November 27, 2019

Flow Forecasting and Operations Planning in Saskatchewan

2019 Prairie Provinces Water Board Workshop, Edmonton

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Significant Flood Events

2010 – Maple Creek

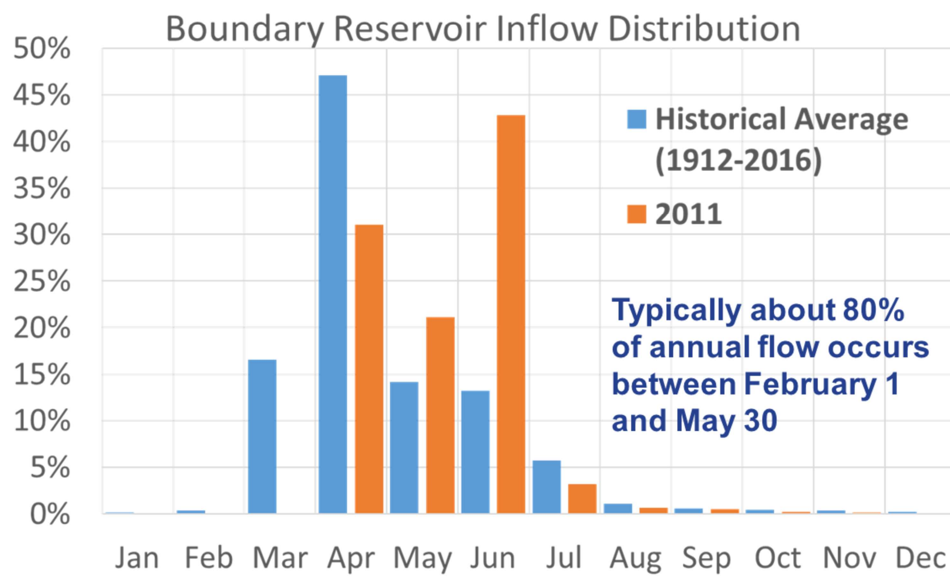
2010 – Good Spirit Lake

2011 – Souris

2014 – East Central Sask.

Common Denominator → GREEN → NO SNOW

Typical Distribution of Annual Flow



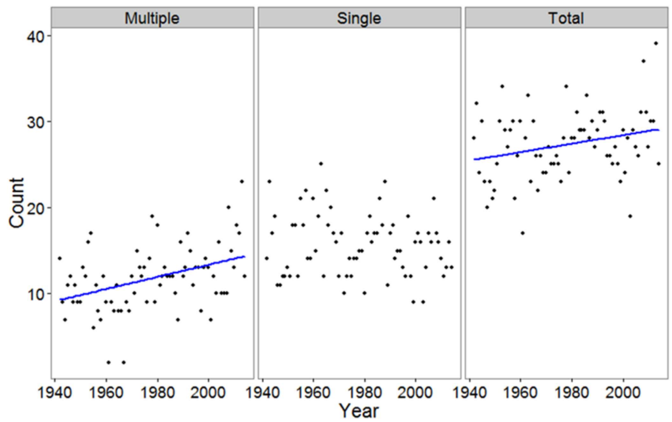
What's happening with our Precipitation in Sask?

- Increase in multi-day rainfall events and more rainfall runoff.

Hydrological regime changes in a Canadian Prairie basin

Stacey Dumanski, John W. Pomeroy* and Cherie J. Westbrook

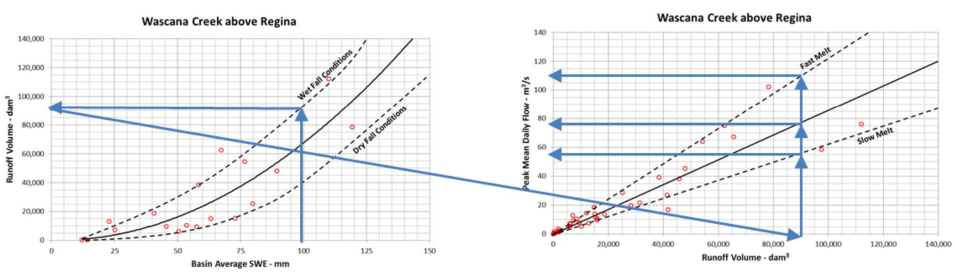
Centre for Hydrology, University of Saskatchewan, 117 Science Place, Saskatoon, Saskatchewan, S7N 5C8, Canada



Current Tools Used by WSA

- Use simple empirical/regression relationships between snow water equivalent, antecedent conditions, and snowmelt runoff volume and peak flow.

- No rainfall runoff modelling, just snowmelt



What is WSA Doing to Improve Tools/Model?

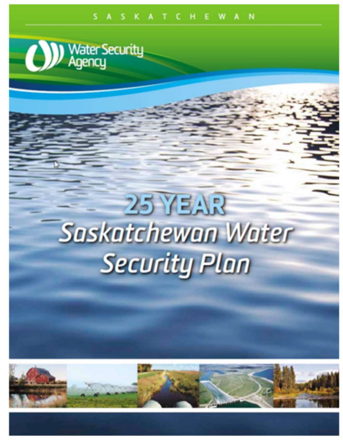
action area 5.1

flood damage prevention and emergency response in developed areas

actions

a. Develop improved flood forecasting tools *(2016)*

- New funding to flood forecasting in the 2014 and 2018 Provincial Budgets to improve flood forecasting functions, enabling the creation and growth of a dedicated flood forecasting unit



University of Saskatchewan Consultation

Key Points

- Most existing hydrological models do not include cold region processes.
- Even fewer models are able to simulate the fill and spill processes of the prairies.
- A physically based model is suggested rather than a statistically or conceptually based model.
  - Likely better equipped for a changing climate and for events outside of those included in the observed record.
- A separate reservoir simulation model is likely required.
- A data handling platform will likely be required.

Recommendations for Saskatchewan Hydrological Modelling

A Report to the Saskatchewan Water Security Agency

Kevin Shook and John Pomeroy

Centre for Hydrology

University of Saskatchewan

117 Science Place

Saskatoon, Saskatchewan

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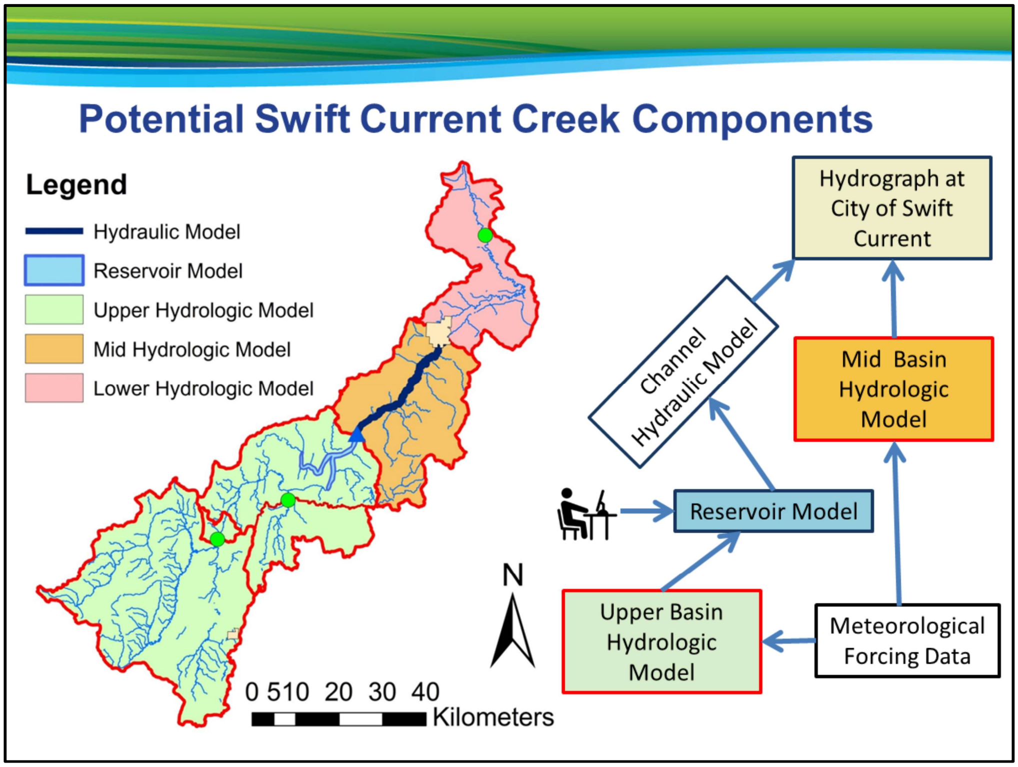
November 30, 2016

University of Saskatchewan

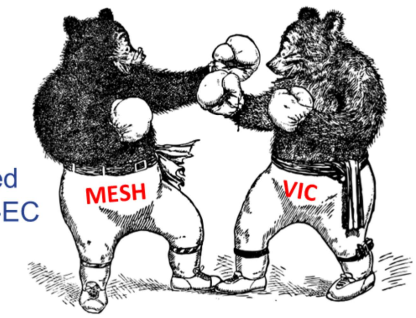
Global Institute for Water Security


Potential Swift Current Creek Components
Legend
Hydraulic Model
Reservoir Model
Upper Hydrologic Model
Mid Hydrologic Model
Lower Hydrologic Model
N
0 510 20 30 40
Kilometers
Hydrograph at City of Swift Current
Channel Hydraulic Model
Mid Basin Hydrologic Model
Reservoir Model
Upper Basin Hydrologic Model
Meteorological Forcing Data

Model Inter-Comparison Project

We are in the end-stages of a model inter-comparison project

- Two watersheds
  - Moose Jaw River
  - Swift Current Creek
- Four hydrologic models for each watershed
  - VIC, MESH, SWAT-PDLD, and HBV-EC
  - Working on Raven with Dr. Craig
- Evaluate based on:
  - Data needs
  - Appropriateness for operational use
  - Predictive ability



Objectives

1. To identify several hydrological modelling tools that have the capability to handle Canadian prairie watersheds

2. Evaluate and compare the responses of individual models using the same input data and calibration period

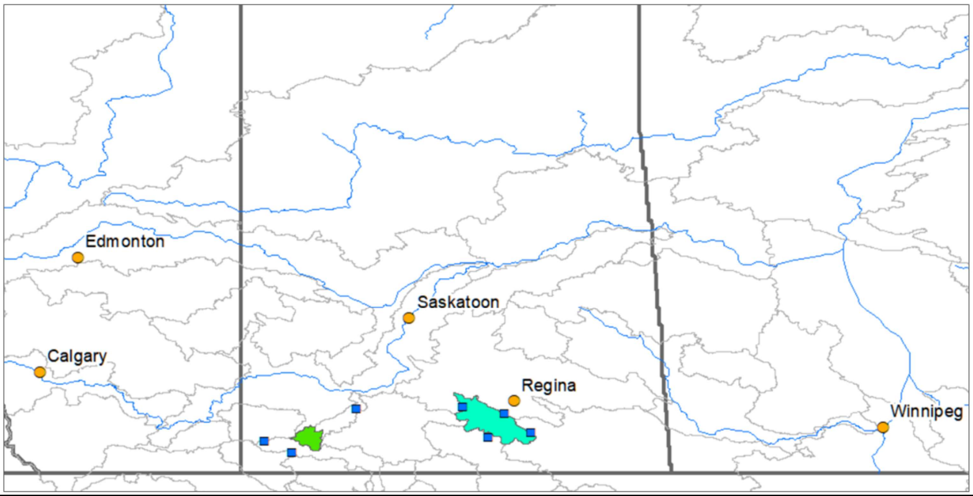
3. Recommend a model or models for operational use

Model Selection

	HBV-EC	VIC	MESH	SWAT-PDLD
Response Unit	Sub-catchments based Response Unit	Grid based Response Unit	Grouped Response Unit (landuse based)	Hydrological Response Unit
Processing time (running MJ model from 2009 to 2015)	**1.1 min**	**2.9 min**	**6.5 min**	**6 sec**
Hydro-meteorological input	**Daily forcing data**	Hourly forcing data	Hourly forcing data	Hourly forcing data
Flow routing	No routing is used	No routing is used	Continuity Equation	Variable Storage Routing Method
Snowmelt	Degree day method	**Energy balance method**	**Energy balance method**	Degree day method
Evapotranspiration	Conceptual	Physically-based	Physically-based	Penman-Monteith, Priestley-Taylor, or Hargreaves method
Prairie pothole dynamics	**Non-existent**	**Additional components for lakes, wetlands, frozen soil included**	**Use probability distribution function of pothole capacity**	**Use probability distribution function of pothole capacity**

Study Sites

- Two watersheds used
  - Moose Jaw River (~5200 km^2)
  - Swift Current Creek (~1400 km^2)

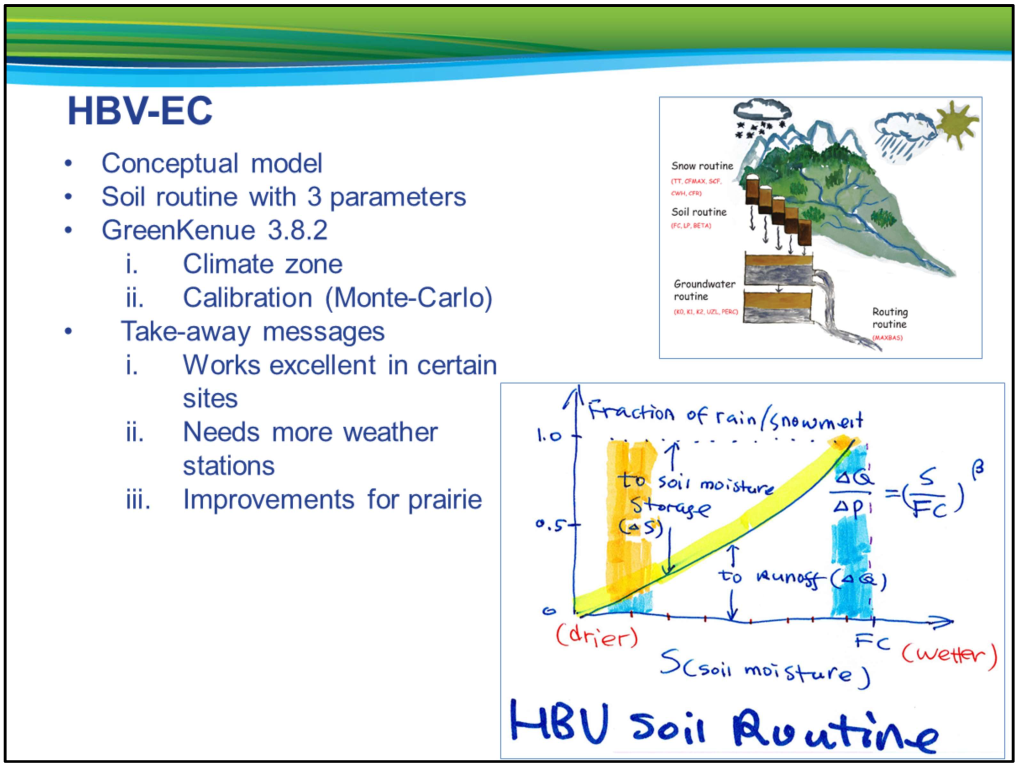


Input data

- Meteorological
  - Weather stations
  - GEM-CaPA (7 parameters)
- Soil
  - HWSD (Harmonized World Soil Database v 1.2)
  - Ecodistricts
  - SLC (Soil Landscapes of Canada)
- Vegetation / Land cover
  - Advanced Very High Resolution Radiometer (AVHRR)
  - Circa2000
  - Global Land Cover (GLCC)
- DEM
- Observed flow

Run and Calibration

- Two years of spin-up
- Calibration from 2010-14
- Validation from 2014-18
- Only Streamflow is evaluated for comparison purpose
- Objective function is to maximize Nash-Sutcliff values for streamflow

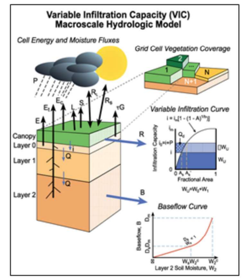


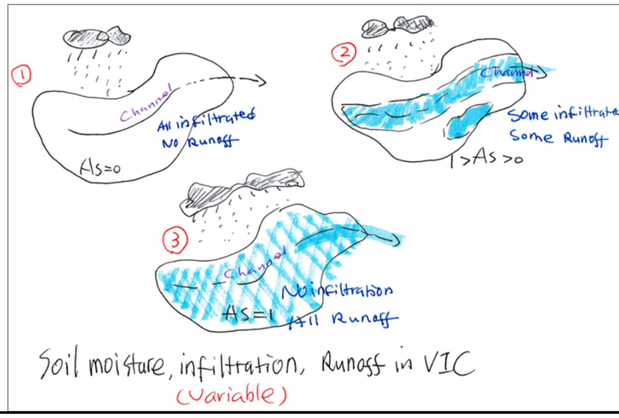
HBV 2 minutes /1 slide
Introduce 4 models used, what they are, what we learned, take-away messages /each 2 minutes

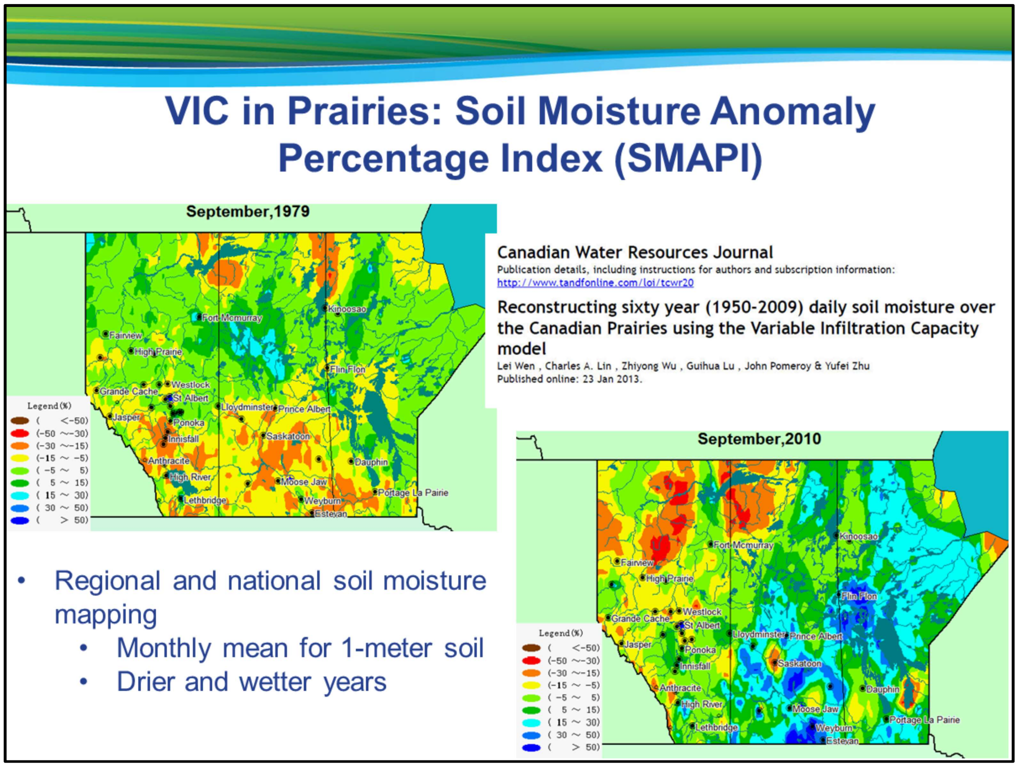
1. Routines (snow, soil, groundwater, and Routing)
2. Soil routine: precipitation and snowmelt, either goes to soil moisture storage or runoff depends on current soil moisture, field capacity of soil, and a shape coefficient(BETA) (source: Bergstrom 1992)
3. LP: soil moisture threshold for reduction of evaporation

Variable Infiltration Capacity (VIC)

- Macroscale and grid-based model
- Three soil layers to 1/1.5 meter
- Extensive soil parameters (53)
- Variable infiltration curve
- R packages for both VIC and calibration tool (hydroPSO)

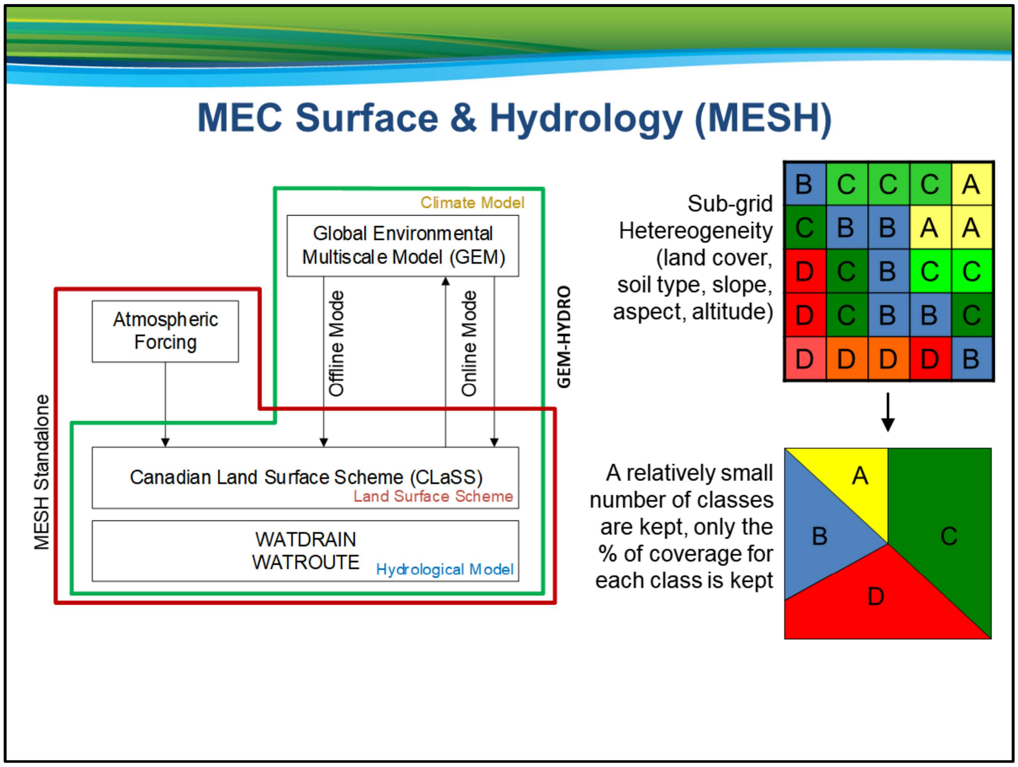




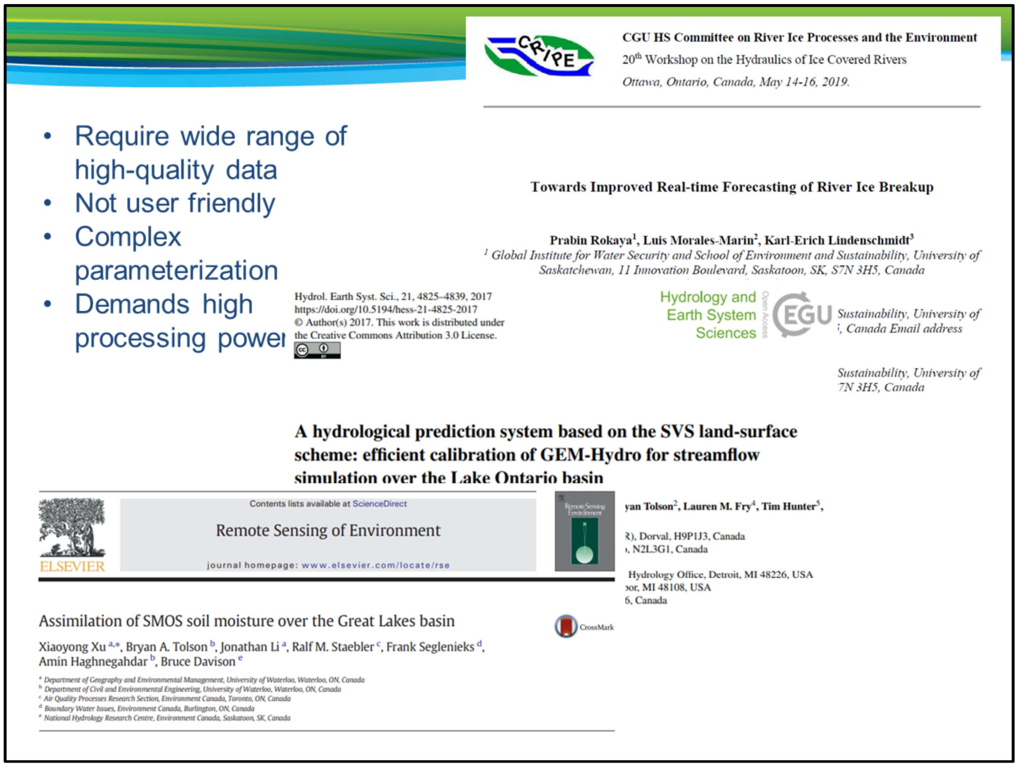


In addition to weather, soil moisture most important in flood and drought forecasting
Most application of VIC is soil moisture mapping
By Lei Wen and others (University of McGill), a part of DRI (Drought Research Initiative) by University of Saskatchewan, almost 10 years ago

1) Monthly average for 1 meter soil layer
2) Soil moisture Anomaly Percentage Index (SMAPI)
3) Example (1979 to 1980 drought) / 2010 wet
4) http://www.meteo.mcgill.ca/~leiwen/vic/prairies/month-seasonal-annual/



MESH is a widely used hydrological model for Canada. It is a grid-based stand-alone land surface hydrology modelling tool developed by Environment and Climate Change Canada (ECCC). It is a combination of the Canadian Land Surface Scheme (CLASS) and WATFLOOD. MESH uses the routing component of WATFLOOD, which is known as WATROUTE and the continuity equation together with the Manning's equation to route water from grid-to-grid. To estimate the generated water within a grid cell and move the water from the land surface to the channel, MESH uses the concept of Grouped Response Units (GRU) from WATFLOOD. MESH allows CLASS to run independently on each of the GRUs within each grid-cell.



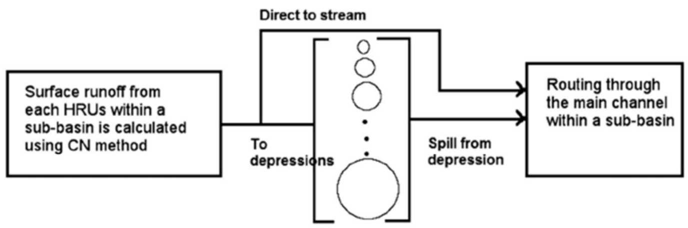
MESH offers some challenges to a modeler. It requires wide range of high-quality data and contains quite complex arrangement of parameters. MESH demands high processing power and it’s often not easy to work with. Despite of these challenges MESH is been used for a number of projects across Canada and it’s considered one of the prominent tool for modelling prairie watersheds.

Soil & Water Assessment Tool - Probability Distributed Landscape Depressions (SWAT-PDLD)

HYDROLOGICAL PROCESSES
Hydrol. Process. (2016)
Published online in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/hyp.10800

Incorporating landscape depression heterogeneity into the Soil and Water Assessment Tool (SWAT) using a probability distribution

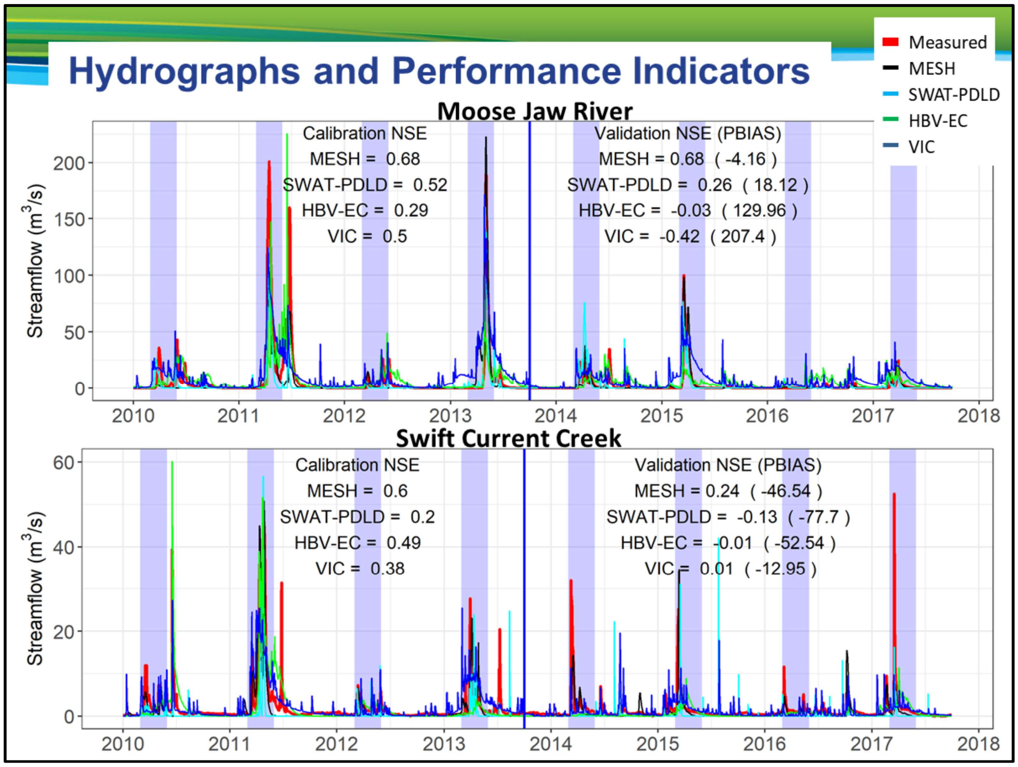
Balew A. Mekonnen,* Kerry A. Mazurek and Gordon Putz
Department of Civil and Geological Engineering, University of Saskatchewan, 57 Campus Dr., Saskatoon, SK, S7N 5A9, Canada



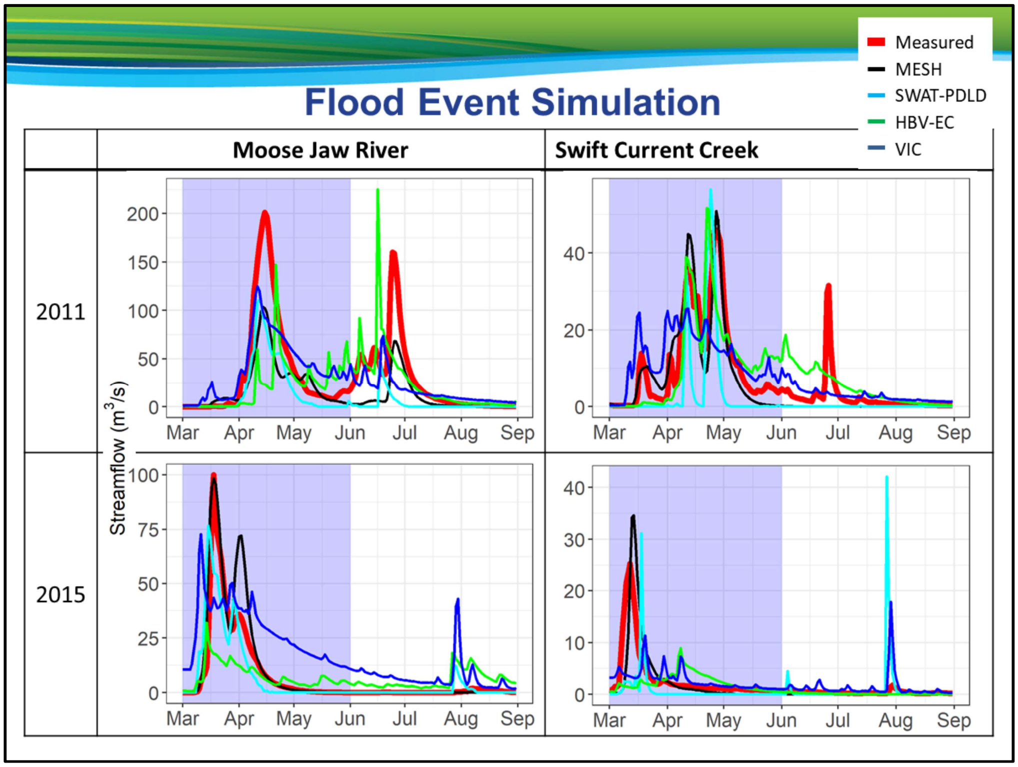
Multiple storages using probability distribution to represent numerous landscape depressions within a sub-basin

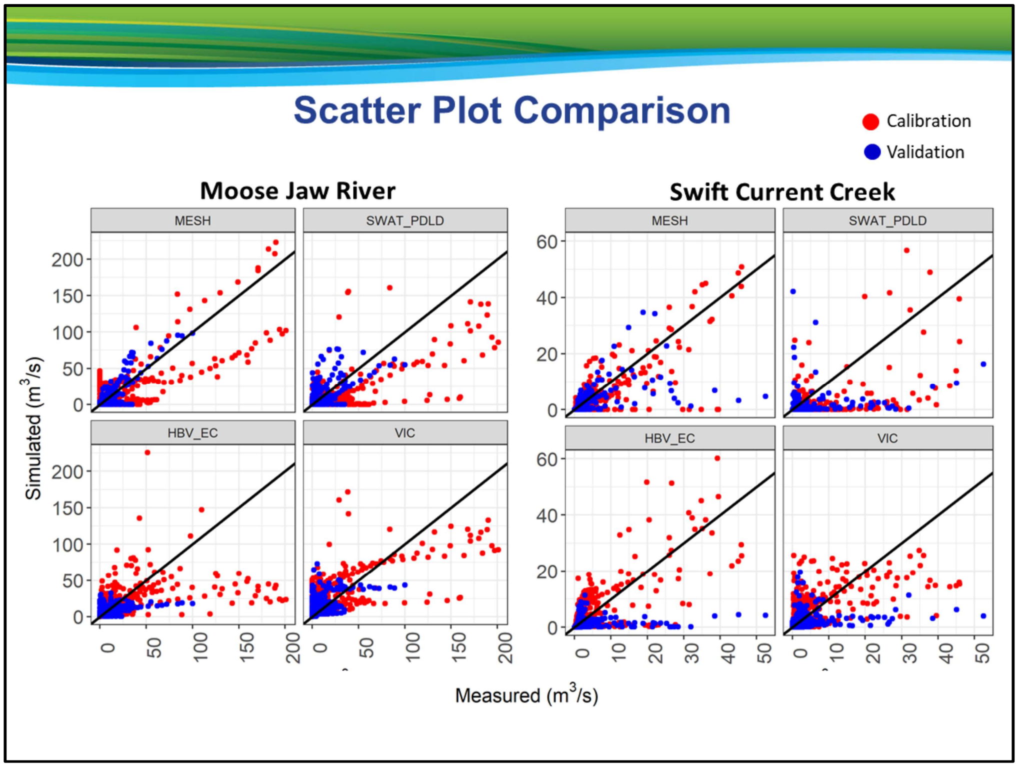
- Experimental setup
- No real-world application yet

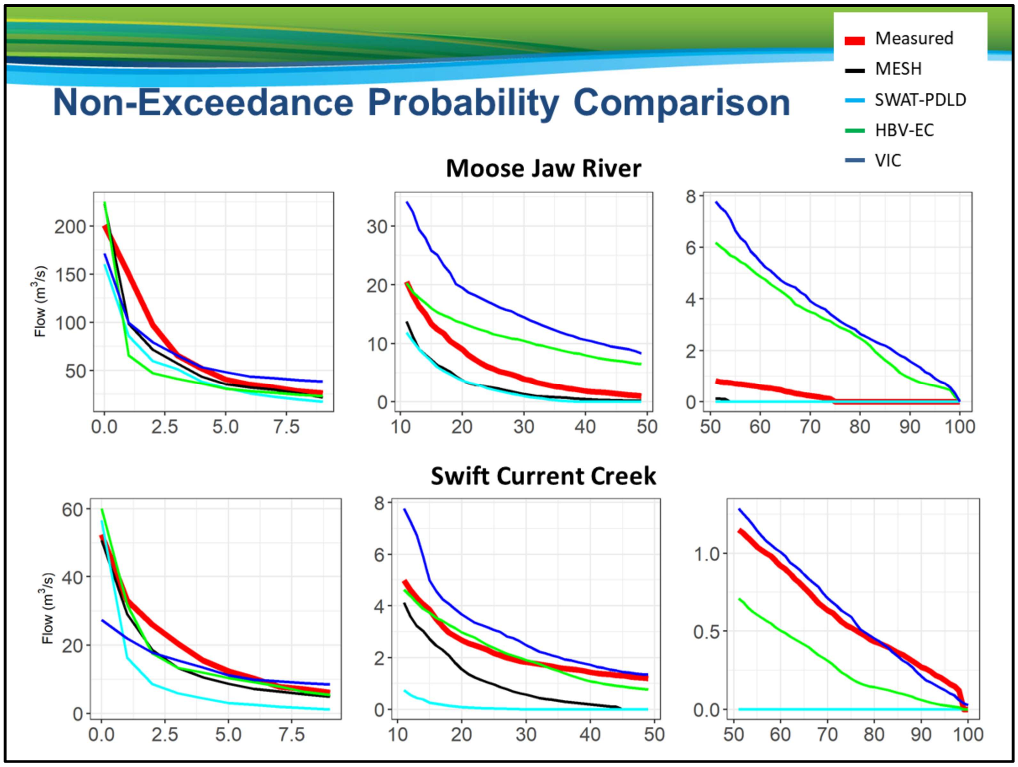
Courtesy to Dr. Balew Mekonnen



Hydrographs and Performance Indicators
Measured
MESH
SWAT-PDLD
HBV-EC
VIC
Moose Jaw River
Calibration NSE
MESH = 0.68
SWAT-PDLD = 0.52
HBV-EC = 0.29
VIC = 0.5
Validation NSE (PBIAS)
MESH = 0.68 (-4.16)
SWAT-PDLD = 0.26 (18.12)
HBV-EC = -0.03 (129.96)
VIC = -0.42 (207.4)
Streamflow (m^3/s)
Swift Current Creek
Calibration NSE
MESH = 0.6
SWAT-PDLD = 0.2
HBV-EC = 0.49
VIC = 0.38
Validation NSE (PBIAS)
MESH = 0.24 (-46.54)
SWAT-PDLD = -0.13 (-77.7)
HBV-EC = -0.01 (-52.54)
VIC = 0.01 (-12.95)
Streamflow (m^3/s)


Flood Event Simulation
Measured
MESH
SWAT-PDLD
HBV-EC
VIC
Moose Jaw River
Swift Current Creek
2011
2015
Streamflow (m3/s)
Mar
Apr
May
Jun
Jul
Aug
Sep


Scatter Plot Comparison
Calibration
Validation
Moose Jaw River
Swift Current Creek
MESH
SWAT_PDLD
HBV_EC
VIC
Simulated (m3/s)
Measured (m3/s)


Non-Exceedance Probability Comparison
Measured
MESH
SWAT-PDLD
HBV-EC
VIC
Moose Jaw River
Flow (m3/s)
200
150
100
50
0.0
2.5
5.0
7.5
30
20
10
0
10
20
30
40
50
8
6
4
2
0
50
60
70
80
90
100
Swift Current Creek
Flow (m3/s)
60
40
20
0
0.0
2.5
5.0
7.5
8
6
4
2
0
10
20
30
40
50
1.0
0.5
0.0
50
60
70
80
90
100

Findings and Path Forward

- Results are suggesting a multi-model ensemble may be required.
  - Help capture uncertainty/enhance decision making
  - Not fully reliant on a single model
- MESH performed well in general.
- RAVEN offers lots of flexibility “Modeller's Model”
- MESH and RAVEN are continuing to be developed/refined:
  - There is ongoing and/or planned work to improve prairie and cold region processes in both
- Both have been proven to work in operational forecasting
- May need to have different model calibrations for operational application (low and high flow, snowmelt and rainfall)
- VIC may be a useful tool for modelling soil moisture to offer insight on antecedent conditions.
- Will continue to explore other models in the future

Thank You!

Hydro-Meteorological Data

- Meteorological data from CaPA-GEM
- Streamflow data from Environment and Climate Change Canada (ECCC) and Water Security Agency (WSA)
- Elevation and landcover data from Geobase
- Soil data from Agriculture and Agri-food Canada (AAFC)
- Vegetation data from Advanced Very-High-Resolution Radiometer (AVHRR)

Meteorological data was collected from CaPA-GEM model of Environment Canada. Streamflow, elevation, and soil data was collected from relevant sources. WSA provided reservoir information and practiced operating rules.

Calibration Parameters

1. River roughness factor
2. Surface storage capacity
3. Surface storages connectivity coefficient (shape factor)
4. Limiting snow depth below which coverage is less than 100%
5. Water ponding depth for snow covered areas
6. Water ponding depth for snow free areas
7. Manning's n for overland
8. Permeable depth of the soil column
9. Fraction of the saturated surface soil conductivity moving in the horizontal direction

Calibration Parameters

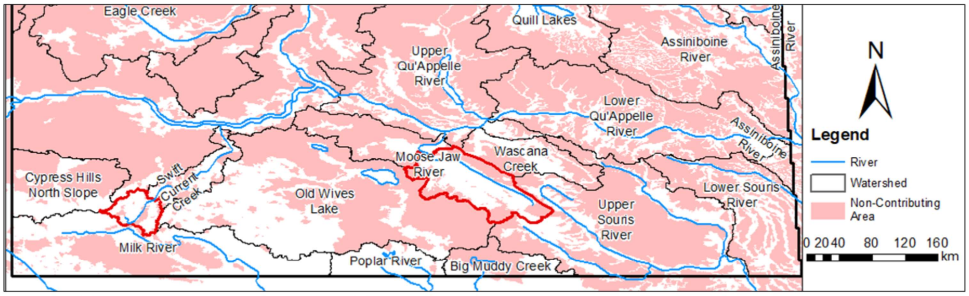
- SCS runoff curve number
- Canopy storage
- Surface runoff lag time
- Baseflow alpha factor
- Snowfall temperature
- Snowmelt base temperature
- Melt rate
- Snowpack temperature lag factor
- Snow water equivalent that corresponds to 50% and 100% snow cover
- Manning's *n* for the main channel

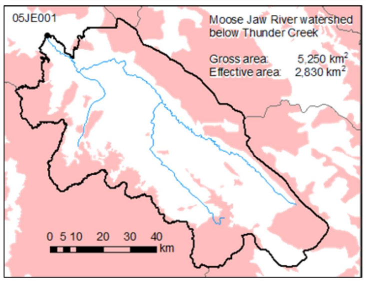
Table I. Parameters selected for SWAT model automatic calibration and resulting optimum values for the three model setups: 'no depressions' approach (Setup-1), single lumped storage approach (Setup-2), and PDLD approach (Setup-3)

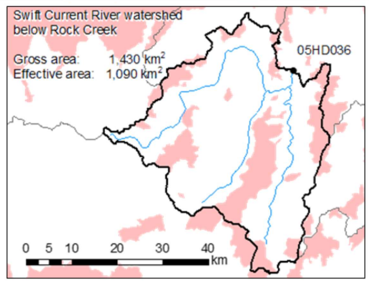
Parameter	Parameter default value	Range of optimization		Optimum parameter values for Assiniboine River watershed			Optimum parameter values for Moose Jaw River watershed		
		Min	Max	Setup-1	Setup-2	Setup-3	Setup-1	Setup-2	Setup-3
CN2[a,b]	Varies	−10	+10	−7.11	3.36	−2.00	−8.00	−2.53	−3.64
ESCO[a,b]	0.90	0	1	0.41	0.82	0.80	0.62	0.52	0.56
SURLAG[a,b]	4	0	10	0.50	1.31	1.00	0.70	1.43	1.00
ALPHA_BF[a,b]	0.048 day	0	1	0.55	0.23	0.34	0.70	0.33	0.49
SFTMP[b]	1 °C	−5	+5	−2.1	−1.21	−0.64	−2.4	−3.20	−4.94
SMTMP[b]	0.5 °C	−5	+5	−0.5	−4.20	−3.29	2.7	−3.33	−2.25
SMFMX[b]	4.5 mm °C^{-1} d^{-1}	0	7	4.0	3.22	2.15	6.9	2.72	2.55
SMFMN[b]	4.5 mm °C^{-1} d^{-1}	0	7	0.6	1.10	0.23	2.5	0.97	0.94
TIMP[b]	1	0	1	0.3	0.21	0.05	0.12	0.08	0.01
SNOCOVMX[b]	1 mm	0	500	195	150	225	195	98	121
SNO50COV[b]	0.5	0	1	0.22	0.10	0.02	0.09	0.13	0.02
SMAX[b]	varies	−0.2%	+0.2%	—	—	+0.13%	—	—	+0.09%
CH_N[a,b]	0.014	0	0.065	0.065	0.055	0.04	0.065	0.061	0.05

[a] Ranked within the first five most sensitive parameter based on the sensitivity analysis of current study.
[b] Parameters that were identified as calibration parameters in previously published SWAT models.

Study Sites







The selection of these watersheds is influenced by availability of good quality hydro-meteorological data, WSA preference, and location