# Using water balance dynamics to understand watershed processes and changing water conditions

Muskoka Watershed Council
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# Project Goal

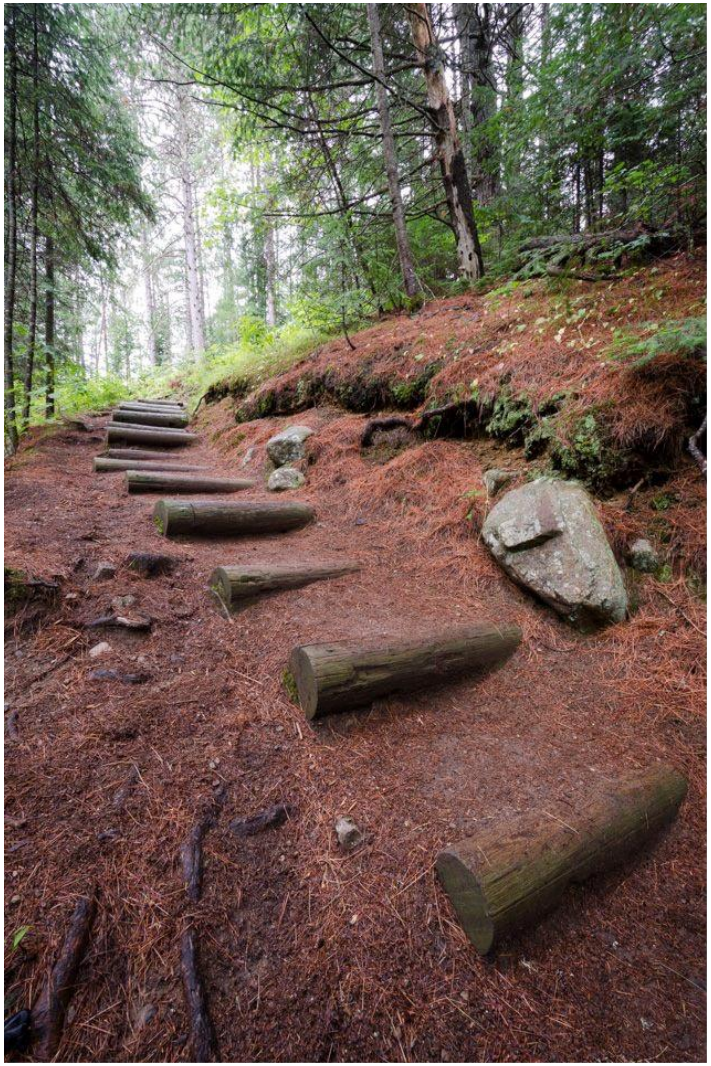
(Opeongo Lake, 2015)

To advance our understanding of the regional hydrology of the Great Lakes Basin and identify watersheds vulnerable to changing water conditions associated with future climate scenarios.

*What does it look like now?*

*What might it look like in the future?*

# Presentation outline



(Beaver Pond trail, 2015)

- Conceptual basis for the study
- Larger project context
- Research activities in the Petawawa River watershed, Algonquin Park

**Takeaway**

*Sound understanding of the water balance, linkages to hydrologic processes, and how knowledge of both are used to understand potential change in water conditions*

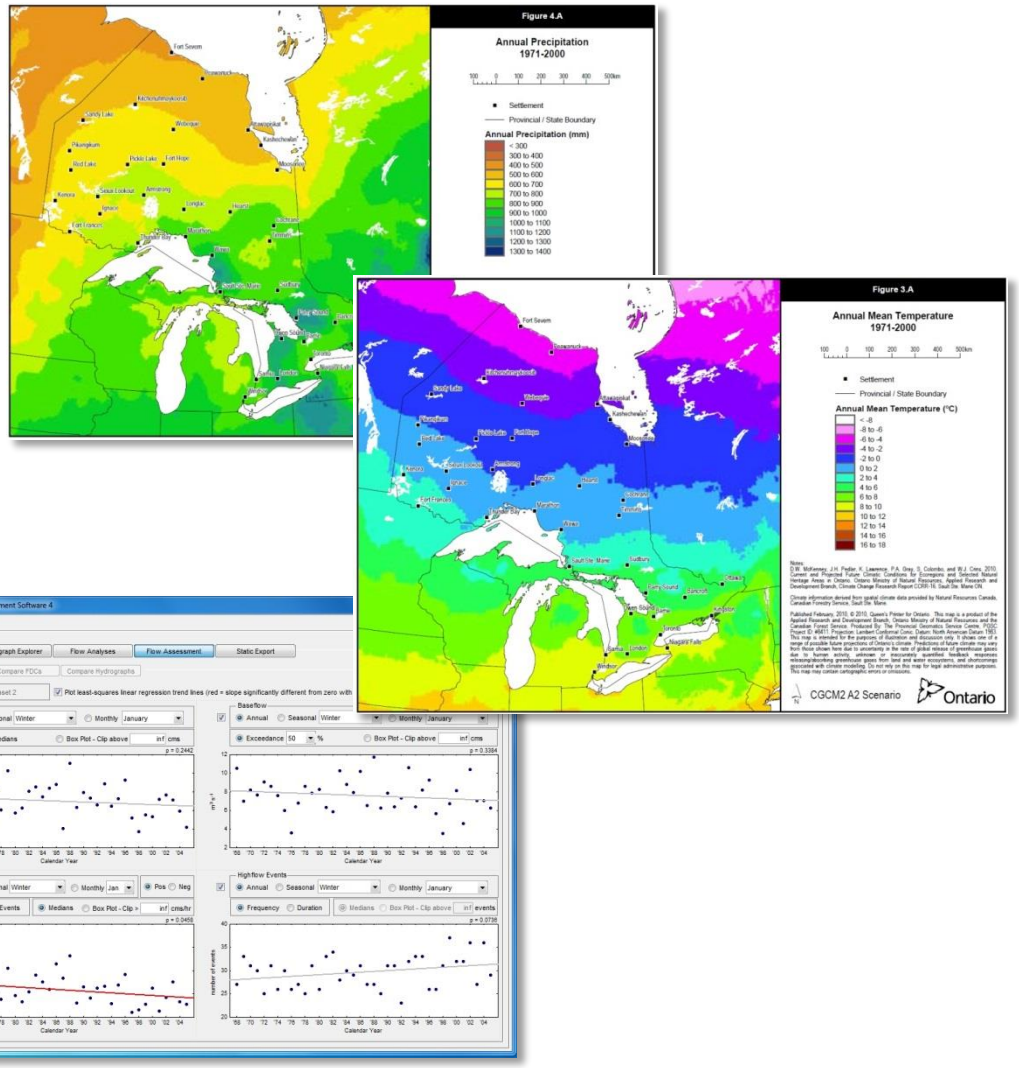
# Inferring change in Ontario's hydrology

## Output from climate models

- Predicted changes in air temperature
- Predicted changes in precipitation

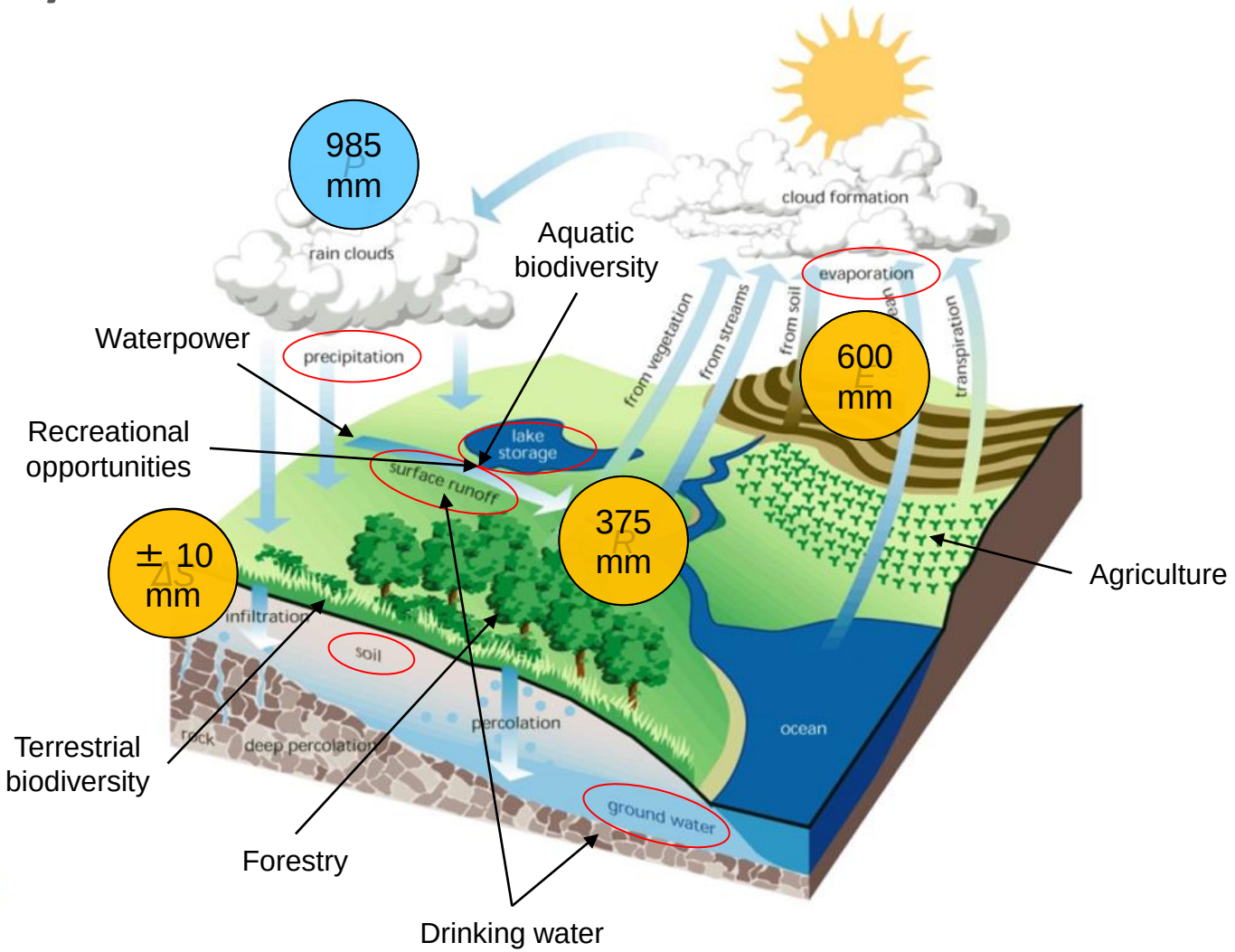
## Trends in streamflow

- High flow events
- Low flow events
- Mean annual flow



# The hydrologic cycle

Our conceptual framework

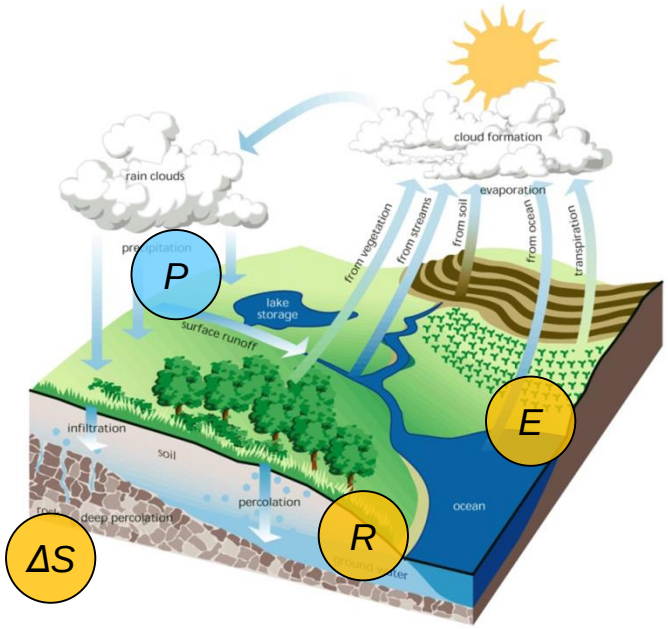



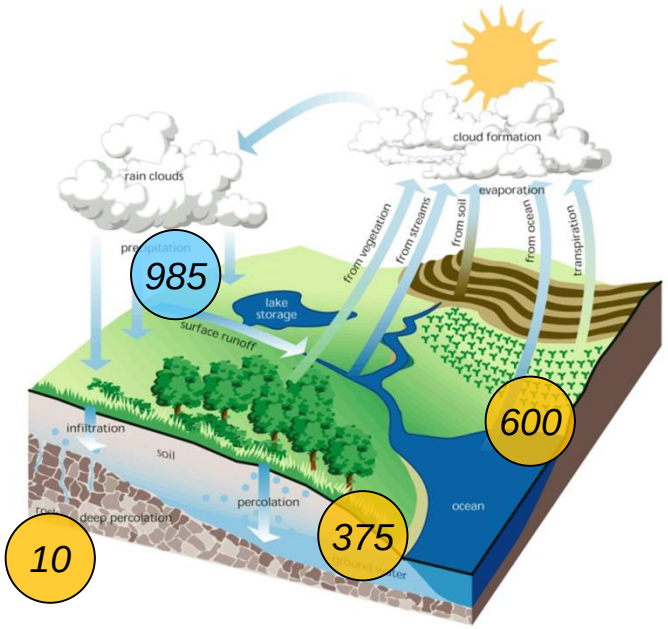
# The water balance

$$Inputs = Outputs \pm \Delta\, Storage$$

$$Precipitation = Runoff + Evaporation \pm \Delta\, Water\ storage \pm \varepsilon$$

$$Precipitation - Runoff - Evaporation = \pm \Delta\, Water\ storage \pm \varepsilon$$



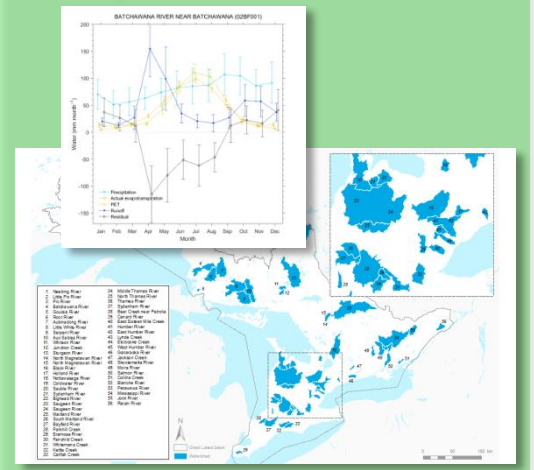



# Using Water Balance Dynamics to Identify Vulnerabilities to Climate Change

## Historical Analyses

*Using historical data (1981-2010 water years) for selected gauged watersheds across the Great Lakes Basin:*

i. Characterize monthly and annual water balances and range of variability.
ii. Identify significant trends.
iii. Investigate regional patterns.

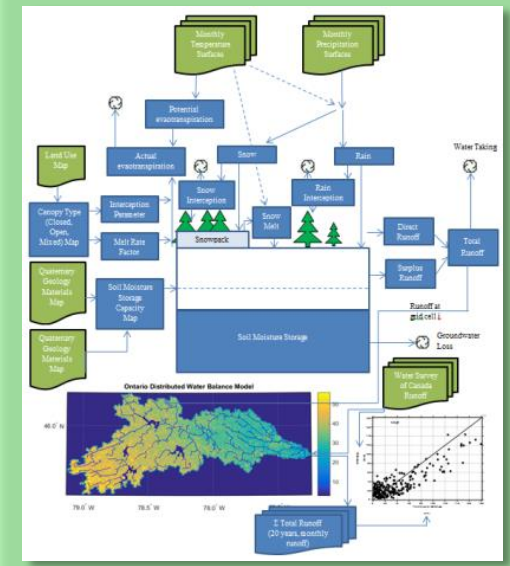



## Experimental watershed

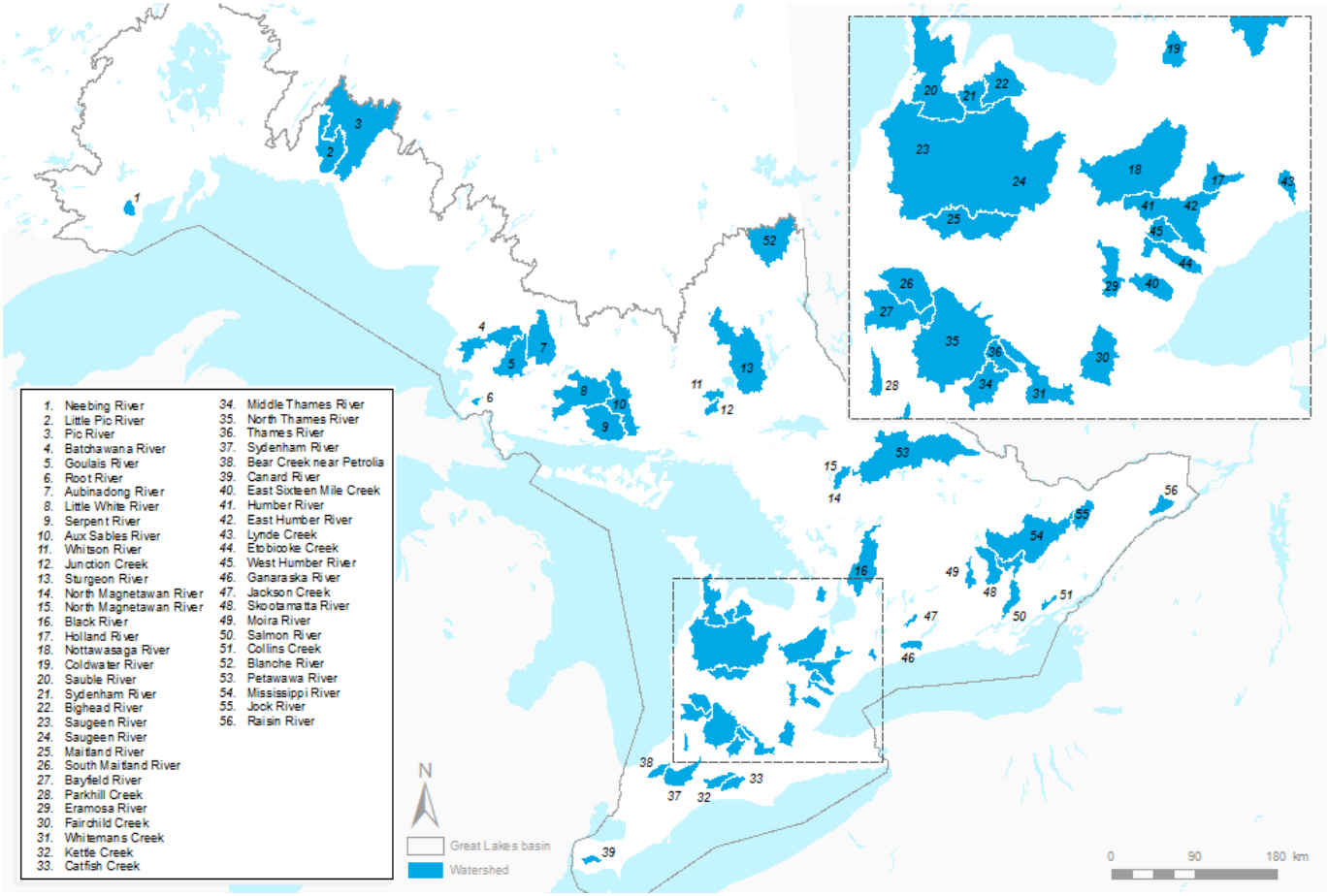
Establish an experimental watershed for direct long-term monitoring of water balance components and to support model development.


## Building a model

Using the historical analyses and experimental watershed, develop a distributed model to predict water balances in ungauged basins and in response to future climate scenarios.



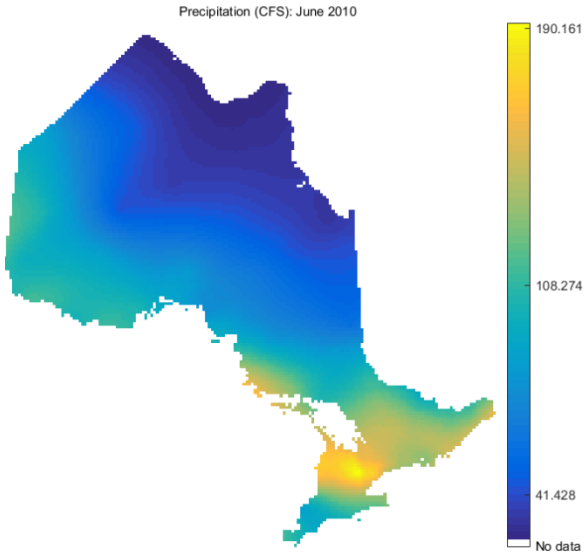
# Gauged basins used to estimate runoff (R) for the 1981-2010 water years



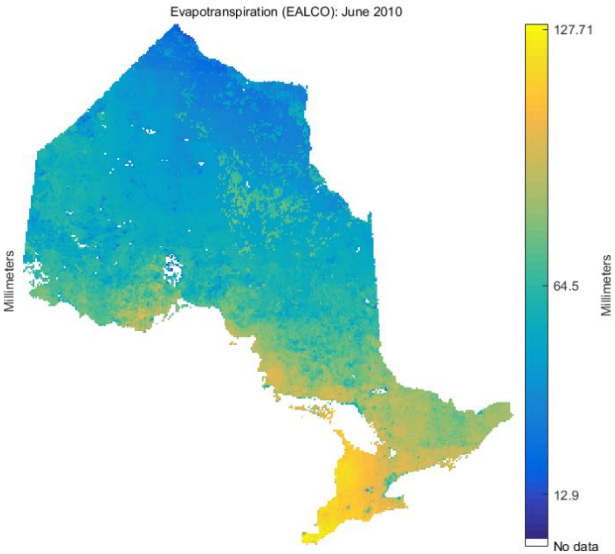

*Precipitation = Runoff + Evaporation ± Δ Storage*

# Data to estimate *P* and *E*

## Precipitation

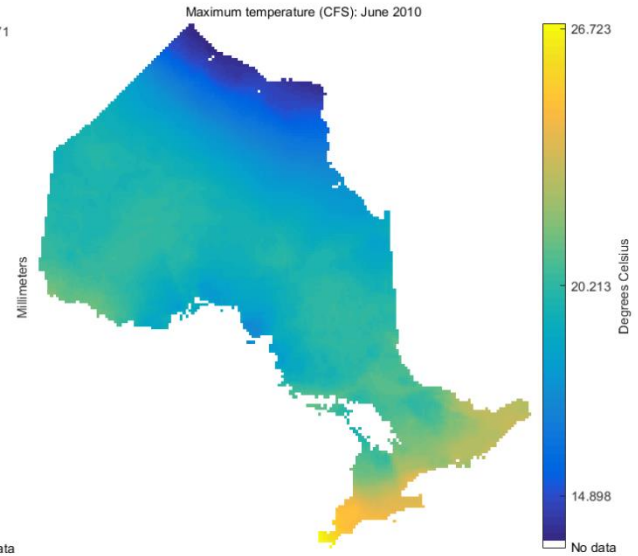



## Evaporation




Ecological Assimilation of Land and Climate Observations (EALCO)

## Potential Evaporation




*PE* = the climatic demand for water relative to the available energy and assuming an unlimited water supply.

$$Aridity\ Index\ (AI) = \frac{PE}{P}$$

*AI* < 1 = more humid
*AI* > 1 = more arid

Precipitation = Runoff + Evaporation ± Δ Storage

# Temperature-based models for estimating potential evaporation

Thornthwaite (1948)

$$PE_{\mathrm{Thorn}}(\mathrm{mm\ month^{-1}}) = k_{\mathrm{Th}}\, c \left(\frac{10\, T_{\mathrm{a}}}{I}\right)^{a}$$

Blaney and Criddle (1950)

$$PE_{\mathrm{B-C}}\ (\mathrm{mm\ month^{-1}}) = k_{\mathrm{BC}} P (0.46 T_{\mathrm{a}} + 8.13)$$

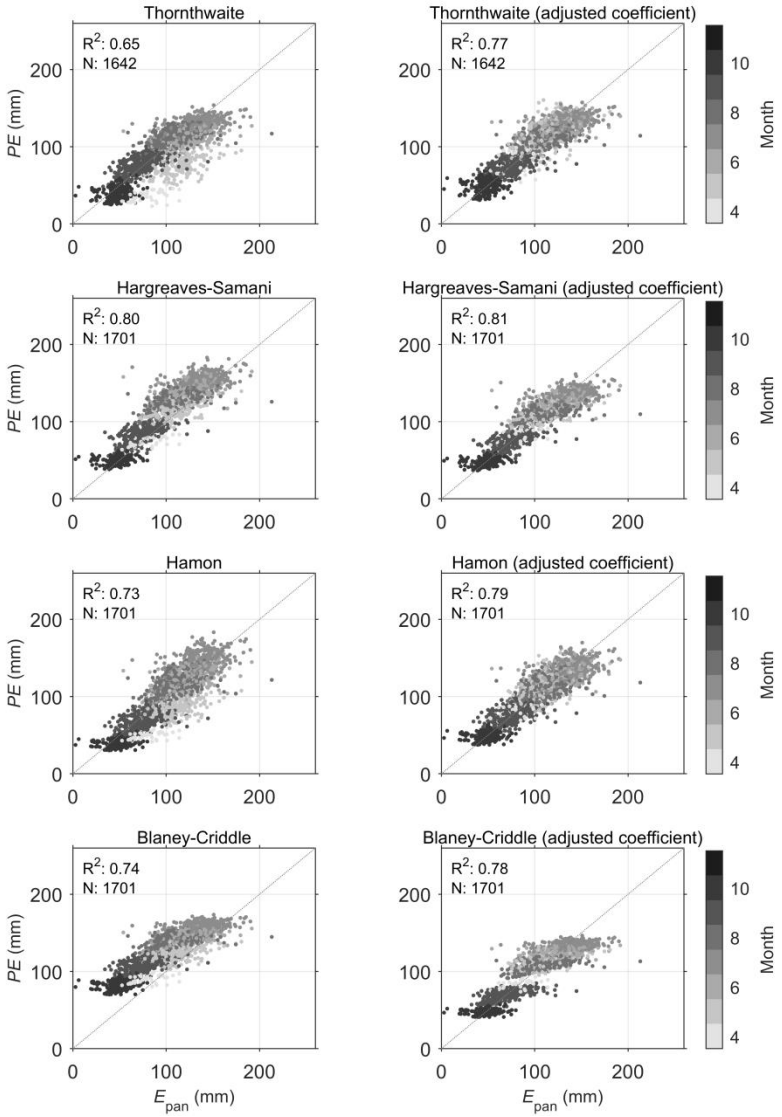
Hamon (1961)

$$PE_{\mathrm{Hamon}}(\mathrm{mm\ month^{-1}}) = \ k_{\mathrm{H}} d N^{2} W_{\mathrm{t}}$$

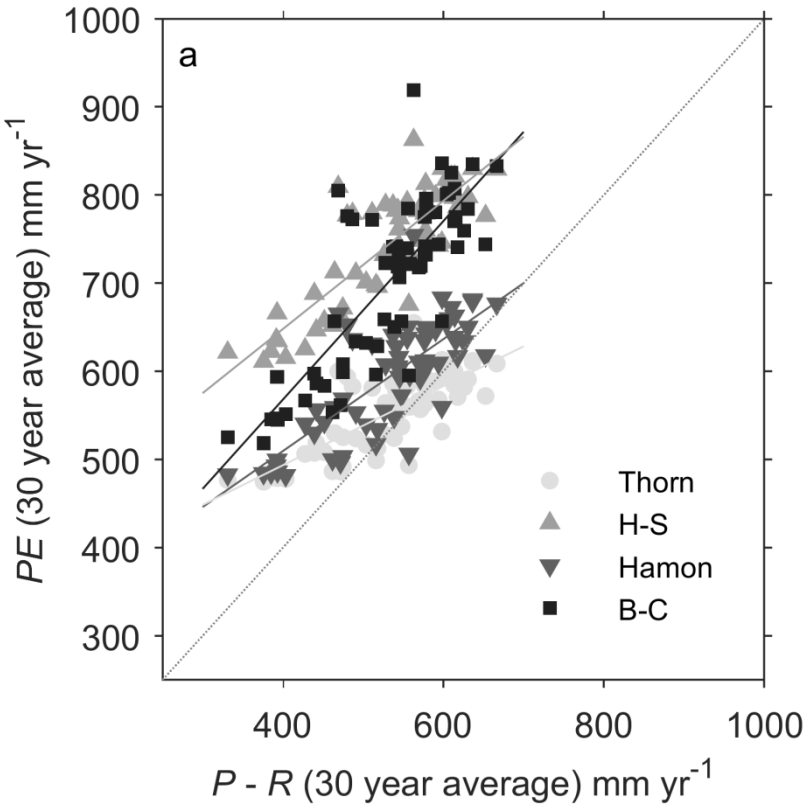
Hargreaves and Samani (1985)

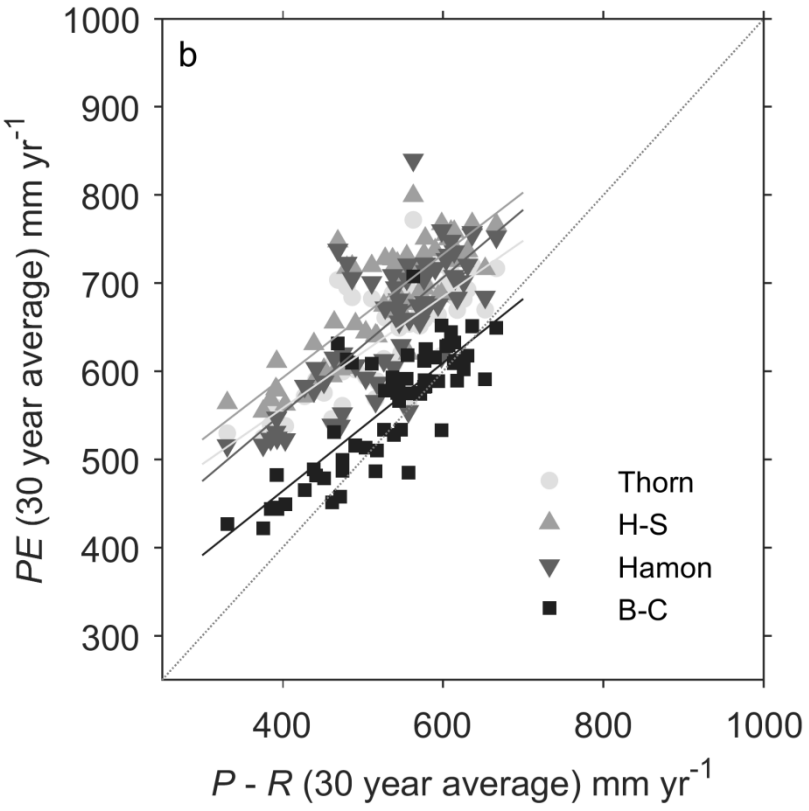
$$PE_{H-S}\ (\mathrm{mm\ d^{-1}}) = \ k_{\mathrm{HS}}\, R_{\mathrm{A}} \sqrt{\delta_{\mathrm{T}}}\ (T + 17.8)$$

# Potential evaporation vs Evaporation pan

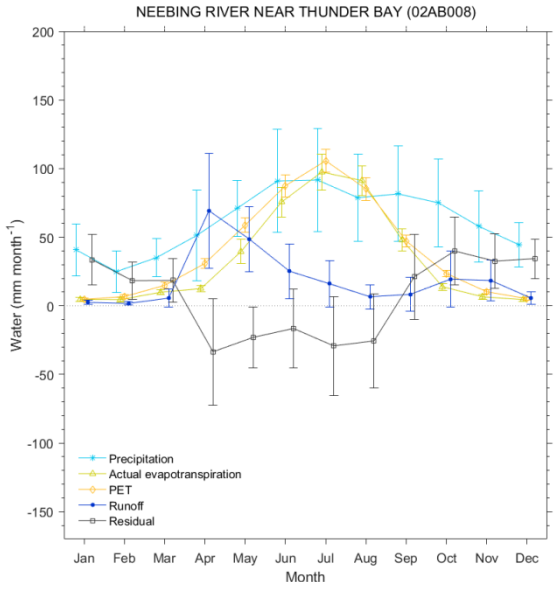


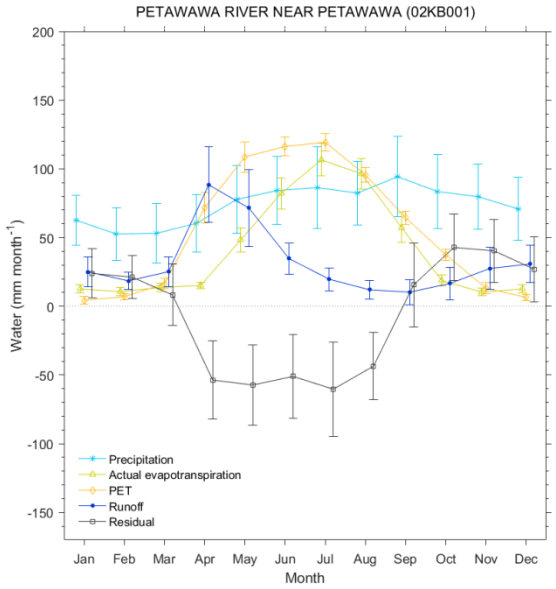
# Potential evaporation vs Evaporation

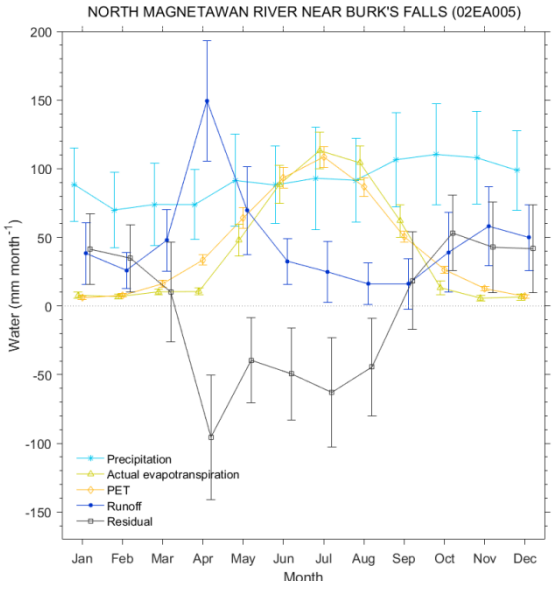


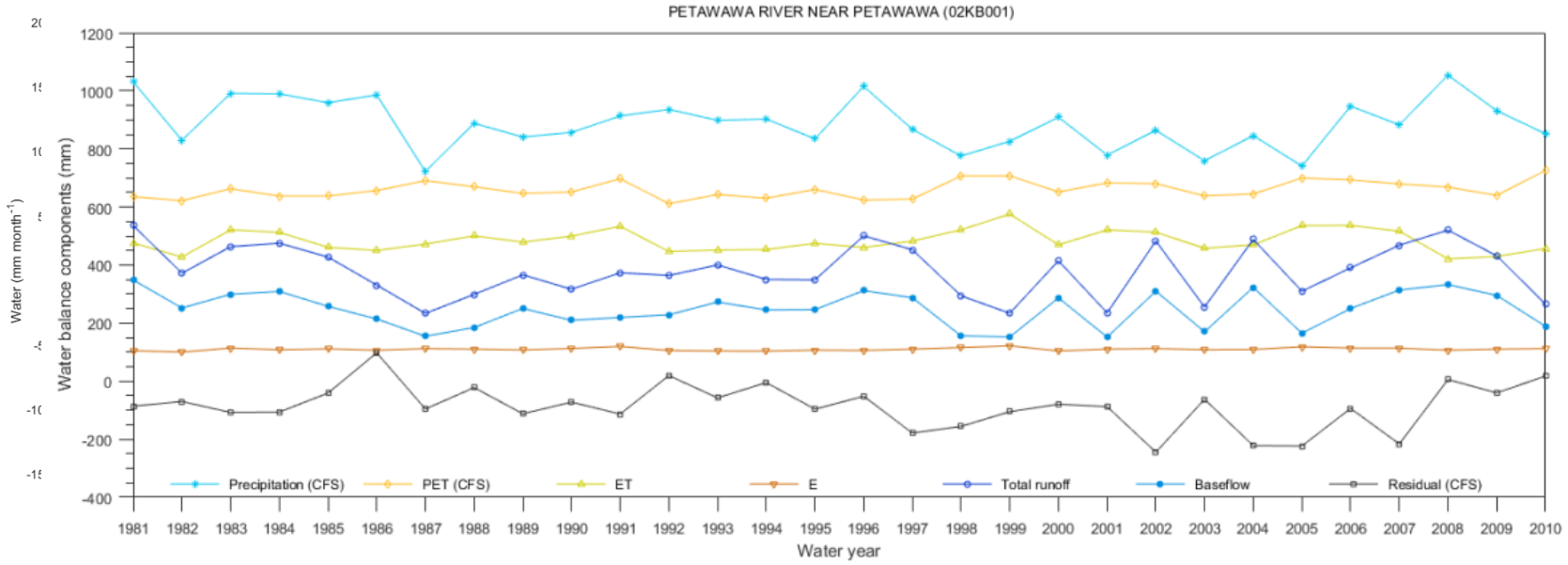



# Mean monthly water balances and trends



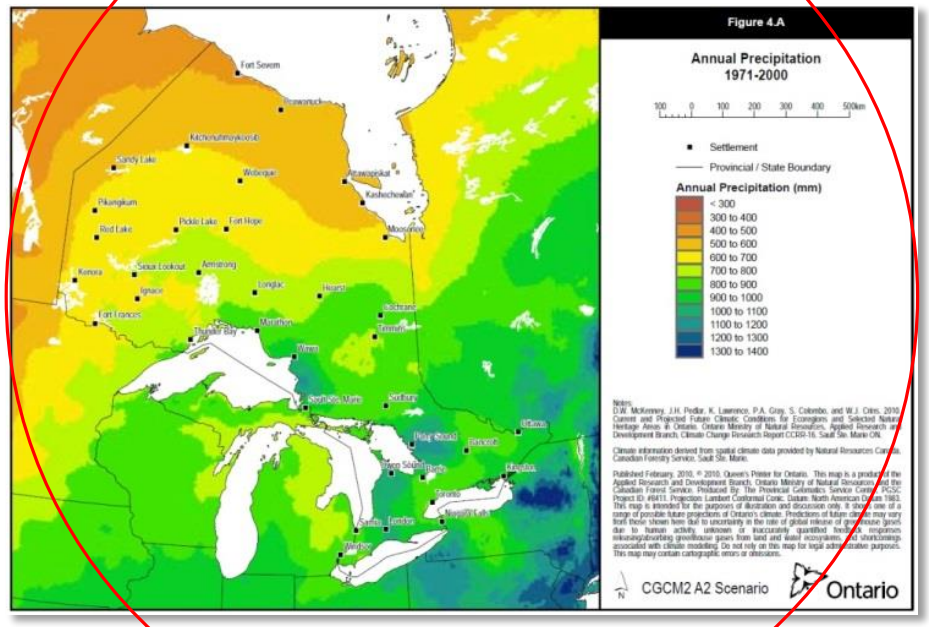
# Trends and sensitivity

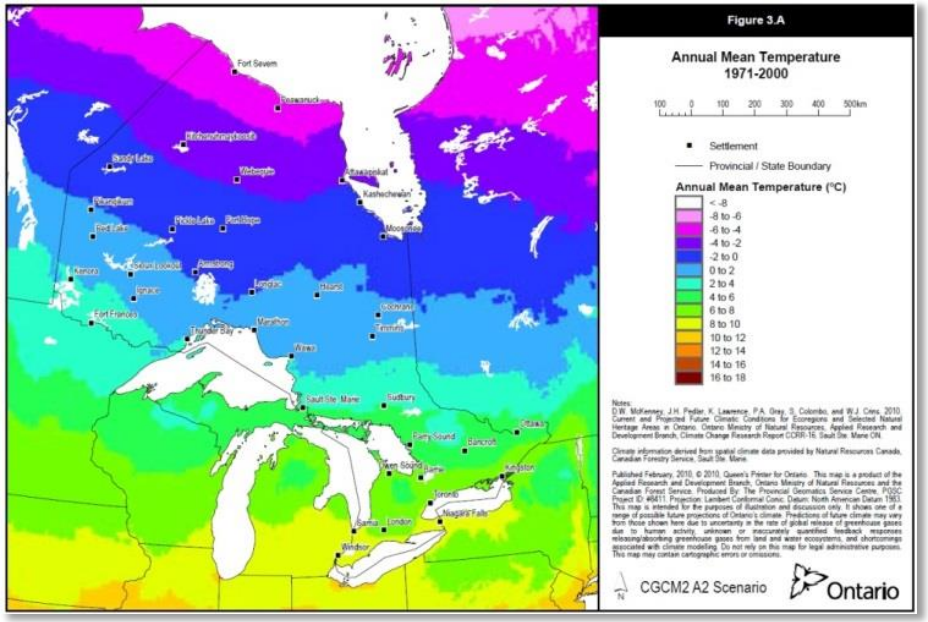
| Number | WSC Gauge Number | WSC Gauge Name | P (mm) | PE (mm) | R (mm) | R_bf (mm) | R_qf (mm) | delta S (mm) | PE/P | R/P |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 02AB008 | Neebing River near Thunder Bay | -0.066 | 0.078 | -0.163 | -0.234 | -0.106 | -0.012 | 0.090 | -0.162 |
| 2 | 02BA003 | Little Pic River near Coldwell | -0.087 | 0.026 | -0.049 | -0.048 | -0.016 | -0.088 | 0.056 | 0.016 |
| 3 | 02BB003 | Pic River near Marathon | -0.063 | -0.012 | -0.058 | -0.061 | -0.018 | -0.059 | 0.041 | -0.008 |
| 4 | 02BF001 | Batchawana River near Batchawana | -0.170 | 0.014 | -0.090 | -0.107 | -0.048 | -0.072 | 0.145 | 0.019 |
| 5 | 02BF002 | Goulais River near Searchmont | -0.122 | 0.007 | -0.083 | -0.100 | -0.038 | -0.052 | 0.096 | -0.002 |
| 6 | 02CA002 | Root River At Sault Ste. Marie | -0.104 | 0.055 | -0.051 | -0.090 | -0.029 | -0.036 | 0.103 | -0.009 |
| 7 | 02CB003 | Aubinadong River Above Sesabic Creek | -0.070 | 0.006 | -0.061 | -0.075 | -0.056 | -0.015 | 0.057 | -0.045 |
| 8 | 02CC005 | Little White River near Bellingham | 0.003 | -0.015 | -0.100 | -0.115 | -0.049 | 0.049 | 0.006 | -0.103 |
| 9 | 02CD001 | Serpent River At Highway No. 17 | 0.056 | 0.018 | -0.043 | -0.078 | 0.038 | 0.040 | -0.028 | -0.061 |
| 10 | 02CE002 | Aux Sables River At Massey | 0.060 | -0.002 | -0.046 | -0.076 | 0.014 | 0.058 | -0.037 | -0.057 |
| 11 | 02CF007 | Whitson River At Chelmsford | 0.042 | -0.015 | 0.030 | 0.027 | 0.040 | 0.026 | -0.030 | 0.002 |
| 12 | 02CF012 | Junction Creek Below Kelley Lake | 0.040 | -0.020 | 0.144 | 0.231 | 0.041 | -0.068 | -0.030 | 0.111 |
| 13 | 02DC004 | Sturgeon River near Glen Afton | 0.025 | 0.005 | 0.023 | 0.007 | 0.017 | 0.001 | -0.007 | -0.005 |
| 14 | 02EA005 | North Magnetawan River near Burk's Falls | -0.027 | 0.044 | -0.021 | -0.020 | -0.011 | -0.006 | 0.047 | -0.011 |
| 15 | 02EA010 | North Magnetawan River Above Pickerel Lake | -0.028 | 0.033 | -0.032 | -0.052 | -0.007 | -0.008 | 0.046 | -0.030 |
| 16 | 02EC002 | Black River near Washago | -0.005 | 0.061 | 0.022 | 0.015 | 0.039 | 0.007 | 0.028 | 0.012 |
| 17 | 02EC009 | Holland River At Holland Landing | 0.049 | 0.089 | -0.026 | -0.142 | 0.047 | 0.054 | -0.009 | -0.048 |
| 18 | 02ED003 | Nottawasaga River near Baxter | 0.073 | 0.097 | -0.057 | -0.078 | -0.015 | 0.083 | -0.016 | -0.095 |
| 19 | 02ED007 | Coldwater River At Coldwater | -0.013 | 0.060 | 0.020 | 0.052 | -0.003 | -0.002 | 0.039 | 0.028 |
| 20 | 02FA001 | Sauble River At Sauble Falls | 0.036 | 0.061 | 0.000 | -0.008 | -0.002 | 0.013 | -0.011 | -0.021 |
| 21 | 02FB007 | Sydenham River near Owen Sound | 0.031 | 0.056 | 0.016 | 0.039 | -0.007 | -0.007 | -0.005 | -0.008 |
| 22 | 02FB010 | Bighead River near Meaford | 0.030 | 0.070 | 0.007 | 0.055 | -0.023 | 0.005 | -0.004 | -0.013 |
| 23 | 02FC001 | Saugeen River near Port Elgin | 0.026 | 0.055 | 0.053 | 0.072 | 0.044 | -0.026 | -0.001 | 0.048 |
| 24 | 02FC002 | Saugeen River near Walkerton | 0.050 | 0.077 | 0.009 | 0.022 | 0.024 | 0.012 | -0.020 | 0.007 |
| 25 | 02FE005 | Maitland River Above Wingham | 0.026 | 0.059 | 0.007 | -0.005 | 0.020 | 0.007 | -0.007 | -0.015 |
| 26 | 02FE009 | South Maitland River At Summerhill | -0.034 | 0.042 | 0.010 | 0.027 | 0.003 | -0.039 | 0.029 | 0.029 |
| 27 | 02FF007 | Bayfield River near Varna | -0.042 | 0.052 | 0.017 | 0.010 | 0.016 | -0.057 | 0.040 | 0.036 |
| 28 | 02FF008 | Parkhill Creek Above Parkhill Reservoir | -0.028 | 0.108 | -0.017 | -0.096 | -0.005 | -0.027 | 0.054 | -0.022 |
| 29 | 02GA029 | Eramosa River Above Guelph | 0.044 | 0.098 | -0.020 | -0.023 | -0.018 | 0.056 | -0.011 | -0.065 |
| 30 | 02GB007 | Fairchild Creek near Brantford | -0.015 | 0.083 | 0.029 | 0.015 | 0.041 | -0.048 | 0.038 | 0.044 |
| 31 | 02GB008 | Whitemans Creek near Mount Vernon | -0.019 | 0.099 | 0.001 | -0.011 | 0.000 | -0.019 | 0.039 | 0.002 |
| 32 | 02GC002 | Kettle Creek At St. Thomas | -0.031 | 0.119 | -0.031 | -0.028 | -0.025 | -0.025 | 0.053 | -0.020 |
| 33 | 02GC018 | Catfish Creek near Sparta | -0.023 | 0.121 | -0.043 | -0.063 | -0.035 | 0.008 | 0.047 | -0.034 |
| 34 | 02GD004 | Middle Thames River At Thamesford | -0.015 | 0.106 | -0.026 | -0.042 | -0.040 | -0.024 | 0.035 | -0.024 |
| 35 | 02GD015 | North Thames River near Thorndale | -0.023 | 0.071 | -0.028 | -0.041 | -0.015 | -0.028 | 0.028 | -0.028 |
| 36 | 02GD021 | Thames River At Innerkip | -0.016 | 0.087 | 0.015 | -0.028 | 0.026 | -0.049 | 0.036 | 0.018 |
| 37 | 02GG002 | Sydenham River near Alvinston | -0.036 | 0.127 | -0.024 | -0.033 | -0.027 | -0.035 | 0.055 | 0.017 |
| 38 | 02GG006 | Bear Creek near Petrolia | -0.028 | 0.101 | -0.011 | -0.071 | -0.002 | -0.046 | 0.044 | -0.016 |
| 39 | 02GH003 | Canard River near Lukerville | -0.007 | 0.120 | -0.013 | -0.088 | -0.007 | -0.022 | 0.029 | -0.006 |
| 40 | 02HB004 | East Sixteen Mile Creek near Omagh | 0.034 | 0.095 | 0.021 | 0.029 | 0.032 | 0.022 | -0.007 | 0.013 |
| 41 | 02HC003 | Humber River At Weston | 0.062 | 0.098 | 0.065 | 0.069 | 0.071 | 0.045 | -0.026 | 0.081 |
| 42 | 02HC009 | East Humber River near Pine Grove | 0.059 | 0.093 | 0.045 | 0.054 | 0.047 | 0.050 | -0.019 | 0.049 |
| 43 | 02HC018 | Lynde Creek near Whitby | 0.011 | 0.092 | 0.039 | 0.030 | 0.037 | -0.014 | 0.013 | 0.055 |
| 44 | 02HC030 | Etobicoke Creek Below Queen Elizabeth Highway | 0.053 | 0.108 | 0.129 | 0.043 | 0.135 | -0.060 | -0.021 | 0.204 |
| 45 | 02HC031 | West Humber River At Highway No. 7 | 0.067 | 0.097 | 0.103 | 0.187 | 0.077 | 0.062 | -0.032 | 0.100 |
| 46 | 02HD012 | Ganaraska River Above Dale | 0.013 | 0.043 | 0.055 | 0.041 | 0.067 | -0.030 | 0.012 | 0.066 |
| 47 | 02HJ001 | Jackson Creek At Peterborough | 0.026 | 0.079 | 0.040 | 0.047 | 0.039 | -0.005 | -0.002 | 0.028 |
| 48 | 02HL004 | Skootamatta River near Actinolite | 0.078 | 0.122 | -0.005 | -0.008 | 0.032 | 0.060 | -0.026 | -0.045 |
| 49 | 02HL005 | Moira River near Deloro | 0.074 | 0.115 | 0.055 | 0.079 | 0.040 | 0.046 | -0.028 | 0.025 |
| 50 | 02HM003 | Salmon River near Shannonville | 0.063 | 0.152 | 0.047 | 0.067 | 0.031 | 0.010 | -0.005 | 0.037 |
| 51 | 02HM005 | Collins Creek near Kingston | 0.013 | 0.167 | 0.002 | 0.003 | 0.010 | -0.002 | 0.039 | 0.012 |
| 52 | 02JC008 | Blanche River Above Englehart | -0.054 | 0.008 | 0.082 | 0.083 | 0.070 | -0.062 | 0.043 | 0.063 |
| 53 | 02KB001 | Petawawa River near Petawawa | 0.012 | 0.058 | -0.005 | -0.014 | 0.021 | 0.001 | 0.023 | -0.015 |
| 54 | 02KF006 | Mississippi River At Appleton | 0.084 | 0.107 | 0.083 | 0.078 | 0.071 | 0.016 | -0.027 | 0.010 |
| 55 | 02LA007 | Jock River near Richmond | 0.042 | 0.061 | 0.053 | 0.062 | 0.059 | 0.006 | -0.003 | 0.041 |
| 56 | 02MC001 | Raisin River near Williamstown | 0.018 | 0.038 | 0.075 | 0.079 | 0.069 | -0.041 | 0.012 | 0.069 |

Seasonal Mann-Kendall Taub-b values for mean monthly water balance variables for each river for 1981-2010. Highlighted values indicate that temporal trends were detected with 90% (green) and 95% (yellow) confidence.

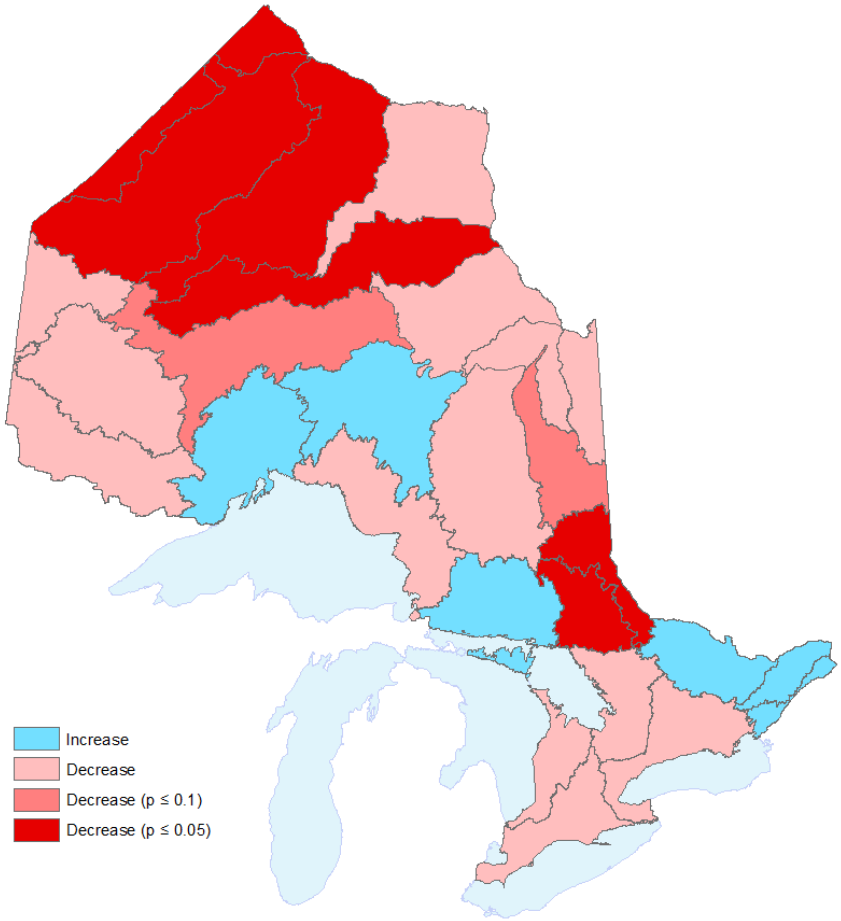
- Some trends in *P* and *PE* have not resulted in corresponding changes in *R*
- Some trends in *R* have not been associated with corresponding changes in *P* or *PE*
- Have subsequently determined that changes in *R* are more sensitive to changes in *P than PE*

# Focussing our efforts

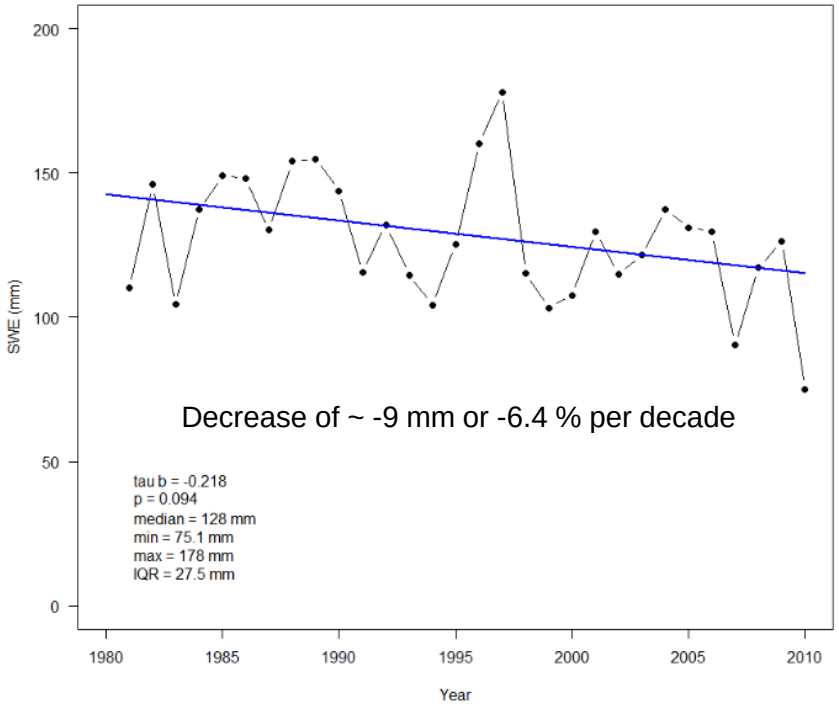


# Snow water equivalent (Globsnow)

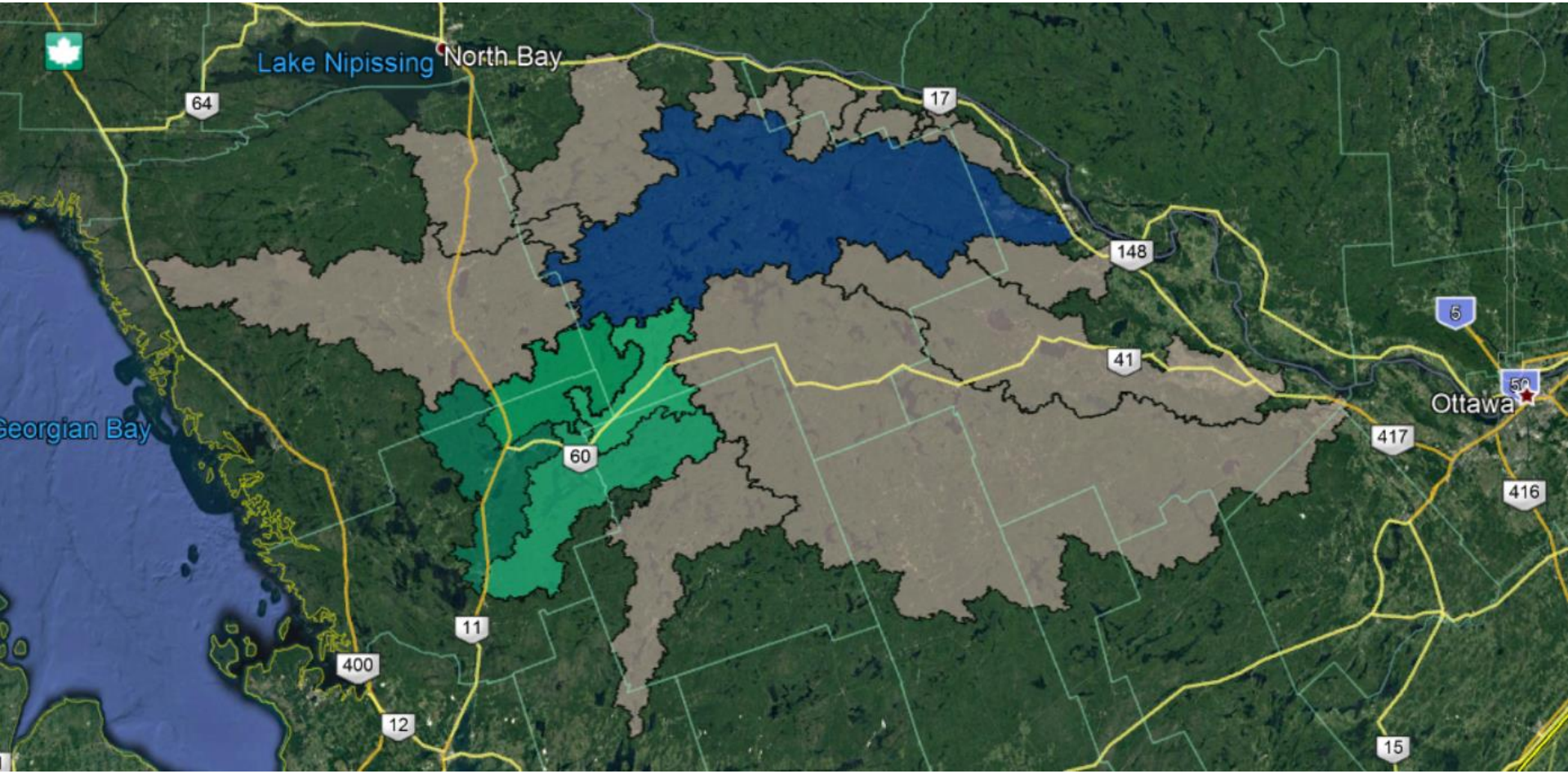



Satellite-derived water year maximum SWE in Ontario
1981 - 2010

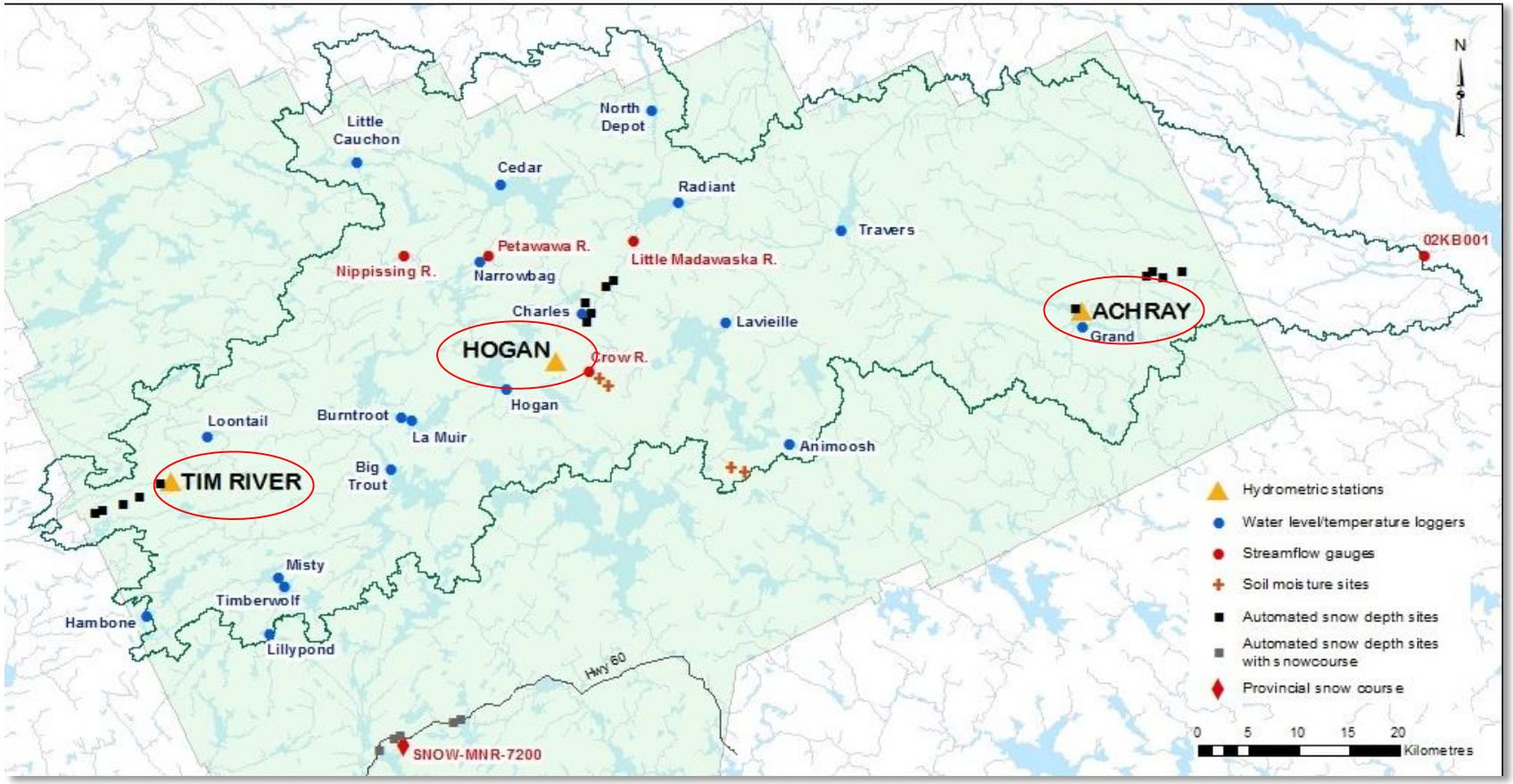



*Trends in annual maximum snow water equivalent (SWE) for secondary watersheds in Ontario, 1980 – 2010.*

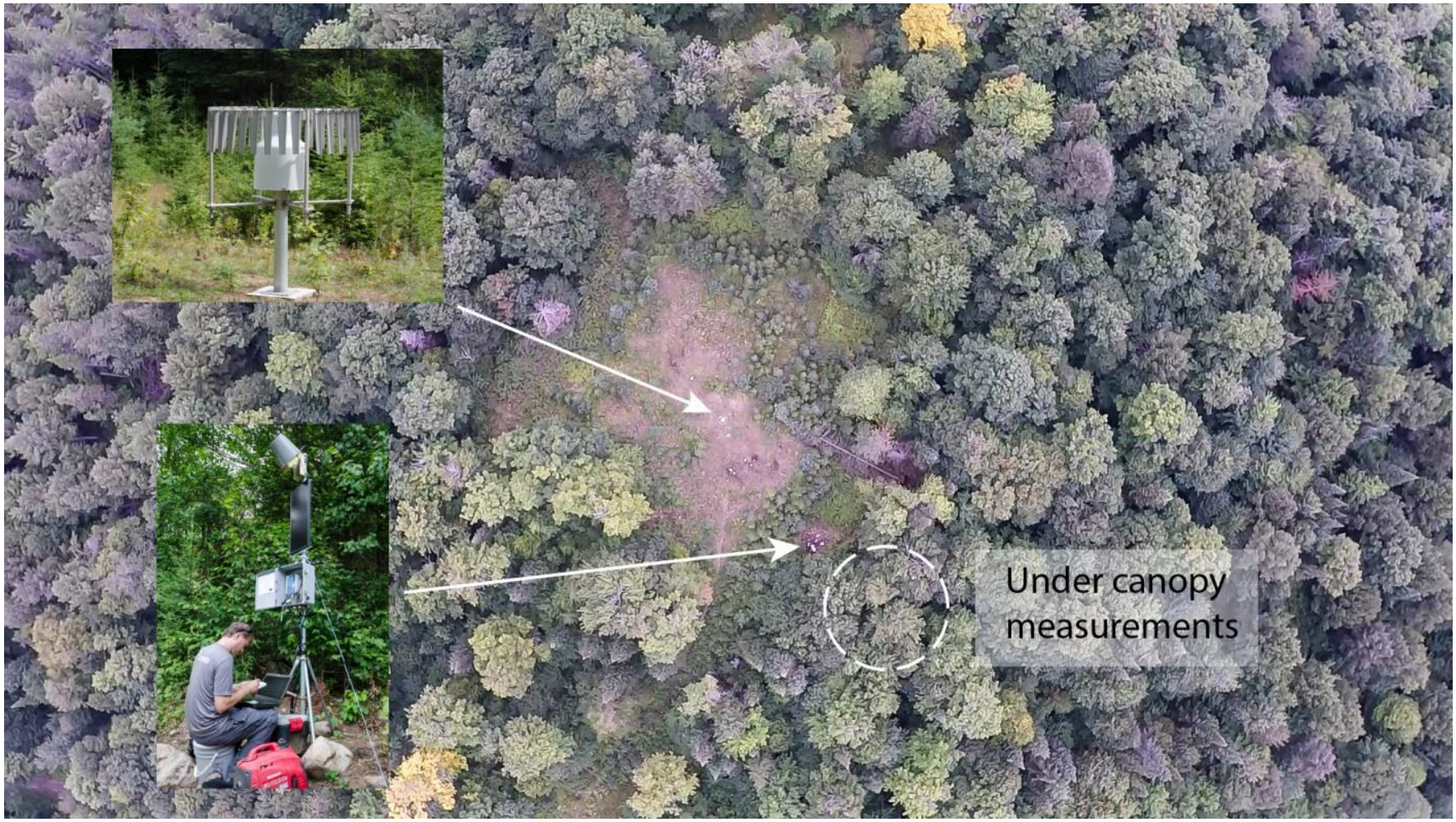
# Petawawa River Experimental Watershed



# Petawawa River Experimental Watershed

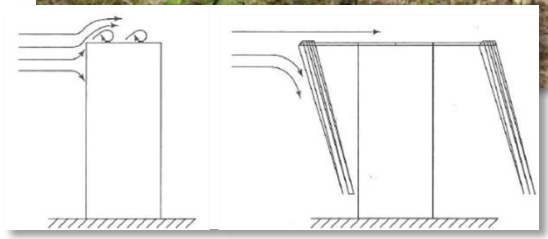


# Hydrometric stations



# Hydrometric stations

Total precipitation gauge with Alter shield



Soil moisture and temperature




Snow depth & air temperature

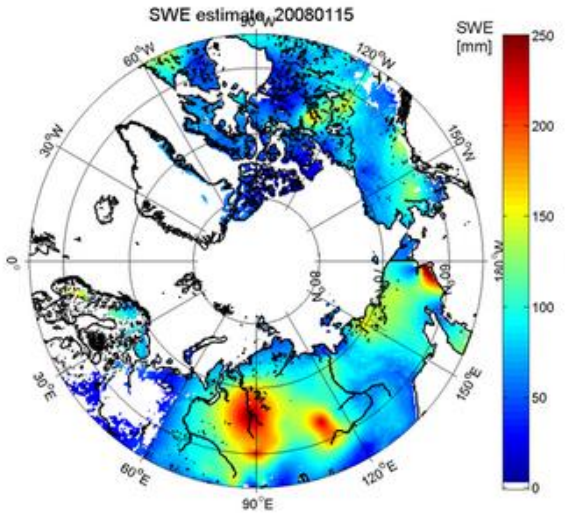
# Distributed soil moisture measurements

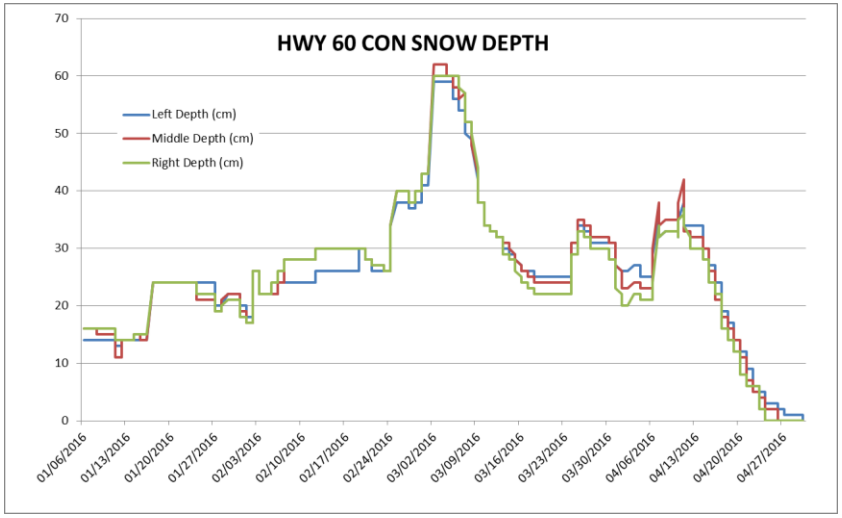
# Lake level monitoring

Vented Pressure Transducers

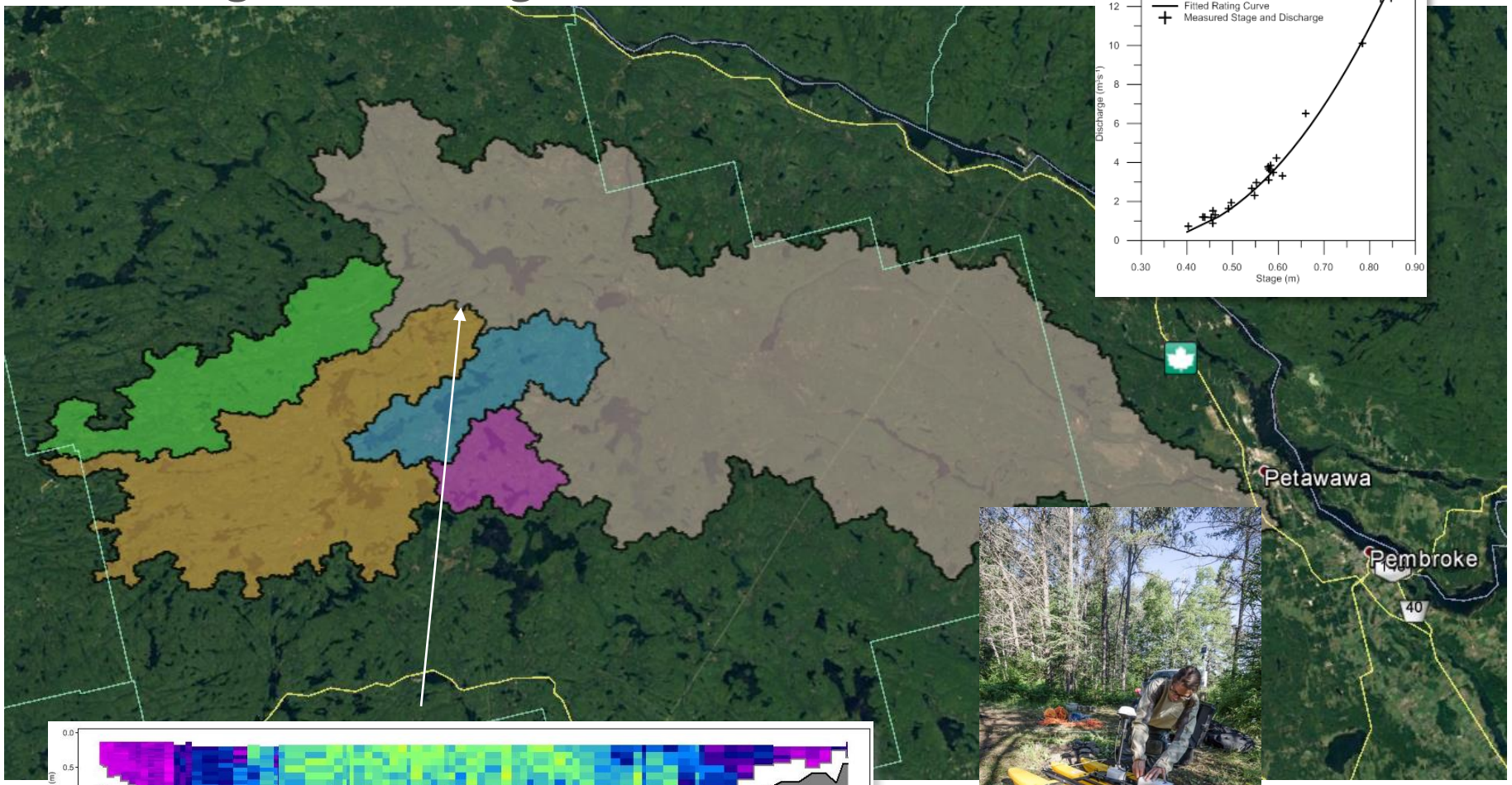
Download Cable Housing

# Snow accumulation and melt



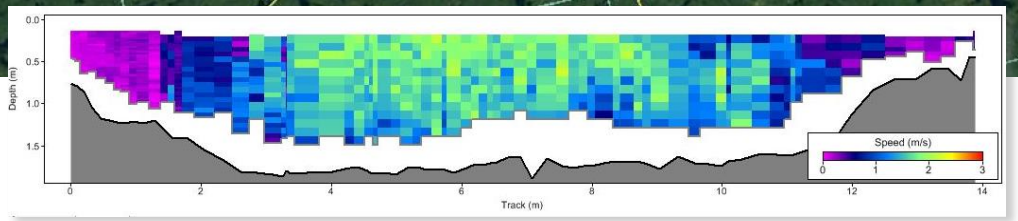




# Discharge monitoring sites





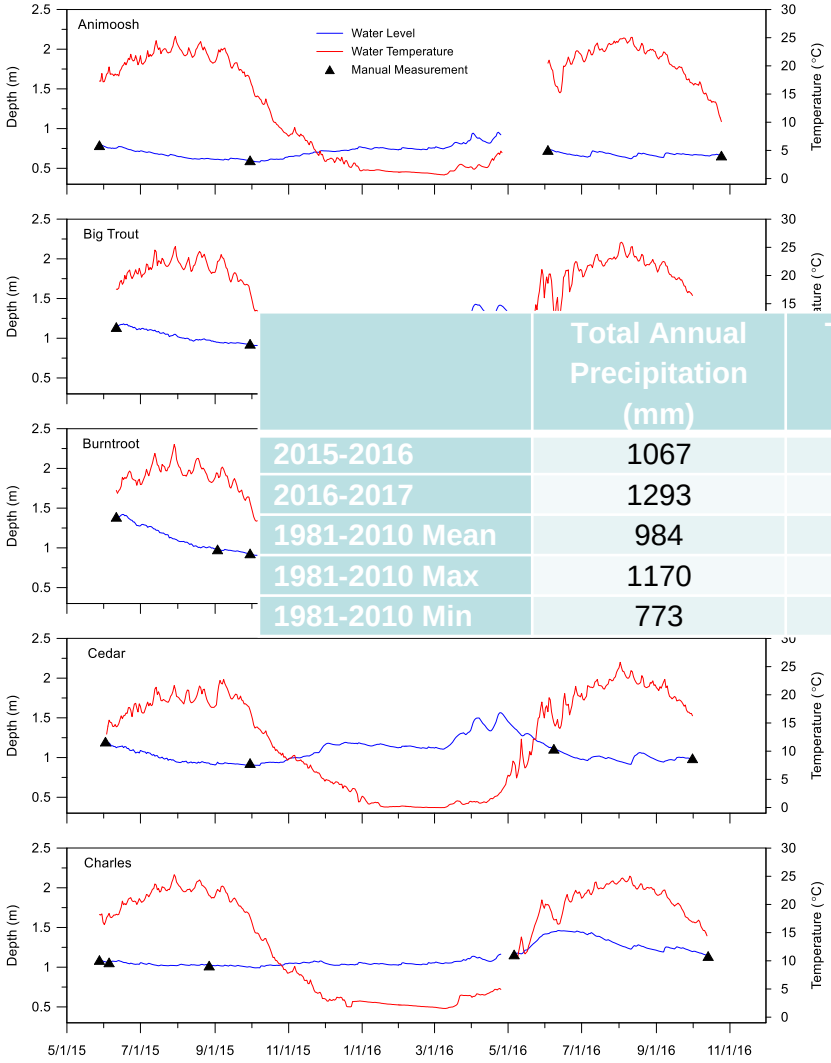






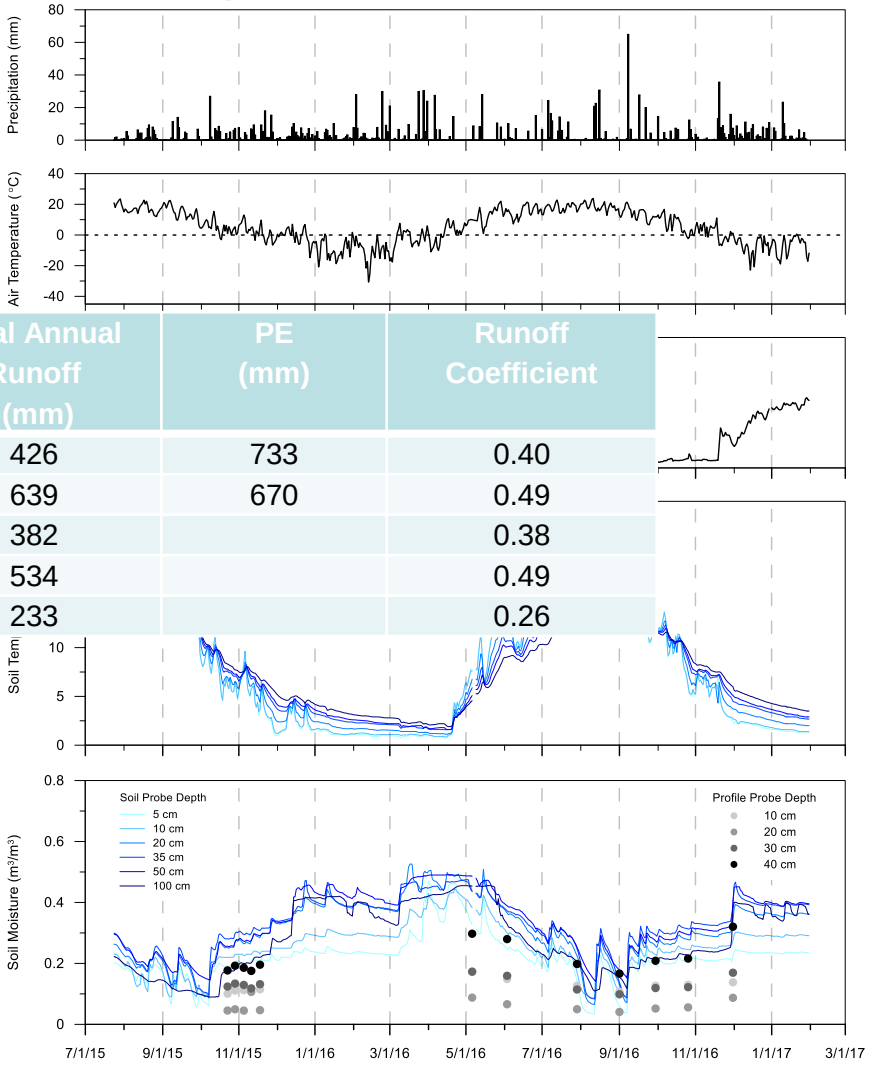

17.8 cms

# Lake data

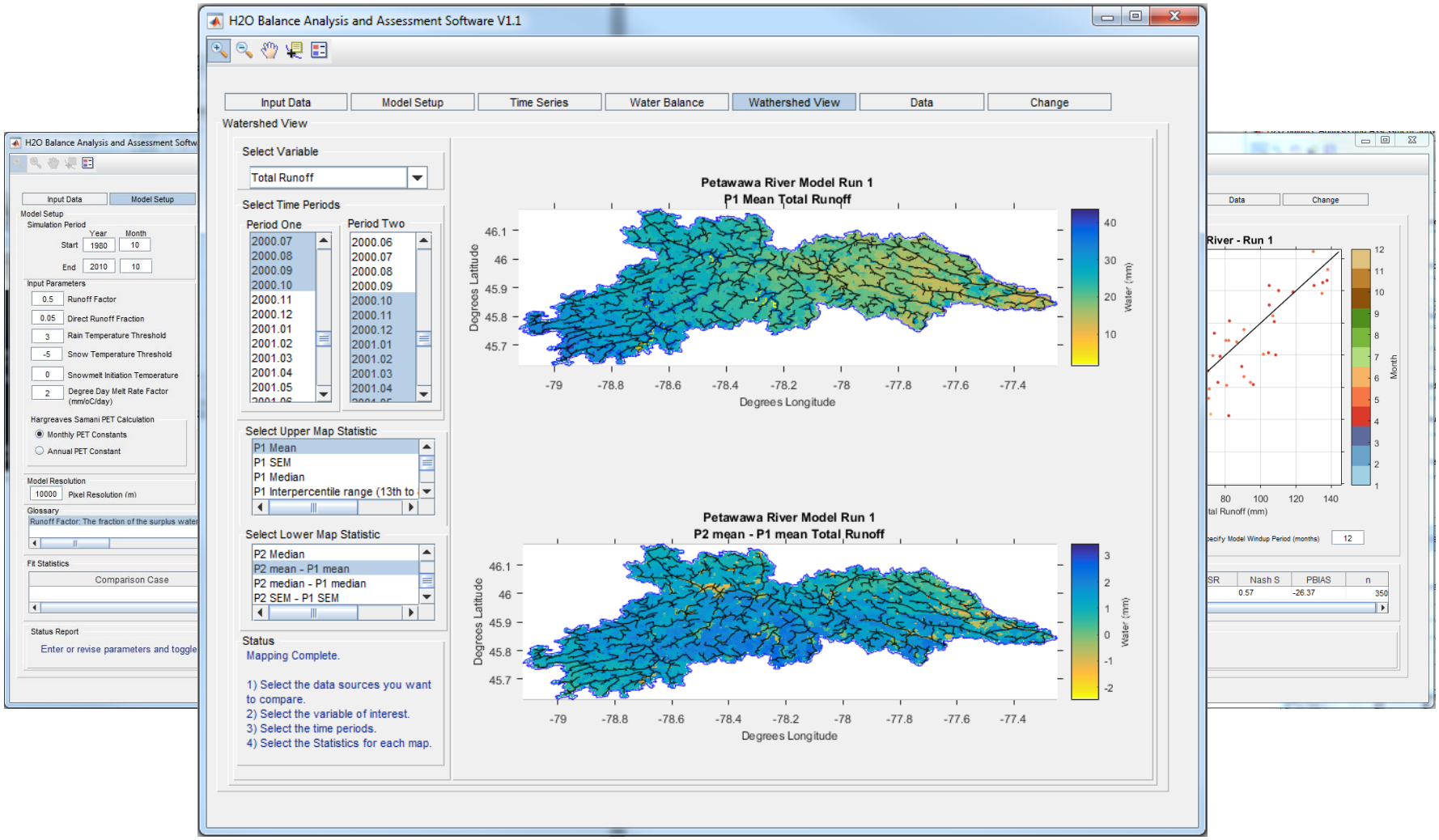



| | Total Annual Precipitation (mm) | Total Annual Runoff (mm) | PE (mm) | Runoff Coefficient |
|---|---|---|---|---|
| 2015-2016 | 1067 | 426 | 733 | 0.40 |
| 2016-2017 | 1293 | 639 | 670 | 0.49 |
| 1981-2010 Mean | 984 | 382 | | 0.38 |
| 1981-2010 Max | 1170 | 534 | | 0.49 |
| 1981-2010 Min | 773 | 233 | | 0.26 |

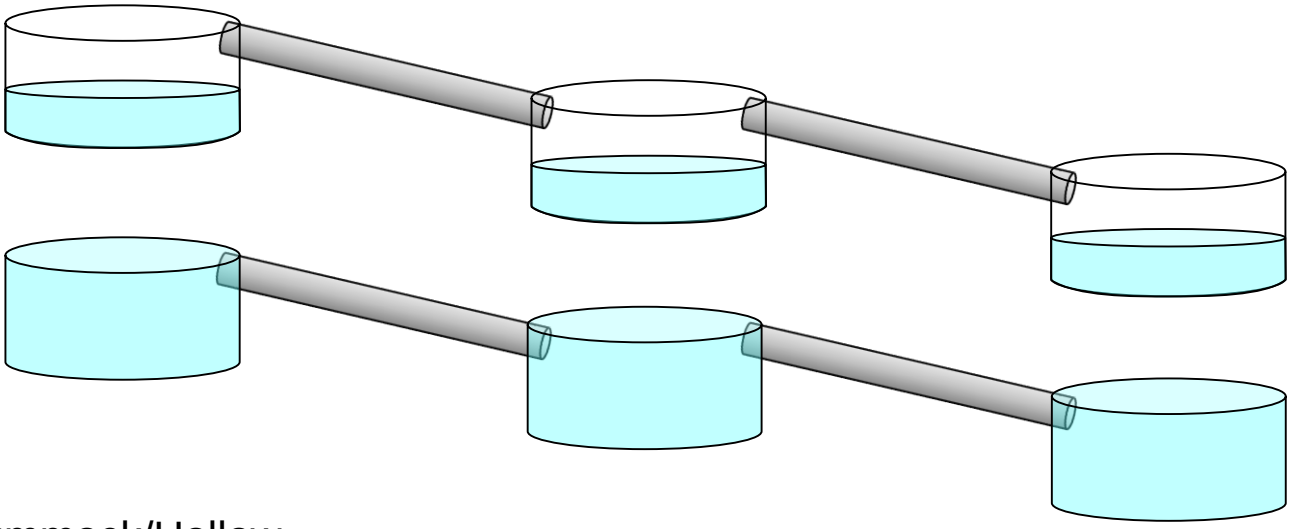
# Hydrometric stations



# Water Balance Analysis and Assessment Software ($H_2OBASS$)



# Changing water balances: The role of surface storage



Hummock/Hollow Micro storage

Ephemeral Pools

Perennial wetlands

# Changing water balances: The role of snowmelt processes

**Takeaway**

*Understanding hydrologic processes and how they might change is essential for predicting potential changes in water balances.*

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(Hogan Lake, 2015)