Groundwater Flow in the Waterloo Moraine

Knowledge Evolution over 125 years

Paul Martin, M.Sc., P.Eng.

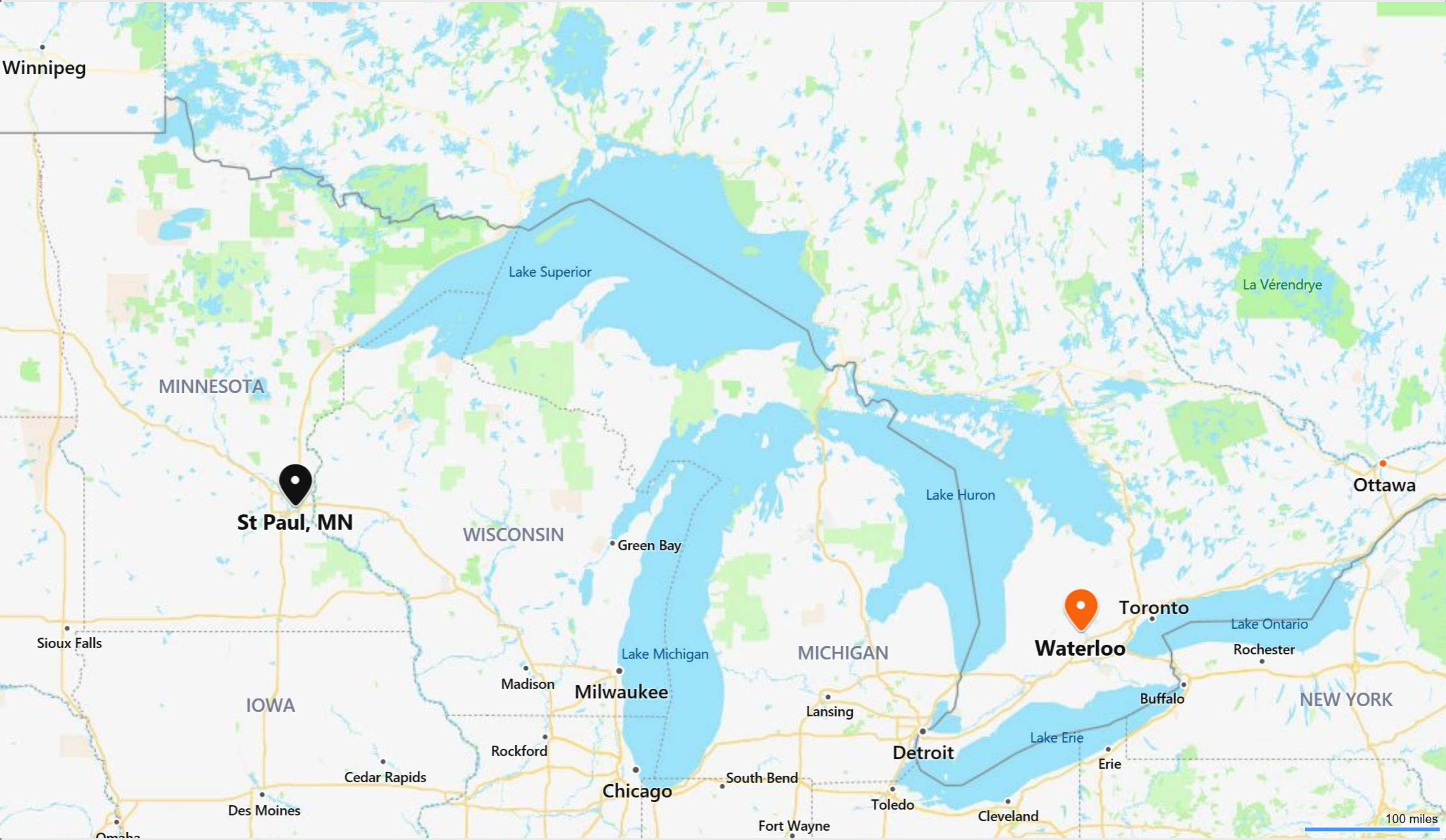
Aqua Insight Inc.

Aqua Insight

Overview

- Region of Waterloo
  - Setting / geology / stratigraphy / hydrogeology
  - Hydrogeologic Conceptual Model
- Recent Investigations
  - Source Water Protection Planning in Ontario
    - Numerical Modelling
    - Water Quantity Risk Assessment

Waterloo, Ontario, Canada



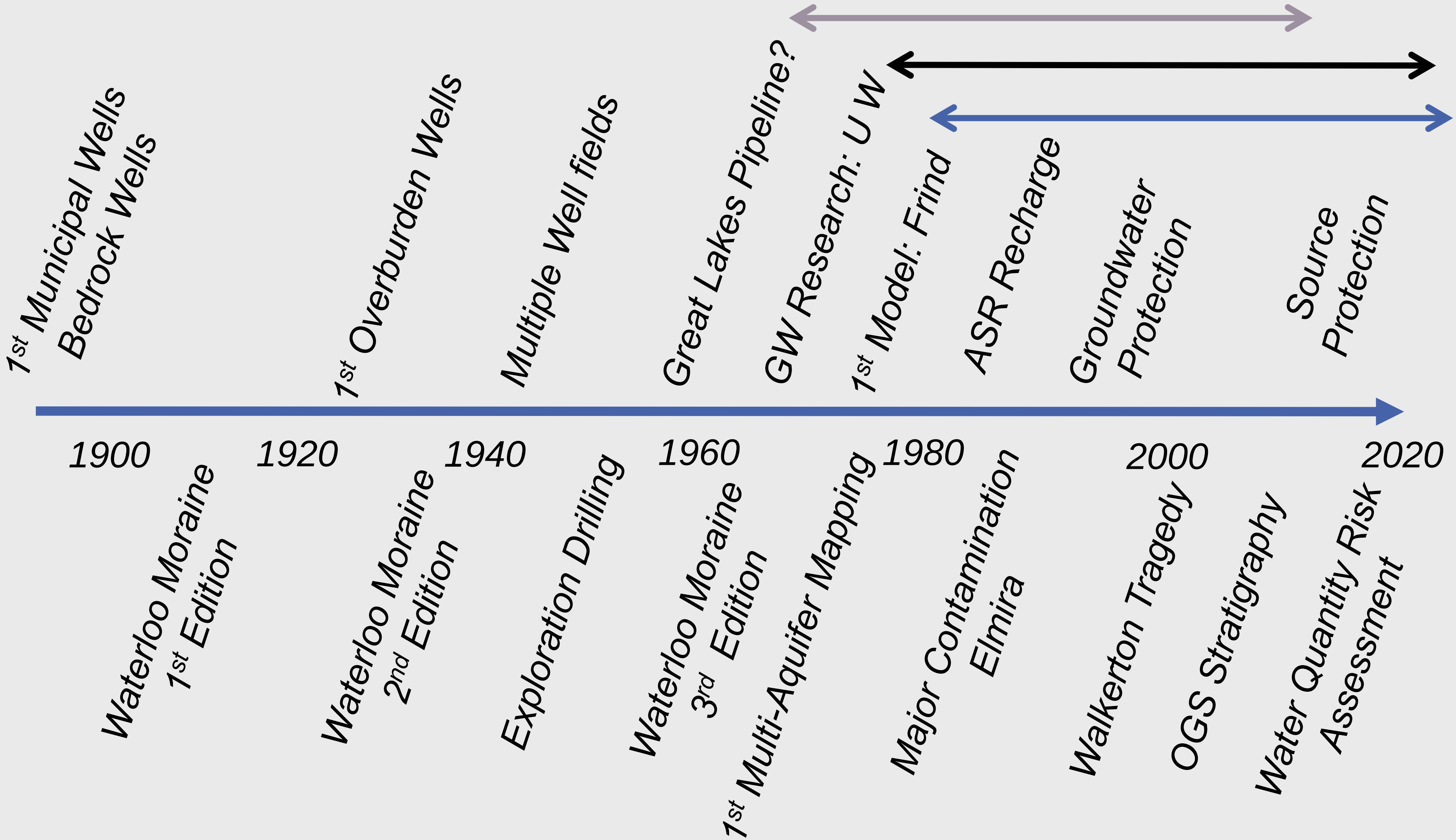
Region of Waterloo

- Urban Centre surrounded by productive farmland
- Population ~ 500,000
- Growing urban water demand
  - Domestic
  - Industrial / commercial
- Glaciated deposits
  - 0-300 ft thick
  - Multiple till sheets
  - Multi-aquifer system
- Paleozoic bedrock
  - Fractured dolostone
  - interbedded shale / dolostone

Highly Productive Farmland

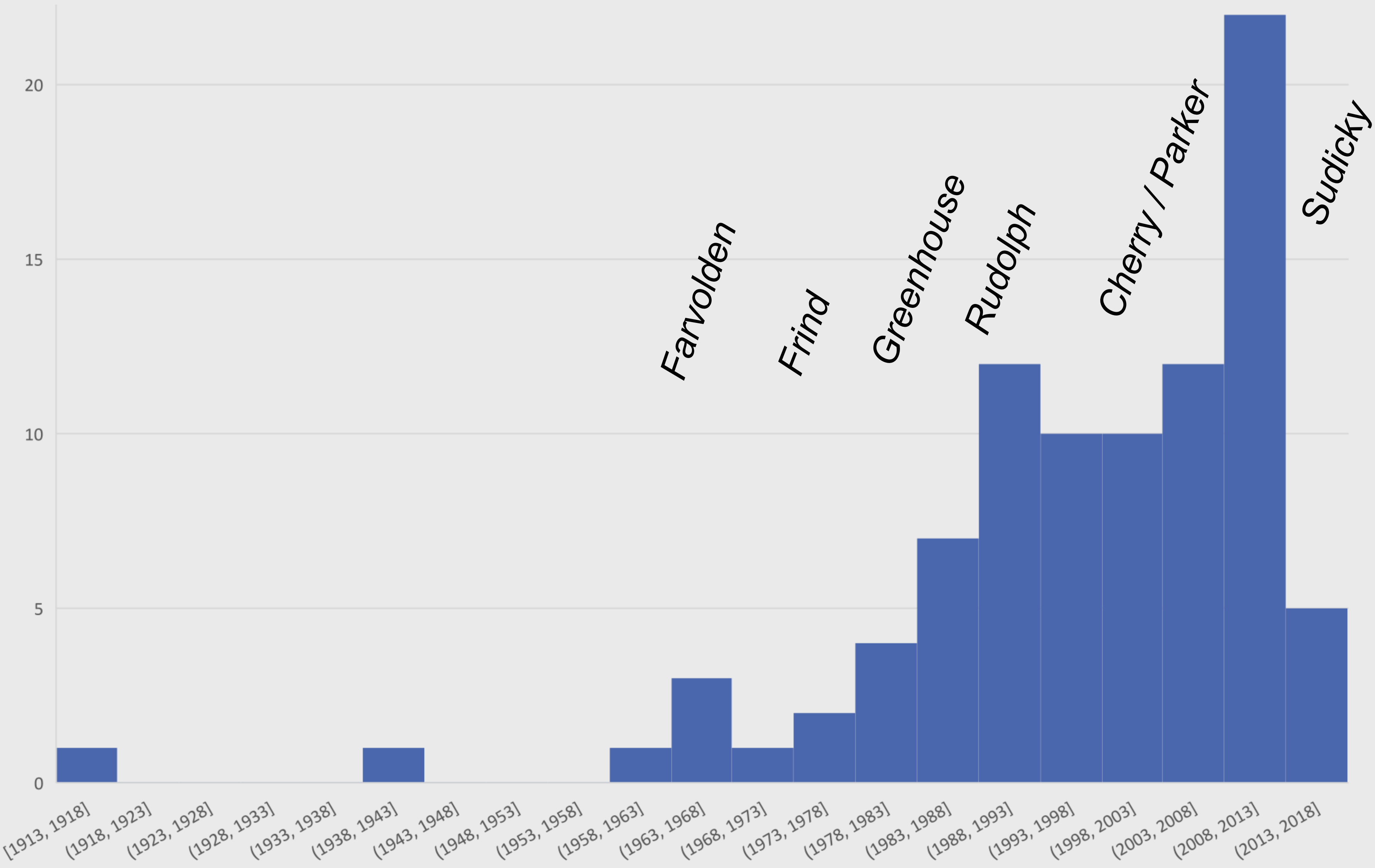
Hummocky Topography & Kettle Lakes

Waterloo Moraine Knowledge Building

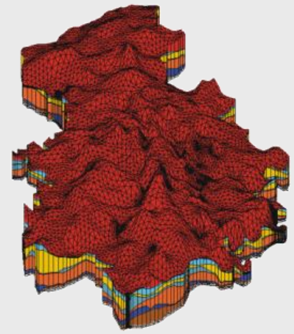


Local Universities

Waterloo Moraine Reports / Papers



Practical Applications Lag Research



Universities

Multi Aquifer Characterization → *2D Model* → *2 ½ D Model* → *3D Model* → *Integrated Models*

Practice / Municipal Adoption

Single Aquifer → *Multi Aquifer* → *2D Model* → *3D Model* → *I.M*

1960 *1970* *1980* *1990* *2000* *2010* *2020*

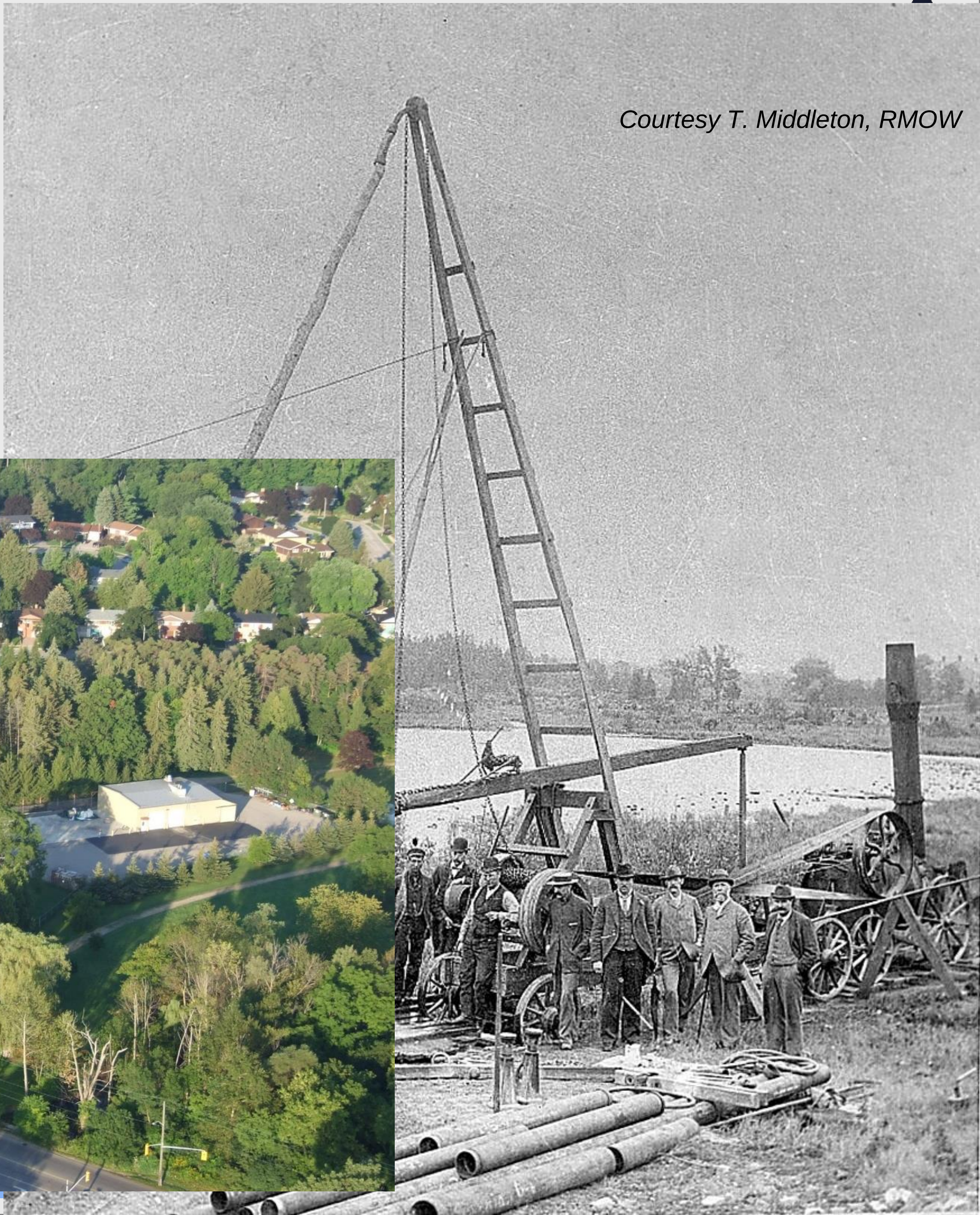
Water Supply c. 1890

- Developed at discharge area
- Drilled municipal wells
  - Late 1800's
  - Targeted bedrock
  - Only accepted Flowing Artesian Wells
  - Rural areas

Courtesy T. Middleton, RMOW

Greenbrook

- *Today: surrounded by urban development*



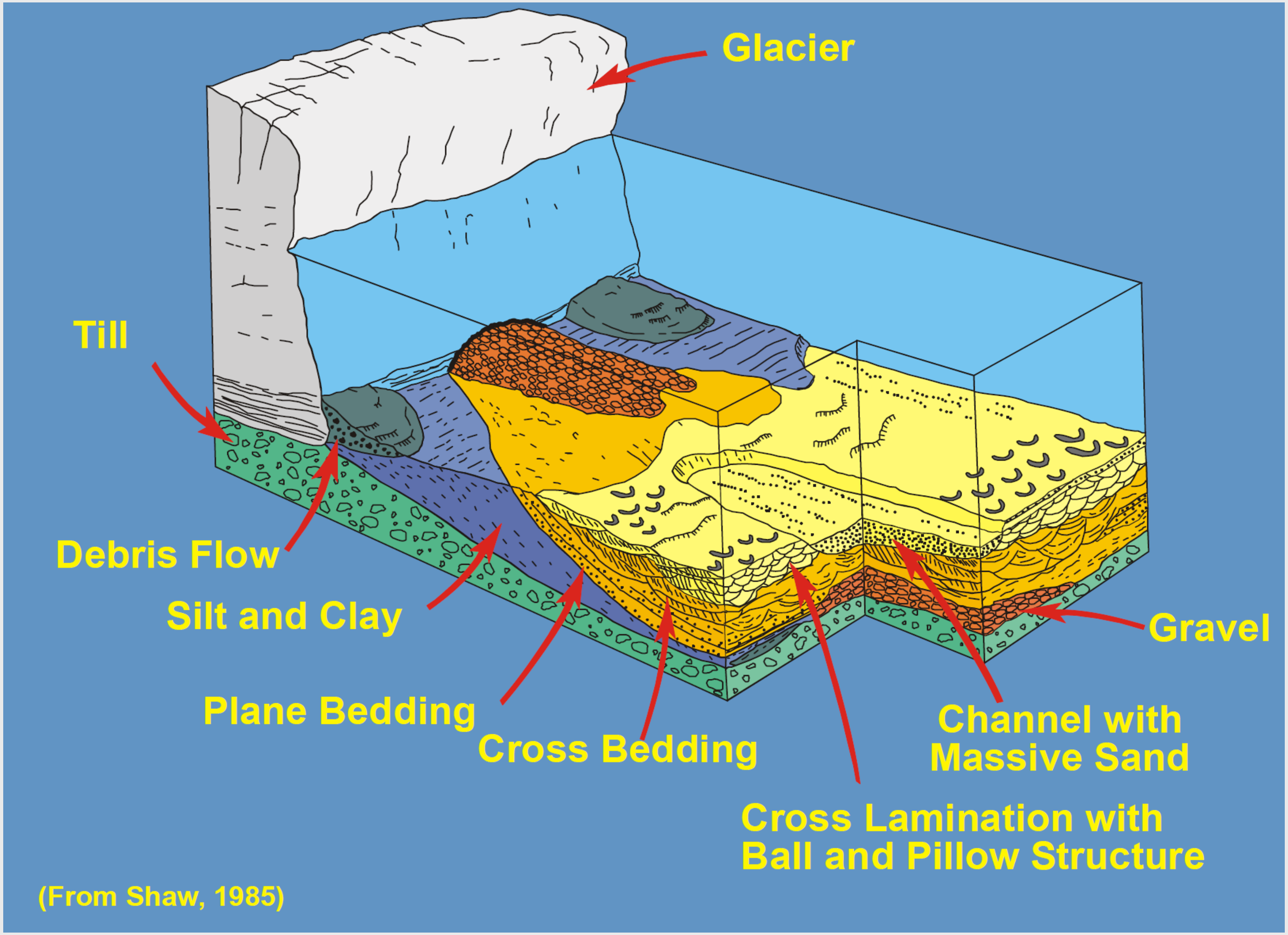
Courtesy T. Middleton, RMOW

Courtesy T. Middleton, RMOW

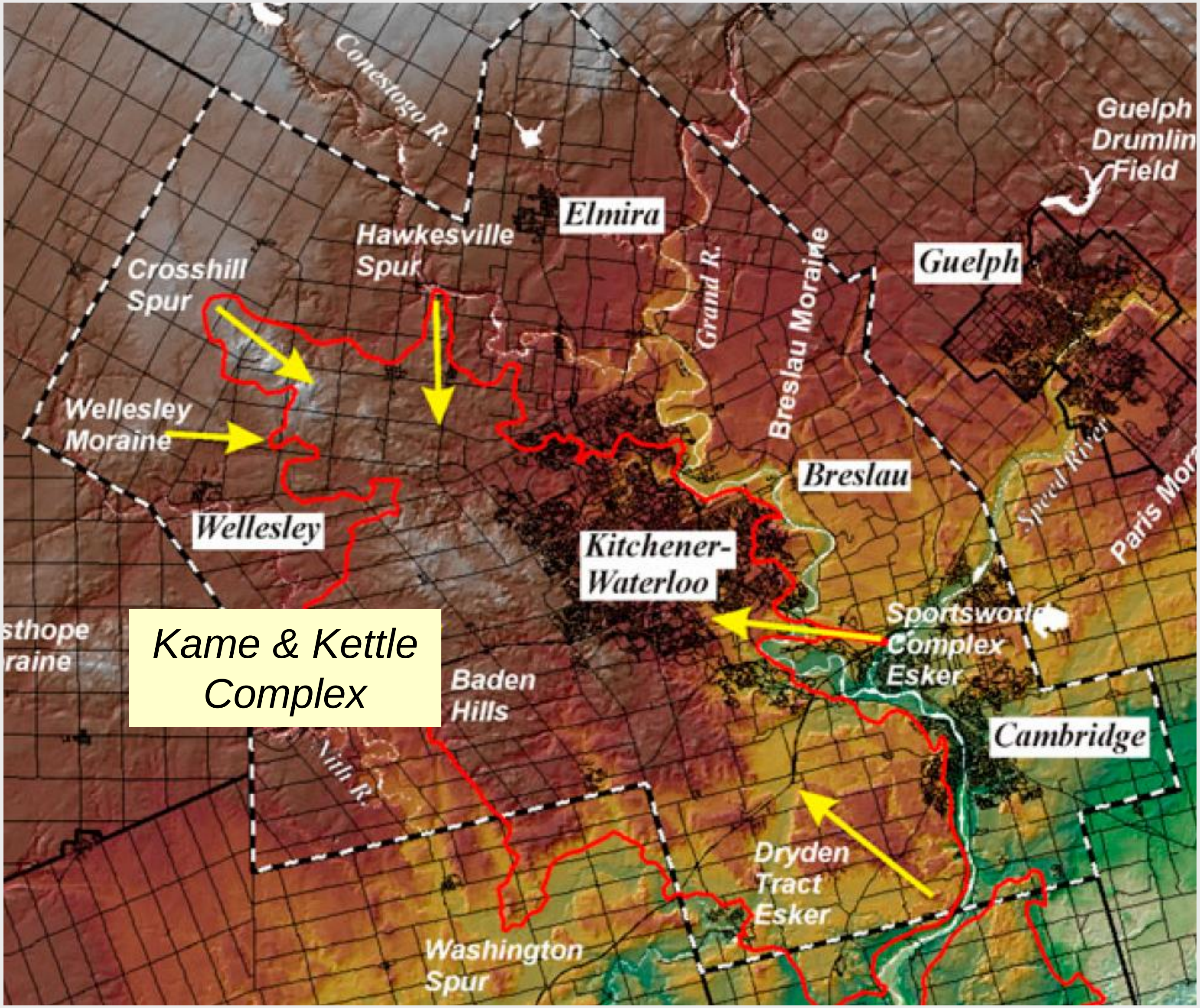
Complex Glacial History

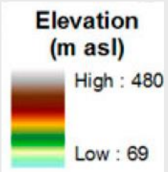
- Multiple Glaciations
  - Lake Erie
  - Lake Ontario
  - Lake Huron
  - Georgian Bay
- Interlobate moraine deposits
- Deposition and erosion from/to different directions

Waterloo Moraine Depositional Model



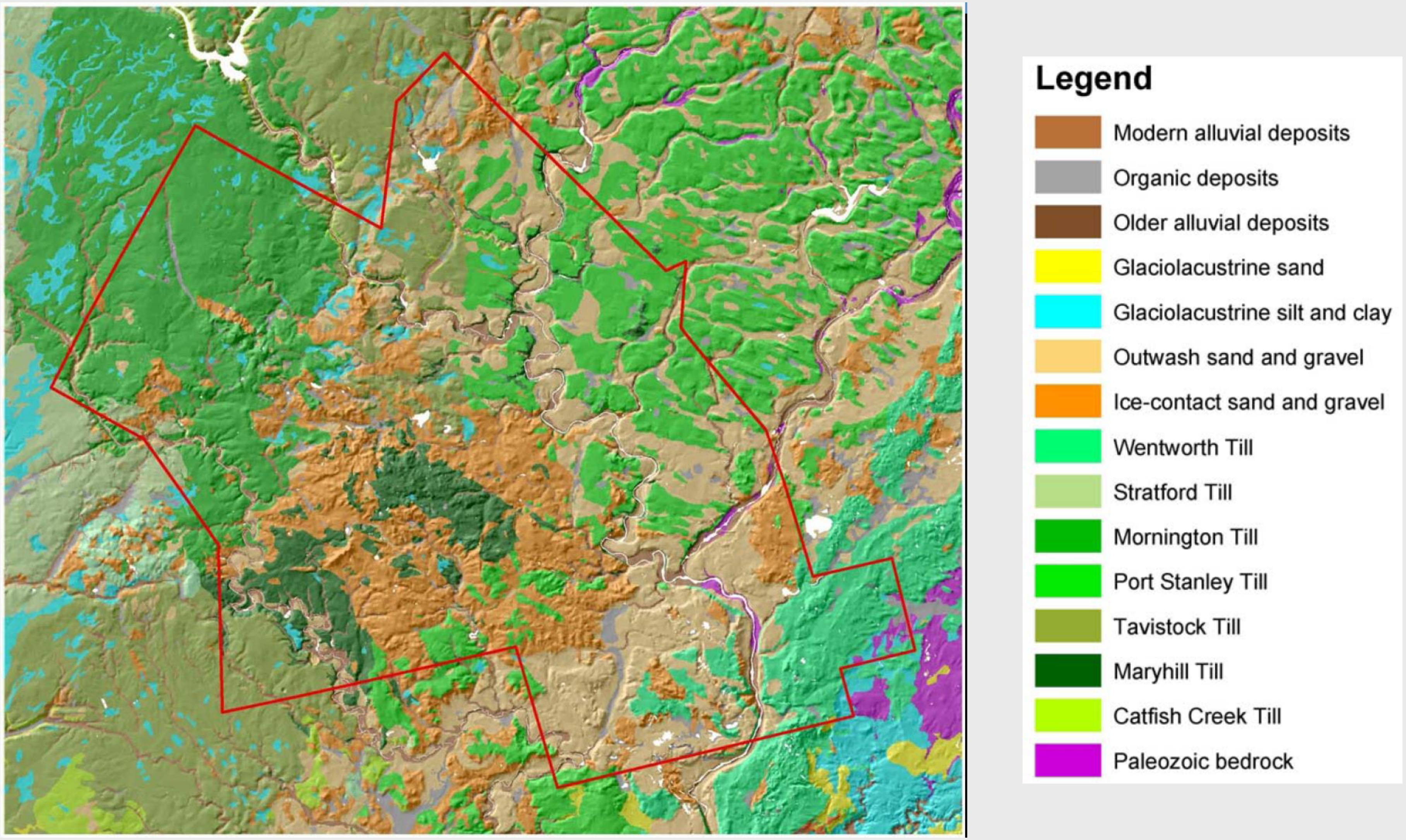
Waterloo Moraine Extents





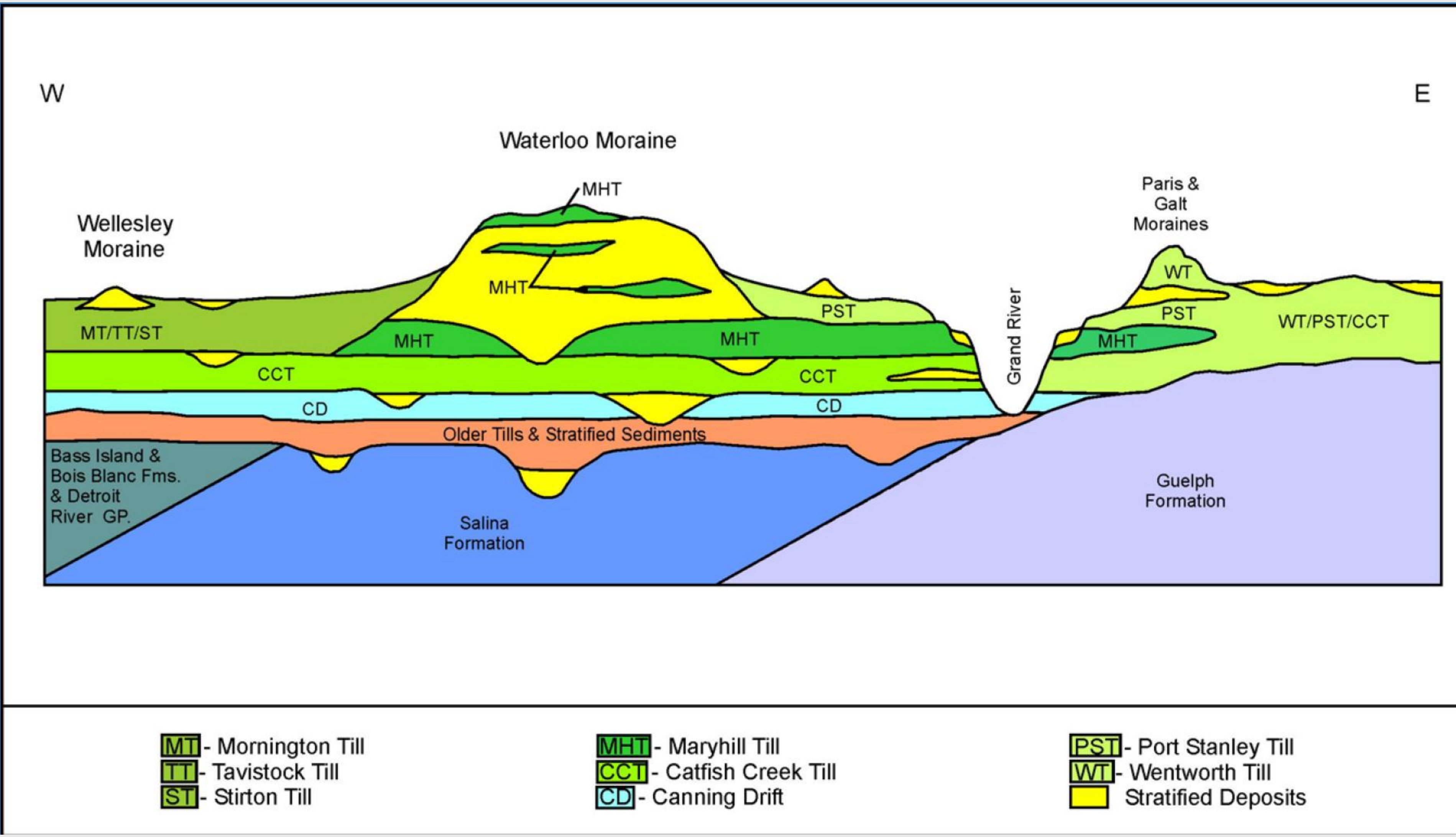
From Bajc, 2007

Surficial Geology

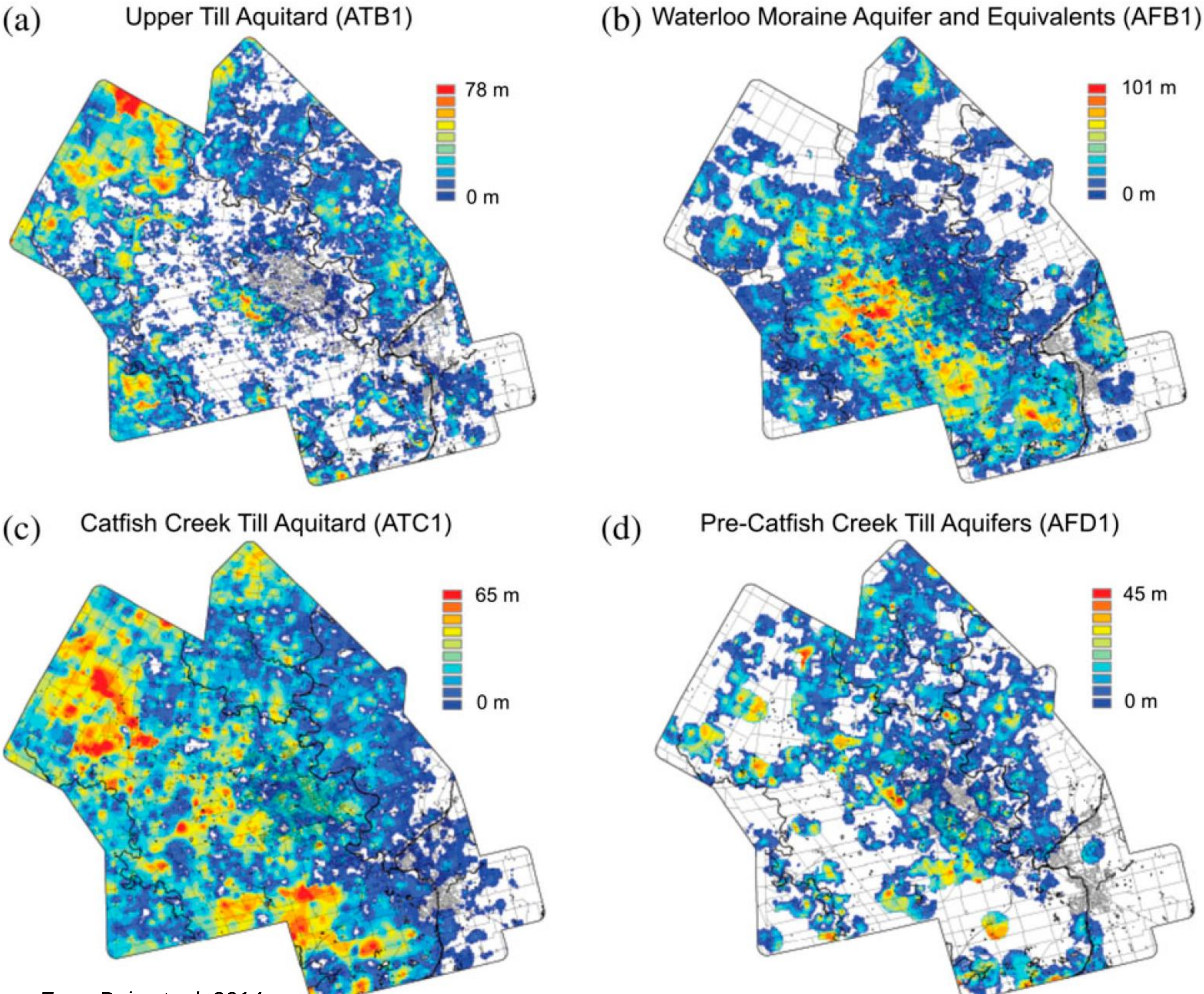


From Bajc, 2007

Stratigraphy – Till Marker Beds

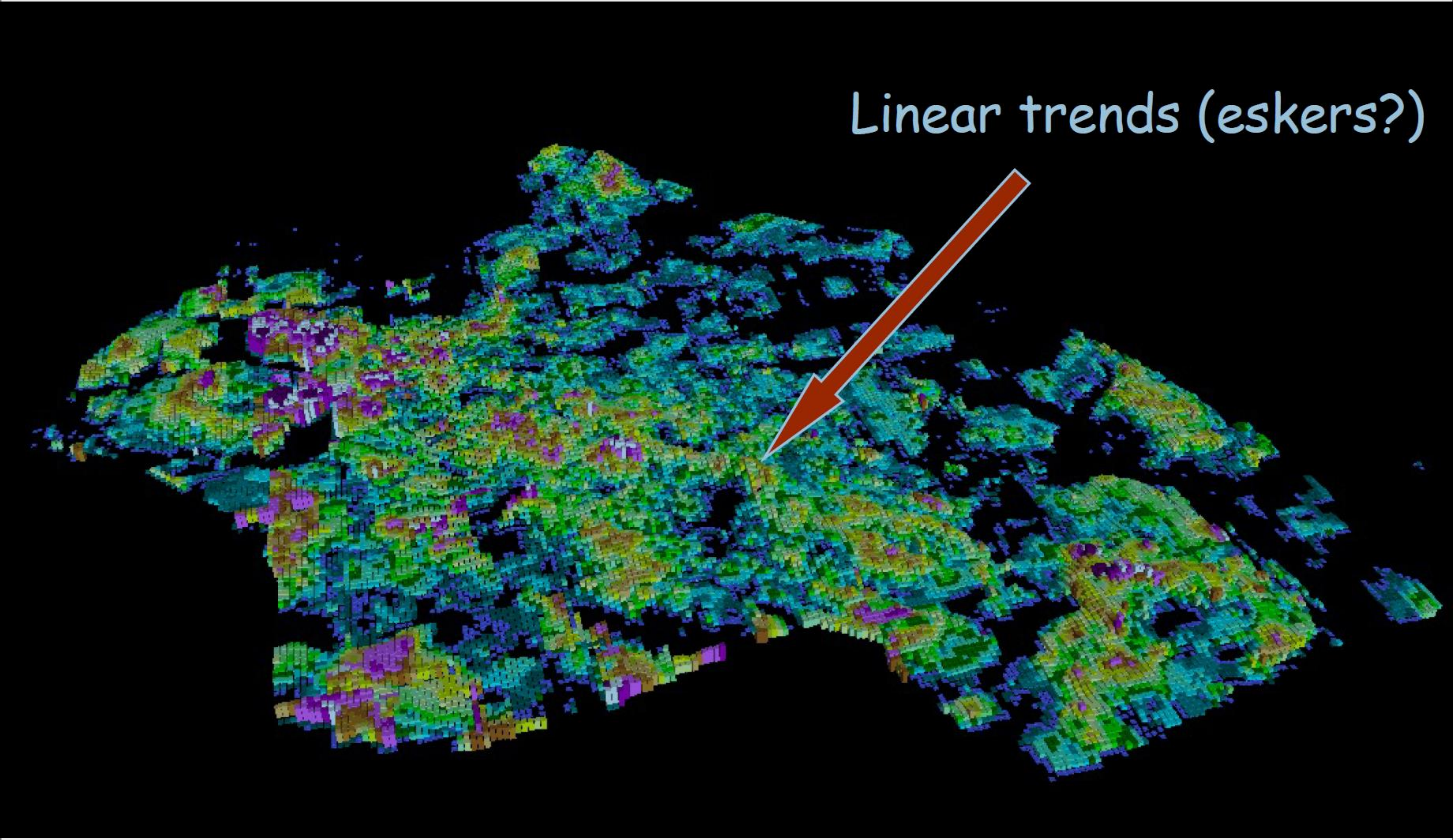


From Bajc, 2007



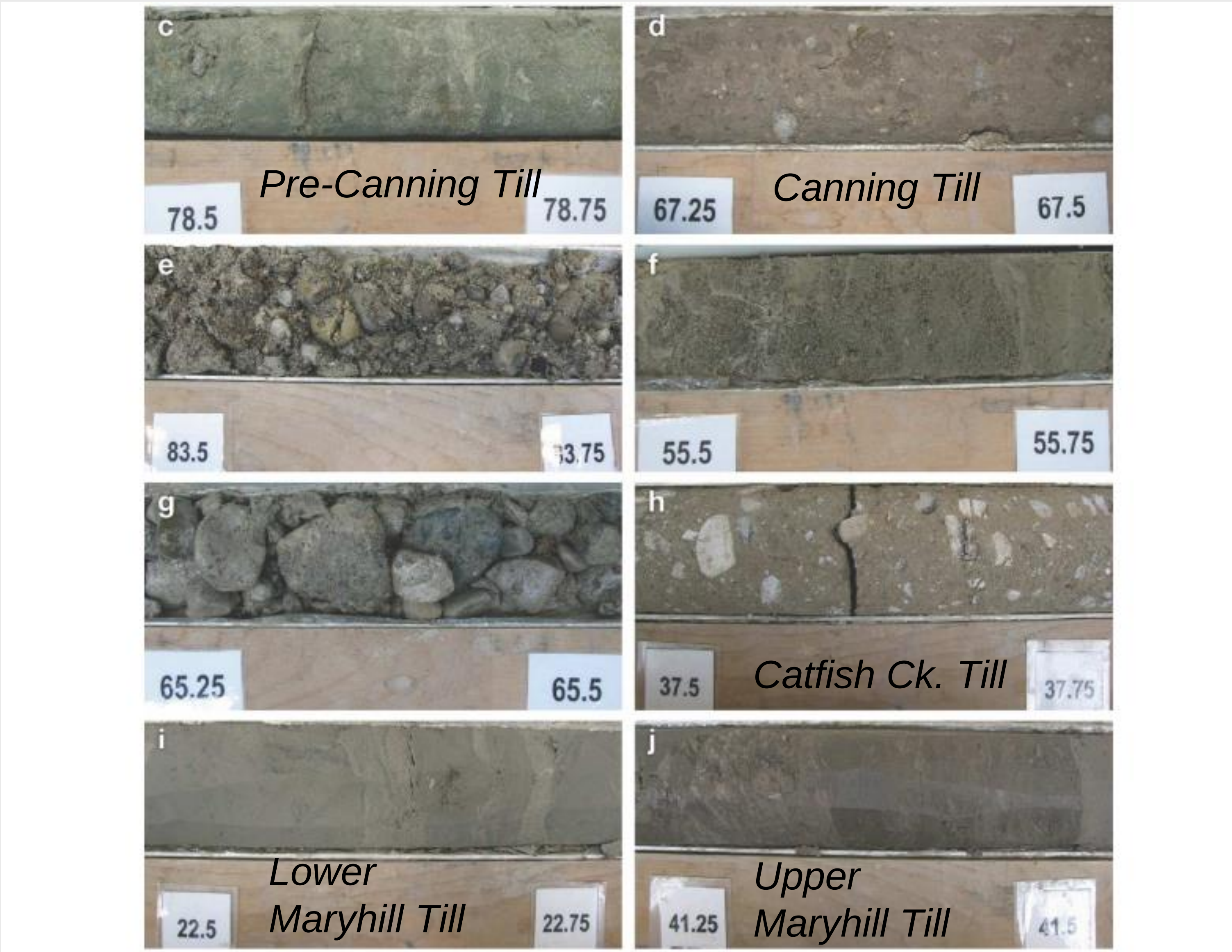
From Bajc et. al, 2014

Goal: Delineate Erosional Deposits that may Result in Till Windows

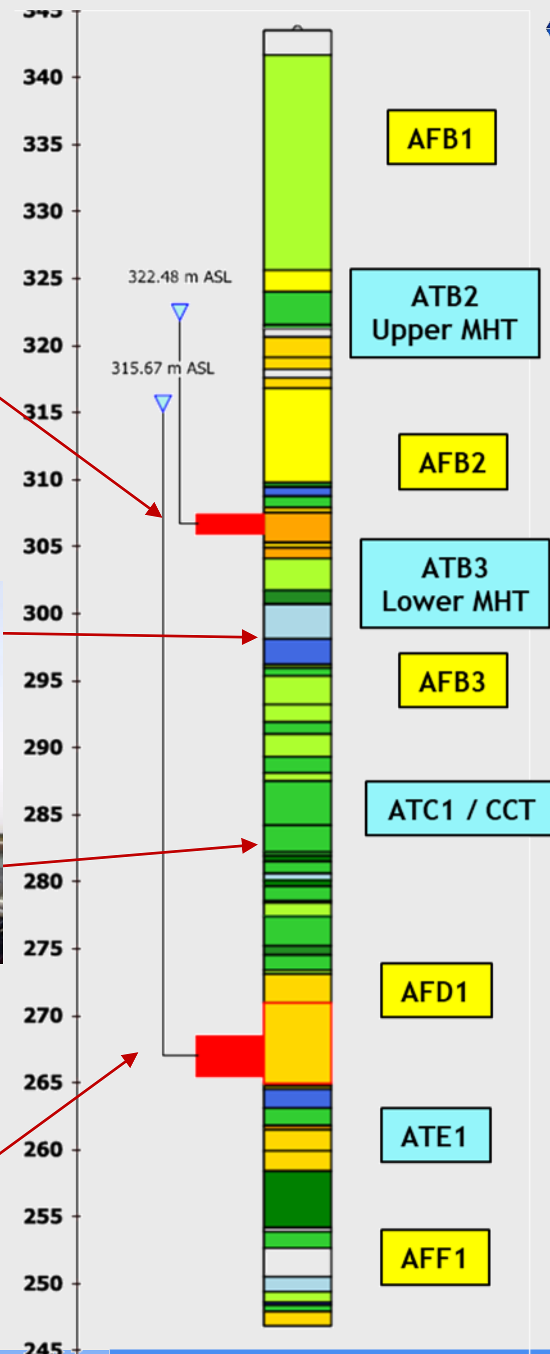


From Bajc, 2007

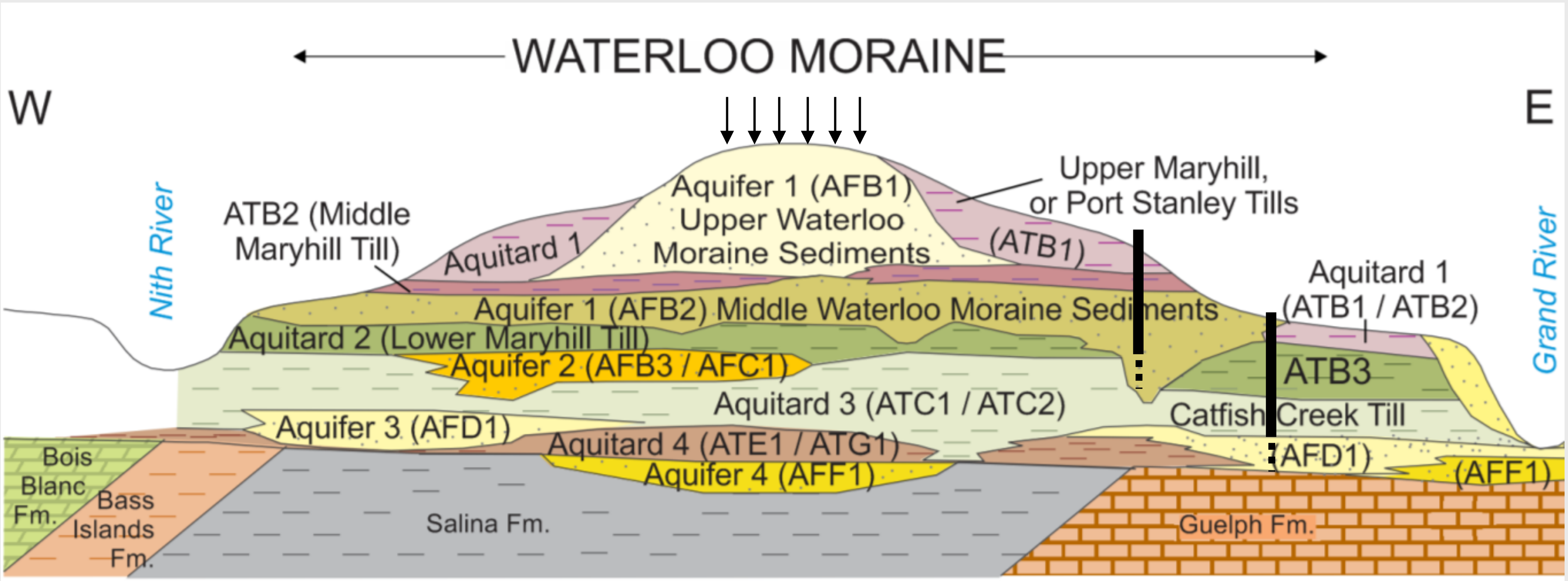
Similar Lithologies Repeated > 300 ft



Typical Borehole Log



Most Recent Hydrostratigraphic Model



after Bajc et. al, 2014

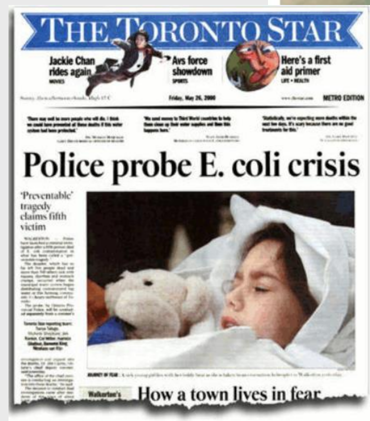
GW Challenge = Balance

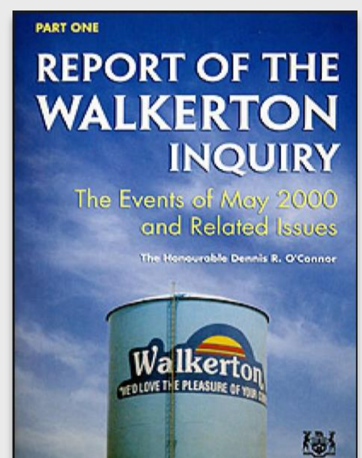
- Balance
  - Needs of Population
    - Domestic, agriculture, industrial, commercial
  - Healthy Ecosystem
- Plan for changing environment
    - urban development, increasing demand , climate change

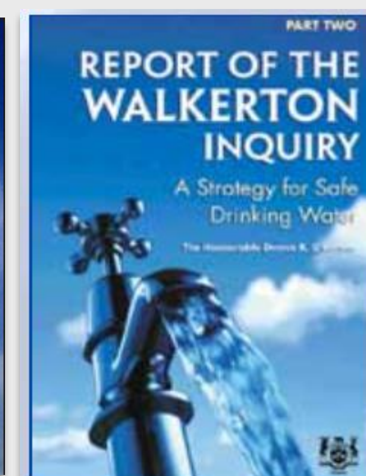
Water Budget & Water Quantity Risk Assessment

Why Water Budgets? …Walkerton

- Tragedy
  - E-coli in water supply wells
  - 2321 people ill
  - 7 deaths
- Causes
  - No well head management or understanding
  - Failure to maintain chlorination system (Negligence)
  - Poor government oversight: Budget Cuts
- Judicial Inquiry
  - Led to Source Protection Planning
    - Water Quality
    - **Water Quantity**
    - Watershed-scale approach

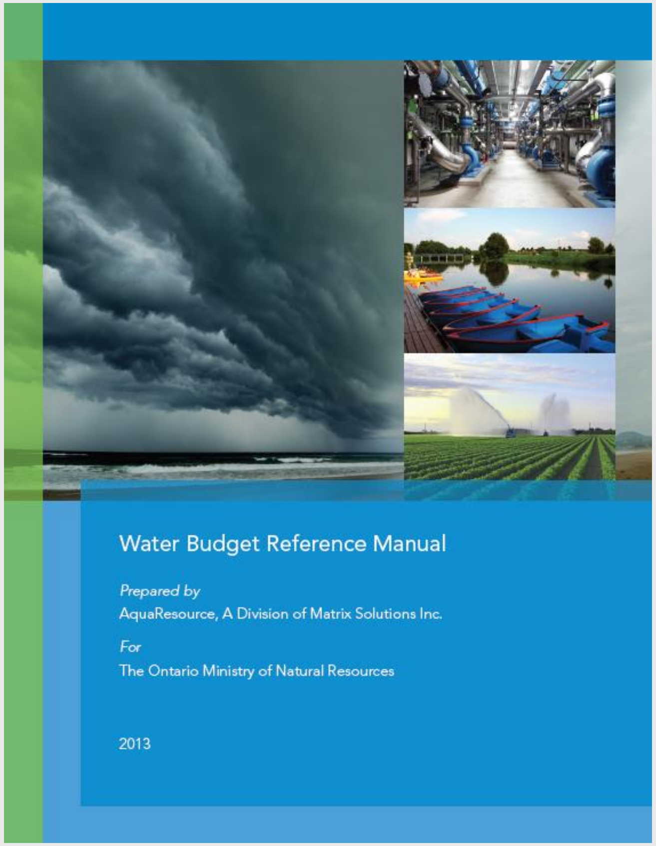

THE TORONTO STAR
Jackie Chan rides again
Avs force showdown
Here's a first aid primer
Police probe E. coli crisis
'Preventable' tragedy claims fifth victim
How a town lives in fear





Why Water Budgets? … *opportunity*

- Capitalize on available datasets
- Quantify resources
- Watershed Scale
- Informed decision-making
  - Economic development
  - GW / SW Interaction
  - Social - Ecological balance



"Allow water bottling?"

" Where do we have enough water to support a new ethanol plant?"

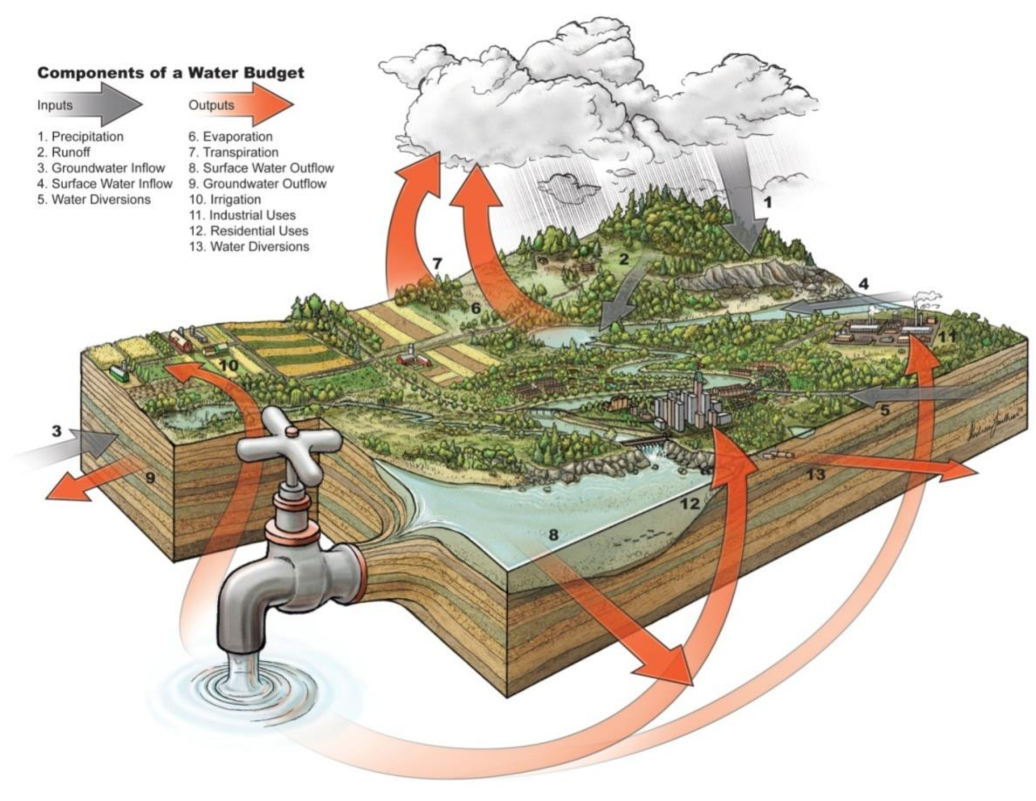
Tier Three Water Budget & Water Quantity Risk Assessment

Approach

- *Risk of well / intake not being able to sustain planned pumping.*

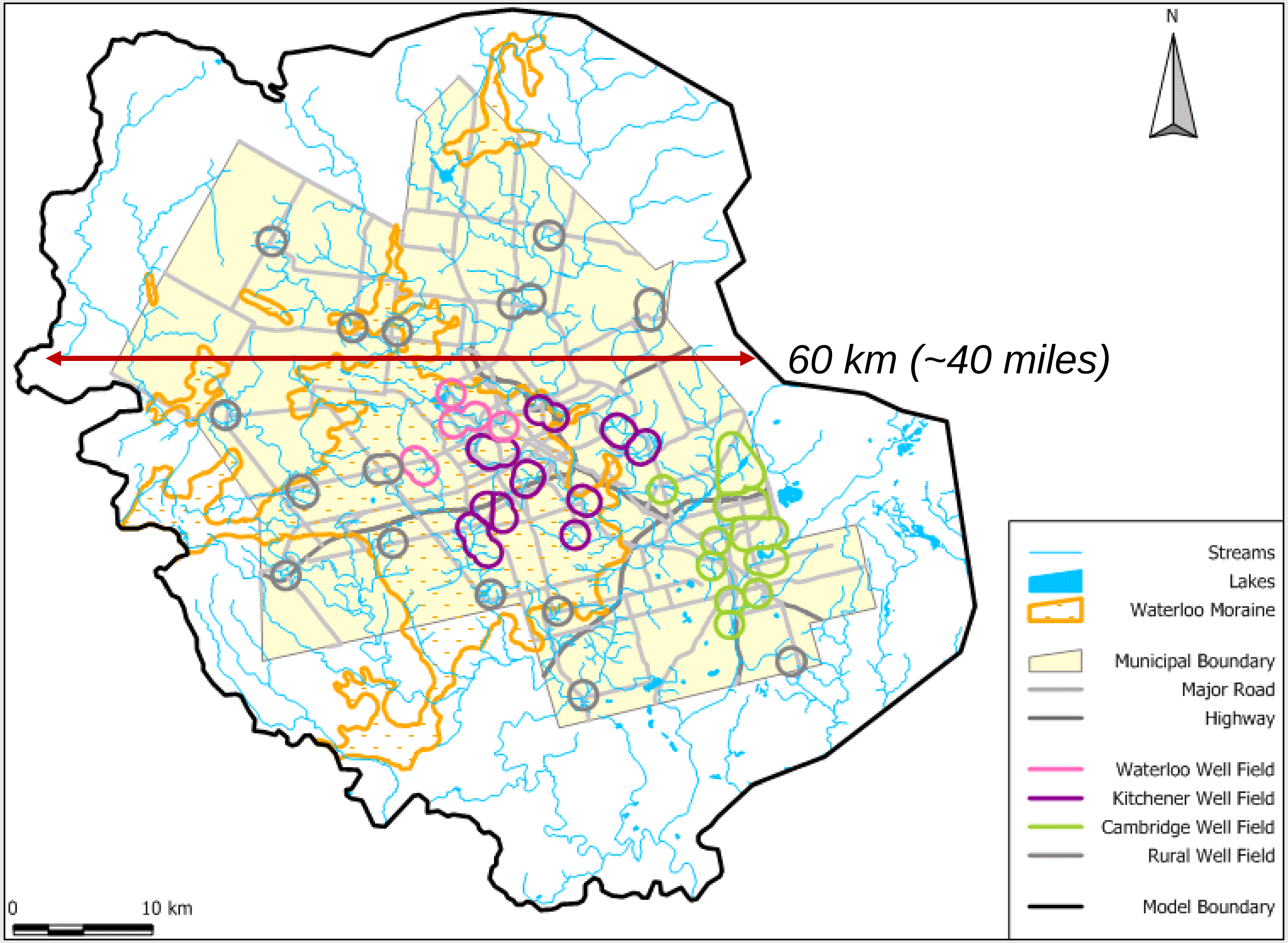
Sustainability Assessment

- *Maintain pumping*
  - *Short term*
  - *Long term*
  - *Cumulative Effects*
- *Surface Water Impact*
- *Drought / Climate Change*



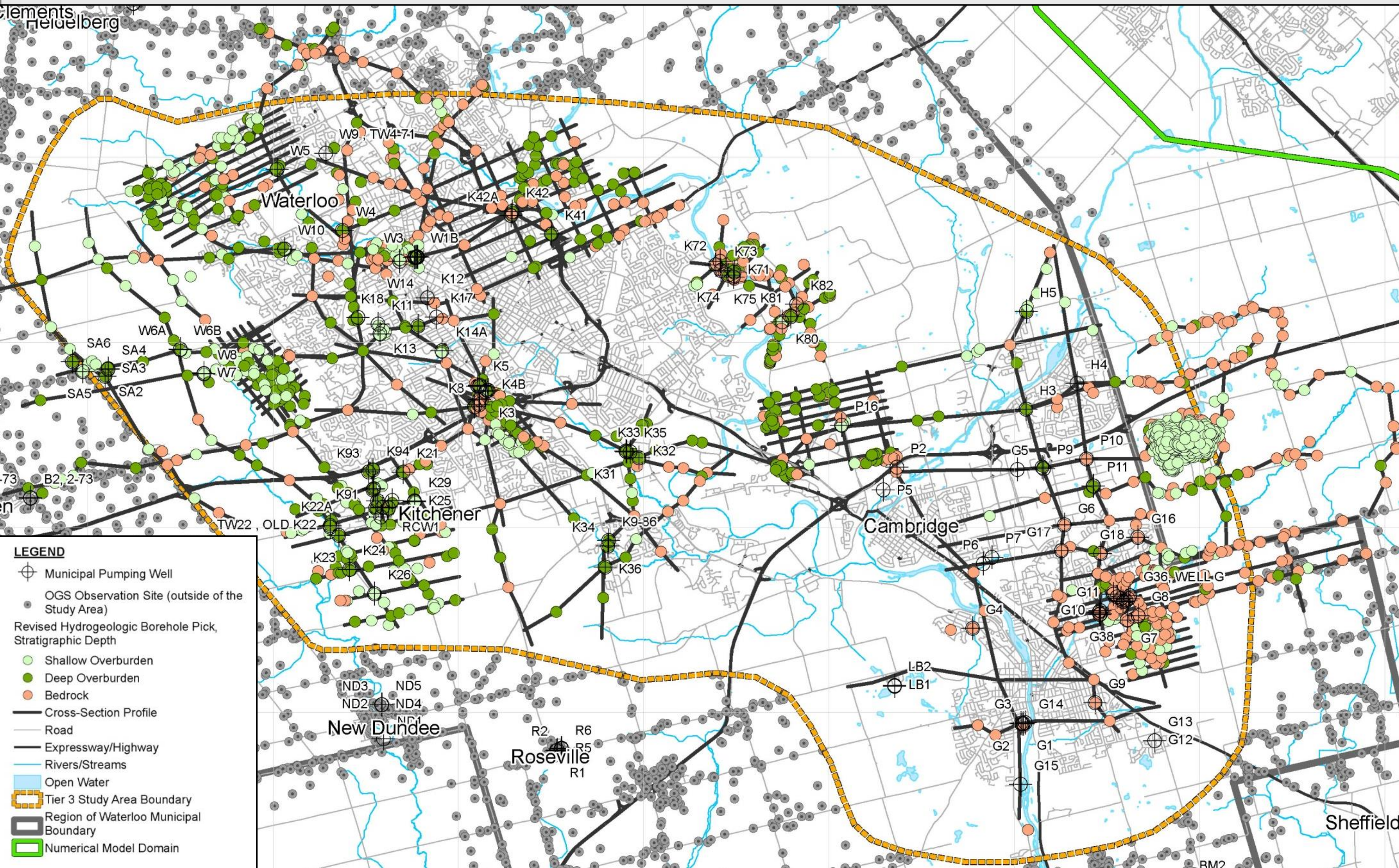
50 Distributed Wellfields

- 1350 mi²
- 133 wells

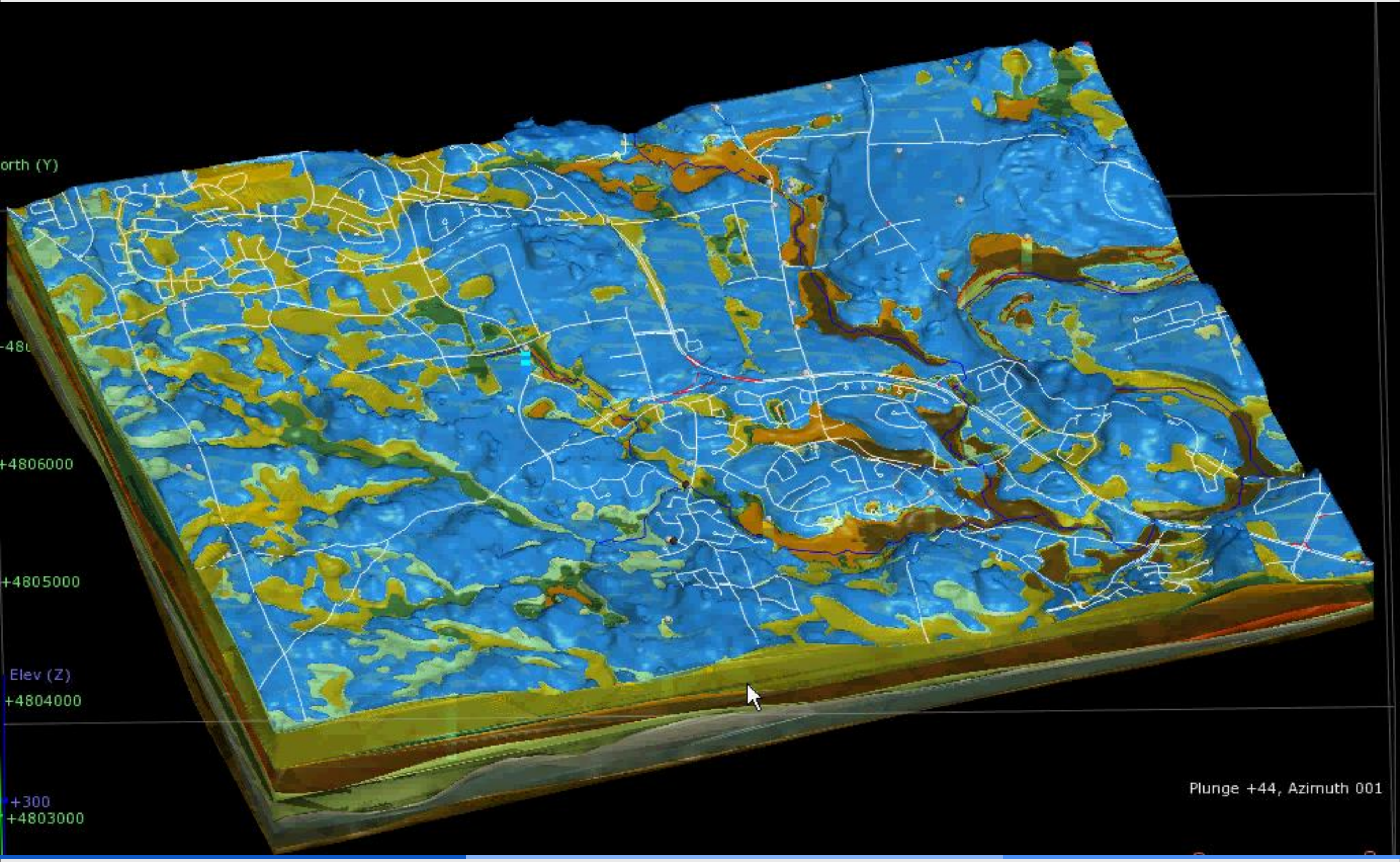


Detailed Cross-Section Locations

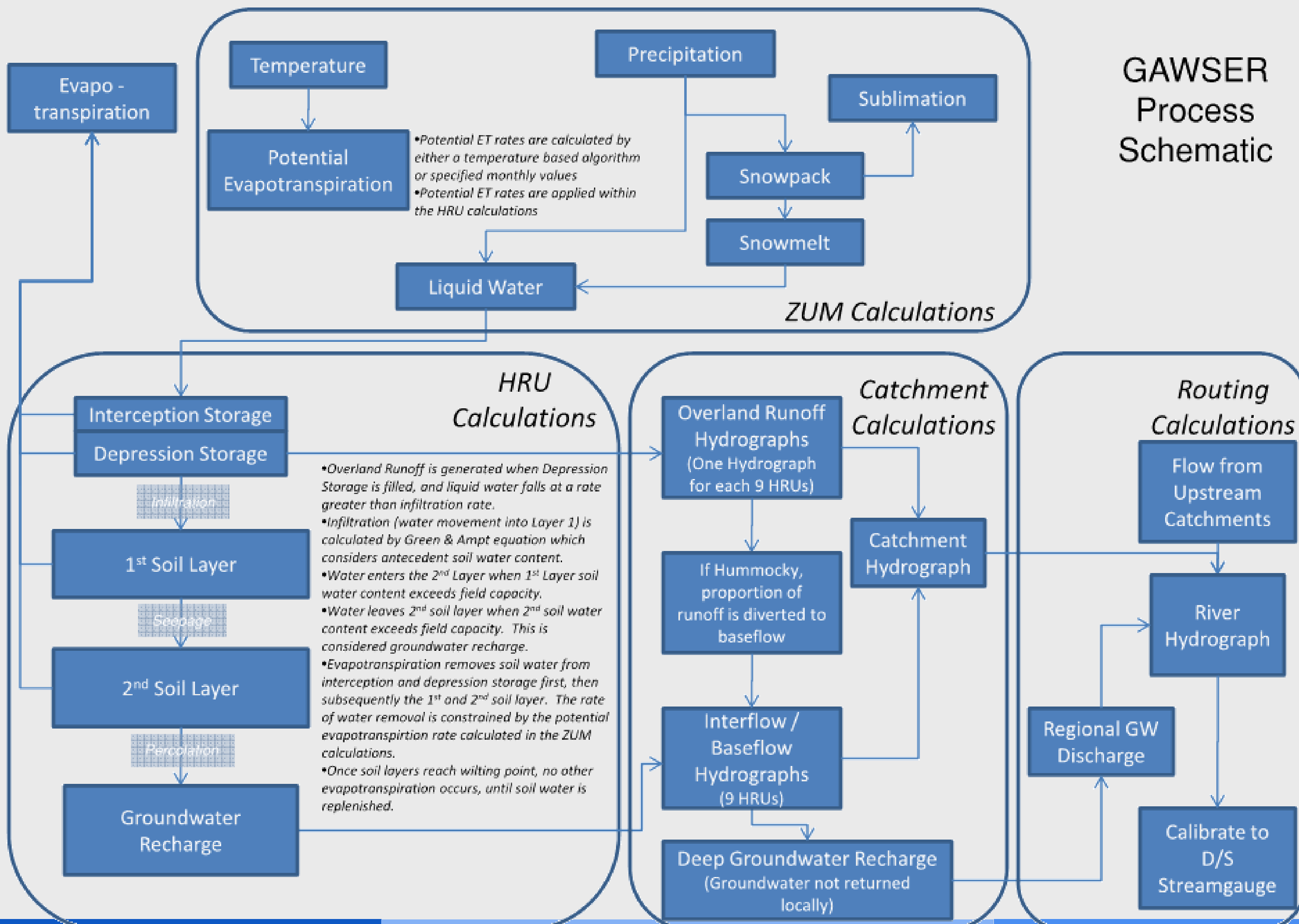
Worked outward from Municipal Wells using OGS stratigraphic model



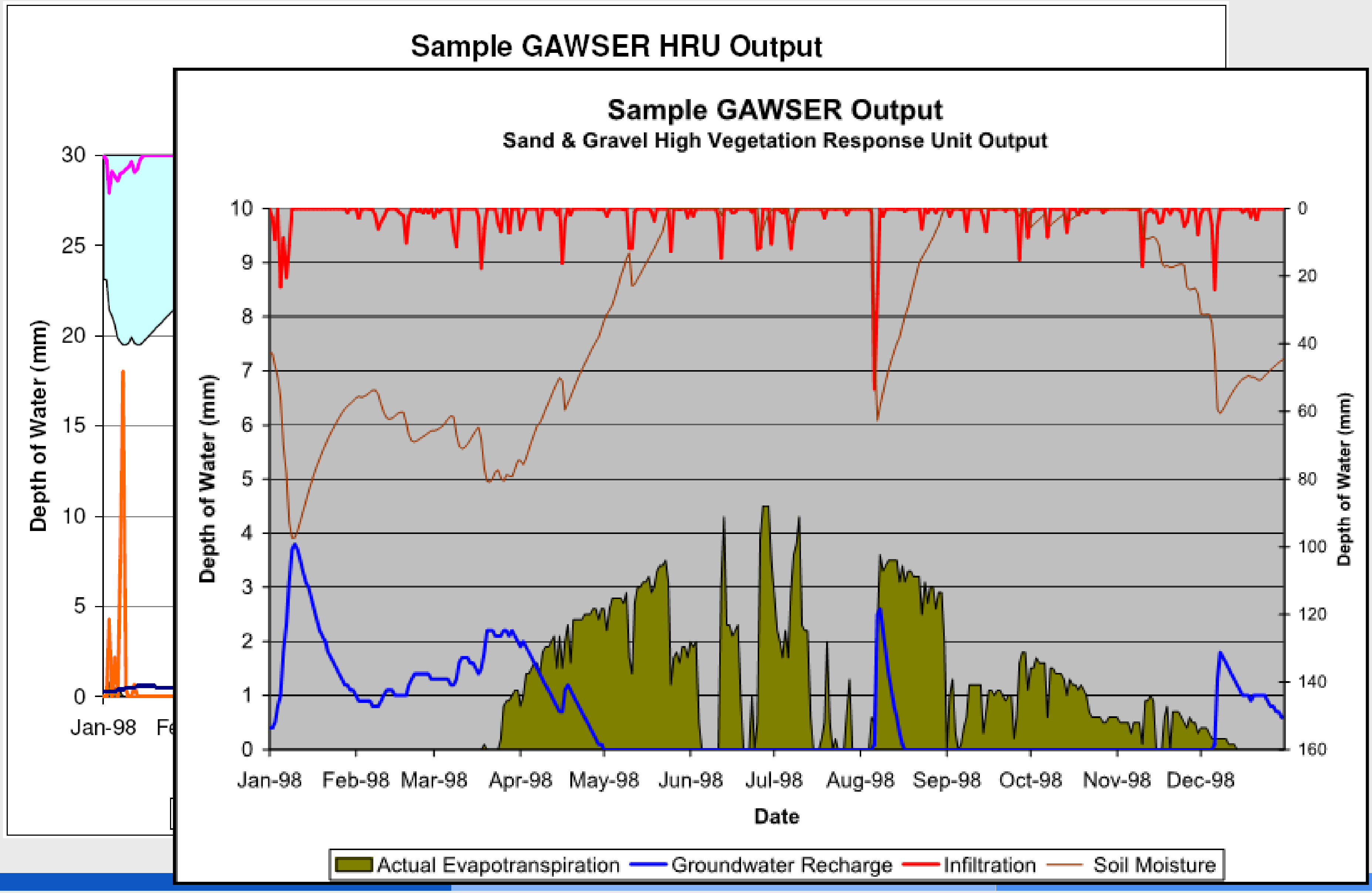
Hydrogeology Characterization



Recharge → Coupled SW Model

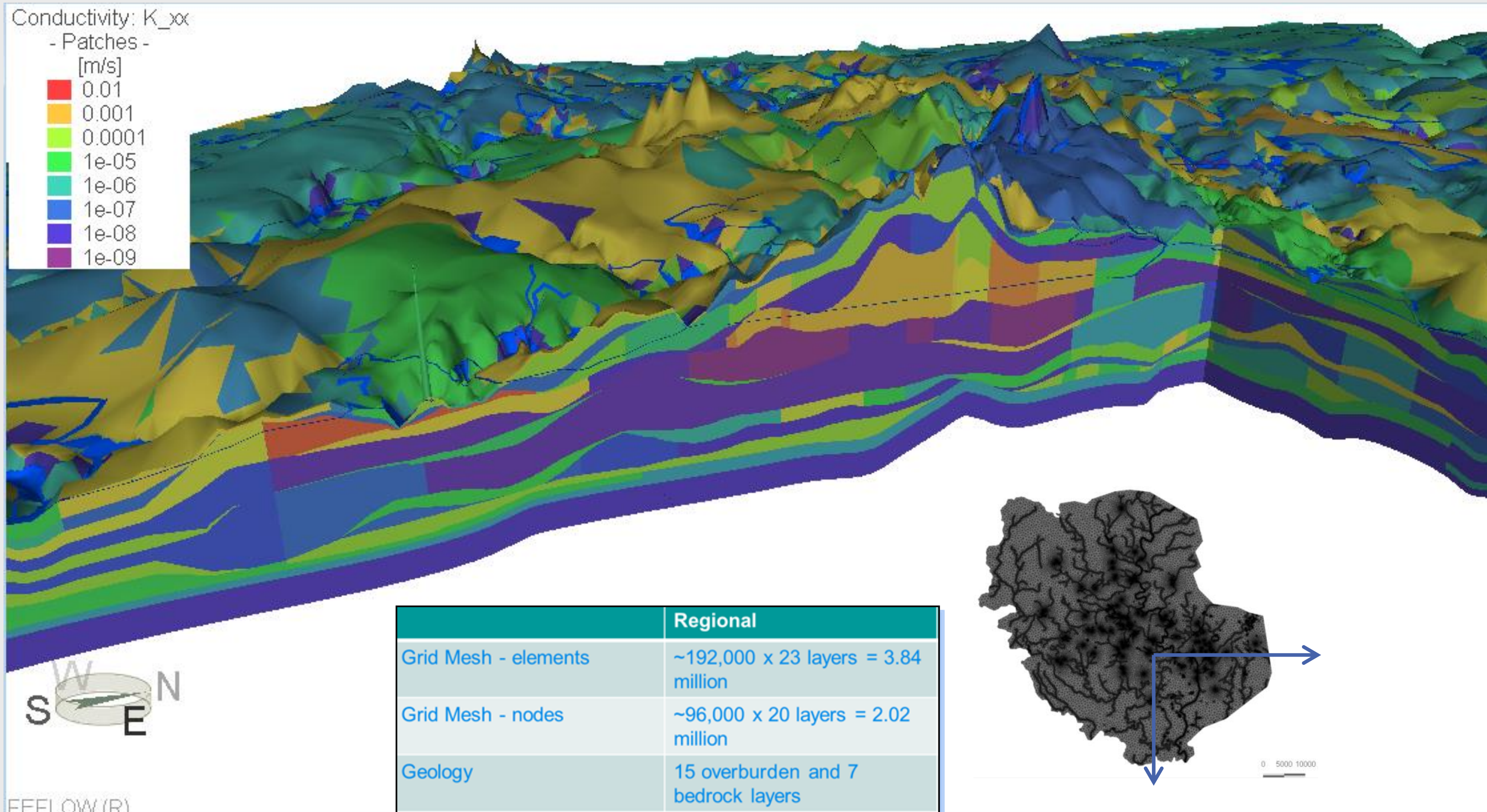


Transient water balance for each HRU



Detailed 3D GW Model

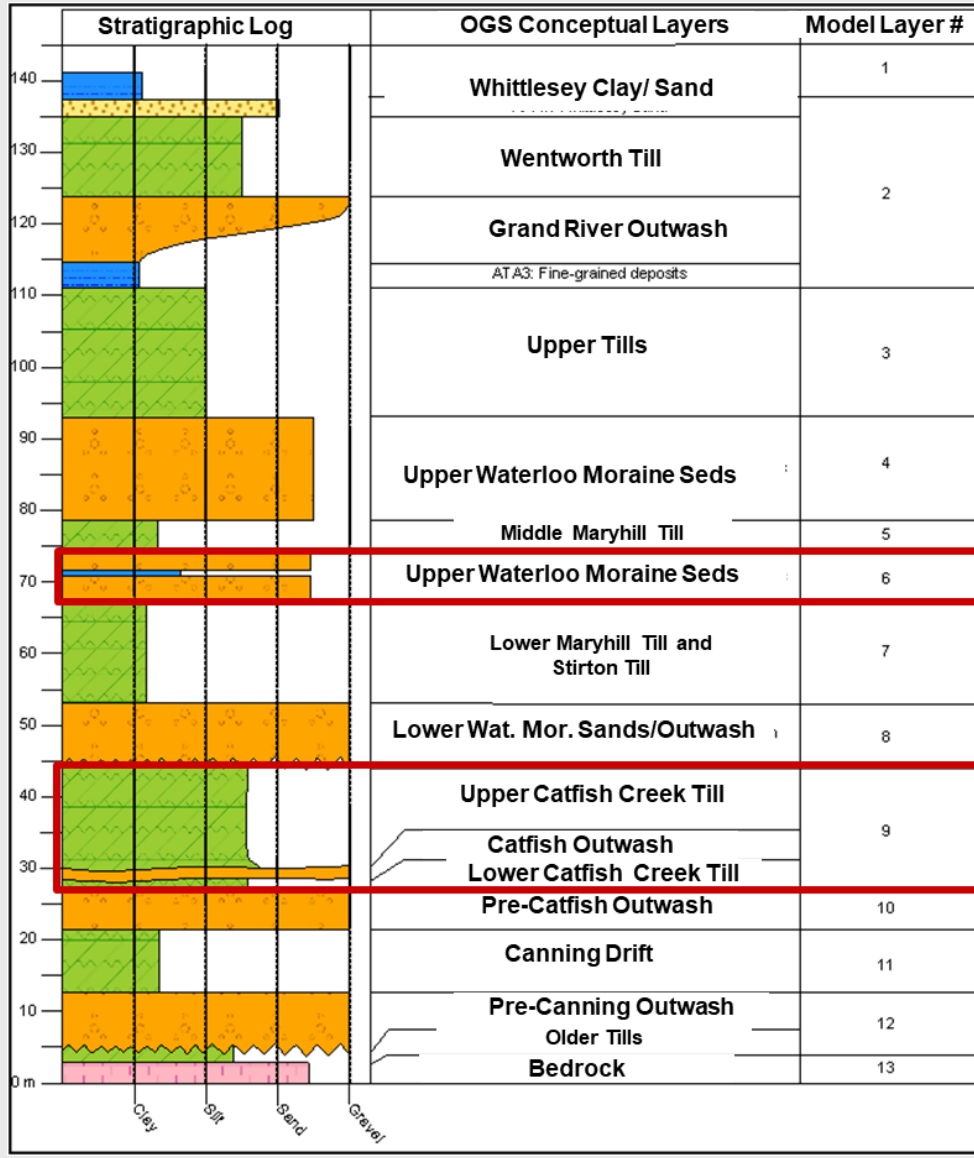
3D Variably Saturated GW Model



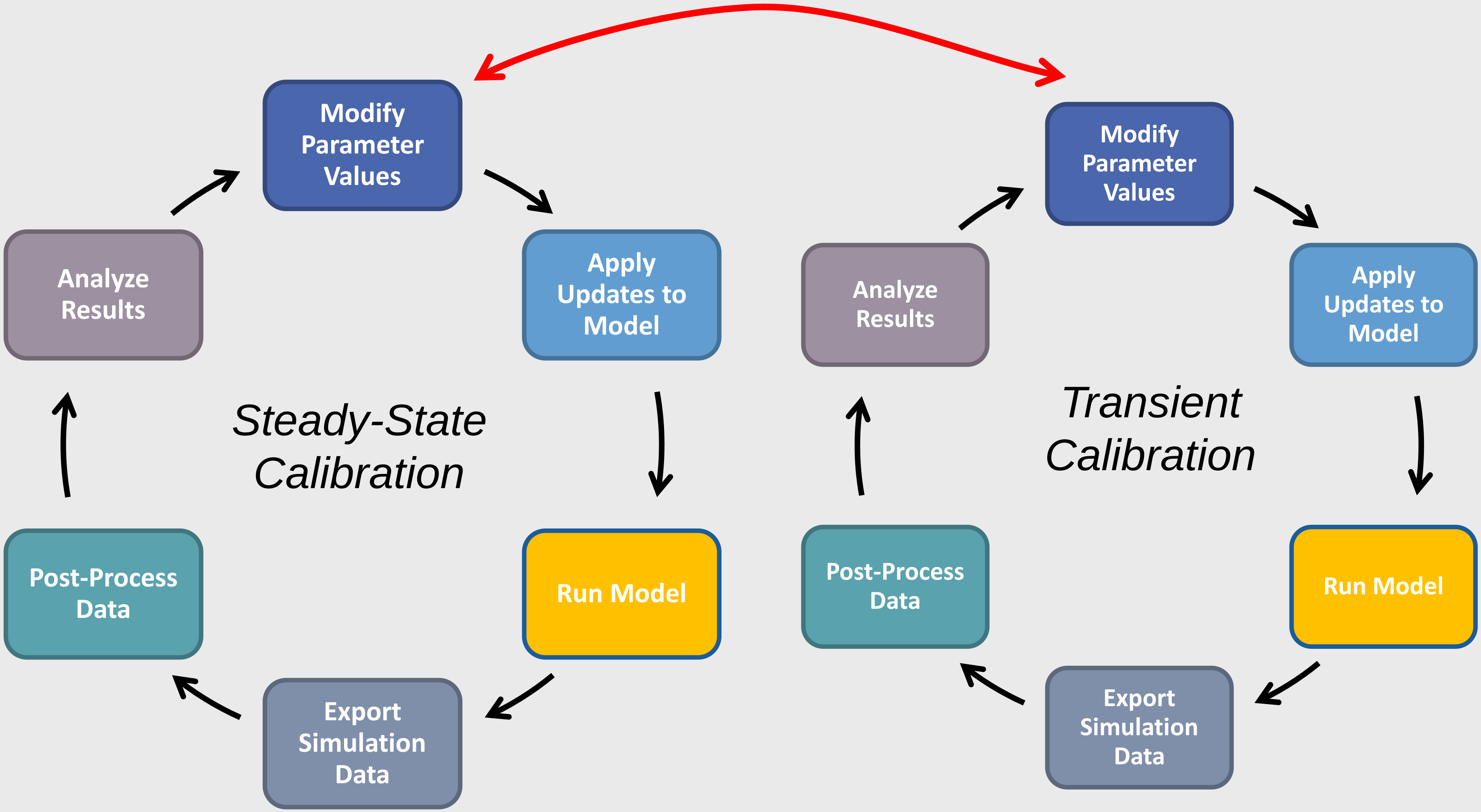
	Regional
Grid Mesh - elements	~192,000 x 23 layers = 3.84 million
Grid Mesh - nodes	~96,000 x 20 layers = 2.02 million
Geology	15 overburden and 7 bedrock layers
Supply Wells	96
Monitoring Wells	1356

Stratigraphic → Numerical Model

- Stratigraphic model
  - 18 overburden layers
  - 5 bedrock layers
- Hydrogeologic model
  - 13 overburden layers
  - 5 bedrock layers



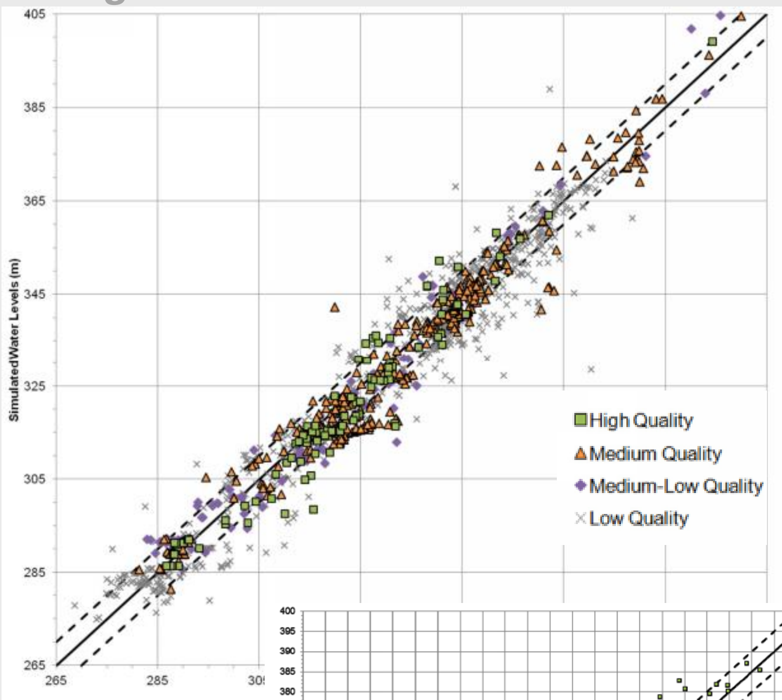
Iterative Calibration Process



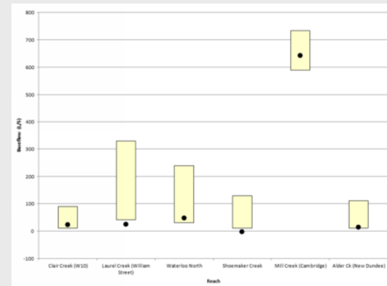
Manual & PEST Assisted Calibration

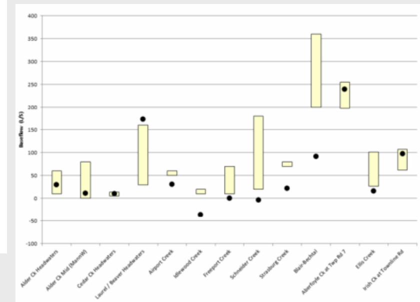
Enhanced Model Calibration

Regional Calibration

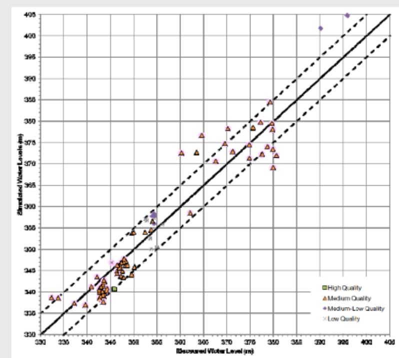


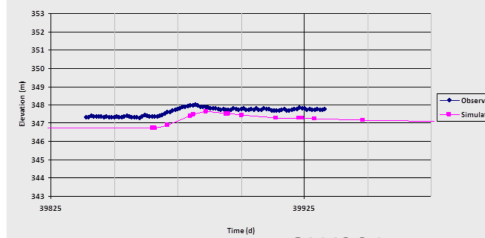
Baseflow Calibration





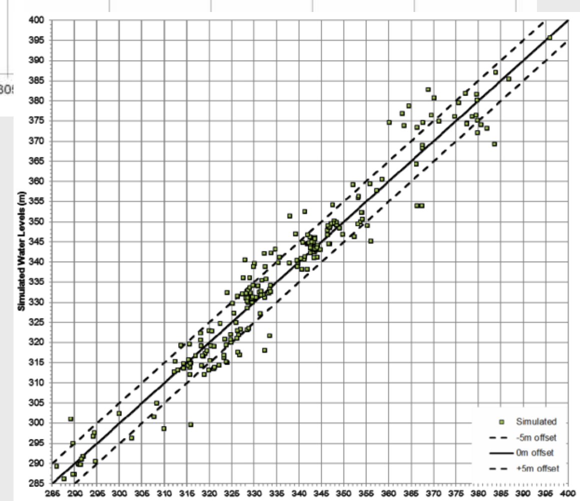
Well Field Calibration



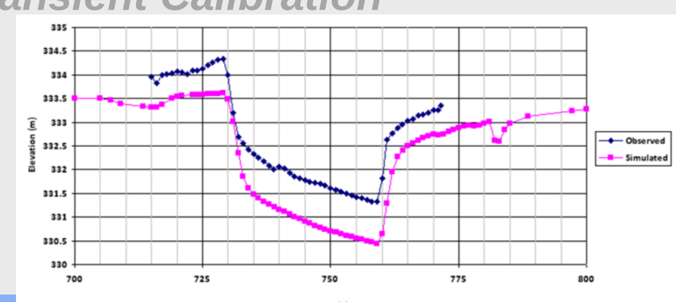


OW331

Independent Verification (2008) snapshot

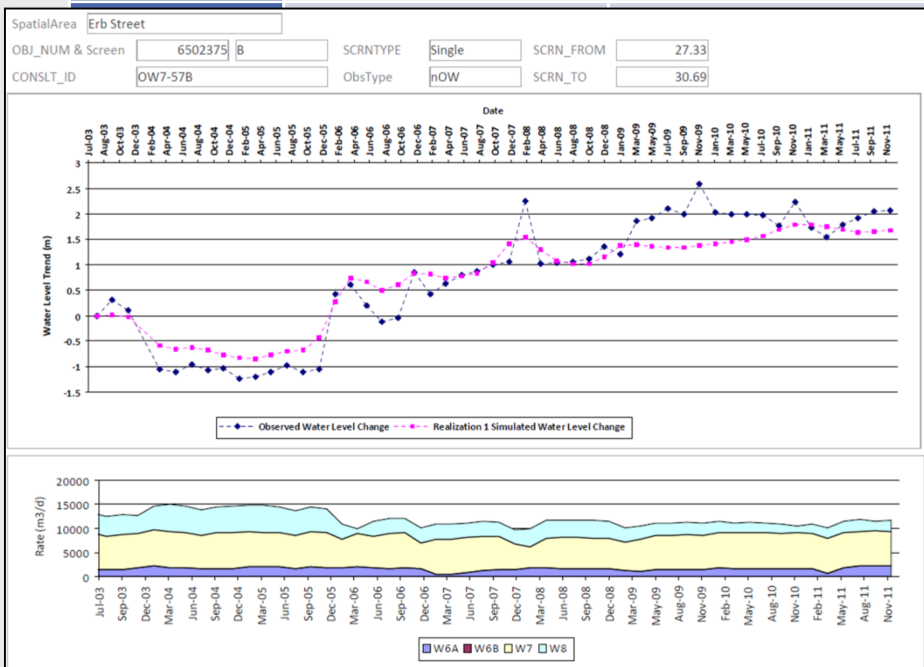


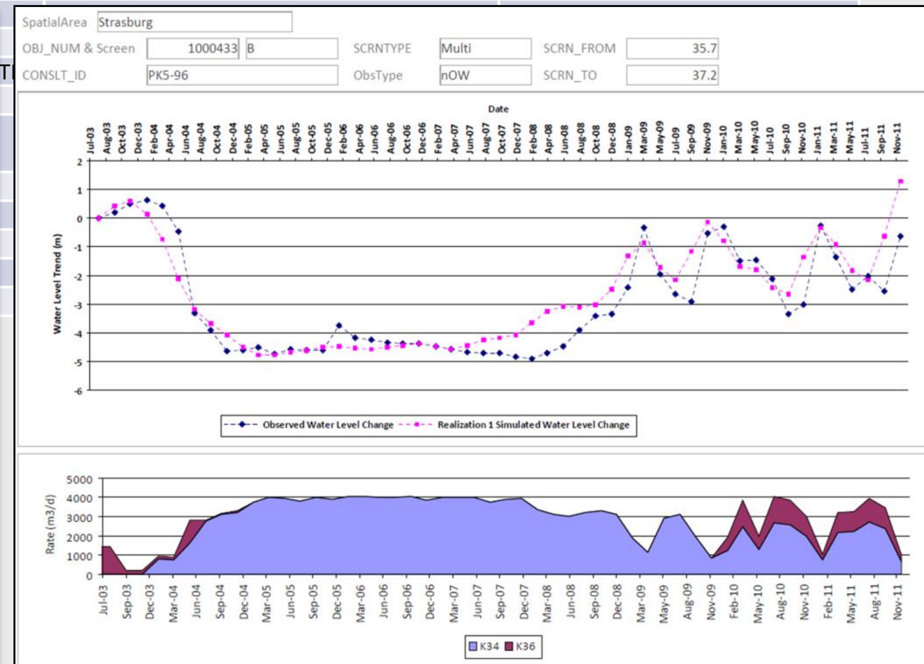
Transient Calibration



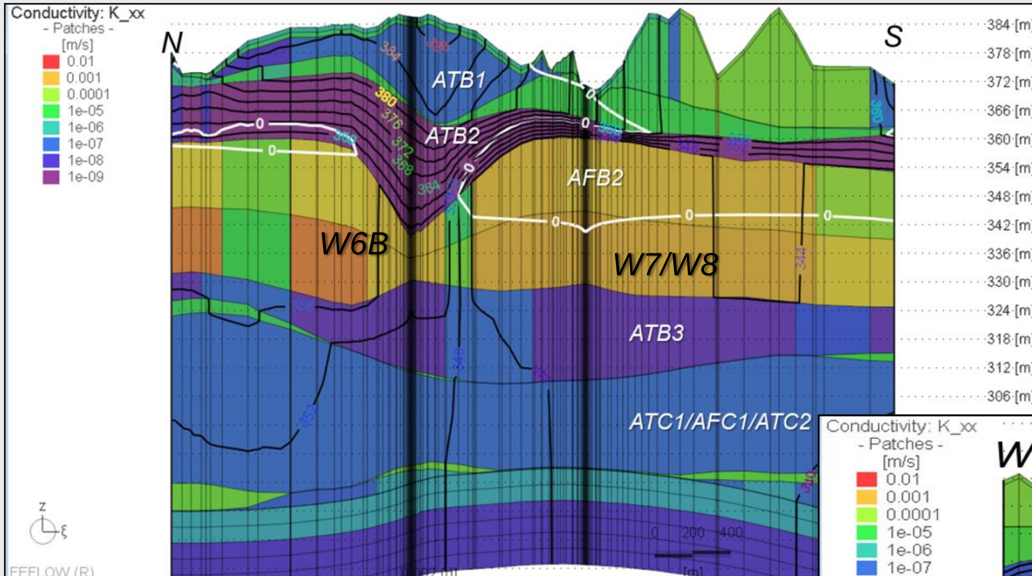
Multiple Transient Calibration Events
Individual Well Field & Whole System

Well Field	Hydraulic Test Type	Wells Tested	Date	Duration
Fountain St.	Pumping	P16, FSTW106	March and July, 2006	7 days
Greenbrook	Shut down	K2, K4B, K1, K8, K5A	Aug 2004 to May 2005	271 days
Lancaster	Pumping	K41, K42A	October 2007	8 and 7 days
Mannheim	Pumping	ASR1, ASR2, ASR3, ASR4, RCW1, RCW2	June to July 2010	30 days
Parkway Strasburg	Pumping Reduction/ Shut down	Reduction: K31, K33 Shut down: K32, K34, K36	First test - Dec 1993; last test Apr 1996	Variable
Pompeii-Forwell	Pumping then Shut down	K72, K73, K74, K75, K70, K71	Pumping: Aug to Nov, 1995 Shut down: Nov 1995-Jan 1996	154 days (74 pumping, 80 shut down)

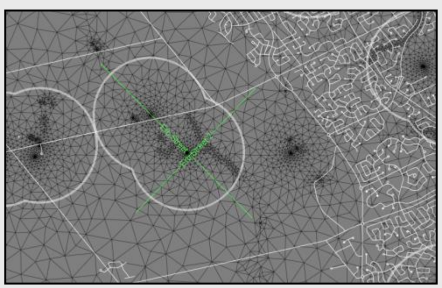


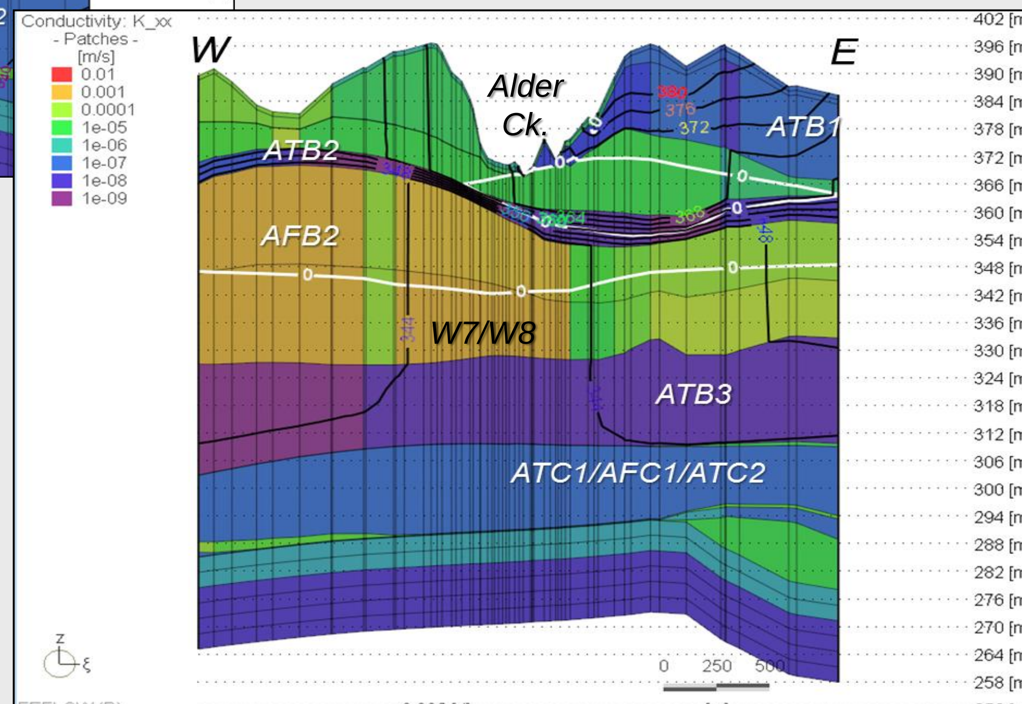


Flow System Understanding Gained

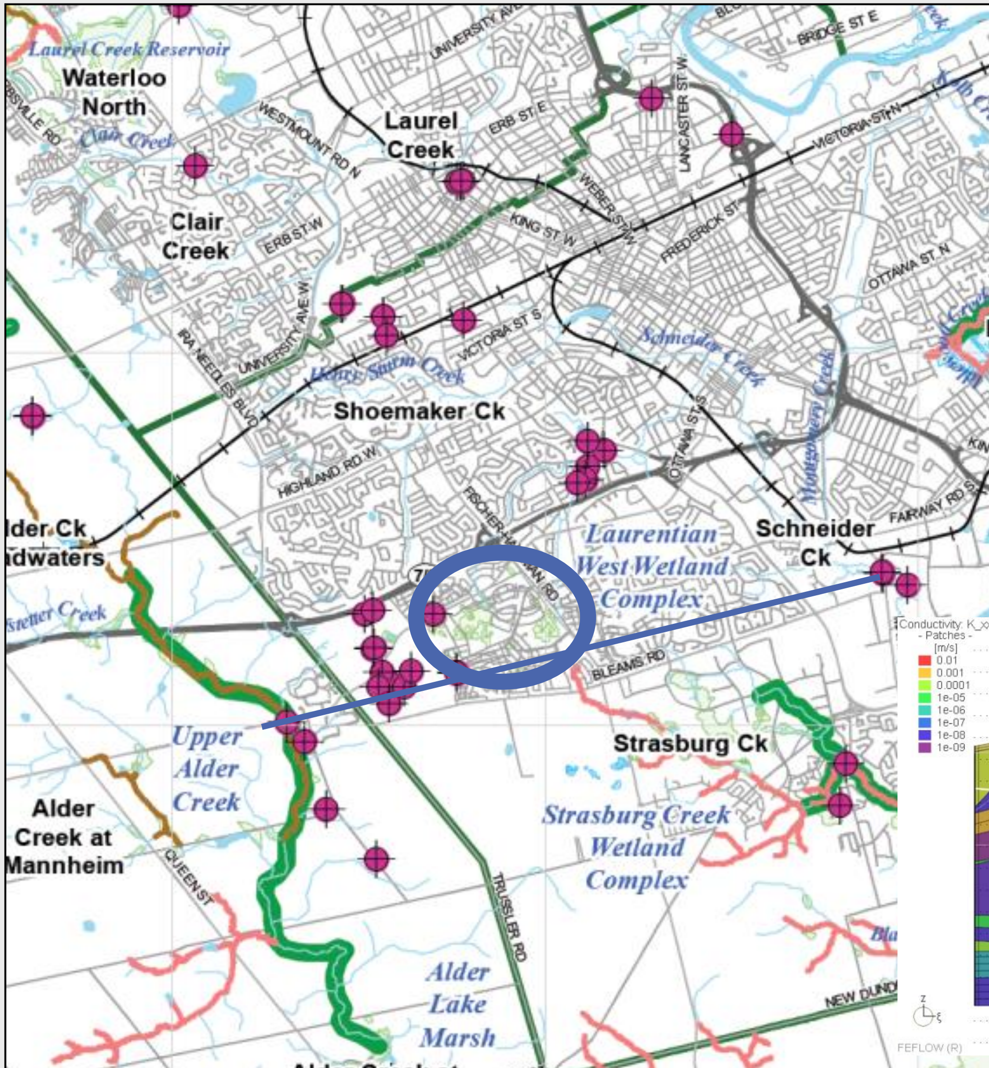


Erb Street Well Field



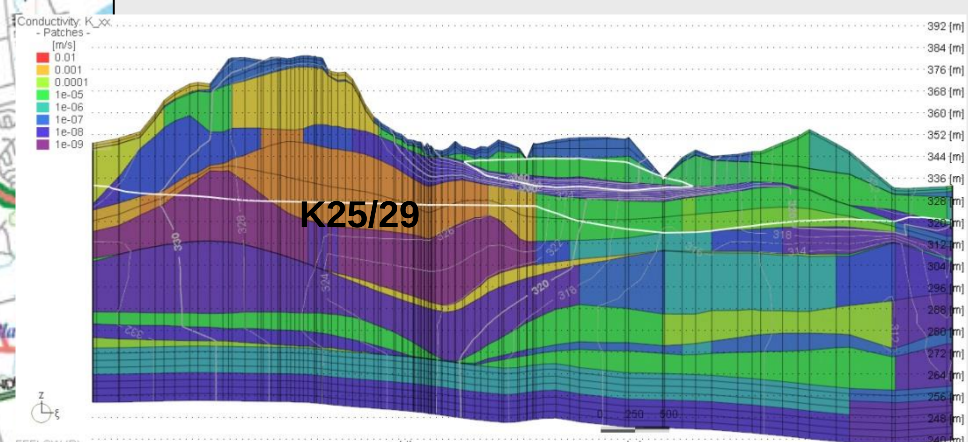


Laurentian Wetland Complex



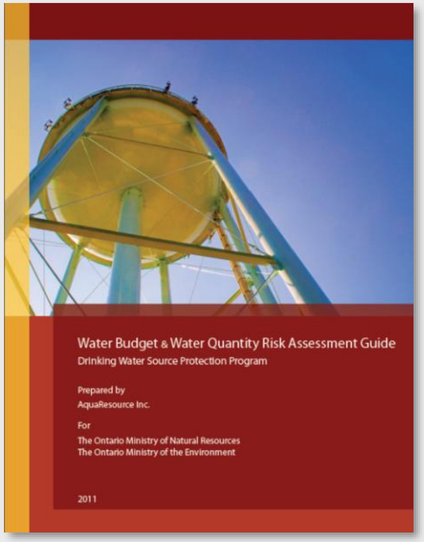
http://waterlooinsider.wordpress.com/2010/04/06/laurentian-wetlands/

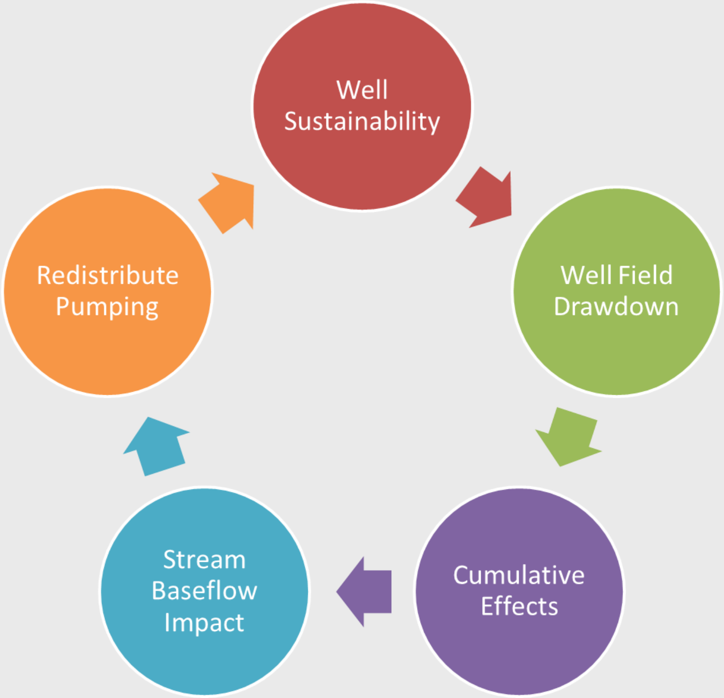
Simulate marsh/swamp as perched and discharging to gw flow system under existing (2008) conditions.



Model Application for Risk Assessment

- Evaluate semi-quantitative ‘RISK’
  - Well able to sustain pumping
    - Multiple scenarios
  - Cumulative assessment
  - Surface water impacts
    - Baseflow reduction
  - Risk mitigation capability
    - Re-distribute pumping
- Evaluate hydrogeologic uncertainty
  - Multiple scenarios
  - Multiple realizations





Risk Assessment Scenarios

Scenario	Time Period	Model Scenario Details			
		Land Cover	Municipal Pumping	Model Simulation	
C	Period for which climate and stream flow data are available for the Local Area (2008)	Existing	Existing	Steady-state, Average Annual Recharge	
D	10 year drought period	Existing	Existing	Transient (1960-2006); Monthly recharge rates (HSP-F)	
G(1)	Period for which climate and stream flow data are available for the Local Area (2008)	Planned or existing plus committed (Official Plan)	Planned plus Existing plus Committed	Groundwater Recharge Reduction and Increase in Demand	Steady-state, Average Annual Recharge
G(2)		Existing	Planned plus Existing plus Committed	Groundwater Discharge Reduction from Increase in Demand	
G(3)		Planned or existing plus committed (Official Plan)	Existing	Groundwater Recharge Reduction	
H(1)	10 year drought period	Planned or existing plus committed (Official Plan)	Planned plus Existing plus Committed	Groundwater Recharge Reduction and Increase in Demand	Transient (1960-2006); Monthly recharge rates (HSP-F)
H(2)		Existing	Planned plus Existing plus Committed	Groundwater Discharge Reduction from Increase in Demand	
H(3)		Planned or existing plus committed (Official Plan)	Existing	Groundwater Recharge Reduction	

Existing Land Cover & Existing Pumping

Average & Drought Climate

Planned Land Cover & Planned Pumping

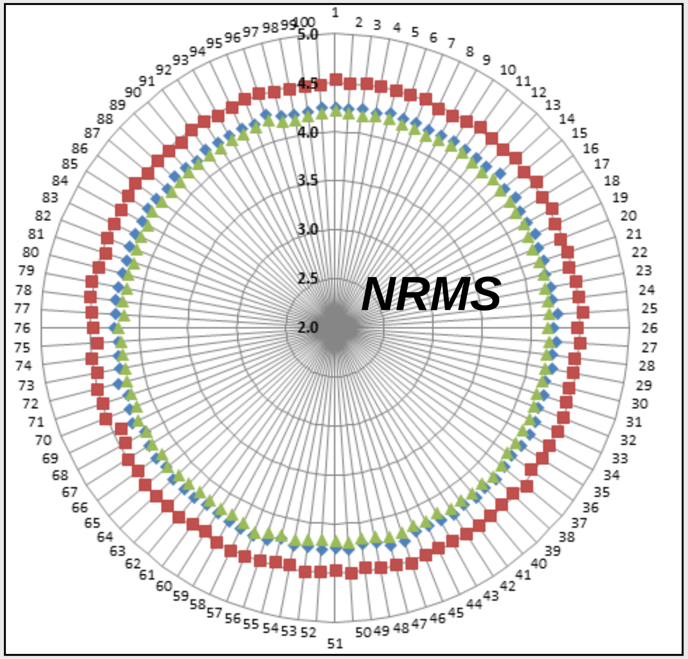
Average Climate

Planned Land Cover & Planned Pumping

Drought Climate

Uncertainty Analysis - Realizations

- Alternative Conceptual Models
  - Lower K Aquitards
  - Leaky Aquitards
  - Higher K Bedrock
- – Uncertainty via PEST: NSMC
  1. Optimize each ACM
  2. Generate equivalently calibrated realizations for each ACM
  3. Predictive scenarios



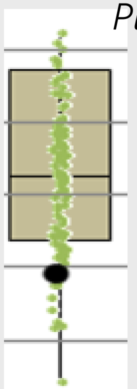
Lower K Aquitards
Leaky Aquitards
Higher K Bedrock

Predicted Pumping Sustainability

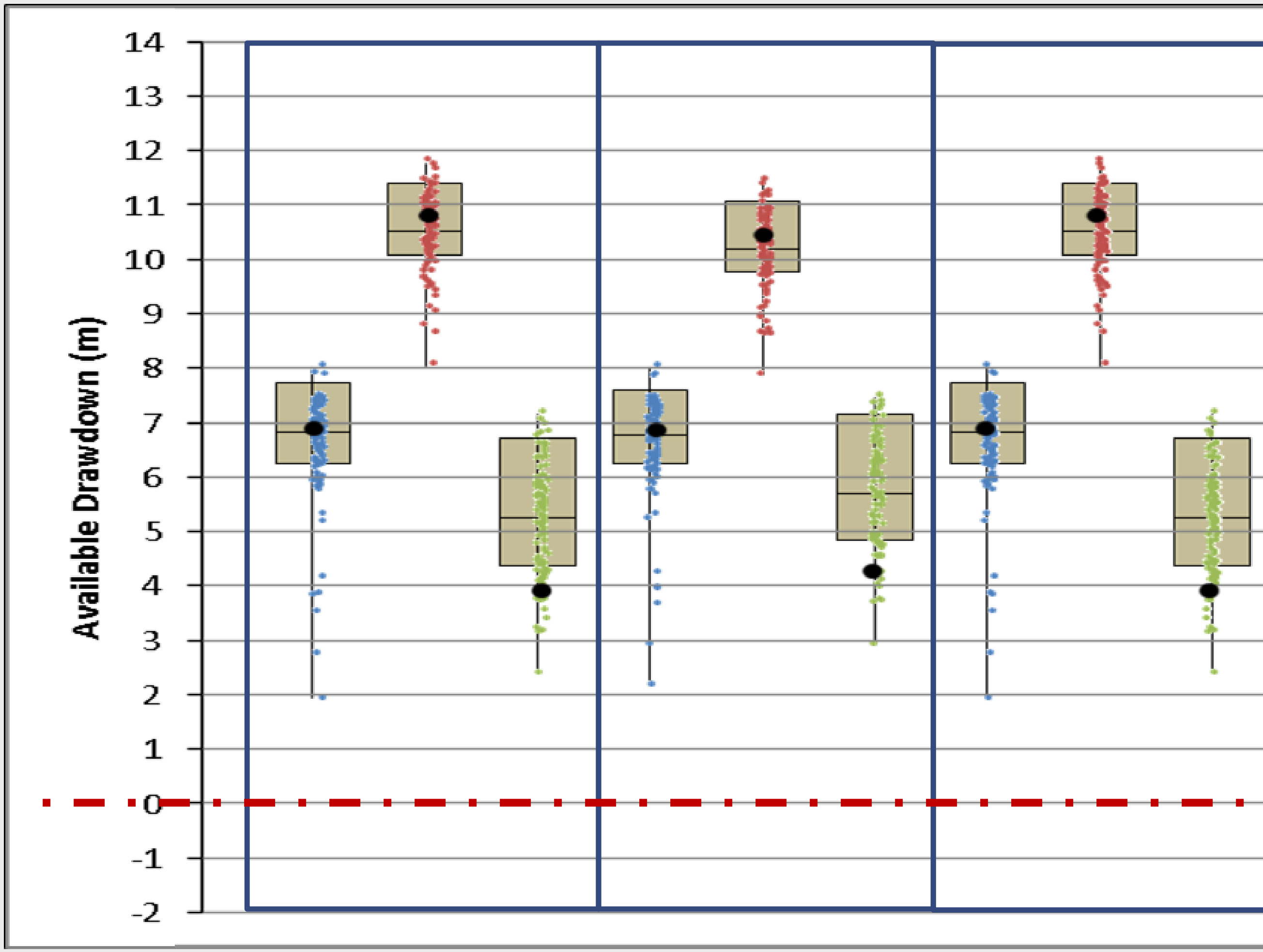
Sustainability evaluated as remaining available drawdown during planned pumping

Well 1 ACM1 ACM2 ACM3
Well 2 ACM1 ACM2 ACM3
Well 3 ACM1 ACM2 ACM3

Box and Whisker Plots



25th %
Mean
75th %
Base Model



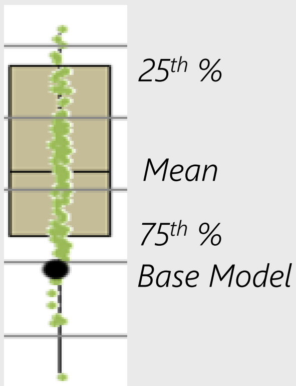
… Well 133

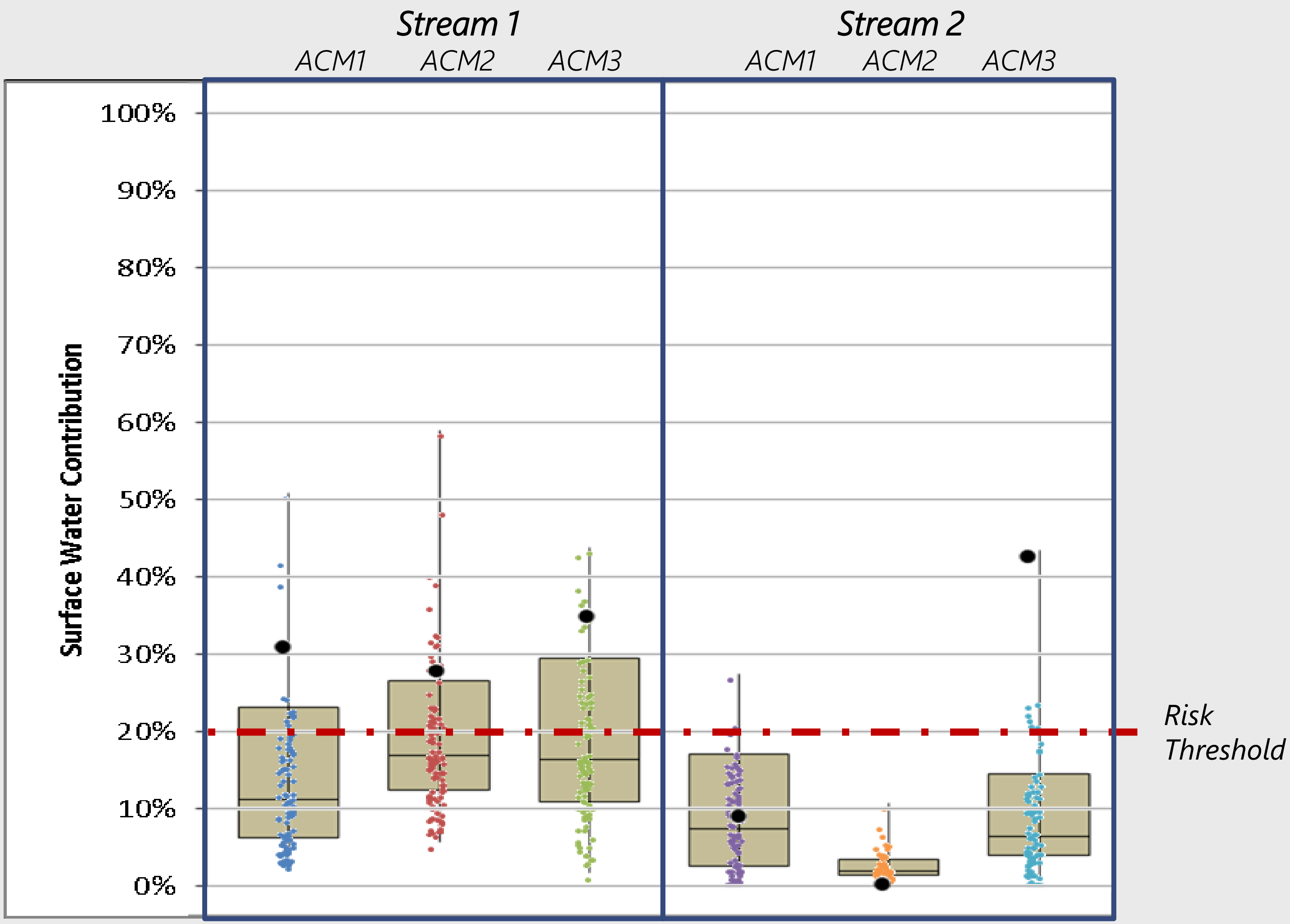
Risk Threshold

ACMs
1. Lower K Aquitards
2. Leaky Aquitards
3. Higher K Bedrock

Predicted GW-SW Interaction

Sustainability evaluated as < 10-20% Stream Baseflow Reduction

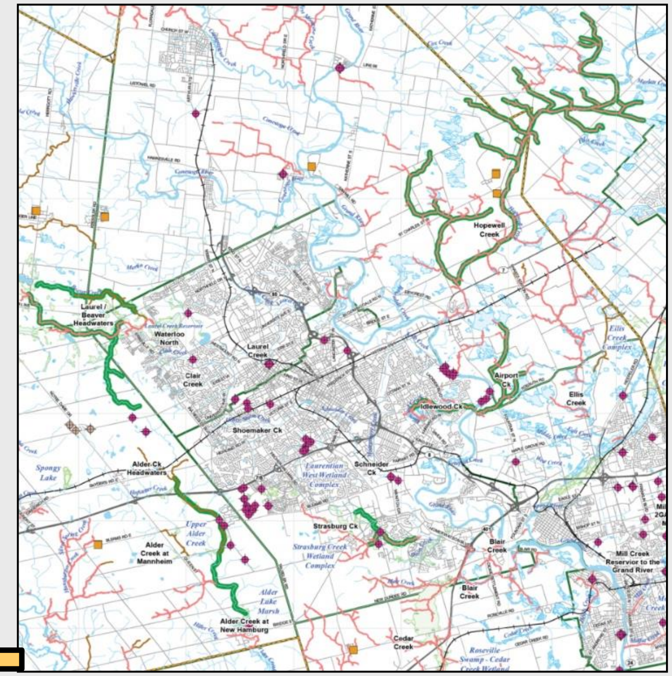




ACMs
1. Lower K Aquitards
2. Leaky Aquitards
3. Higher K Bedrock

Cause of Ecological Impacts

Baseflow Impacts		**Simulated Baseflow (% Reduction)**		
Reach	**Thermal Regime**	**Total G1**	**Pumping G2**	**Recharge G3**
Airport Creek	Coldwater	7%	0%	7%
Alder Creek Headwaters	Coldwater	11%	4%	7%
Alder Creek Mid	Coldwater	15%	1%	13%
Alder Creek Lower	Coldwater	1%	0%	1%
Hopewell Creek	Coldwater	2%	0%	2%
Idlewood Creek	Coldwater	11%	-2%	14%
Laurel/ Beaver Headwaters	LC: CW; BC: WW	11%	6%	5%
Strasburg Creek	Coldwater	20%	1%	19%
Laurel Creek	*Warmwater*	*8%*	*8%*	*1%*
Schneider Creek	*Warmwater*	*3%*	*1%*	*2%*
Shoemaker Creek	*Warmwater*	*19%*	*17%*	*4%*
Clair Creek	*Warmwater*	*32%*	*26%*	*6%*
Freeport Creek	*Warmwater*	*10%*	*0%*	*10%*

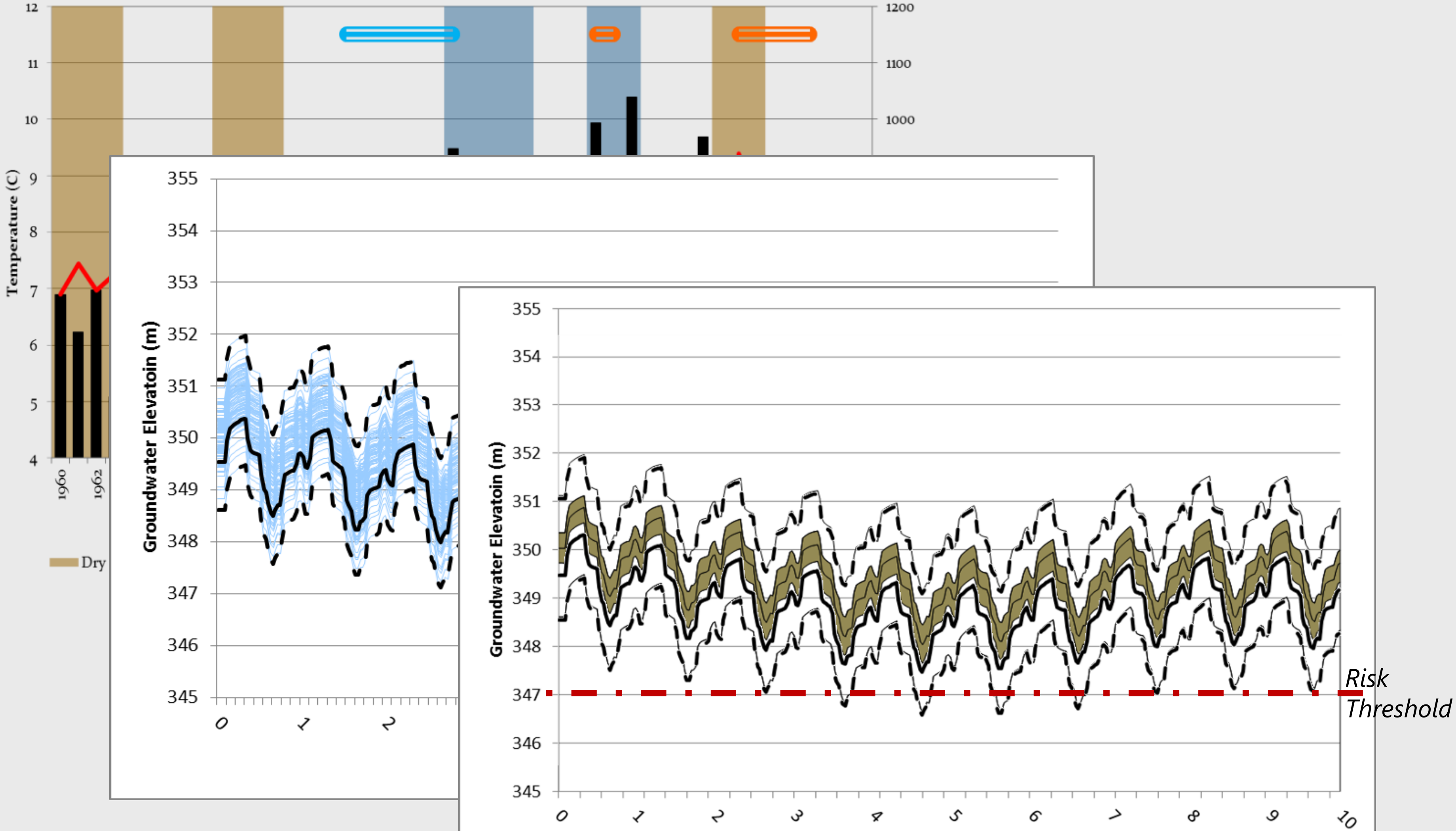


Predicted Recent Baseflow Reduction on Coldwater Streams; Scenario G2

- 0 - 10% Reduction
- 10 - 20% Reduction
- > 20% Reduction

Predicted Water Level under Drought

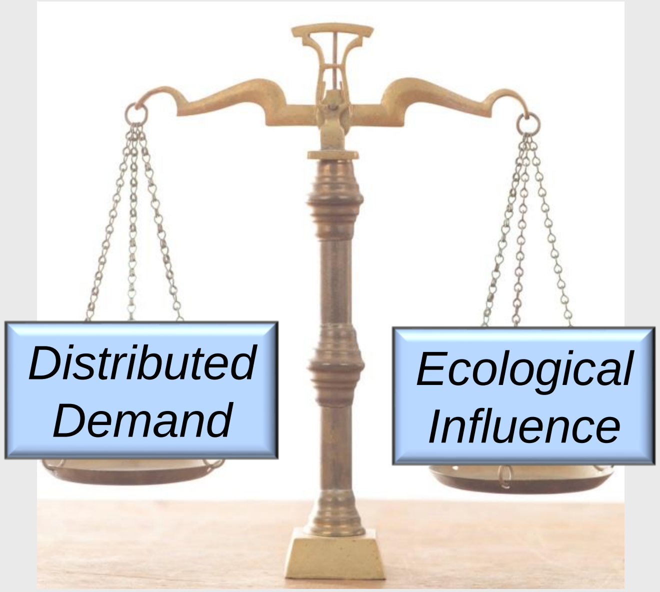
Sustainability evaluated as % time water level is below risk threshold



Potential to violate threshold, but low frequency and probability

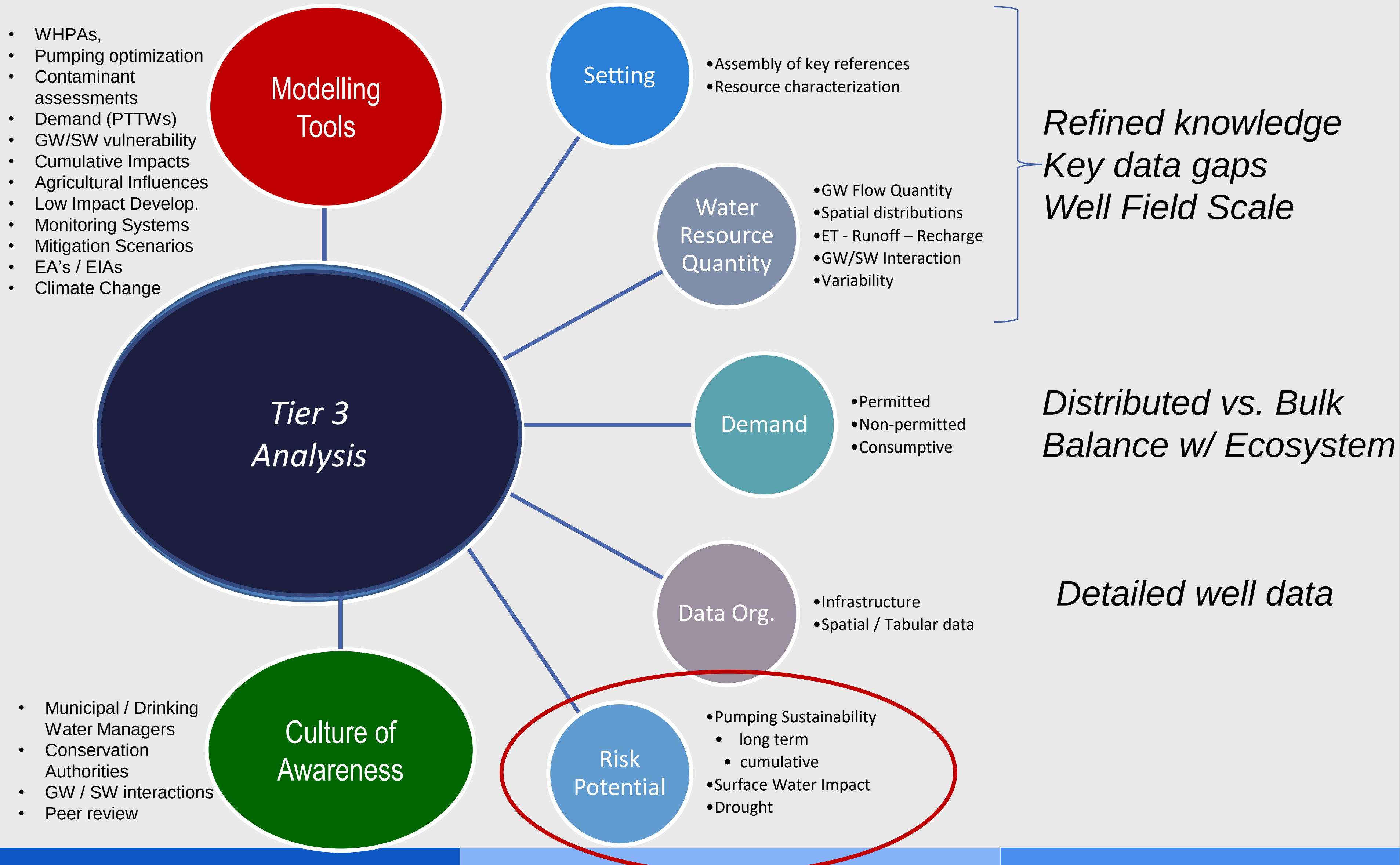
Outcomes and Implications for RMOW

- RMOW's integrated well network and ASR system can meet demand without adverse impacts
  - Short Term
  - Long Term
  - Cumulative Pumping Influences
  - Surface Water Influences
  - Drought



- Pipeline?
  - not in foreseeable future

Tier 3 Modelling Study Achievements



Acknowledgements & Contact Info

- AquaResource / Matrix Solutions
- SSPA, Stantec, Golder, Blackport
- RMOW, GRCA, Ontario MNR

Paul Martin

pmartin@aqua-insight.com

www.waterbudget.ca