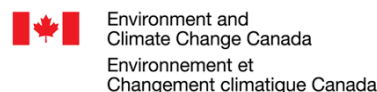




# Multi-model Intercomparison Project on the Saskatchewan-Nelson-Churchill River Basin (Nelson-MiP project)

Monthly meeting - 11 March 2020





# Agenda

1. Selection of natural gauge stations for calibration/validation for Phase 0 & Phase 1
2. Decision on time periods for model calibration/validation
3. Discussion on a standardized meteorological forcing data: WFDEI-GEM-CaPA vs ERA5
4. Discussion on routing scheme and geophysical input data
5. Deliverables for next meeting



# Selection of gauge stations for calibration/validation (Phases 0 & 1)

- **Search criteria:**

Station == Natural

Data Period == 1970 to 2016

Total Years  $\geq 35$

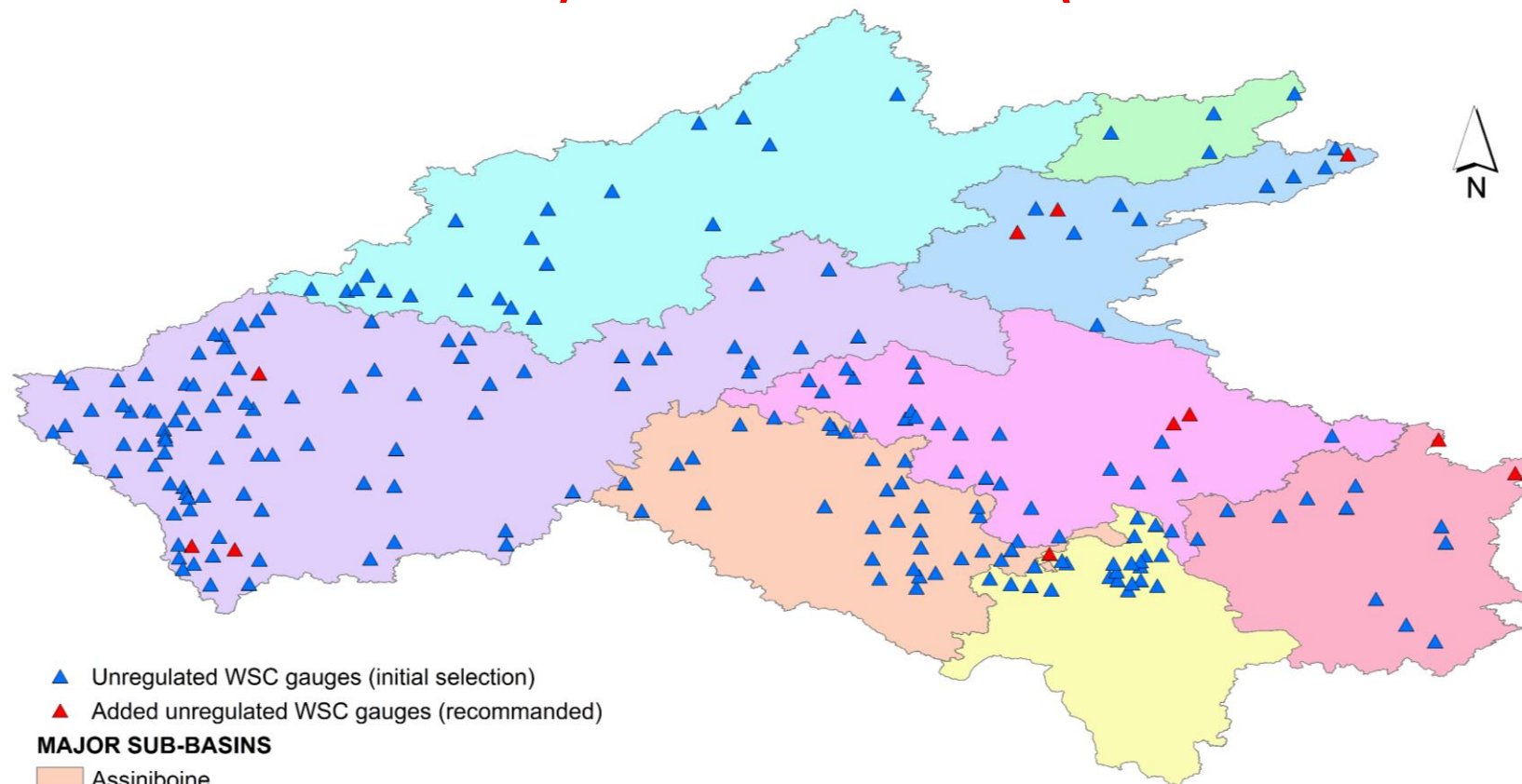
Drainage area  $\geq 200 \text{ km}^2$

+

Stations submitted but not meeting search criteria

- 291 (natural) gauge stations identified + **11 stations added**

# Selection of natural gauge stations for calibration/validation (Phases 0 & 1)



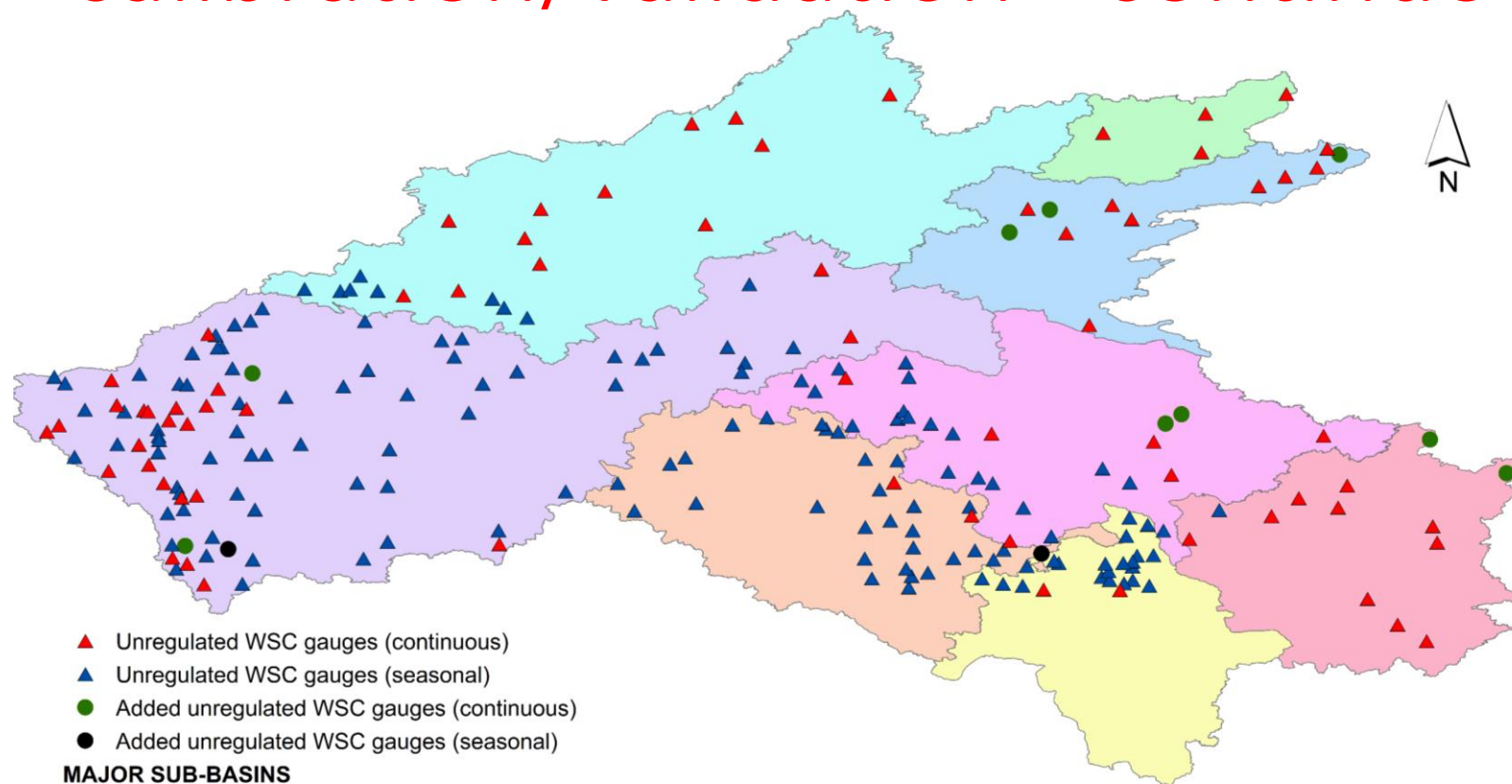
- ▲ Unregulated WSC gauges (initial selection)
- ▲ Added unregulated WSC gauges (recommended)

## MAJOR SUB-BASINS

- Assiniboine
- Lake Winnipeg
- Lower Churchill
- Nelson
- Red River
- Saskatchewan
- Upper Churchill
- Winnipeg

Sub-basins	Number of WSC natural stations
Assiniboine	32
Lake Winnipeg	28
Winnipeg river	13
Upper Churchill	20
Lower Churchill	4
Saskatchewan river	94
Red River	23
Nelson river	12

# Selection of natural gauge stations for calibration/validation - continuous vs seasonal



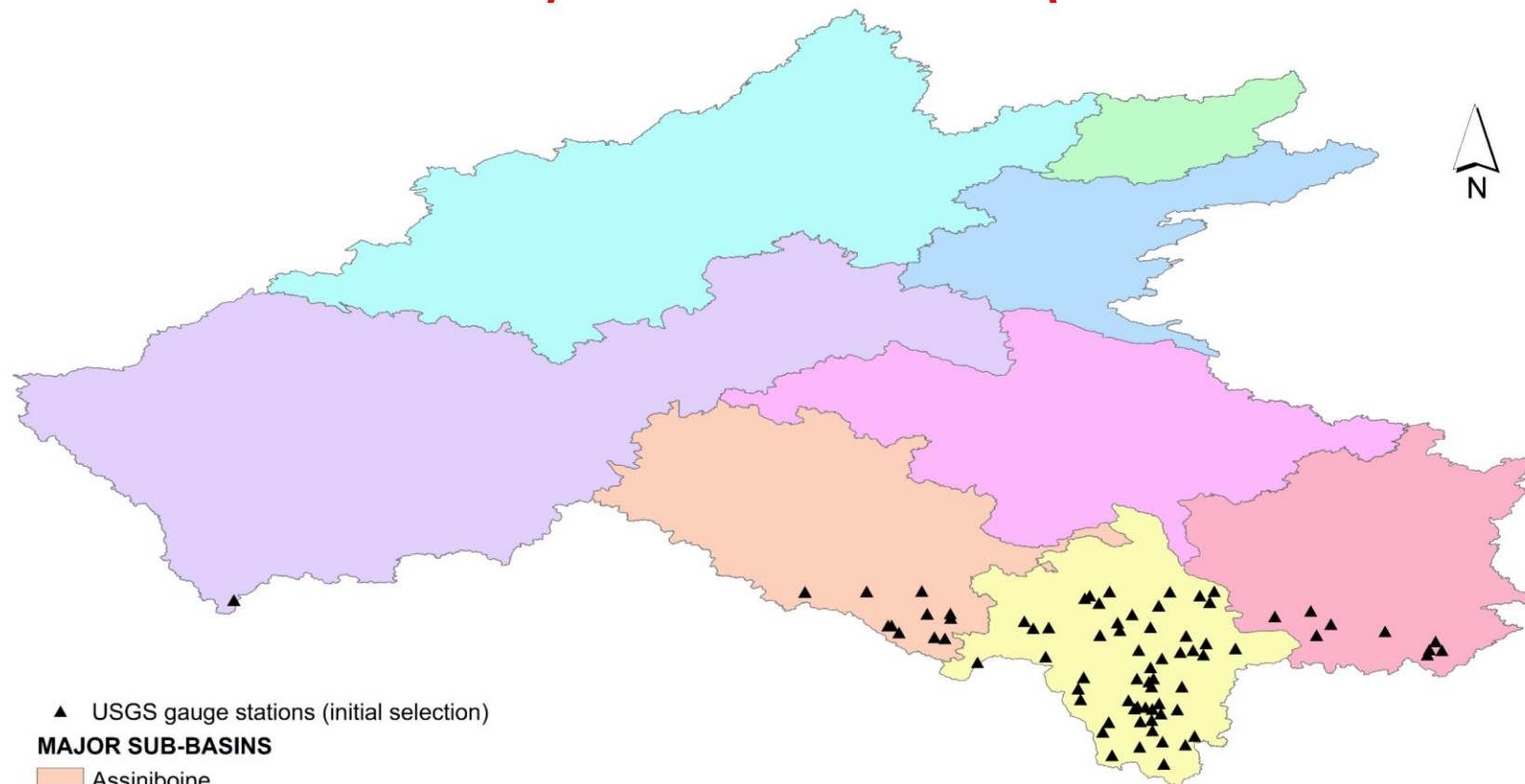
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## MAJOR SUB-BASINS

- Assiniboine
- Lake Winnipeg
- Lower Churchill
- Nelson
- Red River
- Saskatchewan
- Upper Churchill
- Winnipeg



# Selection of natural gauge stations for calibration/validation (Phases 0 & 1)



▲ USGS gauge stations (initial selection)

## MAJOR SUB-BASINS

- Assiniboine
- Lake Winnipeg
- Lower Churchill
- Nelson
- Red River
- Saskatchewan
- Upper Churchill
- Winnipeg

Sub-basins	Number of USGS stations
Assiniboine	11
Lake Winnipeg	-
Winnipeg river	9
Upper Churchill	-
Lower Churchill	-
Saskatchewan river	1
Red River	55
Nelson river	-



# Time periods for calibration/validation

- Calibration

	80				85					90					95					00					05					10					15					19
HYPE																																								
SWAT-GIW																																								
SWAT-GWF																																								
VIC																																								
HEC-HMS																																								
SUMMA																																								
WATFLOOD-MH																																								
RAVEN																																								
HBV-EC																																								
WATFLOOD-MI																																								
MESH																																								
SWAT-RRB																																								
Noah-MP																																								

No calibration for SUMMA





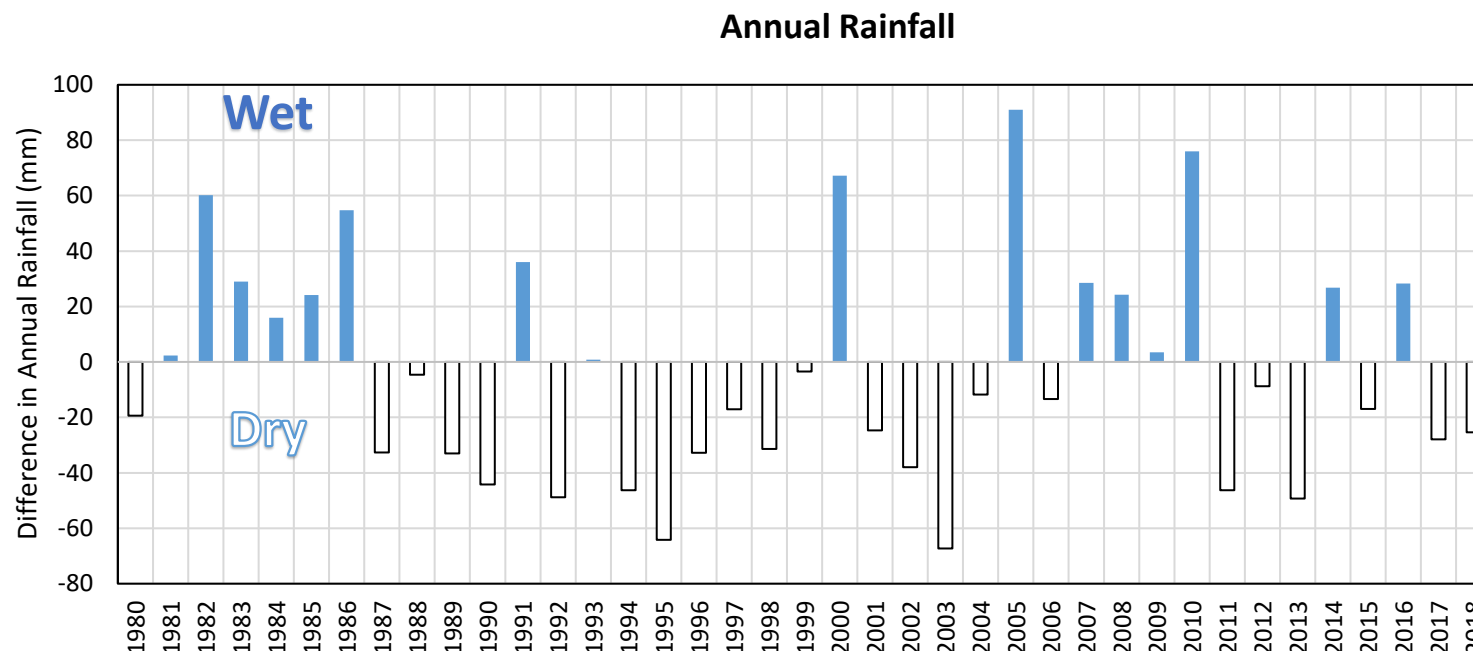
# Time periods for calibration/validation

- **Validation**

	80					85					90					95					00					05					10					15					19
HYPE																																									
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# Time periods for calibration/validation



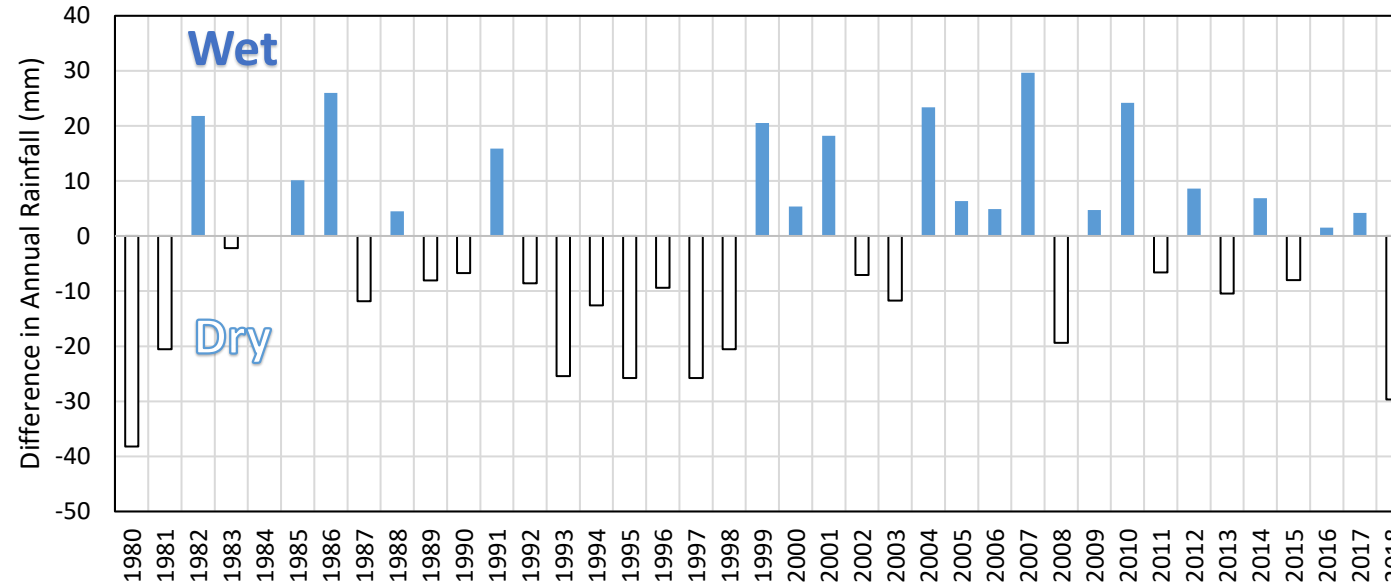
The wet and dry years selection is based on precipitation fields derived from the HydroGFD met. forcing product

Calibration	Validation
1981-1985 (wet)	1986-1990 (Dry)
1991-1995 (Dry)	1996-2000 (wet and Dry)
2001-2005 (Wet and Dry)	2006-2010 (Wet)
2011-2018 (Wet and dry)	

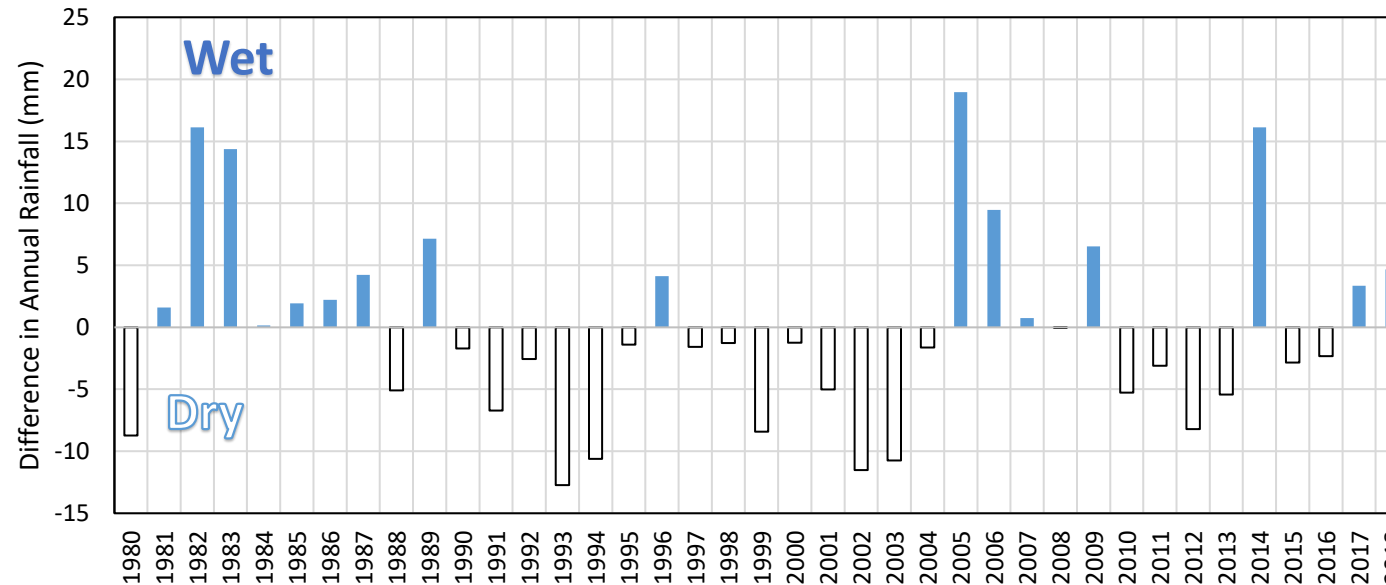
# Time periods for calibration/validation



Spring



Winter





# Standardized meteorological forcing data

	ERA5	WFDEI-GEM-CaPA	NCEP-CFRS	Standard MiP data
HYPE	X			X
SWAT-GIW		X	X	
SWAT-GWF				
VIC				
HEC-HMS	X			X
SUMMA	X			
WATFLOOD-MH				
RAVEN				
HBV-EC				
WATFLOOD-MI				
MESH		X		
SWAT-RRB		X		X
Noah-MP				

- We have to choose between WFDEI-GEM-CaPA and ERA5
- WFDEI-GEM-CaPA (<https://doi.org/10.5194/essd-2018-128>) → 3-hourly, 0.125° ~ 10 km, 1979-2016 (variables are: huss, pr, ps, rlds, rsds, sfcWind, tas)
- ERA5 (<https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era5>) → 1-hourly, ~31km-grid, 137 levels from surface up to 0.01hPA (~ 80 km), 1979-near real time



# Hydrologic routing scheme

- We should decide on using a standardized routing scheme or not.
- All groups were tasked to consider offline routing advantages/disadvantages
- Bryan Tolson's group (UWaterloo) offers to produce a routing scheme (including lakes) if all modelers will use it.
- If Bryan idea is accepted, we should also decide whether the routing scheme shall be derived using HydroSHEDS 3-arc sec DEM (~90m) (<https://hydrosheds.cr.usgs.gov/dataavail.php>) or MERIT Hydro 3-arc sec data products (<https://doi.org/10.1029/2019WR024873>).

# Hydrologic routing scheme



## Subwatershed-based lake and river routing products for hydrologic and land surface models applied over Canada

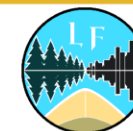
Ming Han<sup>1</sup>, Juliane Mai<sup>1</sup>, B. A. Tolson<sup>1</sup>, J. R. Craig<sup>1</sup>, Etienne Gaborit<sup>2</sup>, Hongli Liu<sup>1</sup>, Konhee Lee<sup>1</sup>  
<sup>1</sup>Civil and Environmental Engineering Department, University of Waterloo, Waterloo, N2L 3G1, Canada  
<sup>2</sup>Environment Canada, Environmental Numerical Prediction Research (E-NPR), Dorval, H9P 1J3, Canada



GLOBAL WATER FUTURES  
SOLUTIONS TO WATER THREATS  
IN AN ERA OF GLOBAL CHANGE



UNIVERSITY OF  
WATERLOO



### Introduction

Lakes and reservoirs have critical impact on hydrological, biogeochemical, and ecological process, and they should be one of the essential components in our hydrological and eco-hydrological models. This is particularly important in Canada where there are tens of thousands of lakes. However, it is common for hydrological models to explicitly represent only large lakes (e.g., >80km<sup>2</sup>).

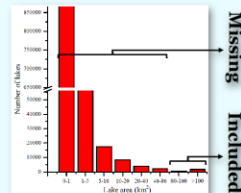


Figure 1. Histogram of Canadian lake areas in HydroLAKES database (Messenger et al., 2018), all lakes > 10 km in area.

### Building hydrologically correct lake-river routing networks

- Lakes are always located at the outlet of any catchment with a lake, so that the outflow of such a lake catchment is controlled by the lake
- Lake drainage areas are derived based on DEM and lake pour points
- Each lake inflow pour point, multiple possible, are explicitly identified
- Lake-river routing structure B and C shown in Figure 2 are both correct, but approach in Figure B is preferred as dozens of small catchments are avoided

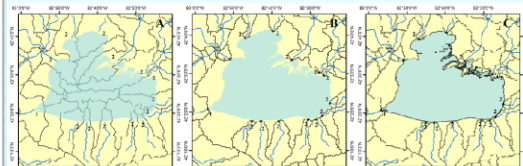


Figure 2. (A) An example of overlaying lake and catchment polygons. (B) An example of lake-river routing structure with a large lake catchment. (C) An example of lake-river routing structure with a small lake catchment. (D) An example of lake-river routing structure with a small lake catchment. The light blue polygons are a sample modelled lake. The solid blue lines are channels in the modelled river networks. The points labeled as 1 is the lake outlet point while the points labeled with 2 are all the lake inflow points from upstream river channels.

### Process to generate lake-river routing products

A workflow to generate of lake-river routing network was developed to derive all catchment, channel and lake properties required to drive a hydrologic routing model at various resolutions across Canada. Figure 3 shows example routing networks for two products. **The workflow is being developed into a flexible and generalized ArcGIS python toolbox.**

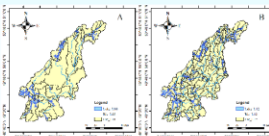


Figure 3. An example of two generated lake-river routing network with HydroSHEDS Level 8 and 12 catchment delineations.

### Data and derived lake-river routing products over Canada

- Products derived from HydroSHEDS 15 are second datasets (Lehner, 2014) and HydroLAKES datasets (Messenger et al., 2016)
- 6372 observation gauges from HYDAT database (HYDAT, 2018) define additional catchment outlets (assumed points of interest for modellers) by snapping them to the closest river reach of HydroSHED river system
- A global database for bankfull width, depth provides bankfull width and depth for each generated catchment river channel (Andreasson et al., 2013)

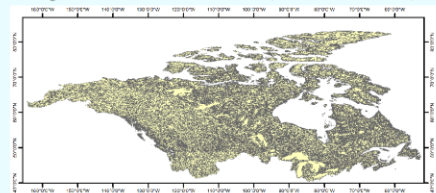


Figure 4. Developed routing product L08-Lake0, which combining HydroSHEDS level 8 product and all lakes with lake area larger than 0 km<sup>2</sup> in HydroLAKES that are connected by river network.

Product Name	Number of catchments	Average catchment area (km²)	Number of lakes	Median lake area (km²)
L7-Lake0	13319	100	10718	0.79
L8-Lake0	90415	135	40674	0.74
L9-Lake0	148159	82	68005	0.69
L10-Lake0	198481	62	81362	0.67
L11-Lake0	259389	46	98962	0.66
L12-Lake0	303736	40	98991	0.66
L7-Lake1	40387	303	11416	3
L8-Lake1	62628	195	19956	3.1
L9-Lake1	100884	121	31277	2.9
L10-Lake1	137411	89	37481	2.8
L11-Lake1	142008	86	37856	2.8
L12-Lake1	143712	81	38088	2.8

Properties included in each of the 12 routing products:

- Catchment properties:** downstream ID, catchment area, averaged slope, observation ID
- Channel properties:** channel slope, bankfull width & depth, mean annual discharge, channel length, flood plain Manning's n (from Modis landuse type), channel Manning's n (back-calculated)
- Lake properties:** lake ID, lake surface area, lake volume, lake depth, and lake type (natural or regulated), vertical side-slopes assumed, lake outlet assumed to behave like a broad-crested weir and assigned a weir width equal to the bankfull width for a channel assuming no lake was present

### Demonstrate routing products for hydrologic routing in Hudson Bay basin (~ 40% of Canada)

#### Data and routing model setup

- Forcings: hourly surface runoff and groundwater recharge from SVS land surface scheme (Asante et al., 2008; Gaborit et al., 2017)
- Hydrologic routing: Raven (Raven Development Team, 2018) in diffusive wave routing mode (no in-catchment routing simulated) and simulating lake water levels & baseflow
- Spatial overlay of gridded forcings and routing network generates weights for Raven, enabling direct read of original resolution gridded forcings (in NetCDF or ASCII format) and then internal conversion to catchment-level forcings
- 3 year simulation period: 2007-01-01 to 2010-10-01; hourly time step
- Results checked at 15 flow gauges (with no upstream reservoirs)

### Runtime of routing model in forecasting mode

Table 2 shows the Raven routing configuration computation times and demonstrates some of the flexibility of Raven as a hydrologic routing tool supporting lake/reservoir routing. Simulation times are reasonable and faster than equivalent-detail gridded routing model benchmark (WatRoute).

Table 2. Raven runtime (serial) with different products in example forecasting type of simulation.

Product	# of catchments	# of lake catchments	Runtime for a 10-day, hourly time step simulation (min.)
L8-lake0	26419	14975	13.4
L7-lake0	15565	8191	6.0
L7-No-lakes	4288	0	0.7

### Impact of lakes on Raven routing results

- Base scenario: routing with all lakes explicitly simulated
- Average NSE for base scenario at all 15 gauges was 0.52. Since the routing model was not calibrated, this good result suggests lake-river routing structure and derived data are reasonable
- The impact of lakes on routing is different across 15 gauges (see Figure 5)
- The base scenario gives better performance than No-lake scenario, because the peak flow was significantly reduced and delayed by including lakes (see for example Figure 6)

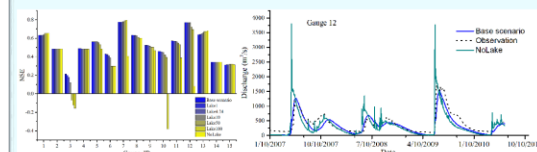


Figure 5. NSE at each gauge for lake representation scenarios. Base scenario means all lakes in the lake-river routing structure were active. Lake0 means lakes with lake area smaller than 1 km<sup>2</sup> were not explicitly modelled compared to Base scenario.

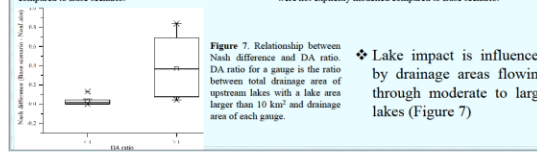


Figure 6. Example of observed hydrograph in comparison with simulated hydrographs from the base scenario (all lakes) and the No-lake scenario. Lake1 means lakes with lake area larger than 1 km<sup>2</sup> were not explicitly modelled compared to Base scenario.

Figure 7. Relationship between Nash difference and DA ratio. DA ratio for a gauge is the ratio between total drainage area of upstream lakes with a lake area larger than 10 km<sup>2</sup> and drainage area of each gauge.

Lake impact is influenced by drainage areas flowing through moderate to large lakes (Figure 7)

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### Conclusions

- The Pan-Canadian lake-river routing products, available as shapefiles, can support a variety of hydrologic routing and lake-focused modelling projects
- Product viability demonstrated with Raven in routing-only mode
- Routing products provide an excellent starting point for building your model
- Future research needed to develop objective strategies for ignoring smaller lakes
- Manuscript being submitted to CWRJ journal

- The discretization methodology can be applied for any user provided DEM
- The resolution of subbasins and lakes represented can be customized
- The outputs of the discretization are a vector-based routing network with complete information needed for lakes and river hydrologic routing
- RAVEN is used to do the routing simulation



# Routing scheme and other geophysical inputs

- **Land use/ land cover**: North American Land Change Monitoring System (NALCMS)
- NALCMS is provided at 250m and **30m** spatial resolution, contains 19 land cover classes, and is publicly available from <http://www.cec.org/tools-and-resources/map-files/land-cover-2010-landsat-30m>.
- **Soil data**: Global Soil Dataset for Earth System Modelling (GSDE)
- GSDE is provided at 30 arc-second resolution (**~1km**), and contains 11 types of soil general information for soil profiles and 34 soil properties for 8 depths up to 2.3 m. It can be downloaded from <http://globalchange.bnu.edu.cn/research/soilw#download>.

All groups were tasked to explore soil datasets & provide recommendations.



# Deliverables & Follow-up

1. All modellers should prepare a 5-min presentation of their model for the next meeting. The 1-3 slides presentation should be sent to Hervé by April 1st 2020 at the latest.
2. Next meeting scheduled for **Wednesday April 8 @10:00AM MST**