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Hydrologic Model Calibration In Rural Watersheds

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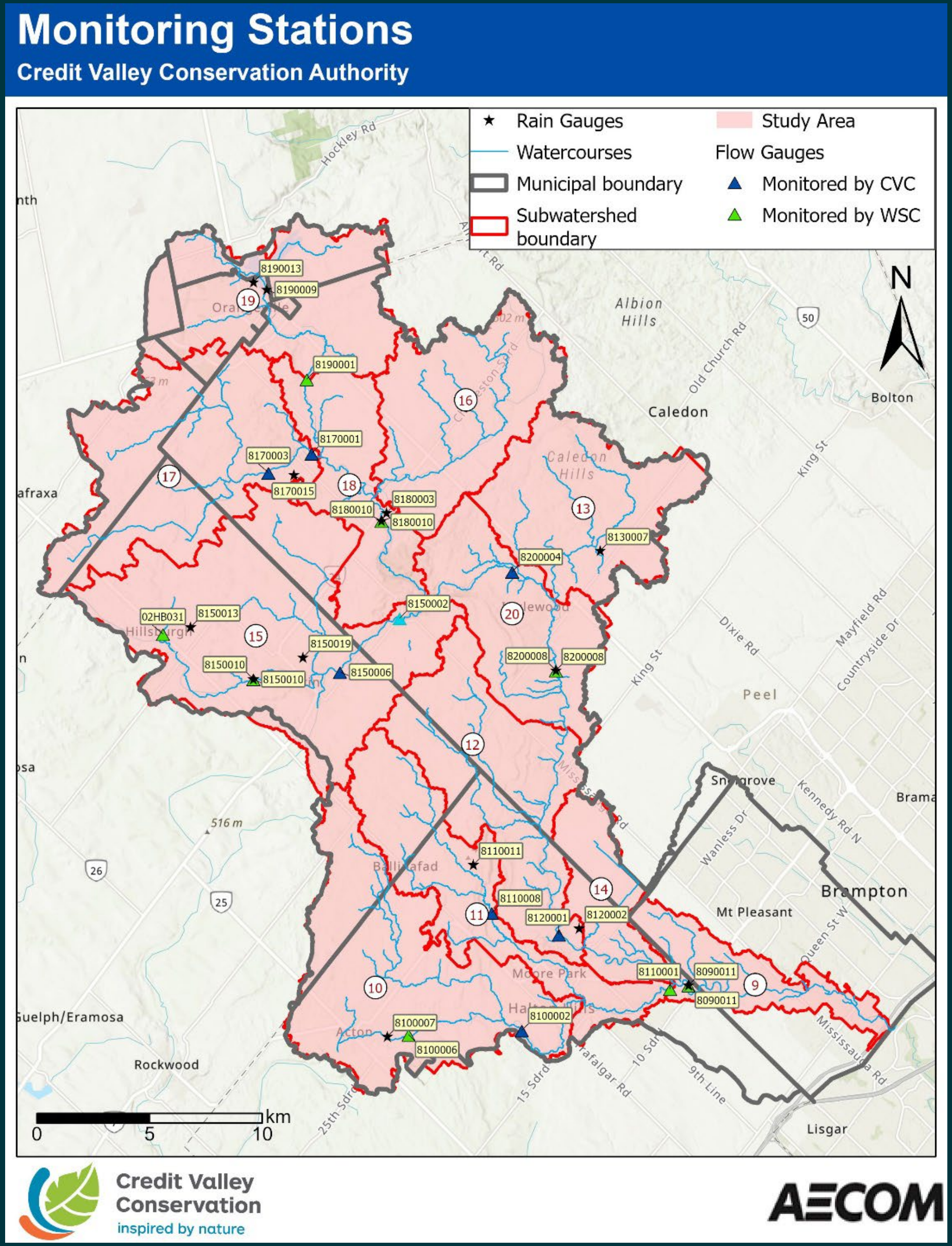
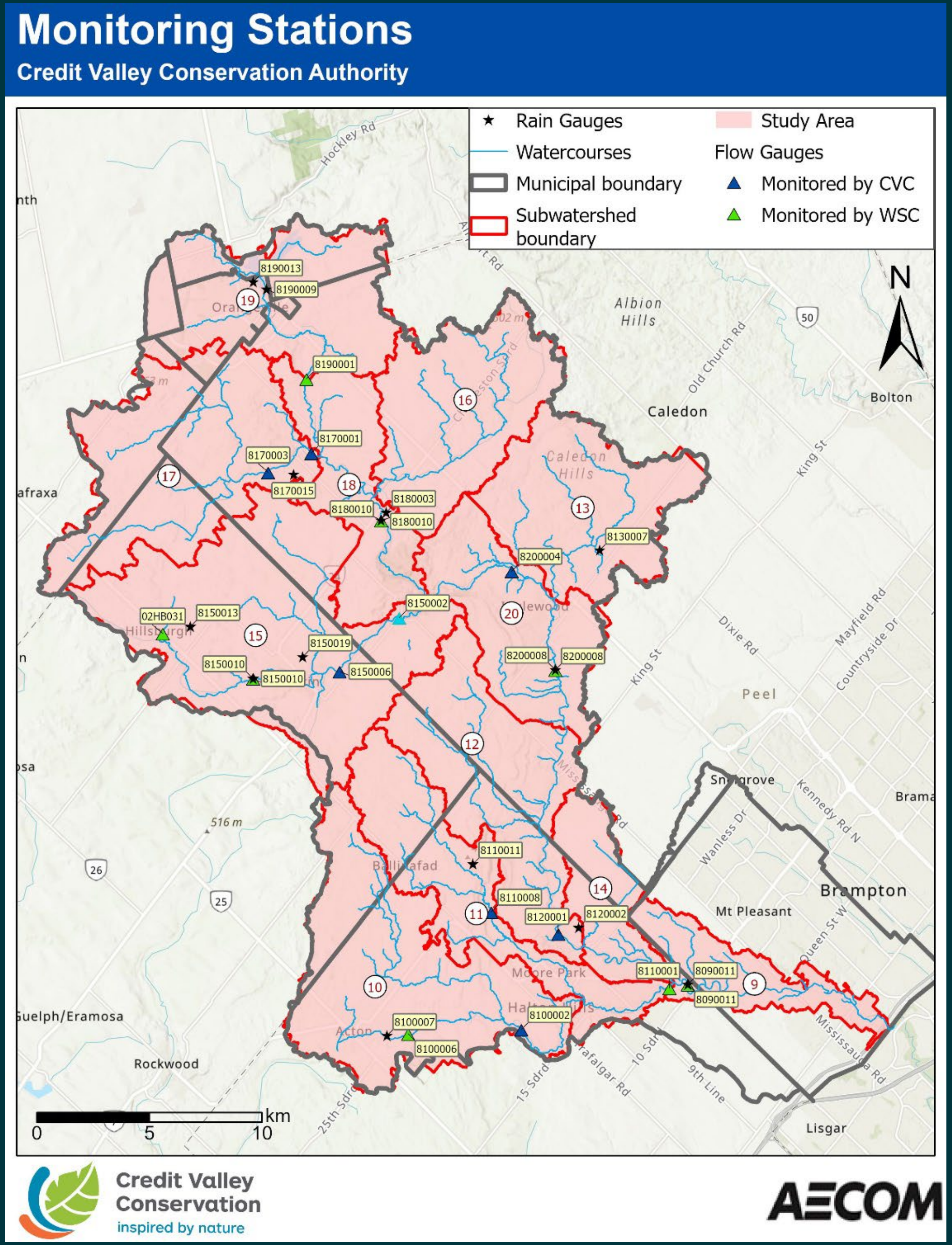
Scope

1. Identifications of largest annual peak flows
2. Model calibration for the largest annual peak flows
3. Model Validation
4. Flood Frequency Analysis



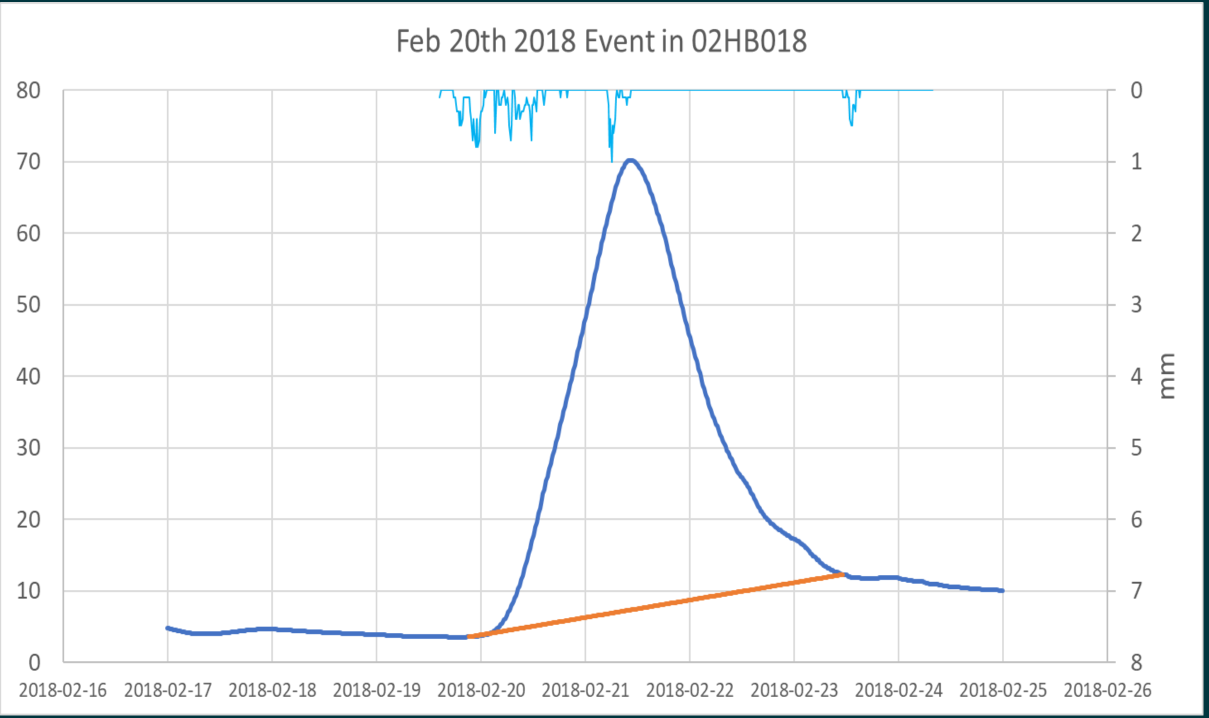
Context

1. Snowmelt contribution to flooding is difficult to predict; the timing, temperature and initial snow depth and distribution, ‘ripeness’ of the snowpack, etc. make prediction of winter floods a challenge.
2. In watersheds like the Credit River, reliable prediction is a critical issue as the rural subwatersheds all drain down toward urbanized areas



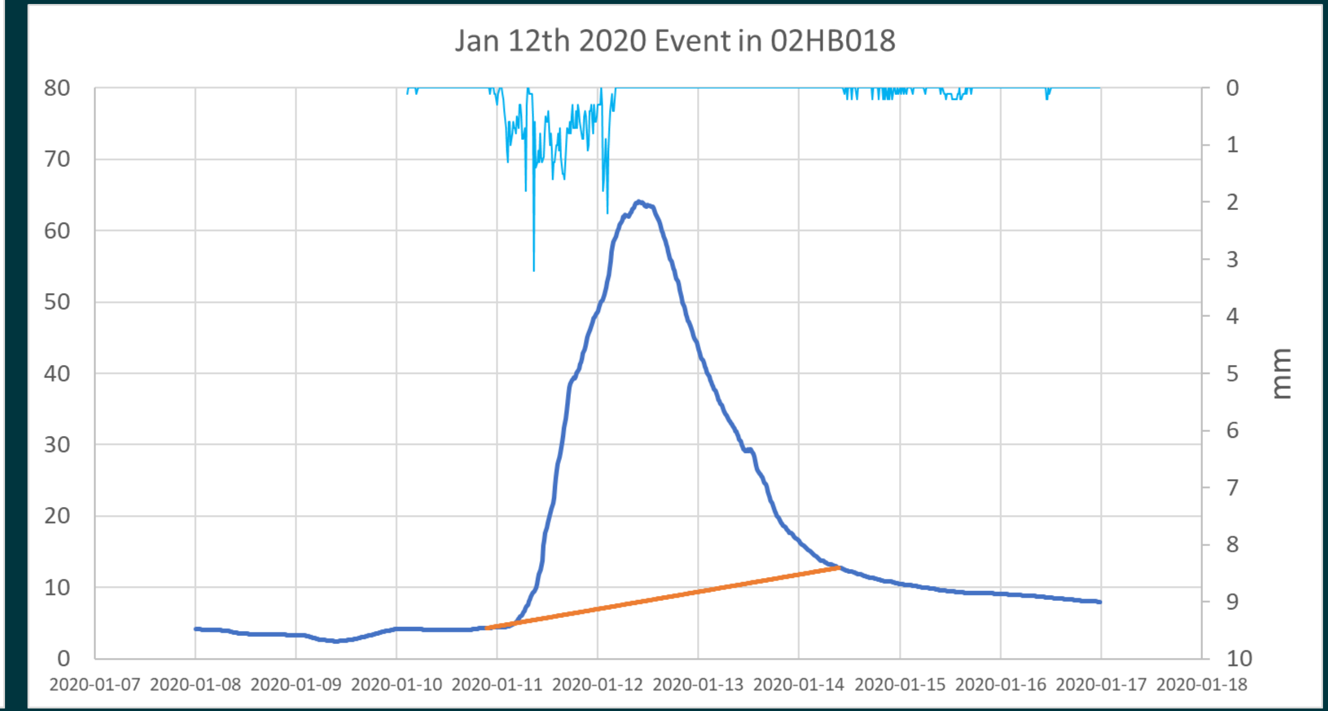
Event Comparison: Feb. 20, 2018 & Jan 12, 2020

25 cm Snow
25 mm Rain



Runoff Volume = 7.5 million m^3

5 cm Snow
85 mm Rain



Runoff Volume = 7.2 million m^3

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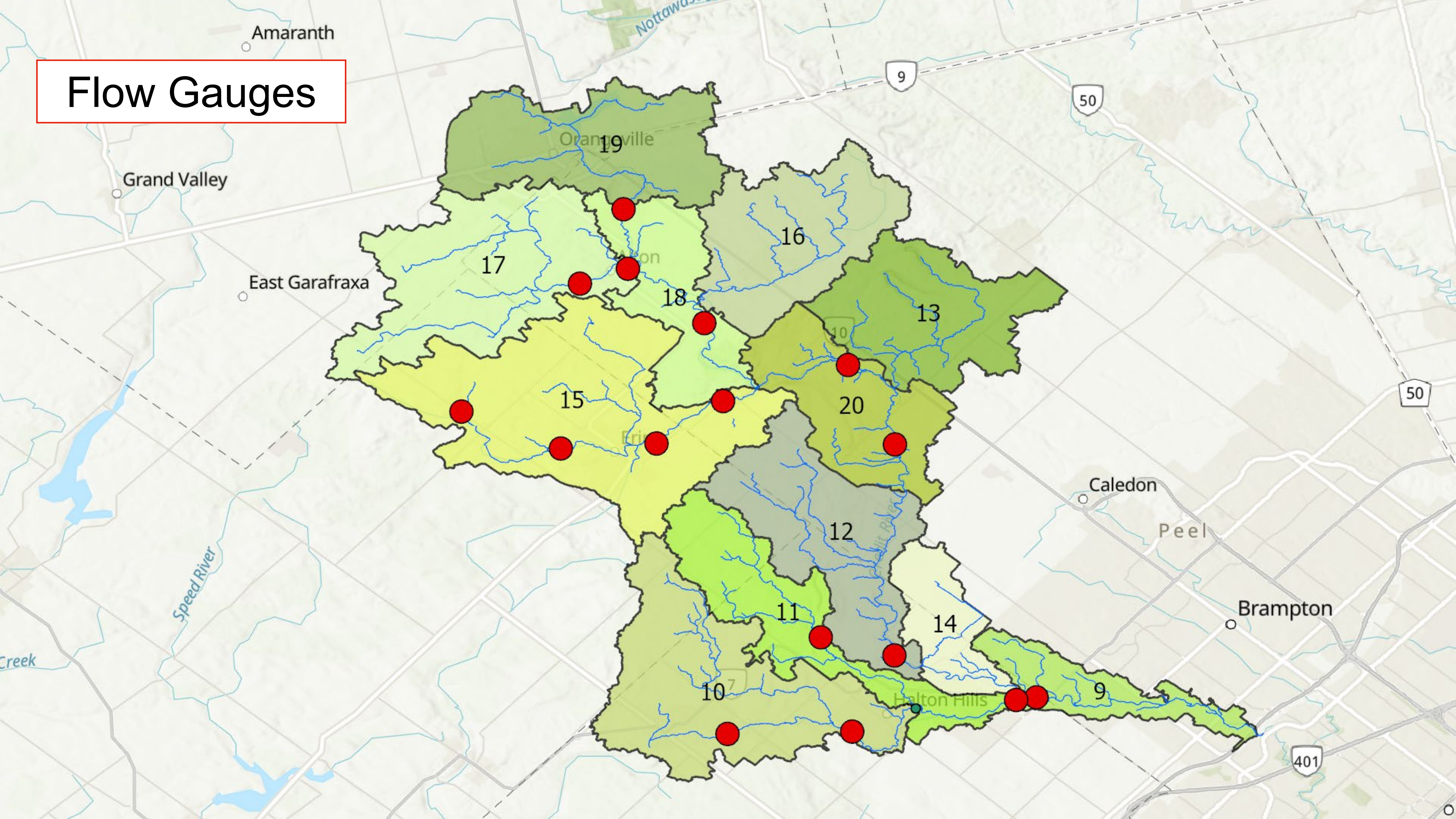
Flow Gauges


Amaranth
Grand Valley
East Garafraxa
Speed River
Caledon
Peel
Brampton
Halton Hills
9
50
401
19
16
17
18
13
20
15
12
11
14
10
9

Model Info

Study Area

12 Subwatersheds

66,813 ha

15 Rain gauges

16 Flow gauges

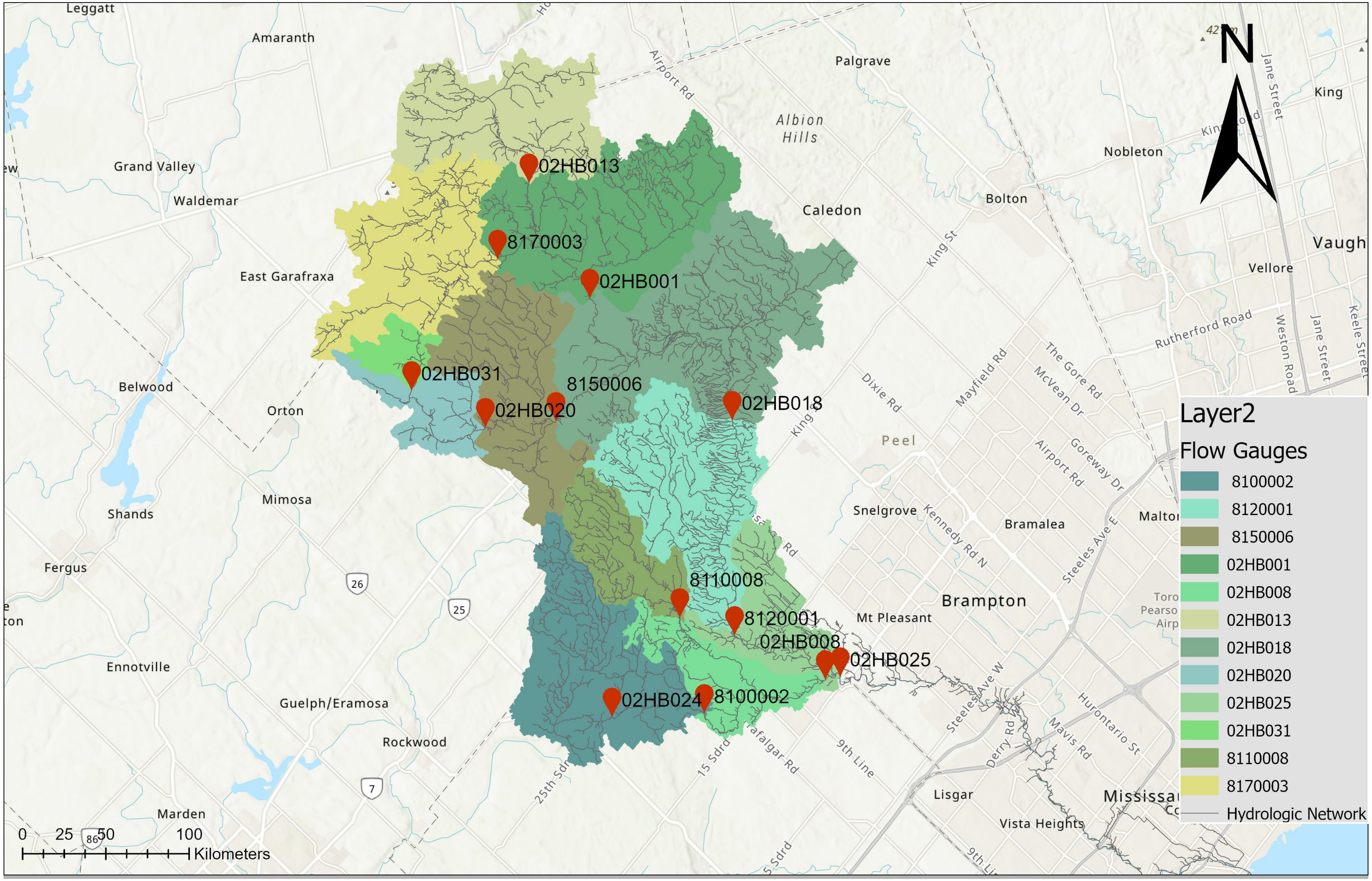
3 Snow gauge (biweekly apart data)

Flow, precipitation and temperature data at 15-minute intervals, for a period up to 53 years*

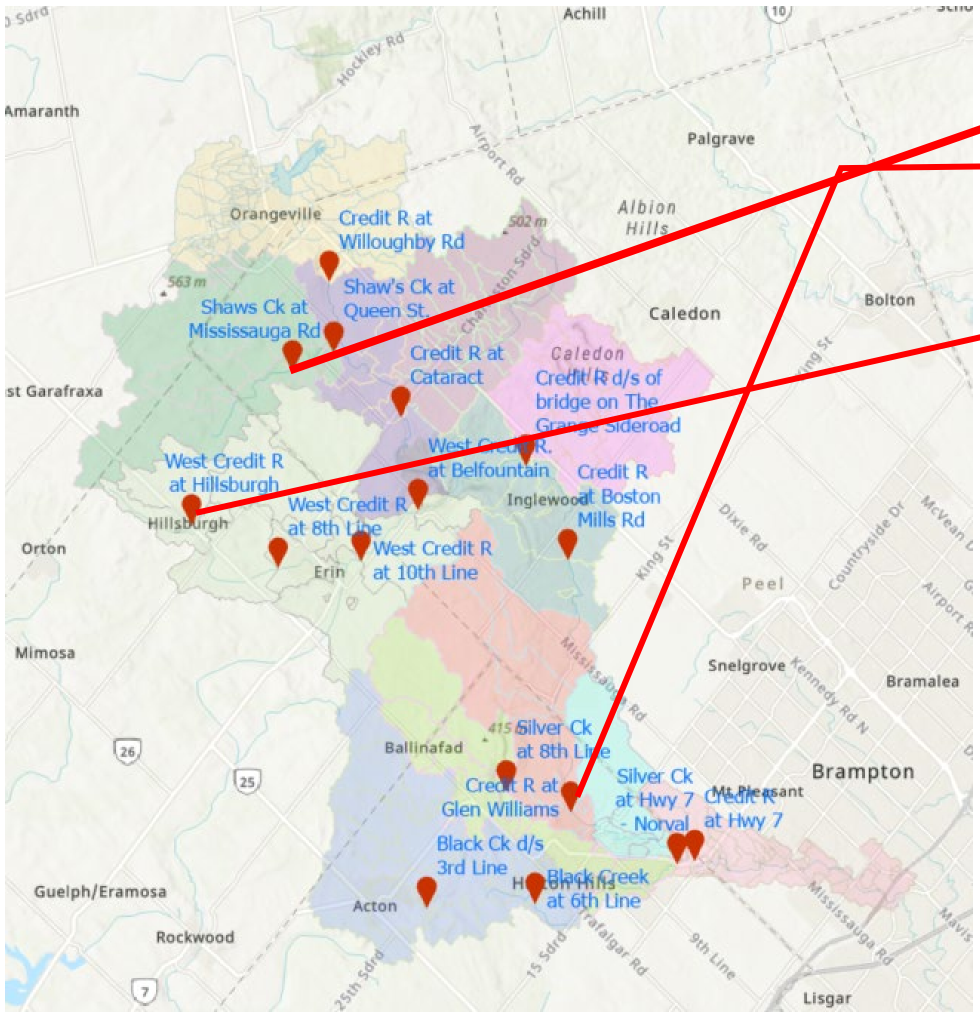
12 Visual OTTHYMO Models

Subwatershed	Number of NasHyd	Number of StandHyd
19	41	48
17	14	7
16	16	6
18	6	0
15	10	4
13	14	0
20	7	0
12	7	2
14	3	2
10	29	10
11	12	7
9	15	6

Flow Gauge Catchment Areas



Identification of Largest Annual Peak Flows



Date	Peak Flow	Type of Event
2018-02-21	107.0	significant rain on snowpack that is depleting
2019-03-15	106.8	significant rain on snowpack that is depleting
2020-01-12	74.1	…at is depleting
2008-12-20	68.9	… ground
2009-02-12	67.6	… ground
2006-03-13	63.1	… ground
2010-03-14	50.2	… ground
2017-06-24	47.8	
2005-02-16	45.5	rain on snow or saturated ground
2011-03-11	33.3	rain on snow or saturated ground
2012-05-04	33.3	rain on snow or saturated ground
2013-04…		… on snow …
2014-04…		… on snow …
2016-0…		… on snow …
2022-0…		… on snow …
2004-05…		… on snow …
2007-0…		… on snow …
2015-04-10	26.0	rain on snow or saturated ground
2021-09-23	24.8	rain only

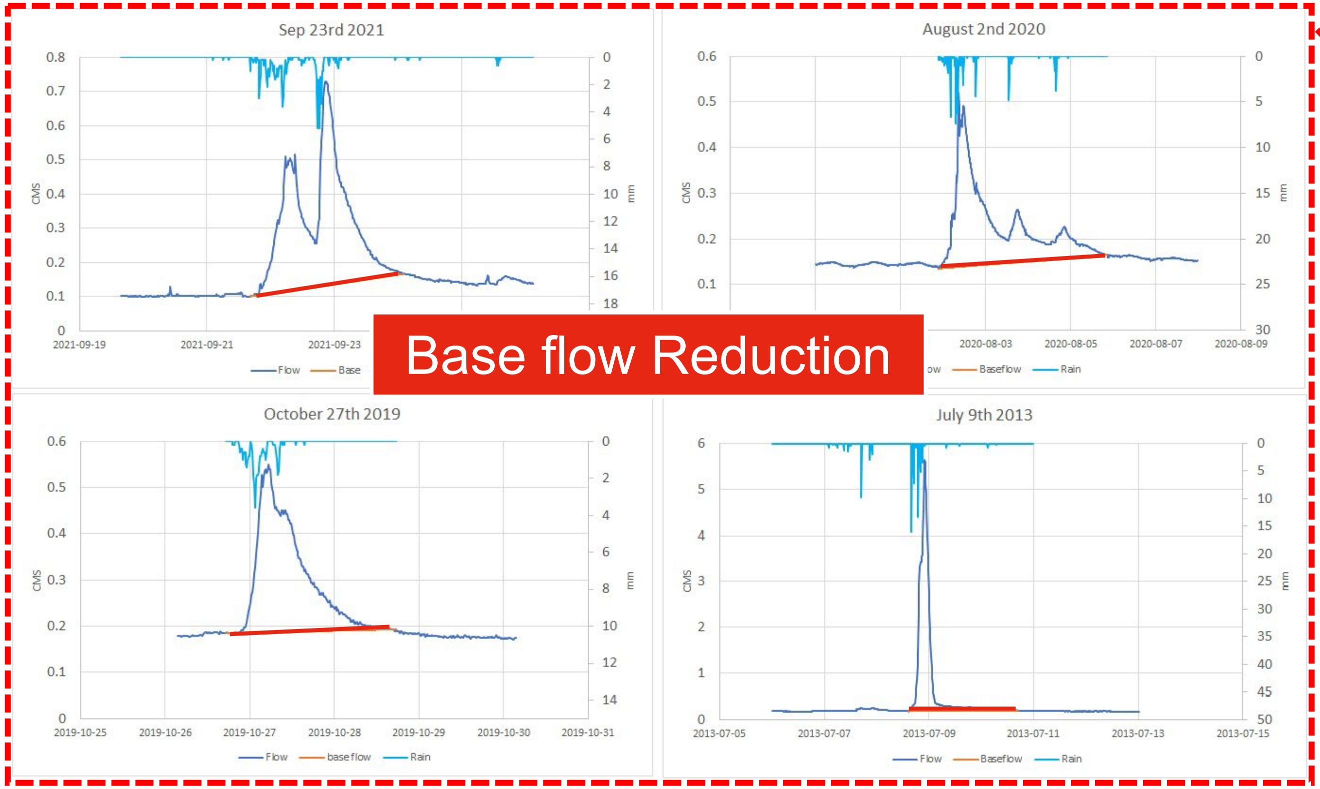
Largest Annual Peak Flows

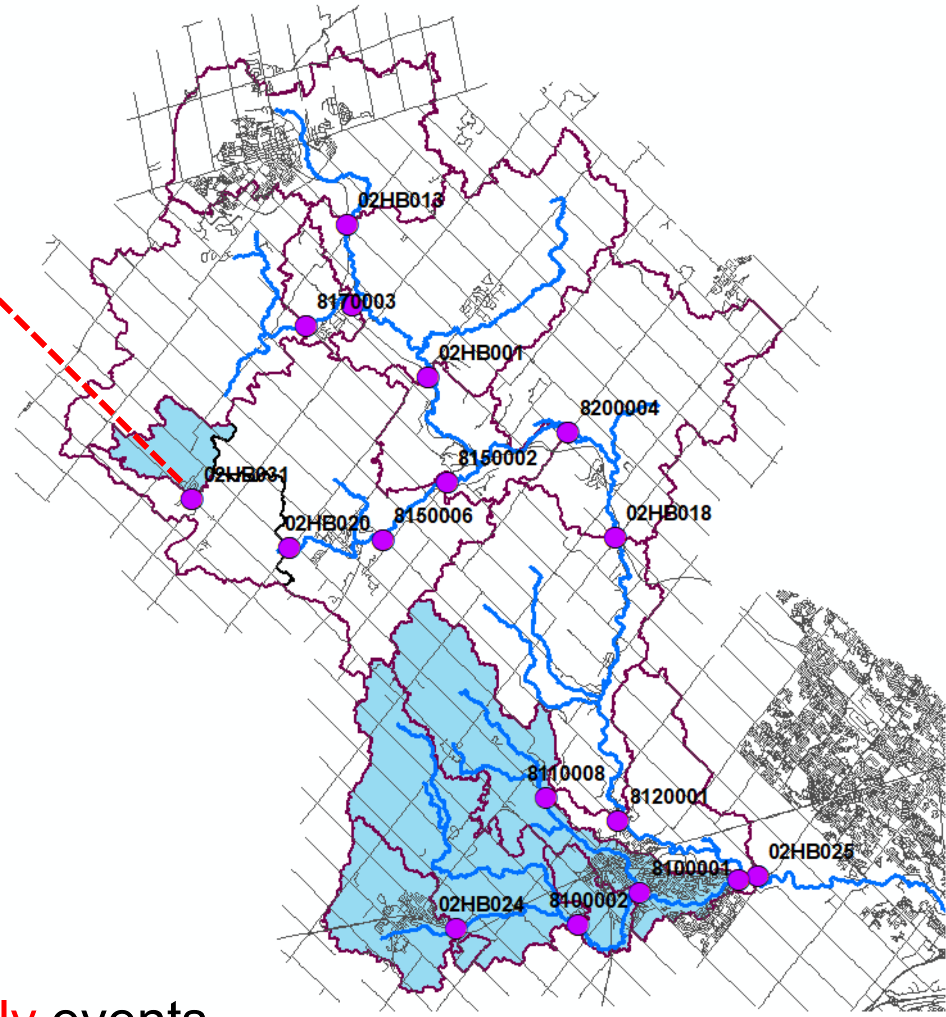
Summer Events

Rain on Snow Events

Summer Events

Summer Event Analysis





White: Rain-on-snow events Only

Blue: Rain-on-snow & Summer/Rain-only events

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Methodology

Assumption based on the event characterization

Precipitation

Initial Abstraction

$$Q = \frac{(P - IA)^2}{P - IA + S}$$

Runoff

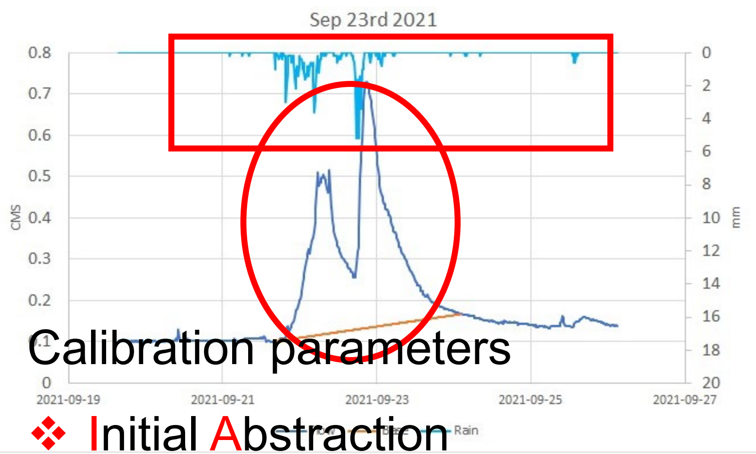
Soil Storage

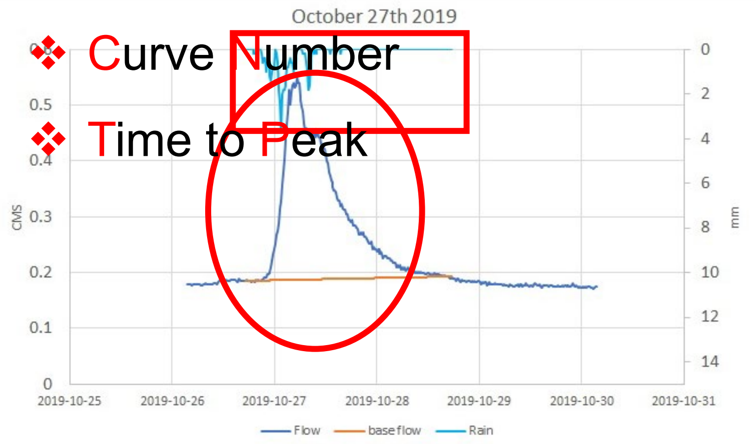
Soil Storage

$$S = \frac{25400}{CN} - 254$$

Curve Number

Each Summer event has a CN to generate the volume





Calibration parameters

- Initial Abstraction
- Curve Number
- Time to Peak

BUT – this method uses discrete AMC's to adjust CN… So how do we categorize the Summer events?

What is the primary factor governing large summer flows in rural areas?

Antecedent Precipitation Index

$$API_{i+1} = \underline{Daily\ Rainfall\ (mm)} + API_i \times \text{Decay Factor}$$

API at time step=i

A factor that creates the best relation between API and CN (Decay factor of 0.6)

$$\text{decay factor on 15}-\text{minute basis} = \sqrt[4\times24]{\text{decay factor on daily basis}} = \sqrt[96]{0.6} = 0.99469$$

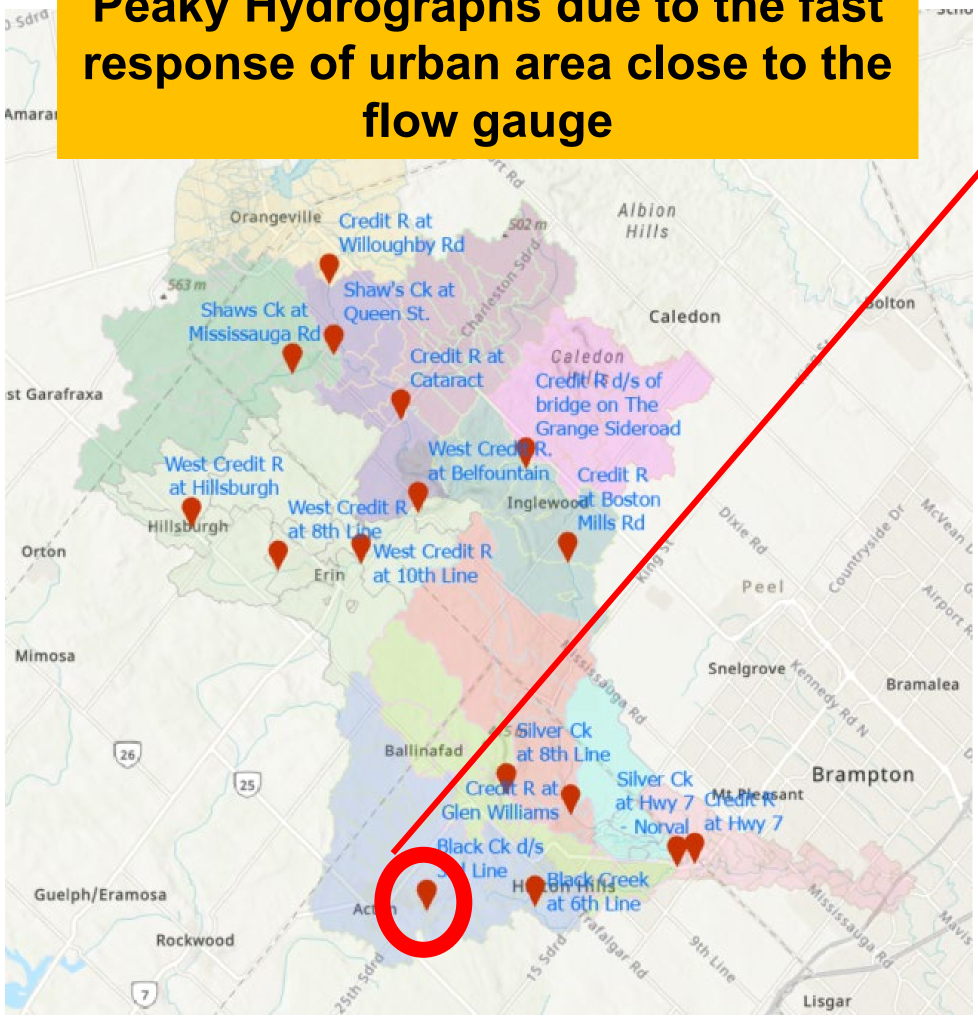
Rainfall timestep is 15 minutes

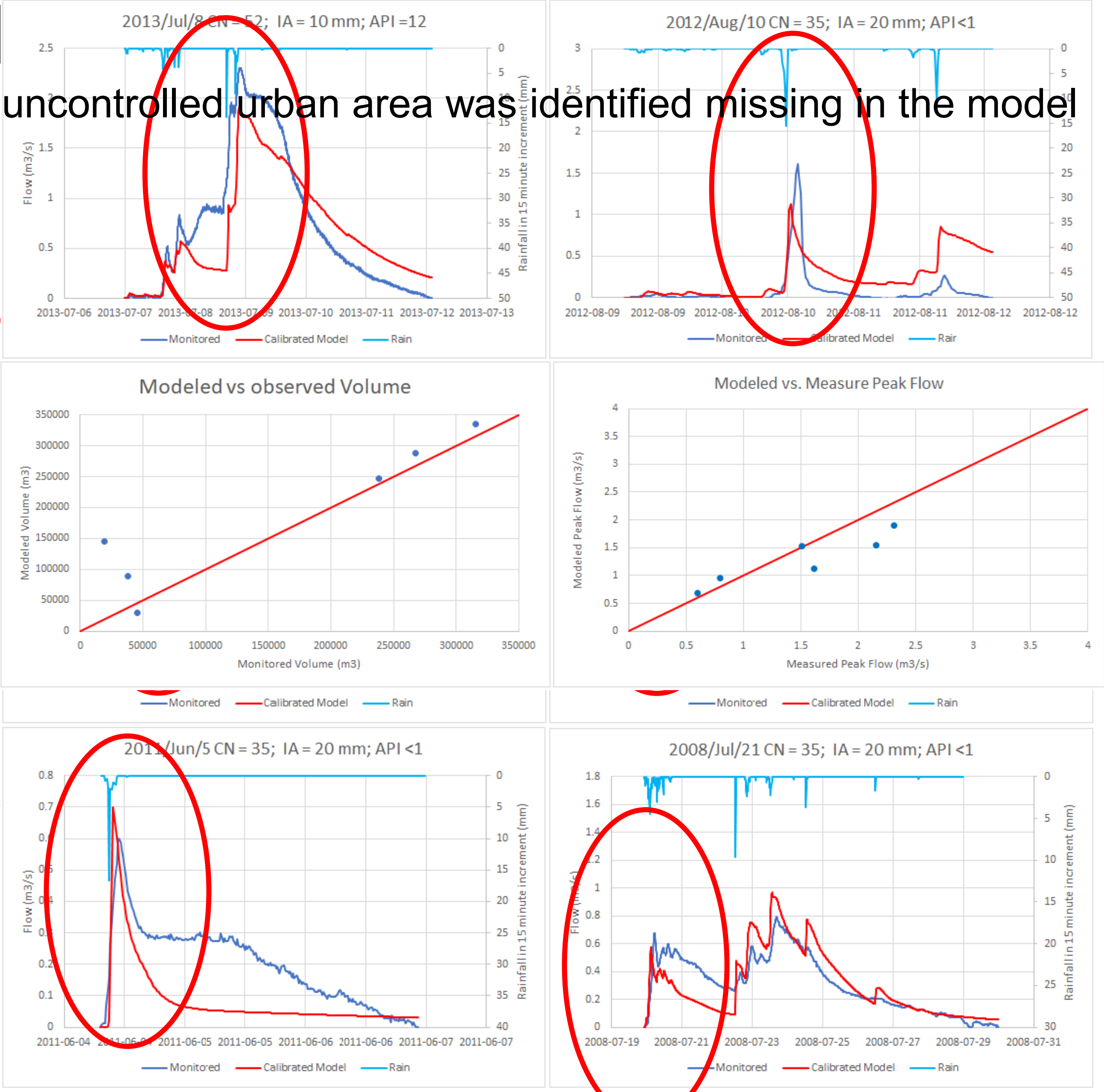
$$\boldsymbol{API_{i+1} = 15 - \text{minute Rainfall (mm)} + API_i \times 0.99469}$$

Gauge 02HB024: Peaky I

70 ha uncontrolled urban area was identified missing in the model

Peaky Hydrographs due to the fast response of urban area close to the flow gauge





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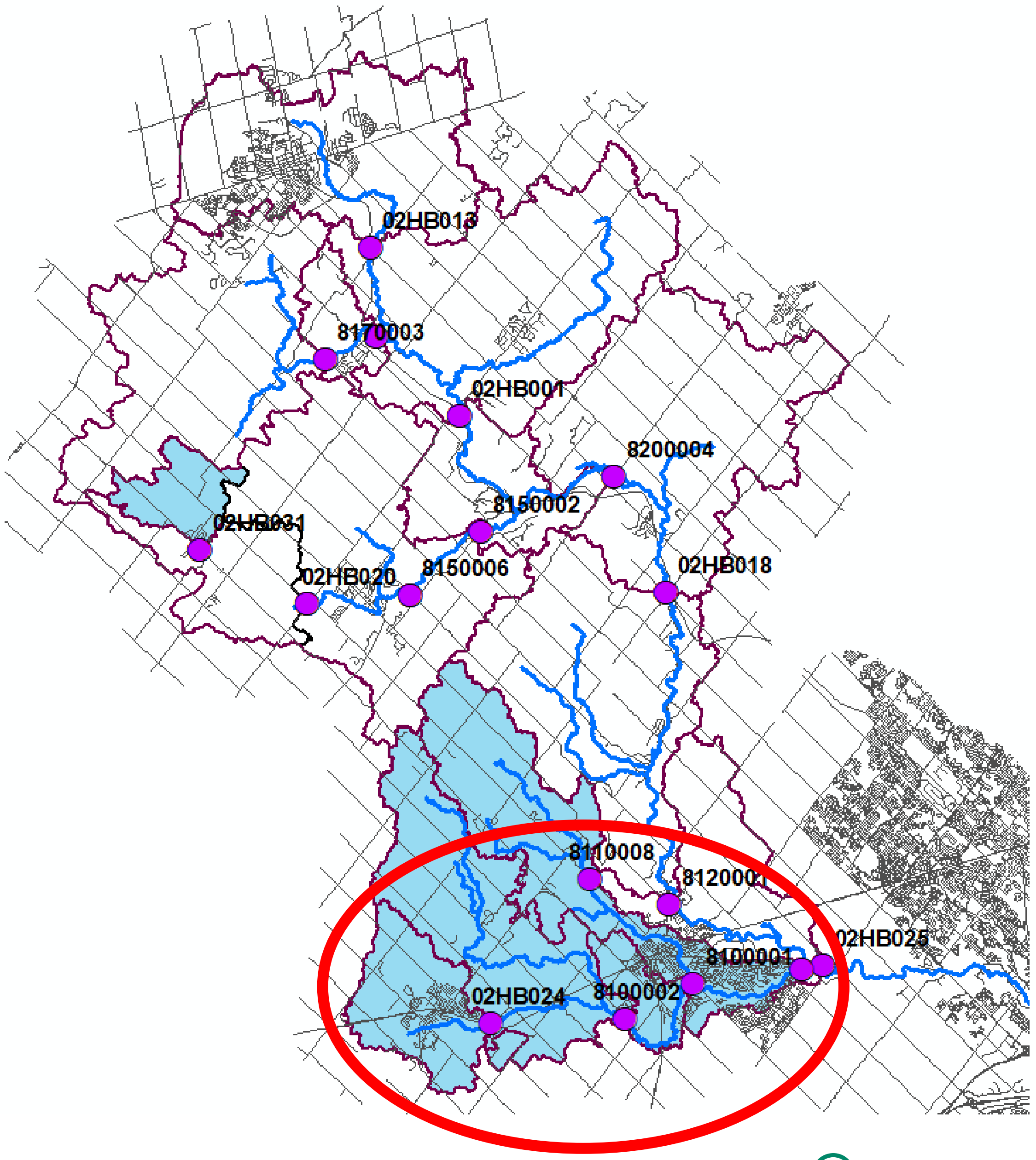
Findings

❖The uncontrolled urban area is the main reason for the large flows during summer events.

❖Large flows in rural watersheds are mainly due to Rain-on-Snow events, and **not** from large rainfall only events (i.e., summer storms)



Rain on Snow Events

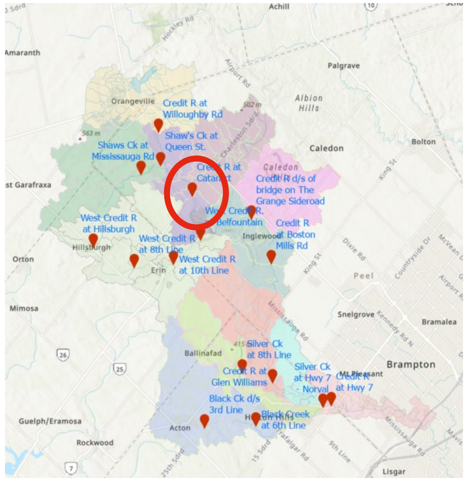
First, Some Context …
Snowpack Reaction to Rainfall

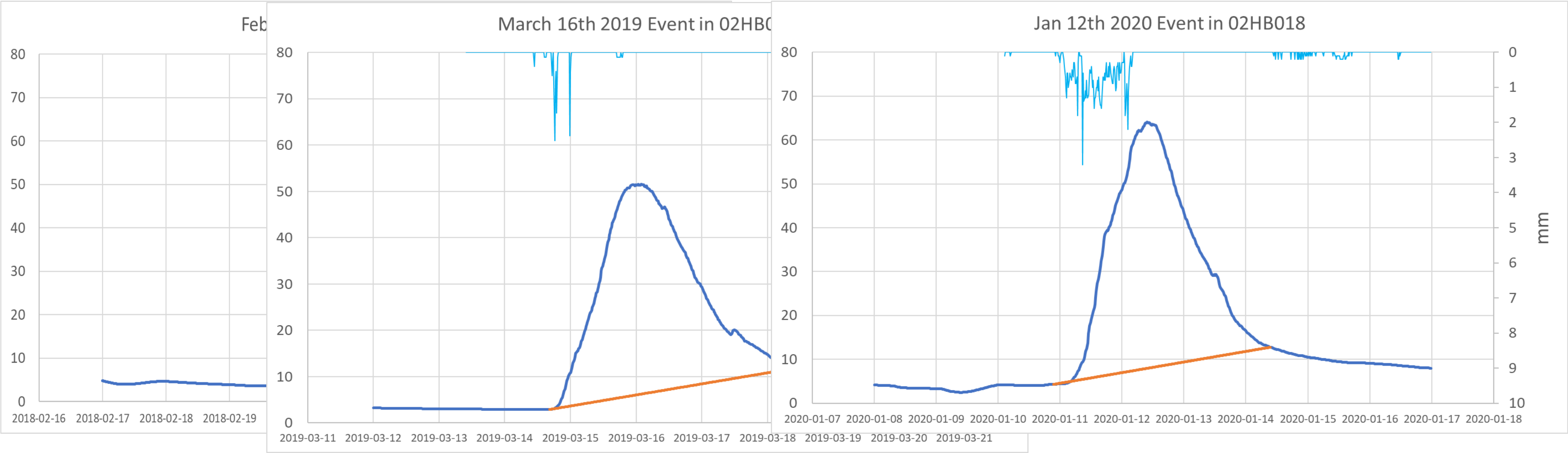
Suitable for Calibration

1) Rain completely gets absorbed into the snow → **Very little or no runoff**	✗
2) Rain is partially absorbed, but also partially melts the snowpack, decreasing the water equivalent of the residual snowpack → **still little runoff**	✗
3) Rain joins a melting snowpack → assisting the melt process → **large runoff**	✓

Rain On Snow Events

February 20th 2018	March 16th 2019	January 12th 2020
25 cm Snow 25 mm Rain	30 cm Snow 9 mm Rain	5 cm Snow 85 mm Rain

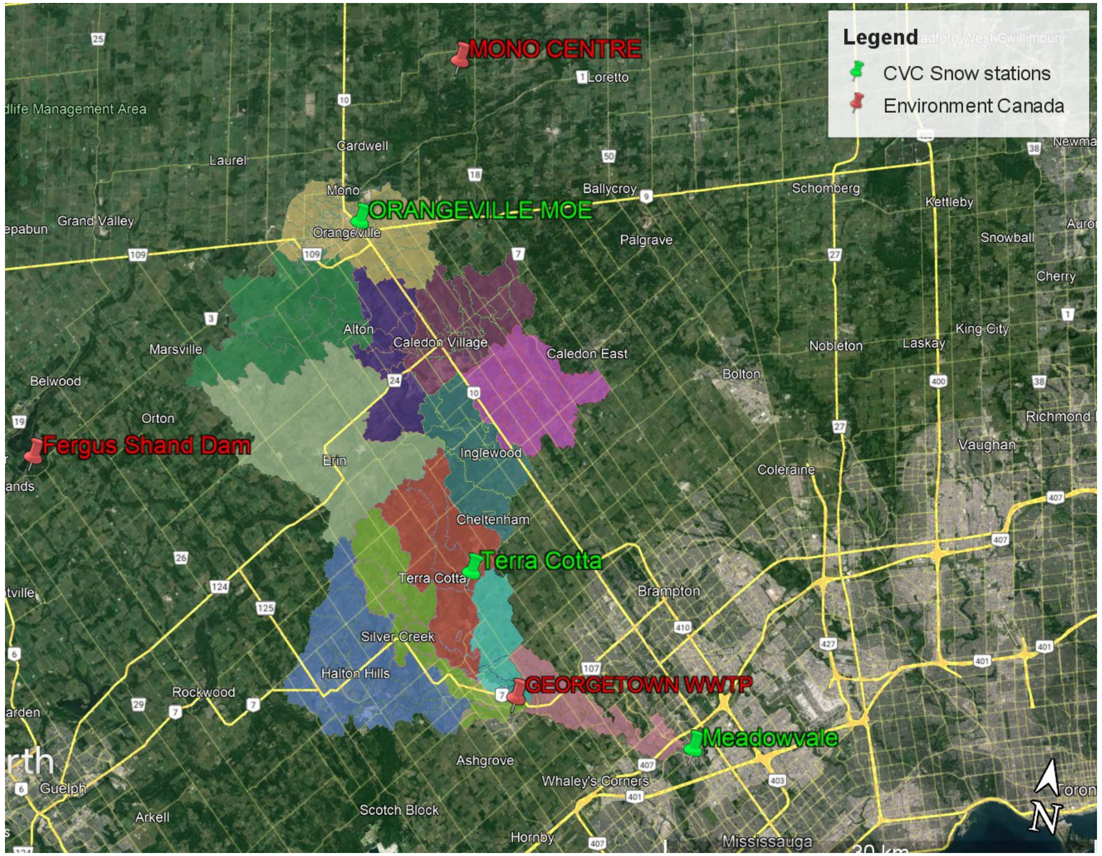




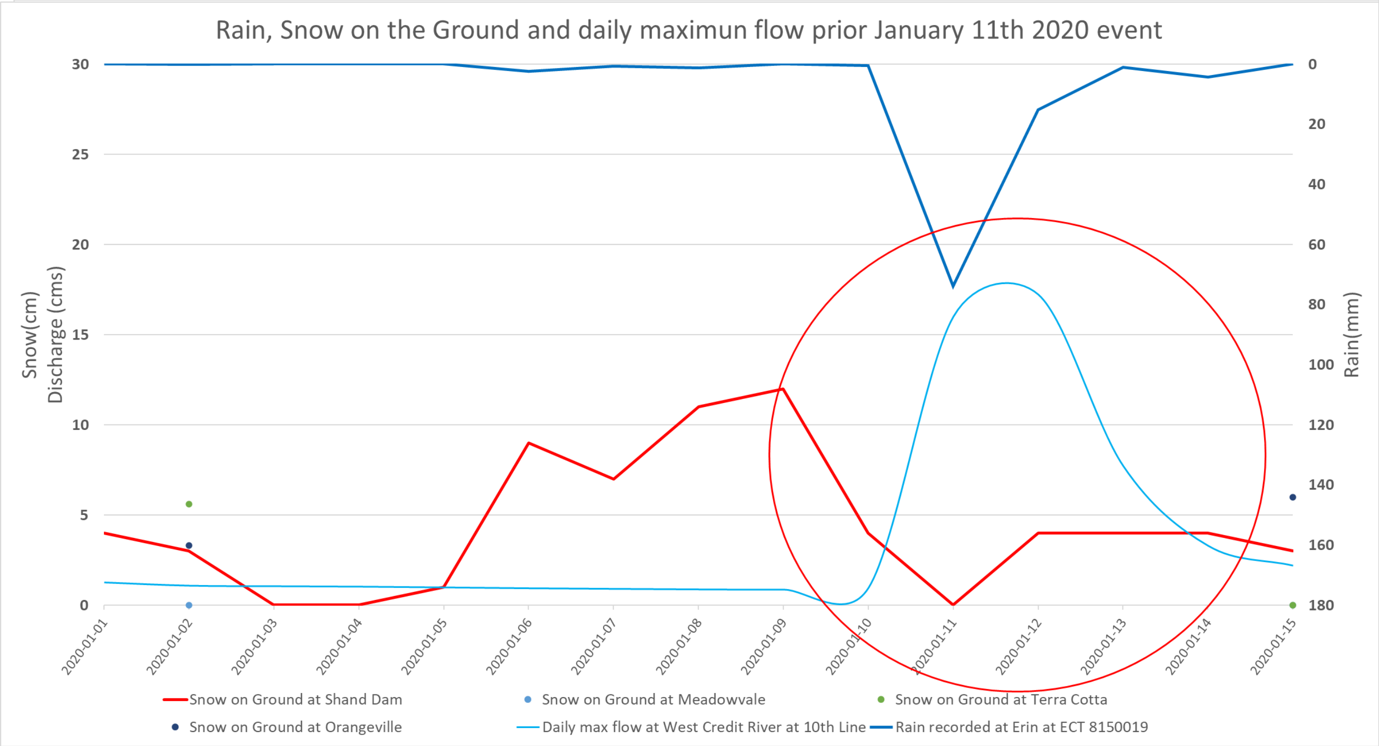
Runoff Volume = 7.5 million m³

Runoff Volume = 7.2 million m³

Snowpack Data



January 2020
February 2019
March 2018



Methodology

$$Degree\ days_{15-min} = \frac{Degree\ days_{daily}}{24 \times 4}$$

$$Snowmelt_i = Degree\ days_{15-min} \times melt\ factor$$

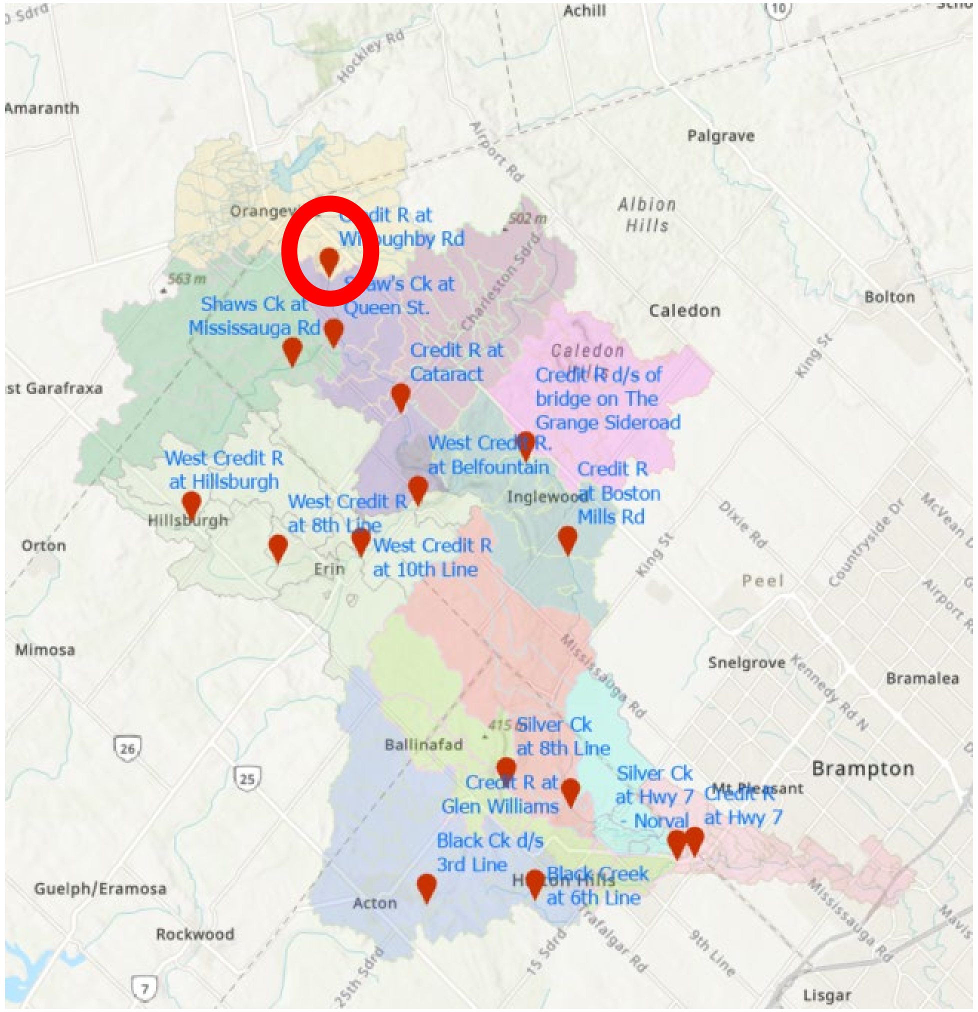
Measured Temperature at each 15 minute time step

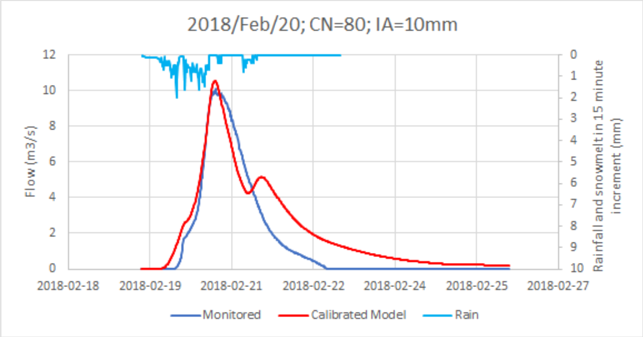
K = 4

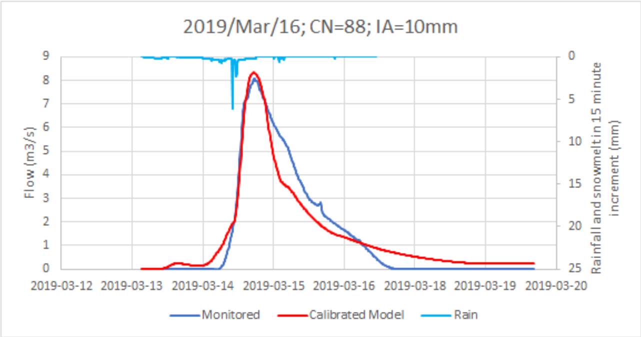
January Event					
Date	Rain Vol	Deg days	Snowmelt (K=4)	sum snowmelt	Rain+Snowmelt
2020-01-09 23:30	0	0.00	0.0	0.0	0.00
2020-01-09 23:45	0	0.00	0.0	0.0	0.00
2020-01-10 0:00	0	0.01	0.0	0.0	0.03
2020-01-10 0:15	0	0.02	0.1	0.1	0.07
2020-01-10 0:30	0	0.02	0.1	0.2	0.08
2020-01-10 0:45	0	0.02	0.1	0.3	0.10
2020-01-10 1:00	0	0.03	0.1	0.4	0.11
2020-01-10 1:15	0	0.03	0.1	0.5	0.12
2020-01-10 1:30	0	0.03	0.1	0.6	0.12
2020-01-10 1:45	0	0.03	0.1	0.8	0.13
2020-01-10 2:00	0	0.04	0.2	0.9	0.15
2020-01-10 2:15	0	0.05	0.2	1.1	0.19
2020-01-10 2:30	0.1	0.06	0.2	1.3	0.33
2020-01-10 2:45	0	0.06	0.2	1.6	0.23
2020-01-10 3:00	0	0.06	0.2	1.8	0.23
2020-01-10 3:15	0	0.05	0.2	2.0	0.22
2020-01-10 3:30	0	0.06	0.2	2.2	0.22
2020-01-10 3:45	0	0.05	0.2	2.4	0.20
2020-01-10 4:00	0	0.05	0.2	2.6	0.20
2020-01-10 4:15	0	0.05	0.2	2.8	0.18
2020-01-10 4:30	0	0.04	0.2	3.0	0.18
2020-01-10 4:45	0.1	0.04	0.2	3.2	0.27

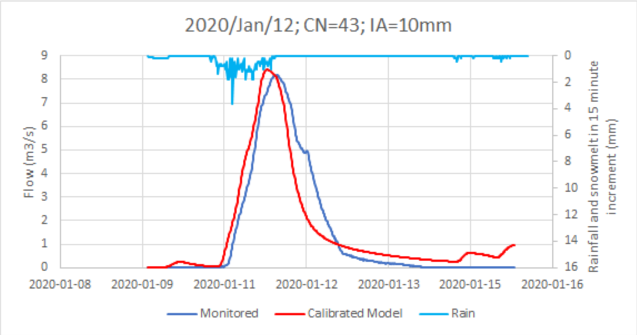
January Event					
Date	Rain Vol	Deg days	Snowmelt (K=4)	sum snowmelt	Rain+Snowmelt
2020-01-10 5:00	0	0.04	0.2	3.3	0.17
2020-01-10 5:15	0	0.04	0.2	3.5	0.17
2020-01-10 5:30	0	0.04	0.2	3.6	0.16
2020-01-10 5:45	0	0.04	0.2	3.8	0.16
2020-01-10 6:00	0	0.04	0.2	4.0	0.17
2020-01-10 6:15	0	0.04	0.2	4.1	0.17
2020-01-10 6:30	0	0.04	0.2	4.3	0.17
2020-01-10 6:45	0	0.04	0.2	4.5	0.16
2020-01-10 7:00	0	0.04	0.2	4.6	0.16
2020-01-10 7:15	0	0.04	0.2	4.8	0.16
2020-01-10 7:30	0	0.04	0.2	5.0	0.17
2020-01-10 7:45	0	0.04	0.0	0.0	0.00
2020-01-10 8:00	0.3	0.04	0.0	0.0	0.30
2020-01-10 8:15	0	0.04	0.0	0.0	0.00
2020-01-10 8:30	0.2	0.04	0.0	0.0	0.20
2020-01-10 8:45	0.2	0.04	0.0	0.0	0.20
2020-01-10 9:00	0.12	0.04	0.0	0.0	0.12
2020-01-10 9:15	0	0.04	0.0	0.0	0.00
2020-01-10 9:30	0	0.04	0.0	0.0	0.00
2020-01-10 9:45	0	0.04	0.0	0.0	0.00
2020-01-10 10:00	0	0.04	0.0	0.0	0.00

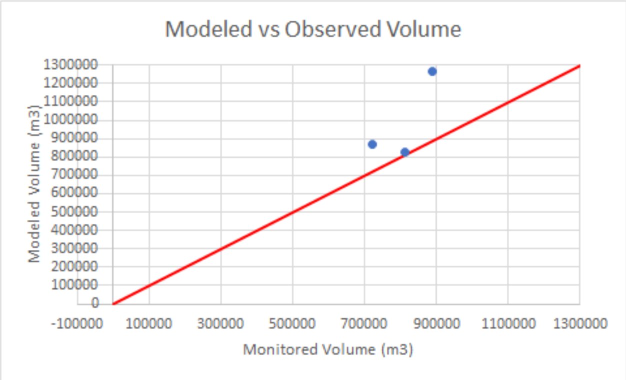
Results: Gauge 02HB013

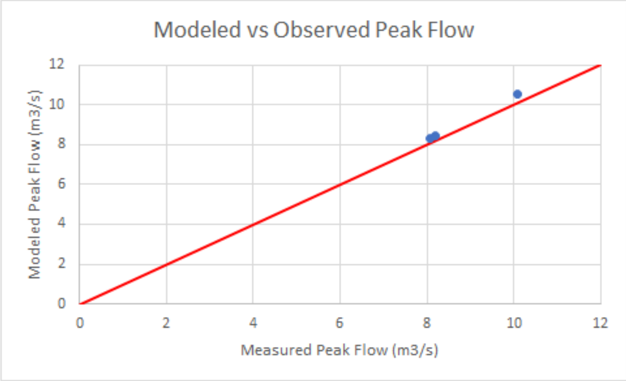




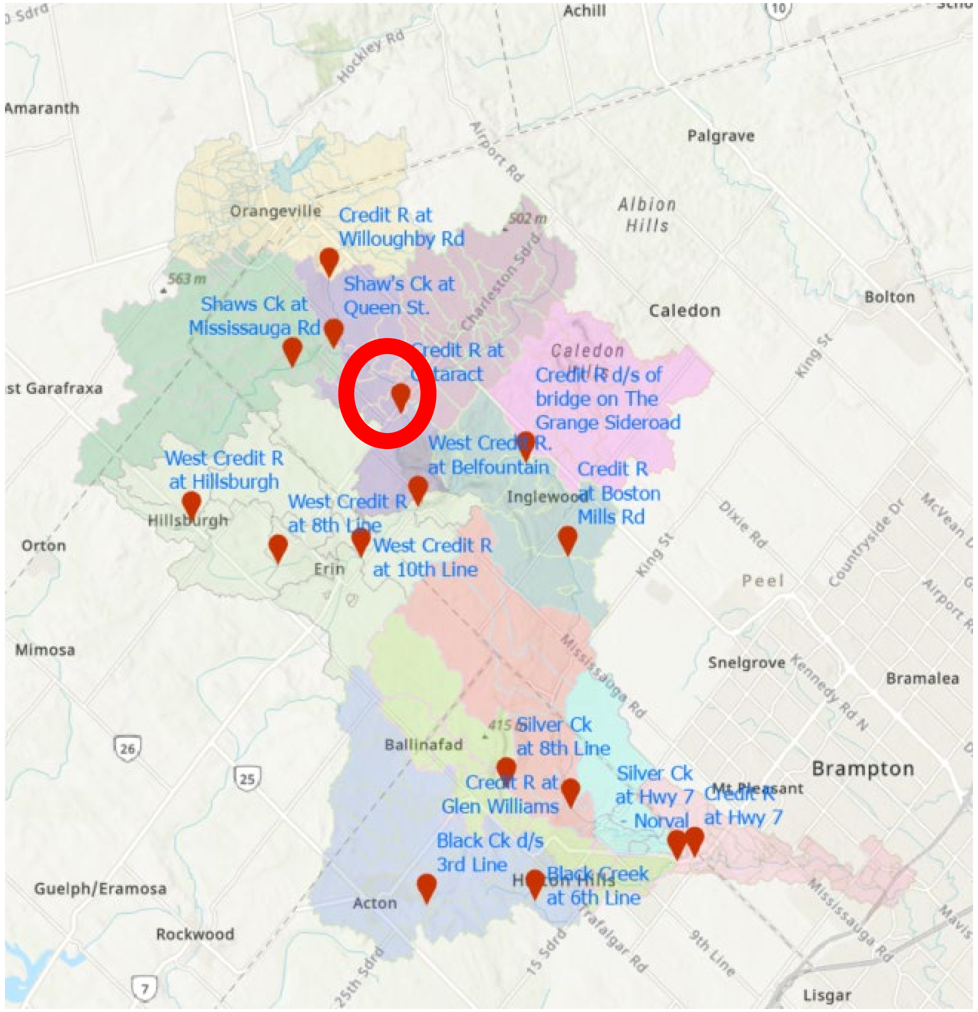


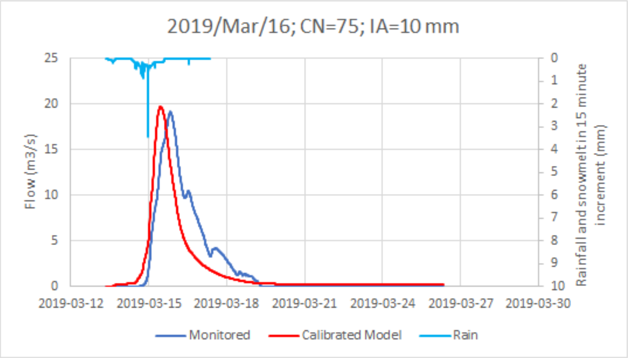


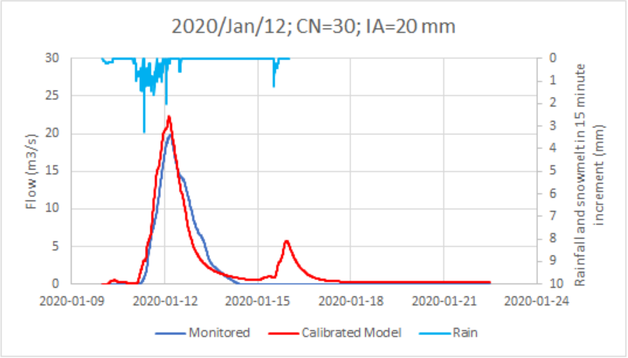


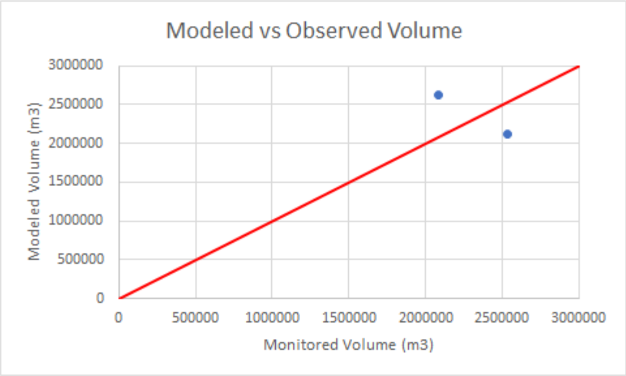


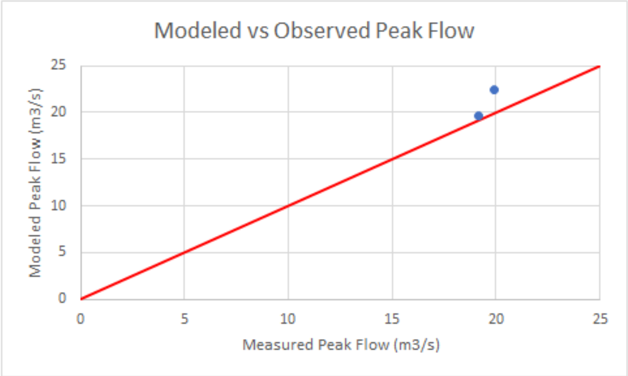
Results: Gauge 02HB001



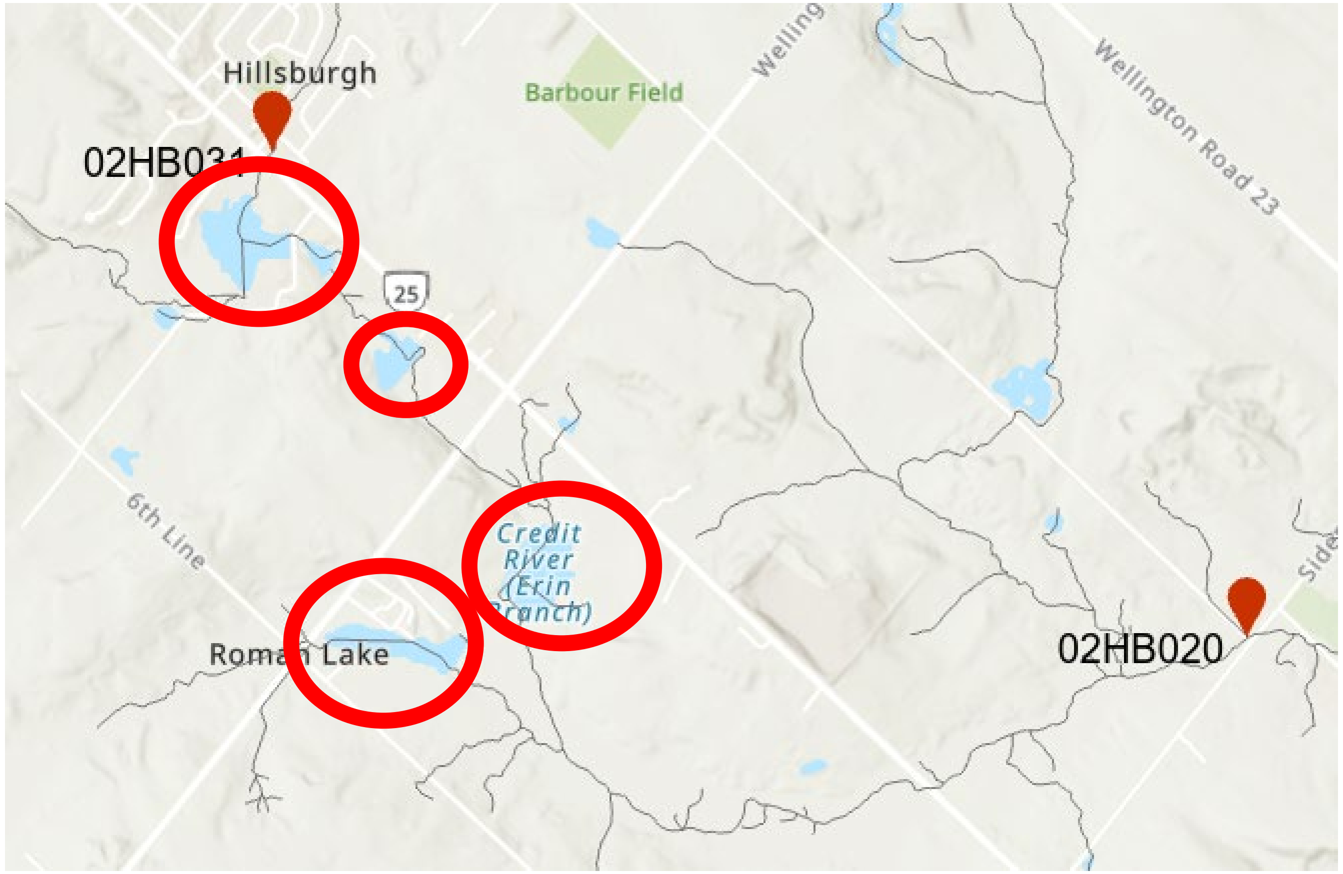








Results: Gauge 02HB020 – 4 Online Ponds

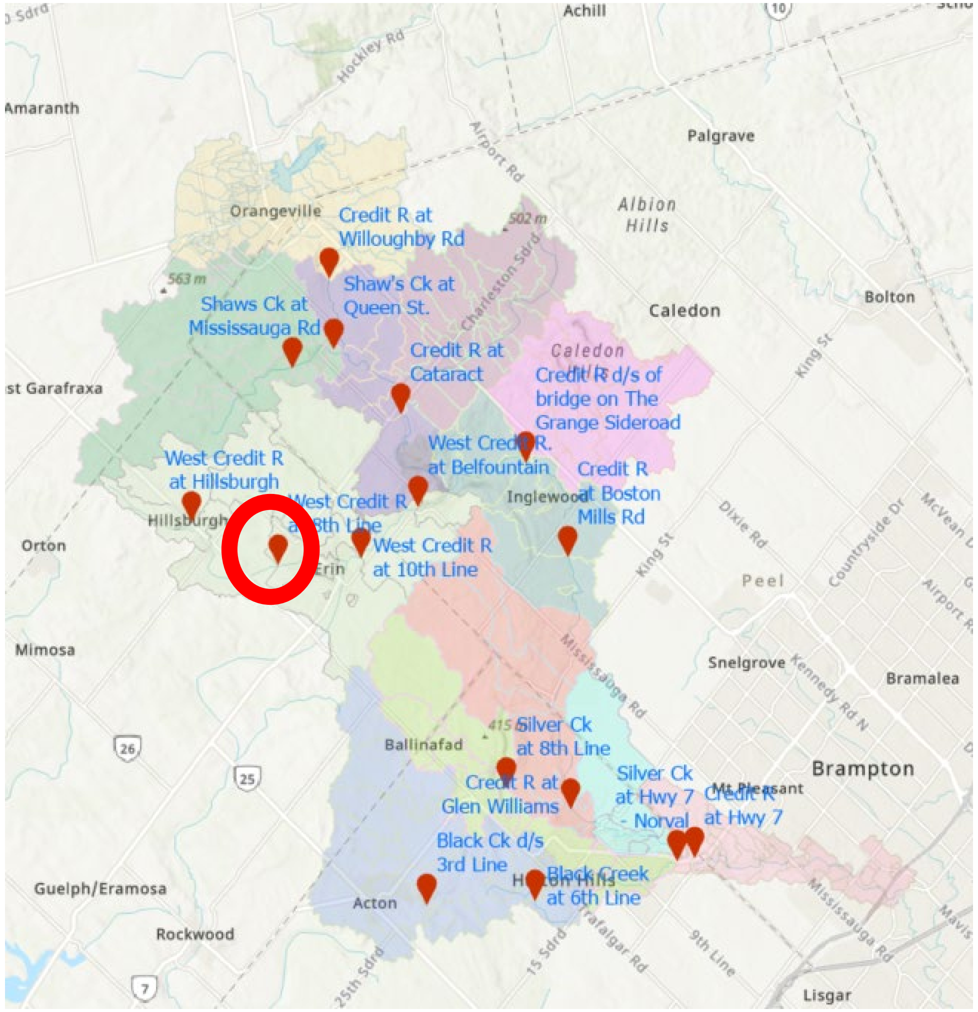


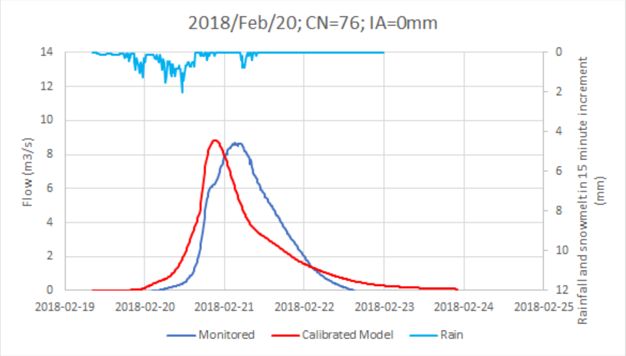
4 online ponds were identified and added to the hydrologic model

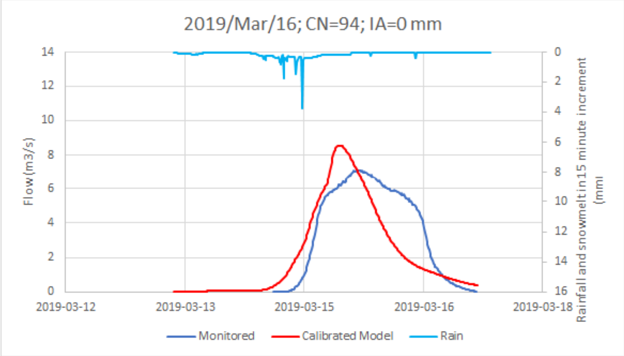
Rating curves were created using:

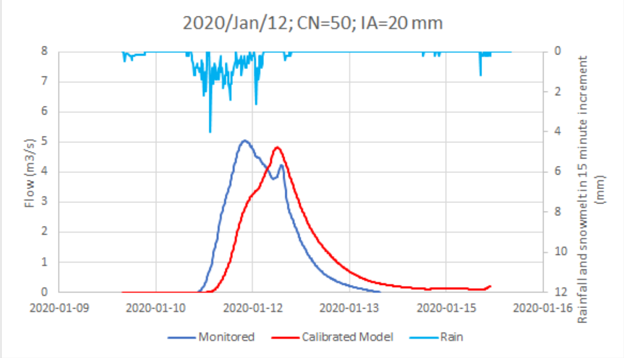
- ✓ Hydraulic models
- ✓ Footprint area of the ponds

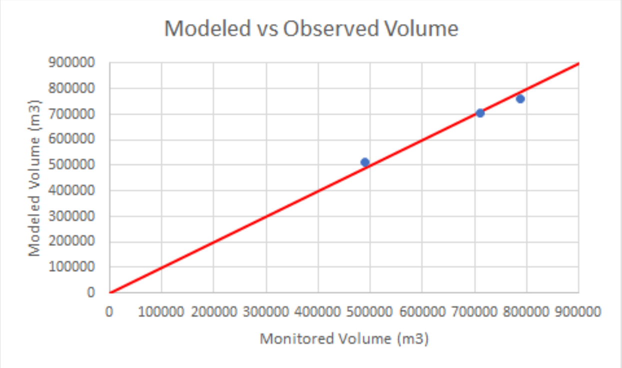
Results: Gauge 02HB020

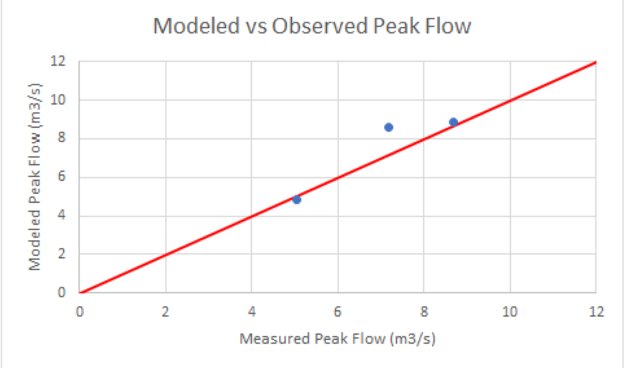




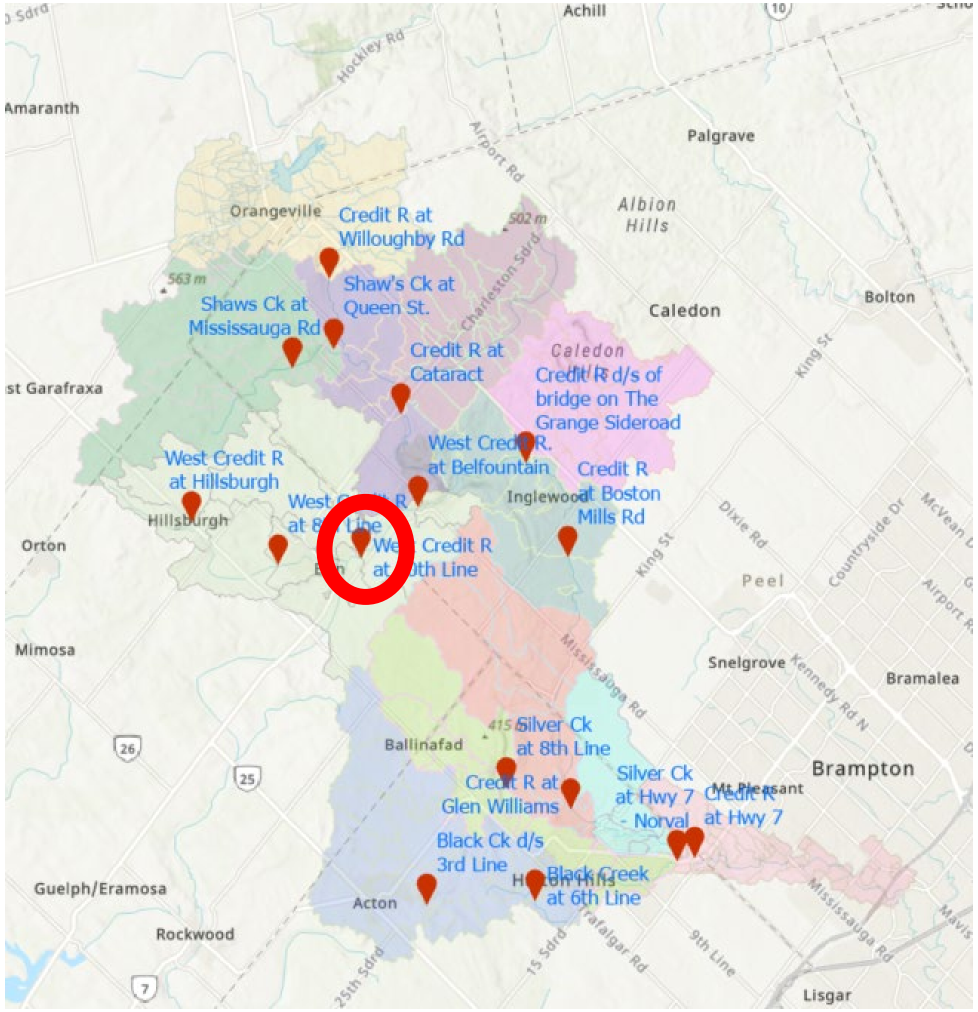


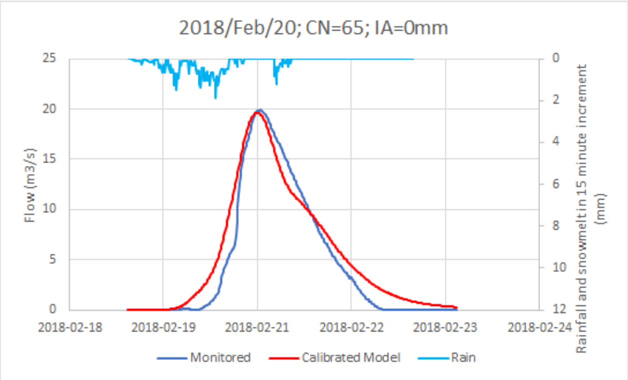


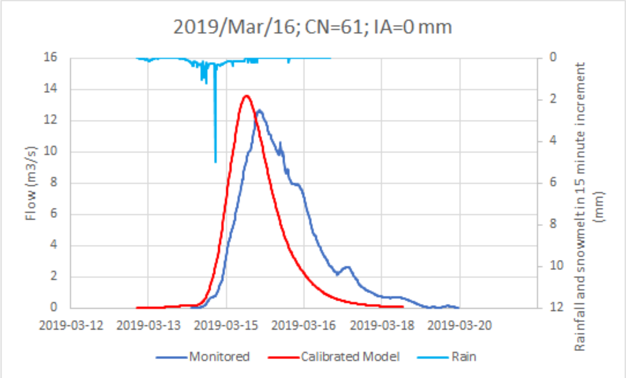


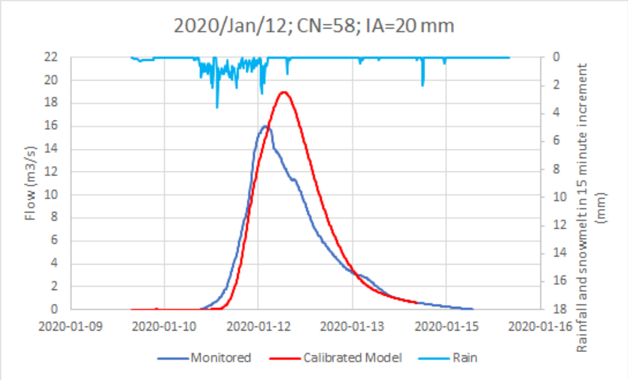


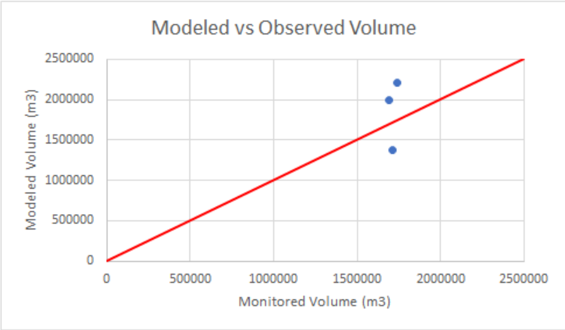
Results: Gauge 8150006

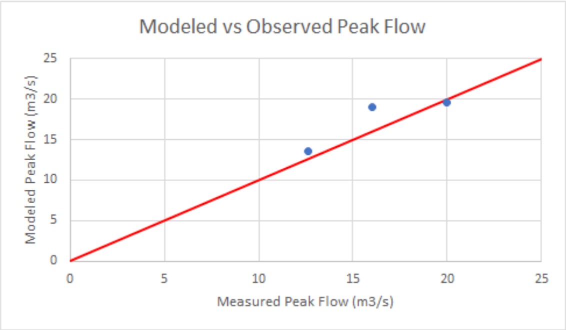






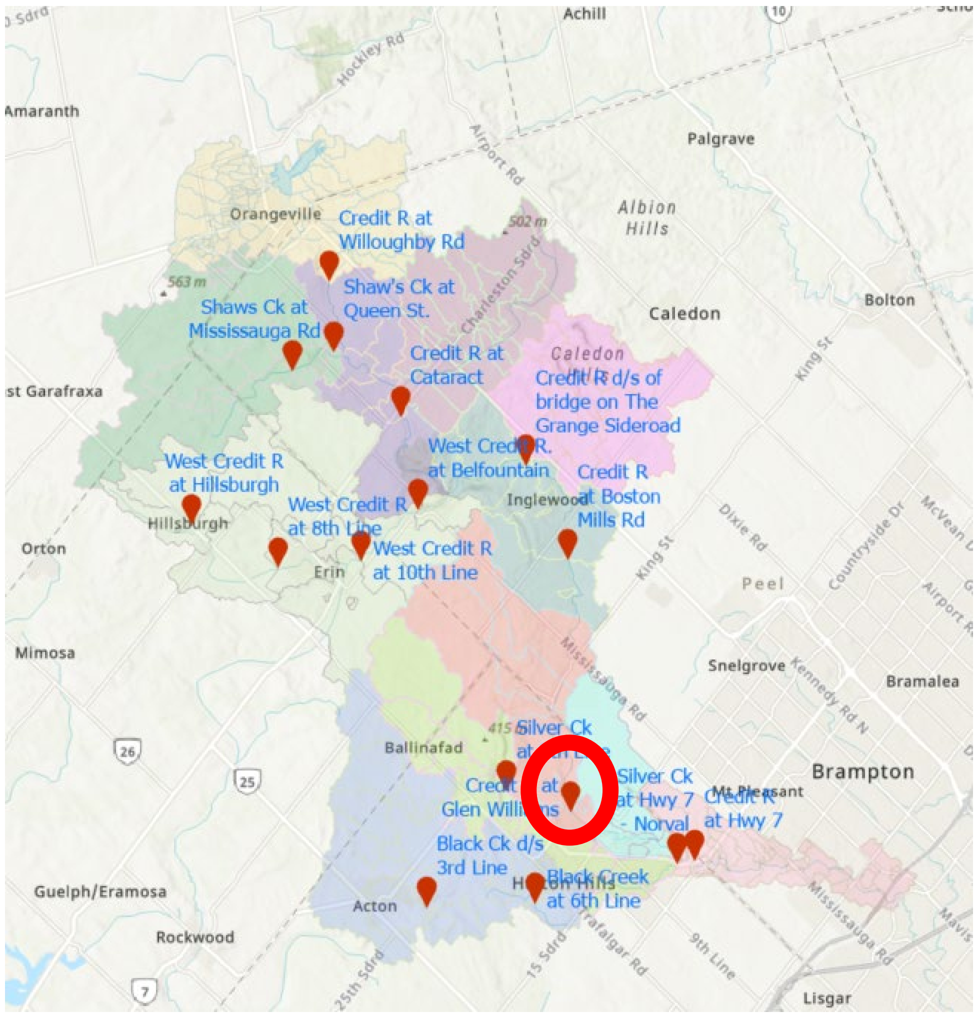


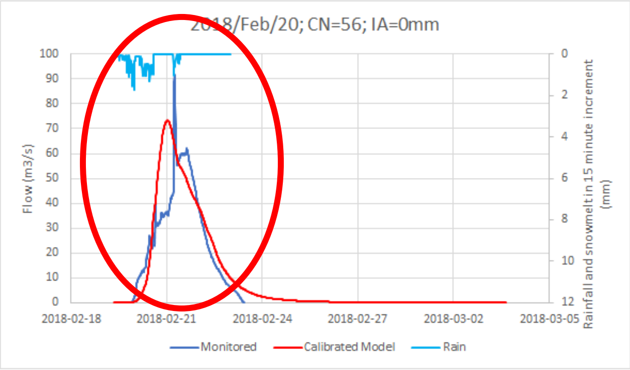


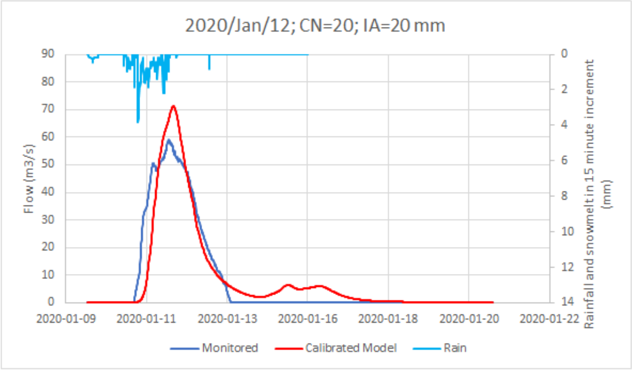


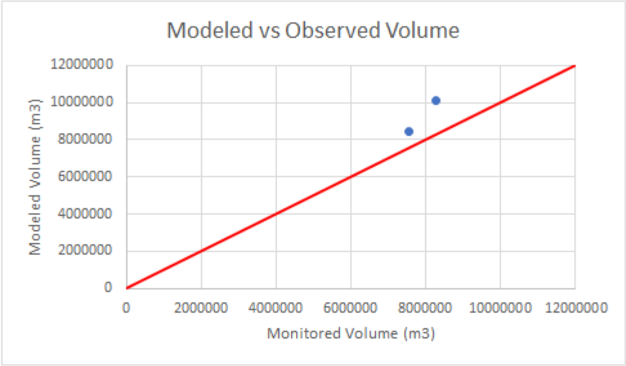
Results: Gauge 8120001

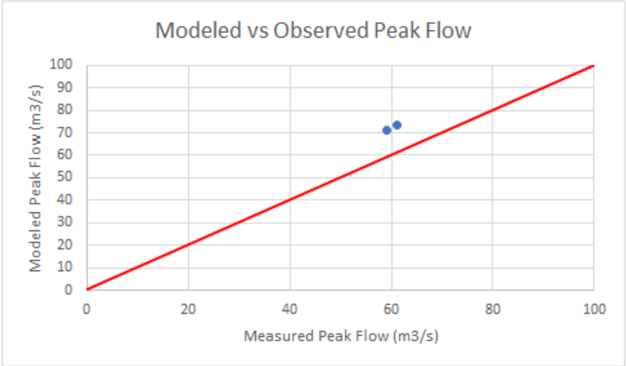
Spike in high flows; Release of an ice jam reported by residents



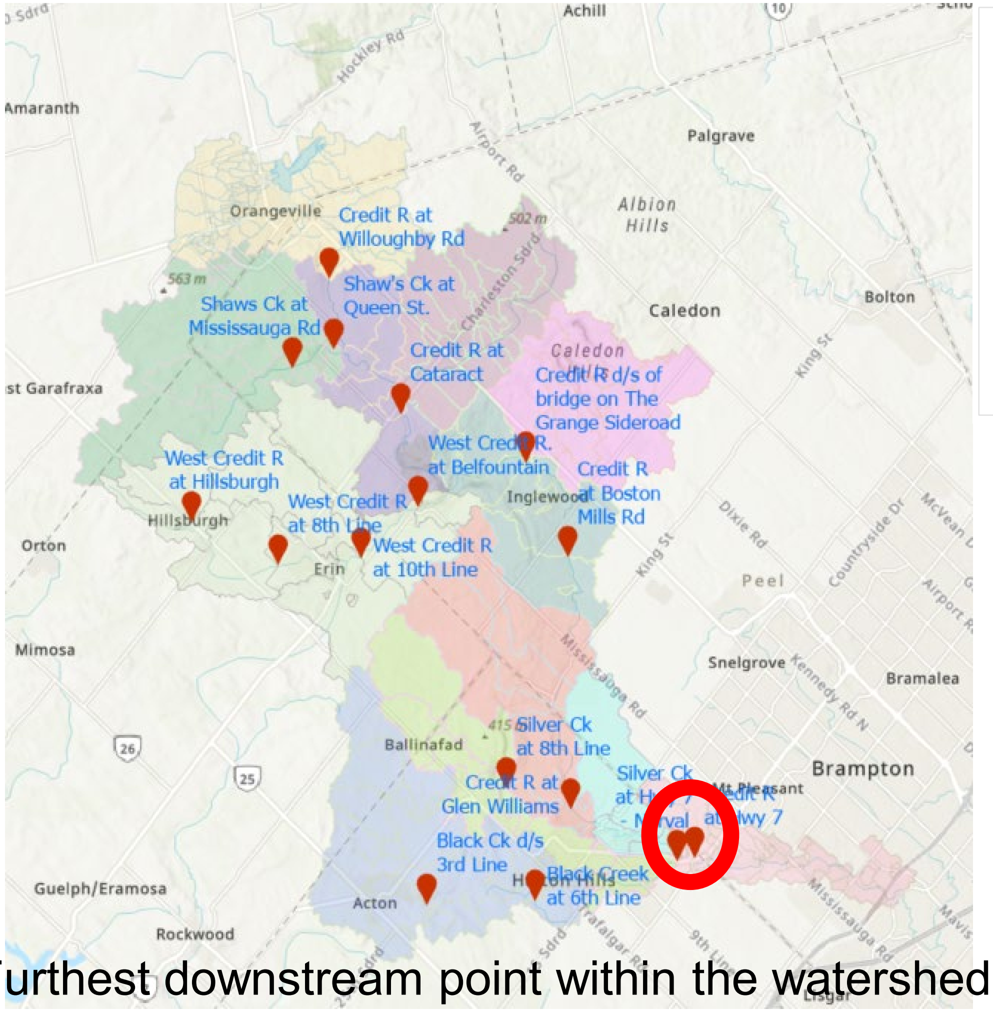






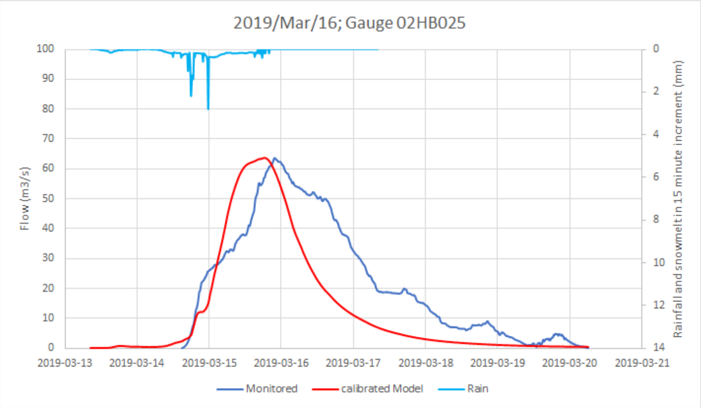


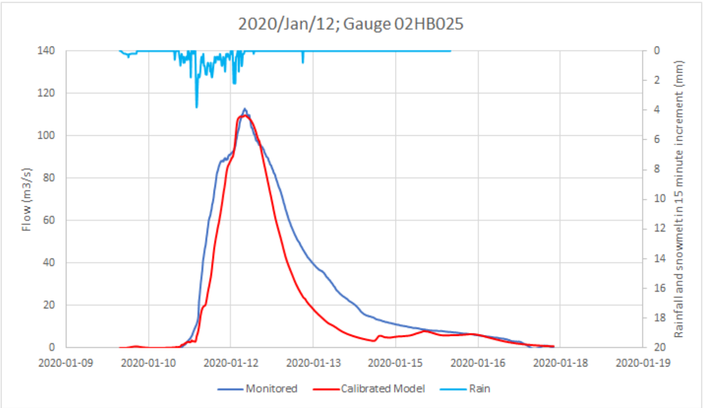
Results: Gauge 02HB025

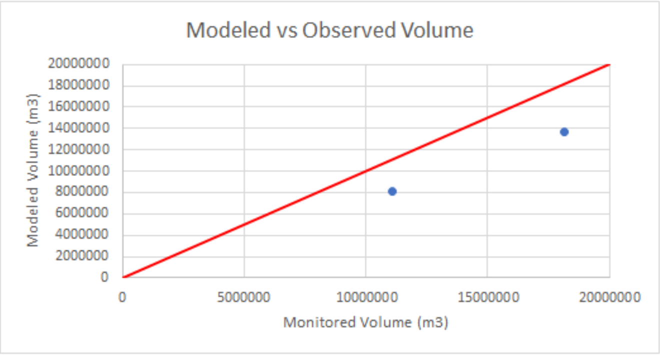


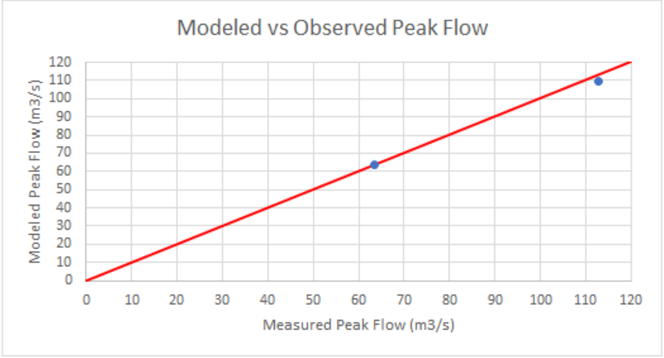
Furthest downstream point within the watershed

Used for Validation









Findings

❖Range of CN for Rain-on-Snow: 55-90

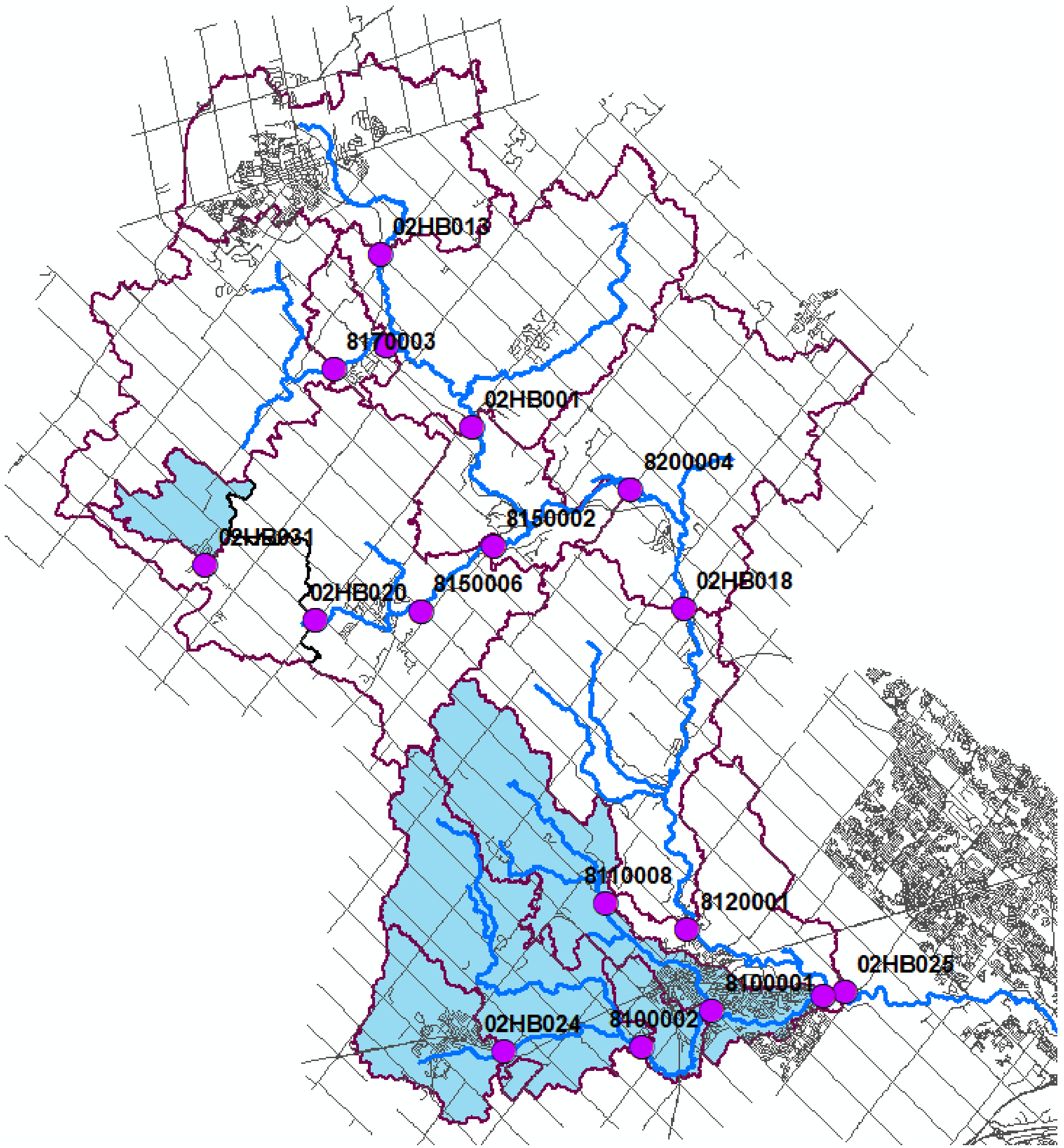
❖Range of CN for Summer events: 10-50

❖Rain-on-Snow events generate flows that are as much as 4-9 times larger compared to equivalent summer events

❖TPs used in Rain-on-Snow are 1.5 times larger than Summer events

❖During Rain-on-Snow events, the timing of rain is more important than its magnitude

❖Antecedent snowpack condition is extremely important in Rain-on-Snow events



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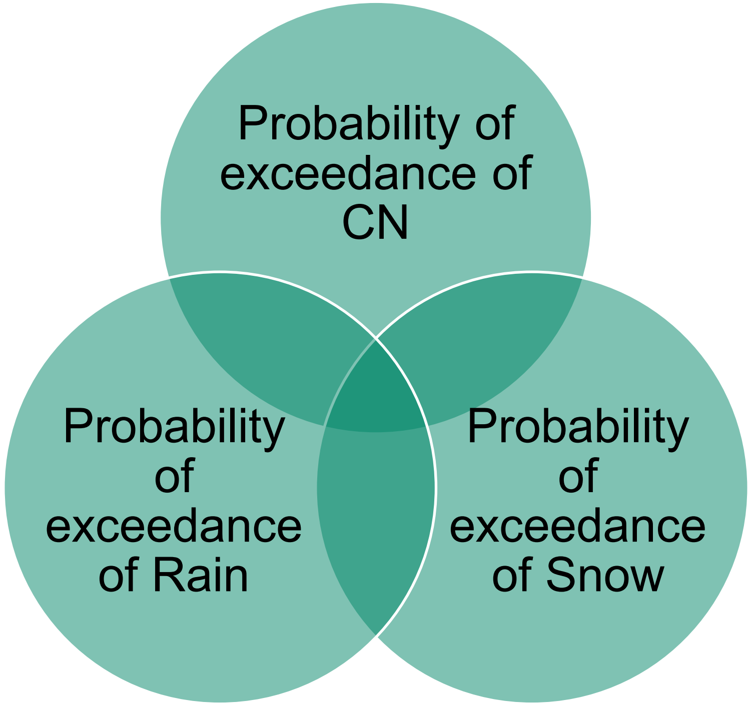
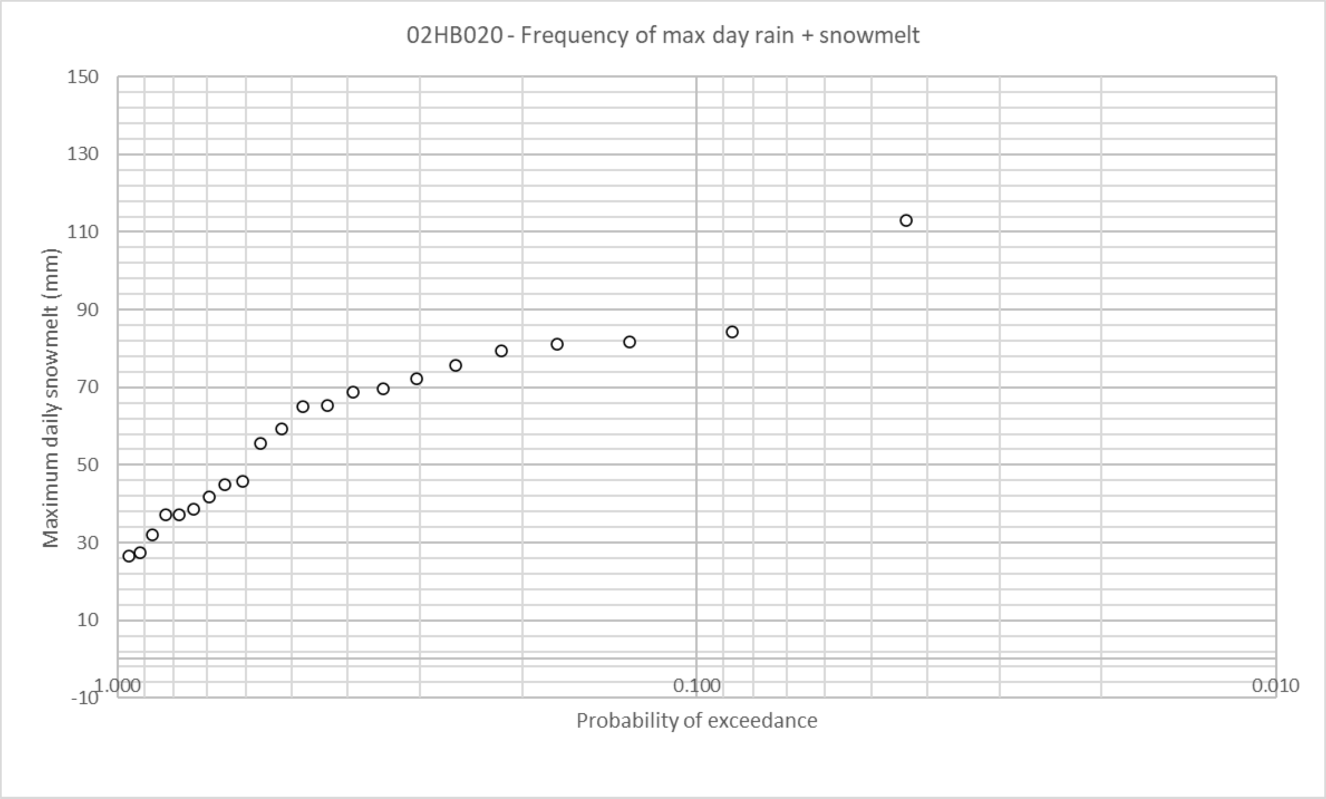


$$P(CN) * P(Rain) * P(Snow) = 0.01$$ 100-year event

$$P(CN) * P(Rain) * P(Snow) = 0.1$$ 10-year event



Rain + Snow Reservoir!

Assumption:

Initially, rain (on snow) does not cause runoff. It first saturates and ripens the snow, which culminates in runoff. Rain on snow acts as a reservoir; melting occurs in an accelerating process that can be characterized according to the modified temperature index method.

Based on the latent heat contributed by the rainfall to the snowpack, the following atmospheric warming was applied to simulate melt rates of the snowpack:

Temperature starts at 0°C*

hour 1: 1°C/hr increase

hour 2: 1.5°C/hr increase

hour 3: 2°C/hr increase

hour 4: 2.5°C/hr increase

After 4th hour, the air temperature remains at 7°C until the depletion of all snow

Flood Frequency Analysis

Uncertainty range is too high in the FFA provided by CVC

Flow gauges	10 year				100 year			
	Model	CVC			Model	CVC		
		flow	range			flow	range	
	cms	cms	cms	cms	cms	cms	cms	cms
02HB013	9.2	10.5	9.4	12.1	12.9	16.1	13.8	19.9
02HB001	31.4	30.3	26.7	35.5	40.3	44.6	37.8	55.3
02HB031	2.1	4	2.7	7.3	2.5	11.5	6.1	34.1
02HB020	6.2	6	5.3	7.1	7.3	10.1	8.4	13.2
02HB018	66.7	55.7	48.7	66.3	83.6	82.6	68.9	103
02HB024	4.5	3	2.7	3.5	5.2	3.5	3.1	4.3
02HB008	23.6	22.9	20.5	26.1	28.8	33.6	29	40.6
02HB025	107.1	94.1	82.3	112.5	134.1	135.7	113.4	175.5

Conclusions

- Rain-on-Snow drives largest annual peak flows in rural subwatersheds
- Higher frequency snowpack measurement data is critical if predictive models are desired
- Significant winter flooding can occur with even gentle, moderately-sized (e.g., 25mm) rainfalls if there is a sizable, ripened snowpack on the ground
- The calibrated models – coupled with the modified form of the Temperature Index Method – demonstrated reliable predictive ability for the estimation of flood flows

This work can improve flood prediction and warning, specifically during winter conditions where small events may have a large impact

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