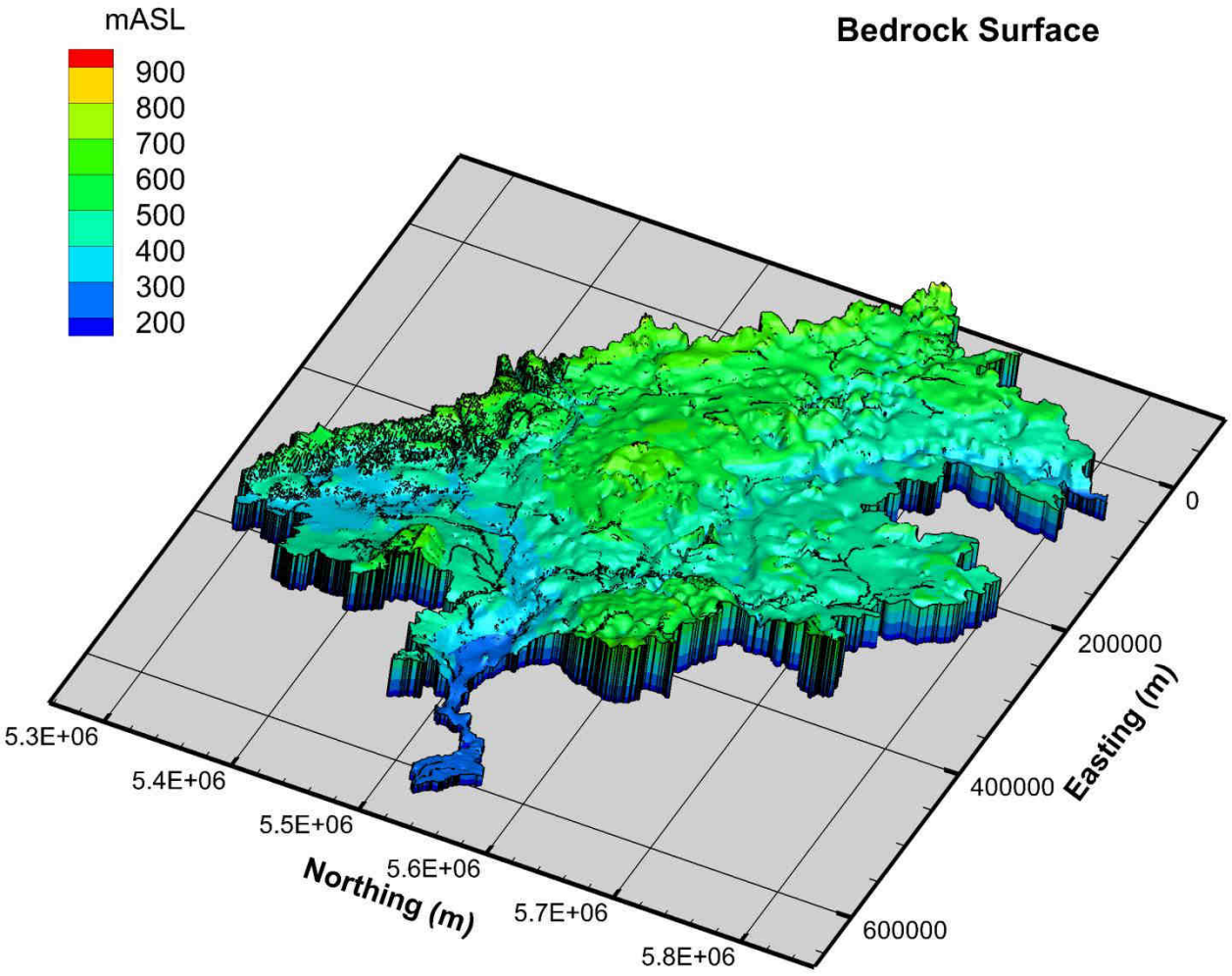
Bedrock Surface Finalized



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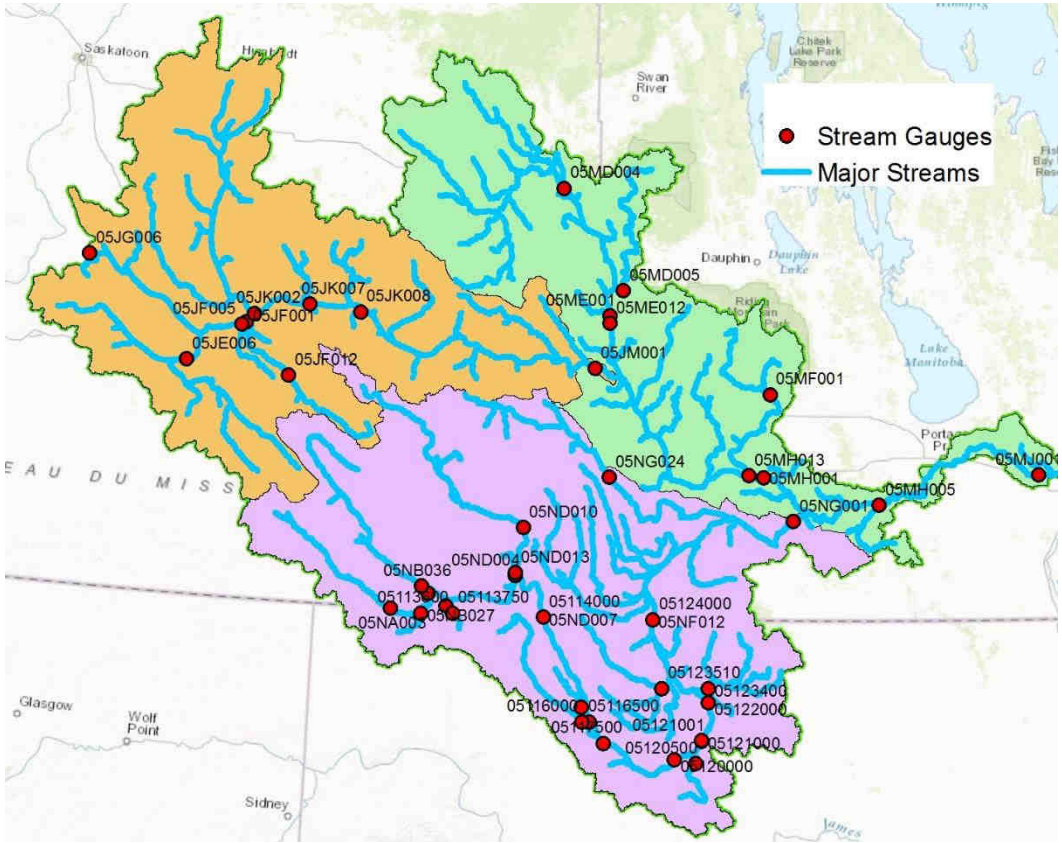
Soil Layer 1

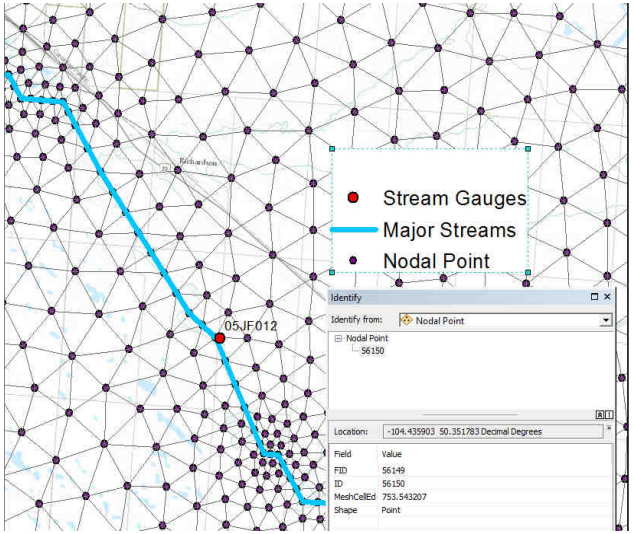
Quaternary Layer 1

Quaternary Layer 2

Bedrock Layer 1

Adding Surface Water Flow Gauges





Major surface water networks and available operational stream gauges within the Assiniboine River Basin. Note that some minor surface water networks are excluded from the basin scale work; however, the sub-basin models will carry a higher level of spatial resolution. In total, 119 stream gauges (78 seasonal stations and 41 continuous stations) selected for use with the basin scale HGS simulations.

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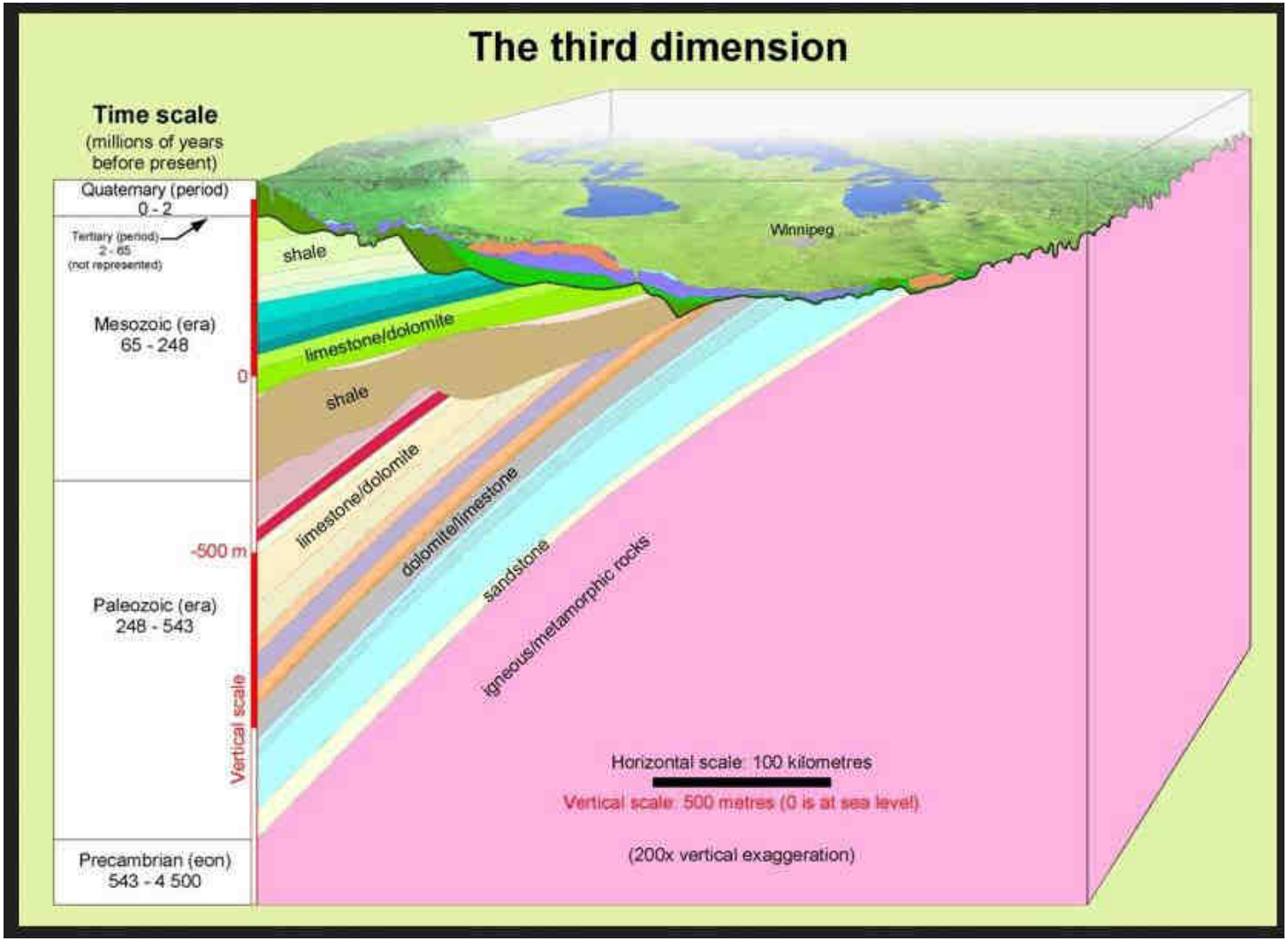
Subsurface Geology

From: http://www.manitoba.ca/iem/geo/gis/sgcms/thirddimension.jpg



Subsurface Geology

From: Palombi, D.D., 2008, *Regional Hydrogeological Characterization of the Northeastern Margin in the Williston Basin*. MSc Thesis, University of Alberta.

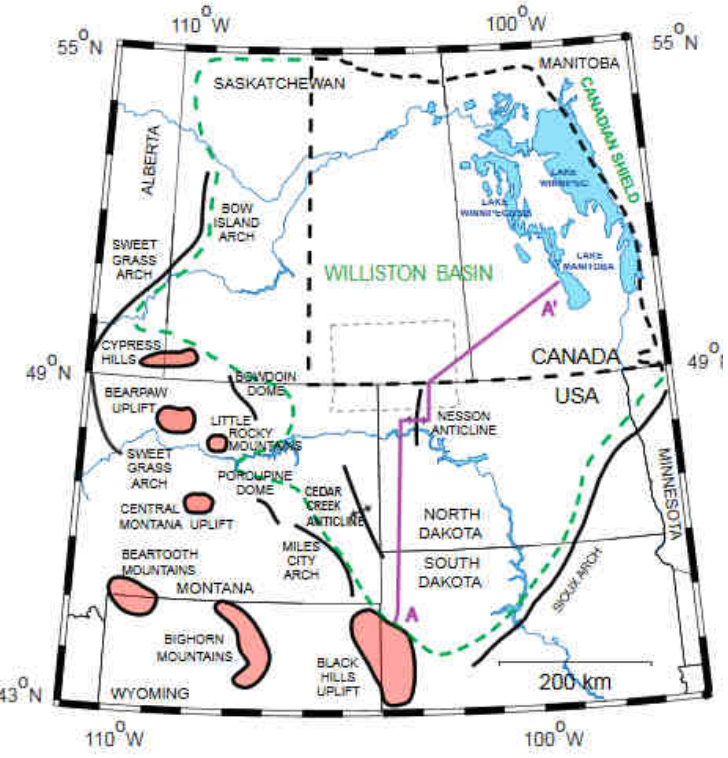


Figure 2.1. TGI-2 study area in dashed black line. Williston Basin boundary shown in a dashed green line with significant physiographic features (modified after Benn and Rostron, 1998). Recharge zones are filled orange and the discharge zone is signified by the lakes in Manitoba. The IEA Weyburn CO_2 Monitoring and Storage project area is also shown in a thin dashed grey line. The location of cross-section A to A' (Figure 2.2) is identified.

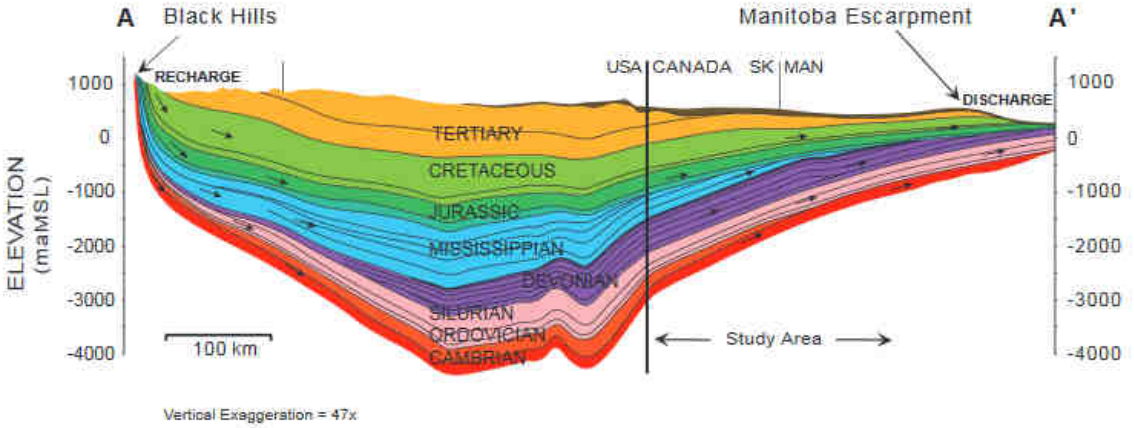
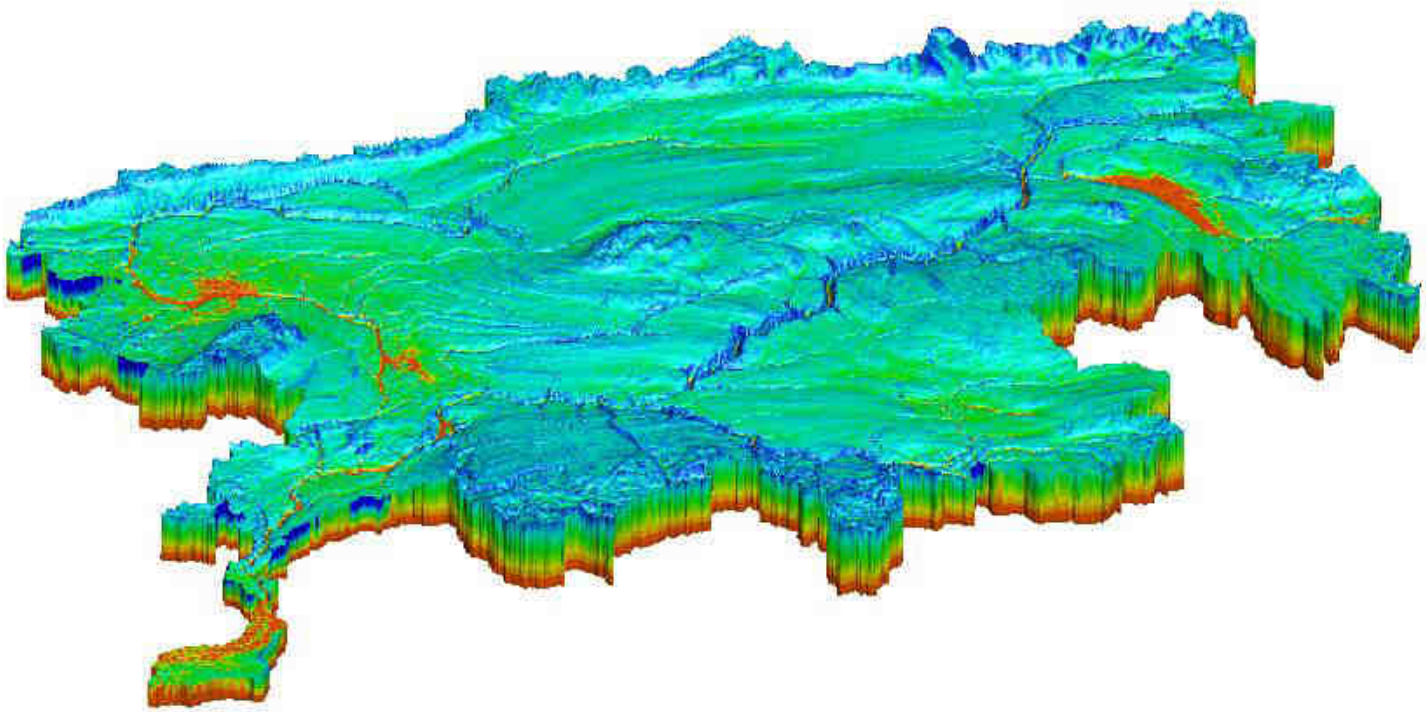
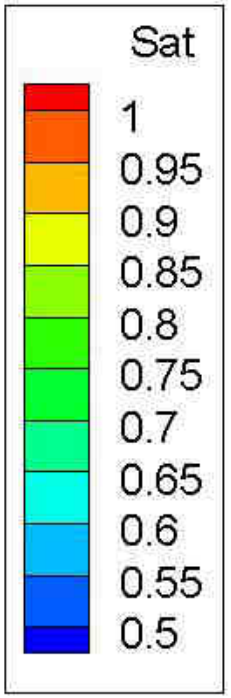
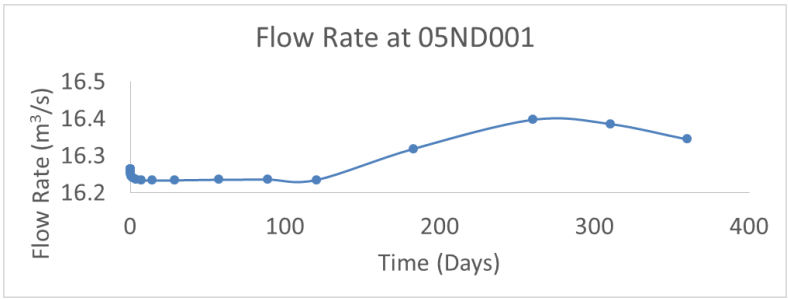


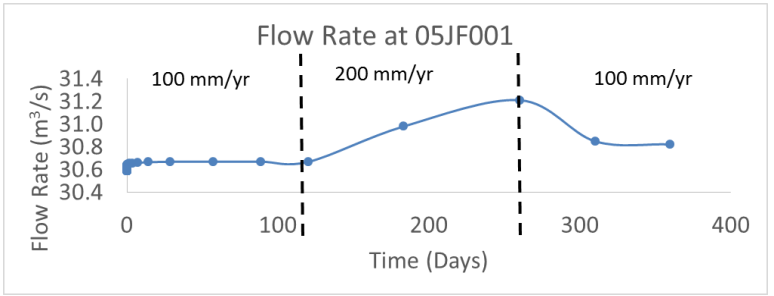
Figure 2.2. Structural cross-section A to A' through the line of section shown in Figure 2.1 (modified after Benn and Rostron, 1998). The hydrogeological characterization includes rocks from the Cambrian to uppermost Cretaceous systems. This study spans from the USA-CANADA border and continues to the edge of Phanerozoic deposition (beyond this section). Recharge is thought to enter the basin in the Black Hills of South Dakota and up-dip discharge to the northeast of the Manitoba Escarpment.

Preliminary Sensitivity Simulations









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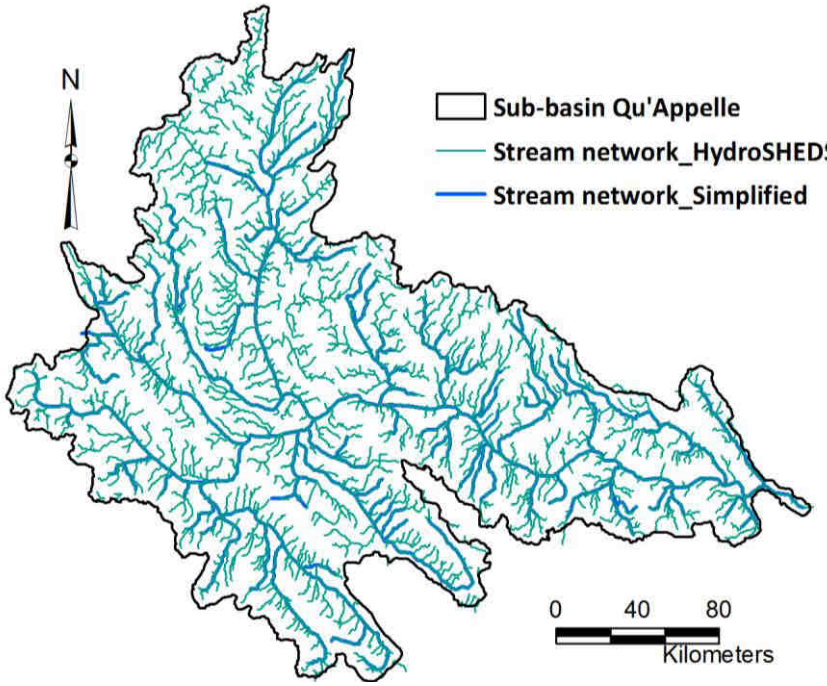
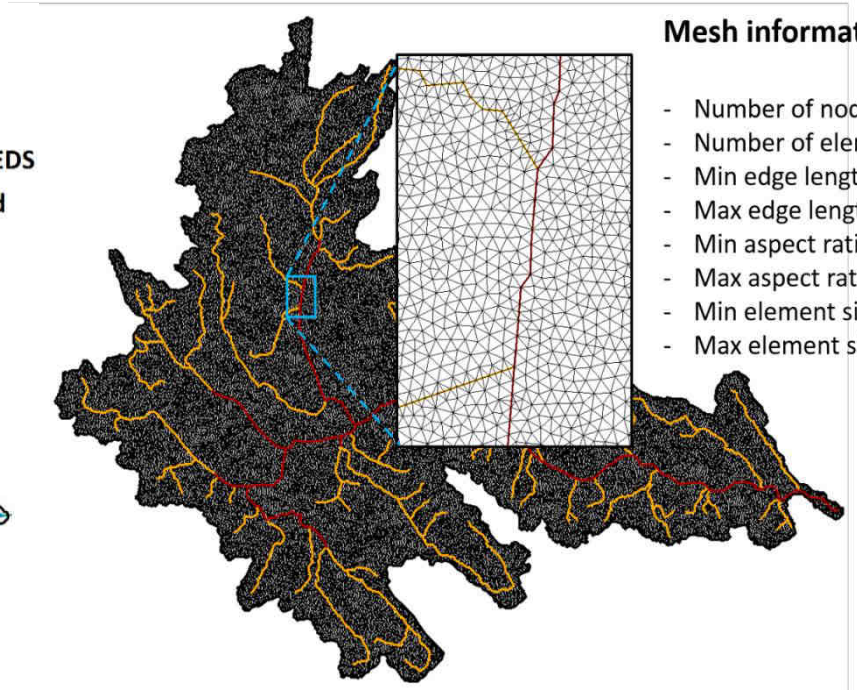
Sub-basin Model Development





Mesh information

- Number of nodes: 177,496
- Number of elements: 351,009
- Min edge length: 202 (m)
- Max edge length: 1,000 (m)
- Min aspect ratio: 1.0
- Max aspect ratio: 3.0
- Min element size: 21,000 (m^2)
- Max element size: 270,280 (m^2)

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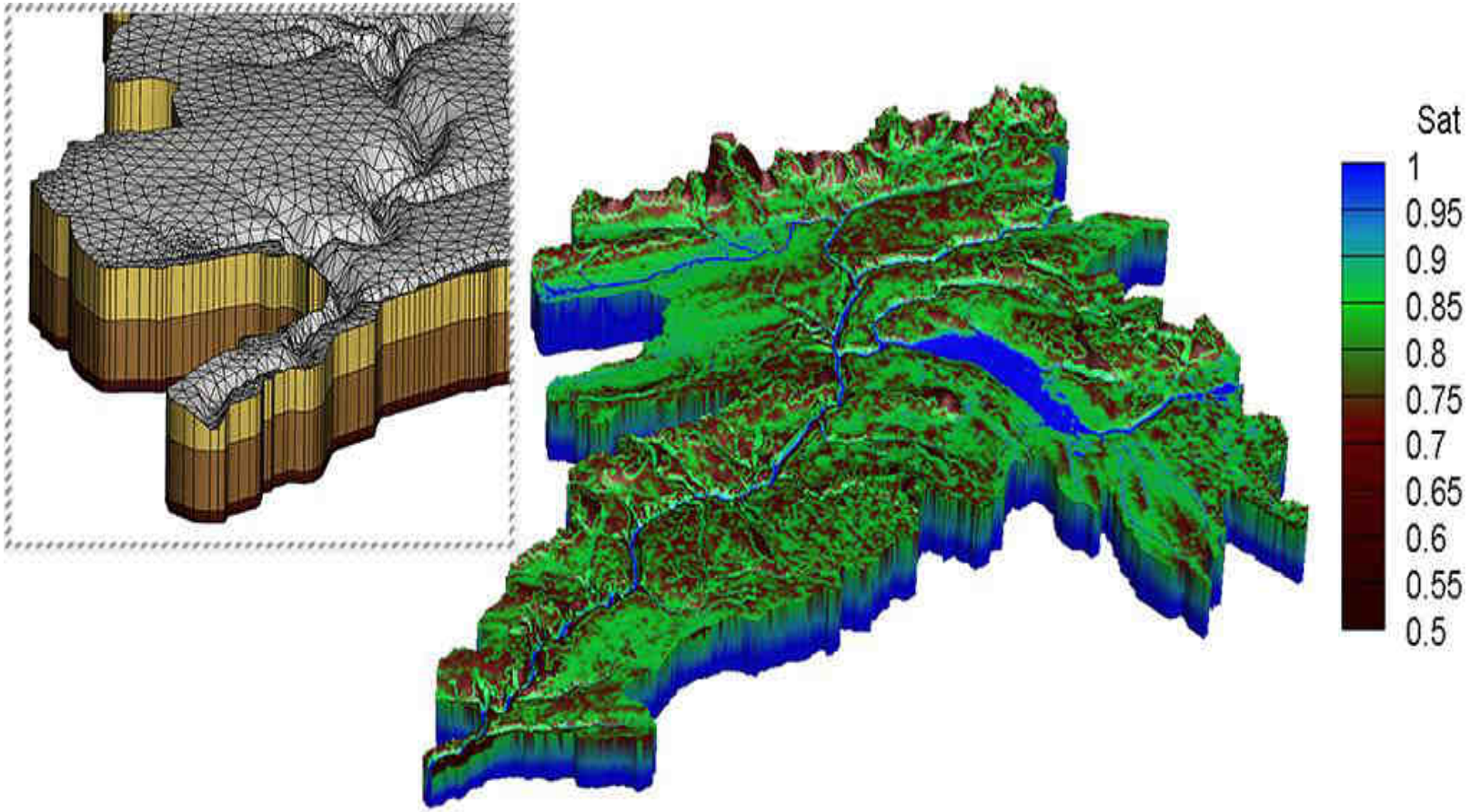
Qu'Appelle Model V1



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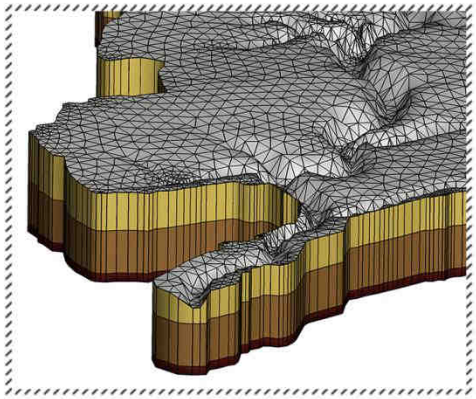
Model Nesting

Qu'Appelle



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Thank You