Data Management and Calibration Strategies for Integrated Modelling

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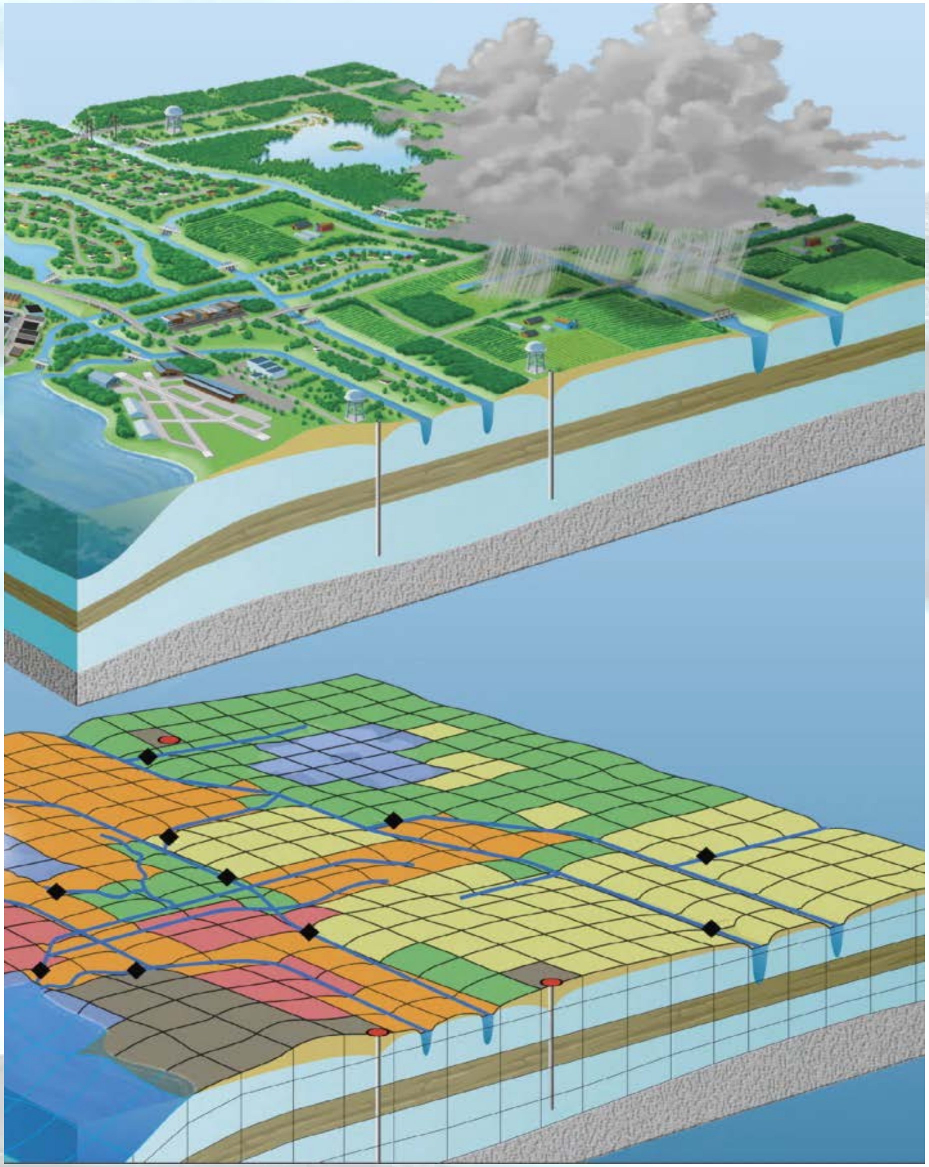
Integrated GW/SW Modelling

- Water simply does not care what we call it (SW or GW)
- Water moves seamlessly between domains
- Integrated models **can** provide an improved understanding of the overall behaviour of the system



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Benefits of Integrated Modelling

- Watershed Scale
  - Water use is a zero-sum game:
    - Permitting, cumulative impact, water budgeting and allocation are fundamentally integrated assessment problems
  - Drought/Flood and Climate Change analysis
    - Understanding system storage, buffers and response lag is essential
- Engineering Scale
  - Many engineering problems involve assessing the impact of a stress on one system (SW or GW), and the response in the other
    - Mine dewatering: GW pumping impact on adjacent wetlands
    - Land development/recharge reduction: Effect on GW levels

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Integrated Models

- Mikes-SHE, Hydrogeosphere or USGS-GSFLOW?
  - Each of these models have unique advantages and disadvantages
  - Ask the developer (or most modelers) and they will talk your ear off!
    - Somewhat like asking my 13 year old daughter if an iPhone is better than an Android phone: “color” seems to be a critical issue!
- My opinion: The subtle differences between model codes is less important than the construction and implementation of the model
  - Do you ask your heart surgeon what brand of scalpel he uses?

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Common Integrated Modelling Problems

- Need for integrated knowledge and teamwork
  - Is there a project team bias? (Are they all GW modelers?)
  - How often do the SW and GW modelers eat lunch together?
- All integrated models are slow
  - Some calibration strategies are better than others
- Model Construction and calibration
  - When should integrated calibration begin?
- Data Management: Is the data integrated?
  - Does the model development process effectively use all the data?
  - Are there barriers to data conceptualization and review?

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Blind Spots (I'm going to get in trouble for this…)

- Common SW Modelling Blind Spots:
  - "The GW system behaves like a linear reservoir"
  - "I don't need a physically based or distributed model"
  - "Historic unit hydrograph response can predict future climate change response"
  - Design storms, "contributing areas", etc., etc……
- Common GW Modelling Blind Spots:
  - Steady state conditions and average recharge estimates
  - Calibration to only measured heads can provide a unique solution
  - Baseflow separation provides a good estimate of GW discharge
  - Richard's equation is all I need to represent flow in the unsat zone
  - Constant head boundary conditions around the entire model
  - Parameter estimation can provide hydrogeologic insight

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Integrated Modelling is Different

- Integrated modelling forces us to address the blind spots (assumptions and simplifications) we make about the “other” (SW or GW) system
- Integrated modelling is better for GW modelers, because:
  - It allows the use of measured fluxes (precip and total streamflow)
  - Forces us to fully address transient response, storage and the wide range of GW flow rates
- Integrated modelling is better for SW modelers, because:
  - Storm response (runoff generation) can be enhanced by water table feedback or buffered by shallow system storage
  - Integrated modelling is physically based and distributed (no “lumped” parameters)

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Calibration and Data Management: Issues and Examples

- The following four case studies show how integrated model calibration and analysis is greater then the sum of the SW and GW modelling parts....

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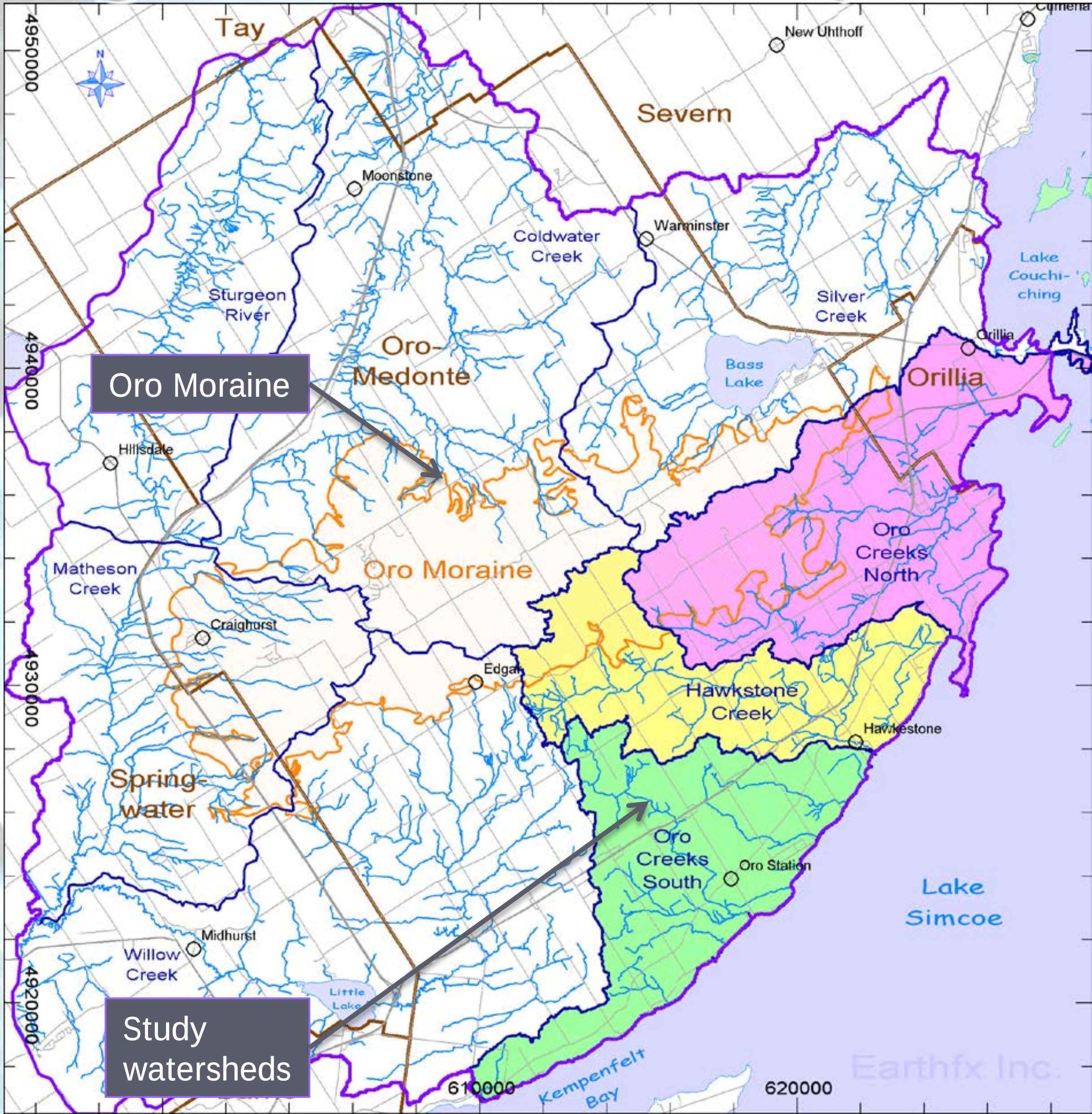
Oro Moraine Integrated Model Example:

- Three apparently similar watersheds located on the northwestern shore of Lake Simcoe
  - Oro North
  - Hawkstone
  - Oro South
- Fully integrated GSFLOW calibration



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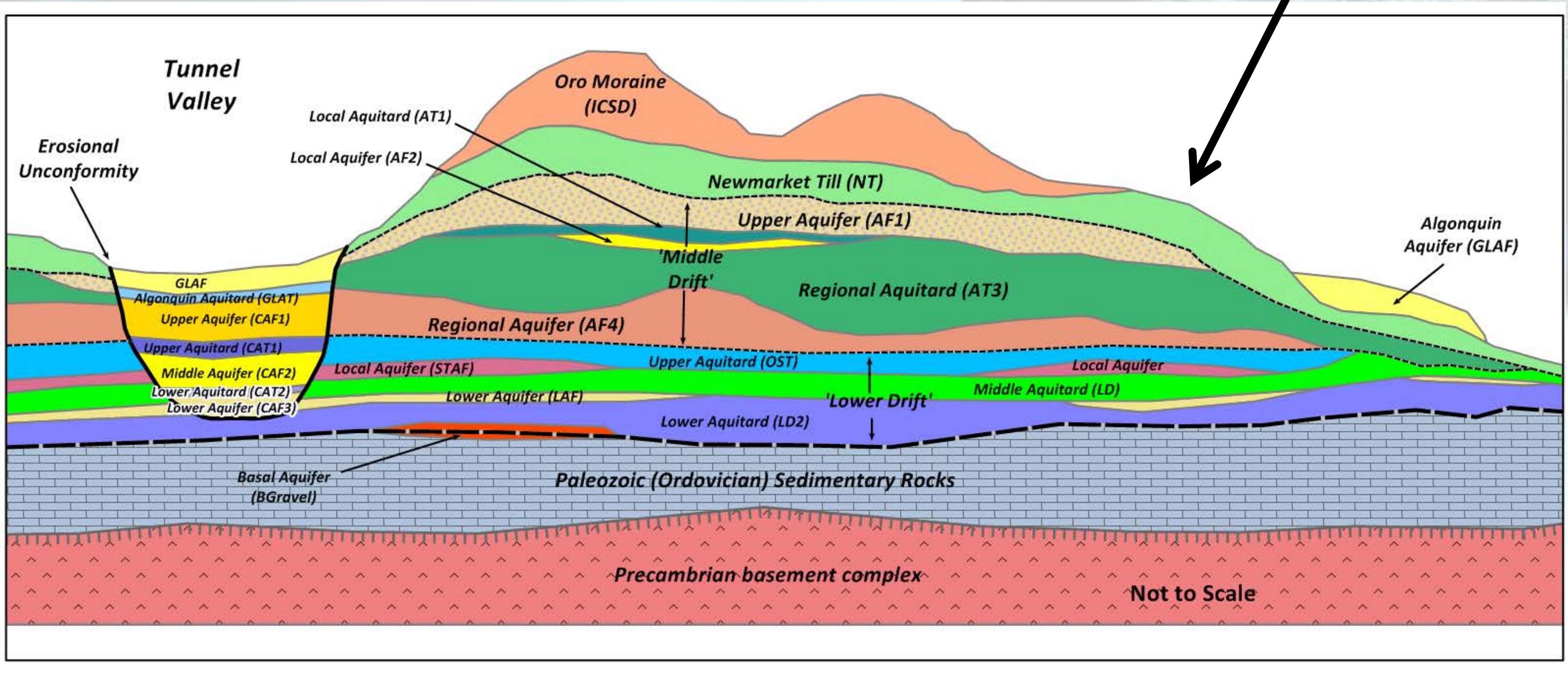
Oro Moraine Hydrogeology

- Complex recharge and discharge flow system
- Objective is to understand behavior of 3 watersheds on the east slope of the moraine



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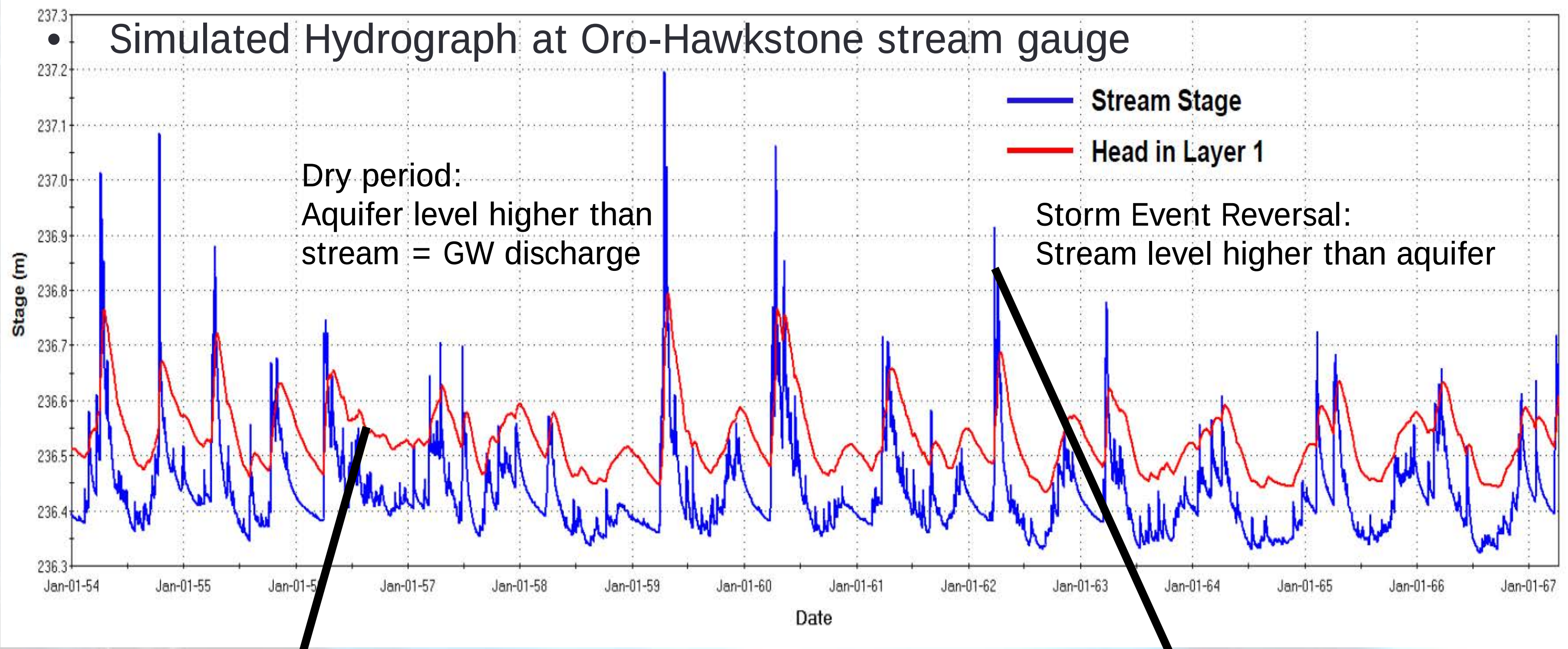
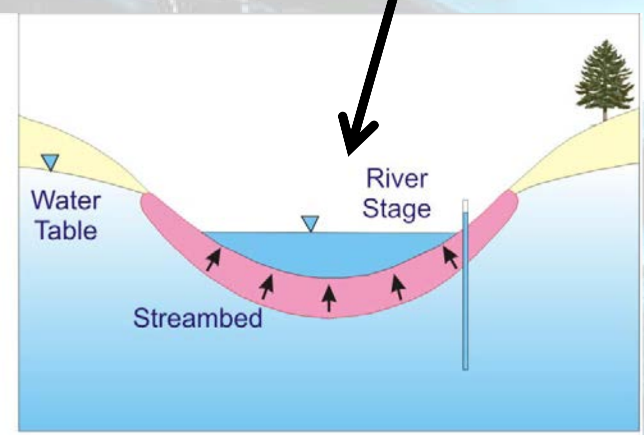
Aquifer Head vs. Stream Stage

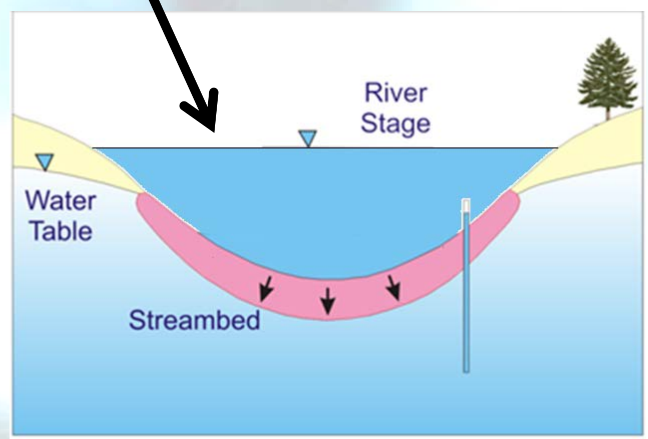
- Simulated Hydrograph at Oro-Hawkstone stream gauge





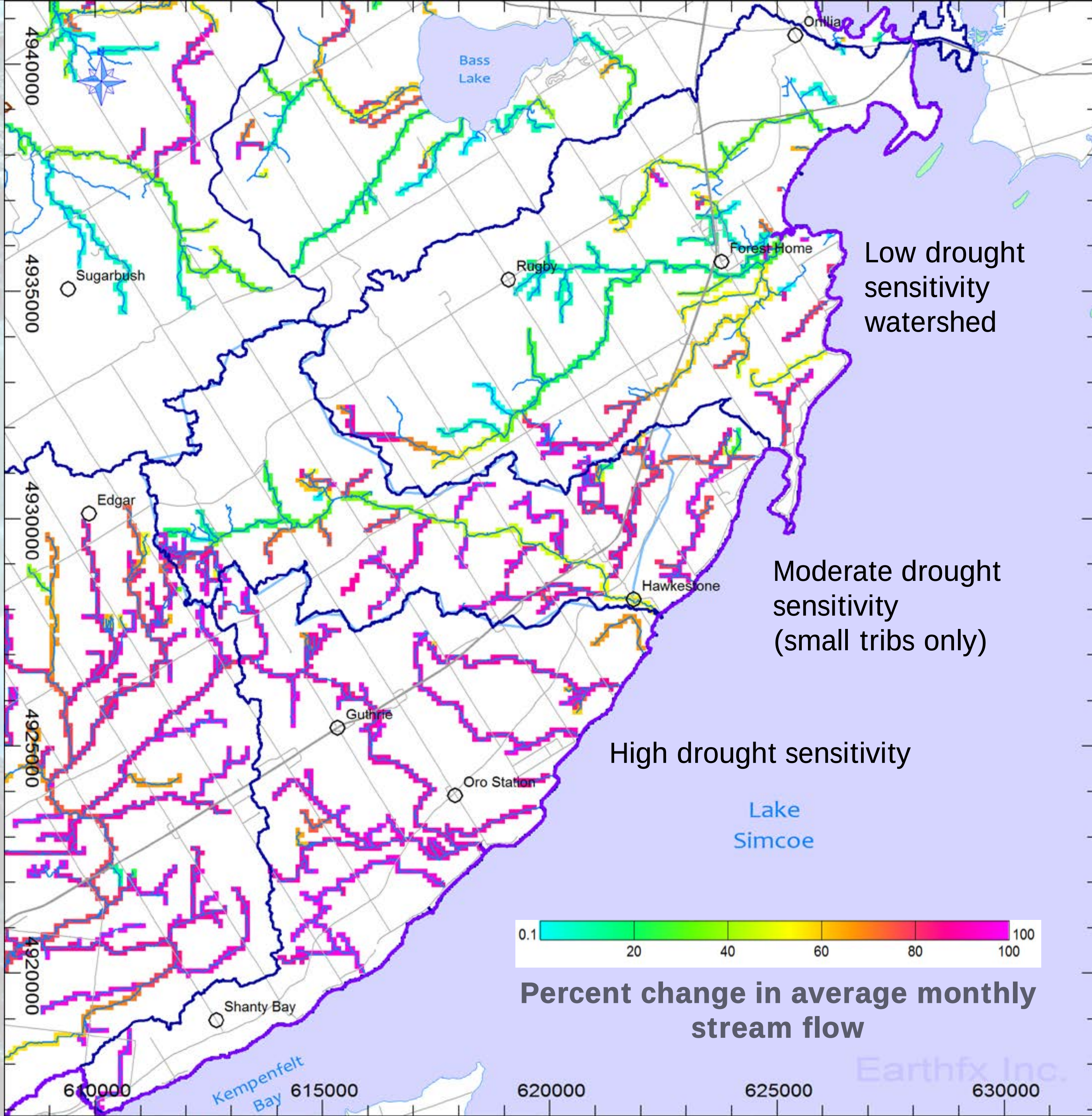
Aquifer head above river stage

- **Groundwater discharges to the stream, except during storm events when leakage <u>reverses</u>!**



Aquifer Head Below River Stage during event

10-Year Drought Response



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Oro Moraine Model: Lessons Learned

- Baseflow separation techniques fail to estimate the reversal in GW/SW leakage during storm events
  - Empirical separation algorithms would incorrectly predict more GW discharge during storm events.
  - Integrated modelling allows calibration to *total measured streamflow* (no need for baseflow separation!)
- Despite similar watershed size and general configuration, the drought sensitivity of the three watersheds ranges from very low to very high, depending on aquifer geometry, storage and flow paths
  - Integrated simulation identifies the aquifer storage and discharge lag that sustains select streams during drought

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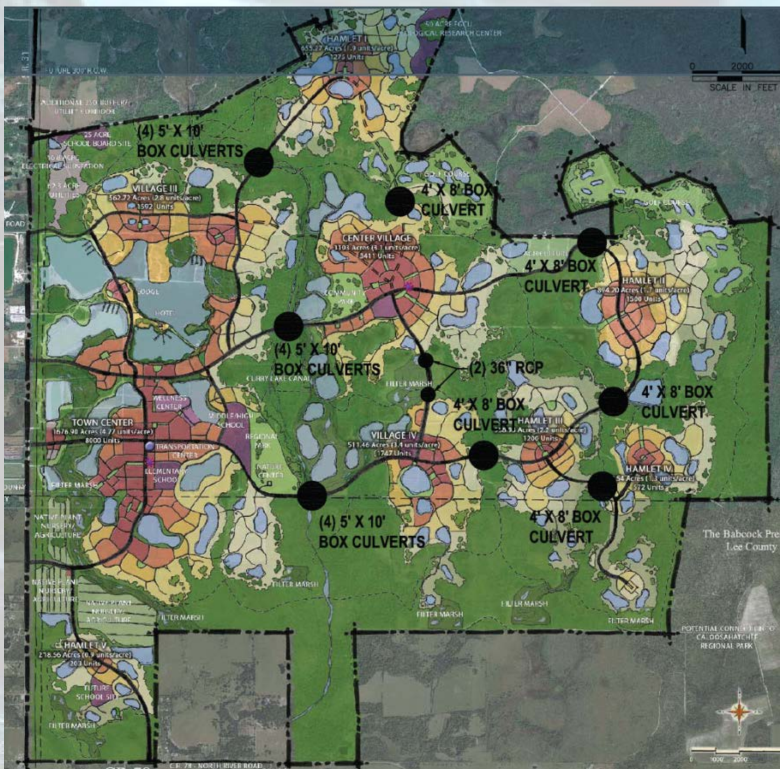
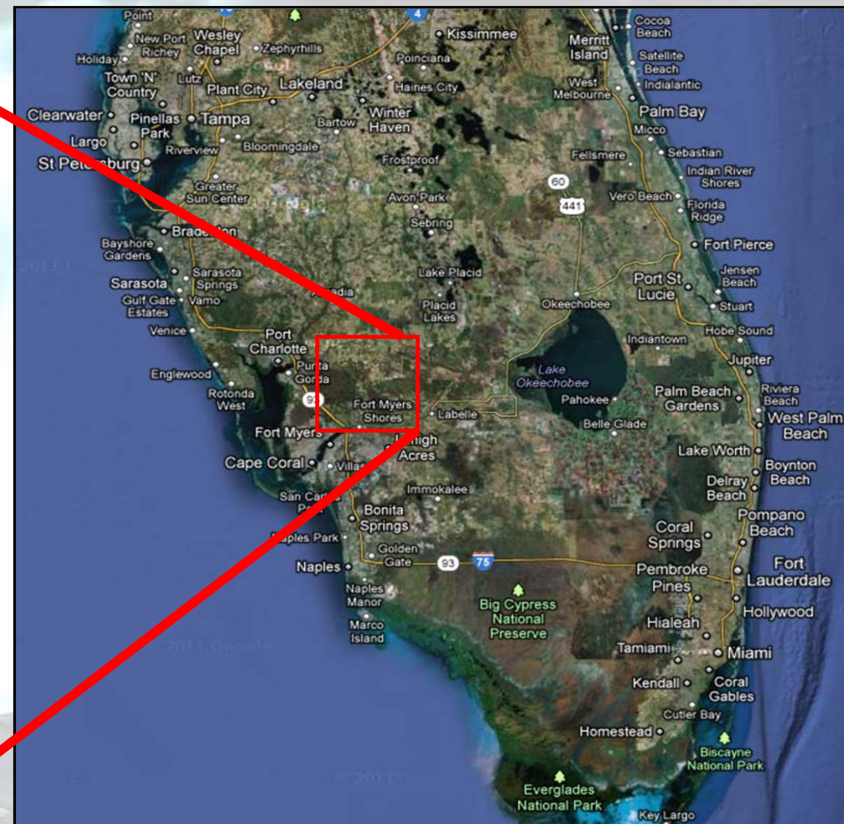
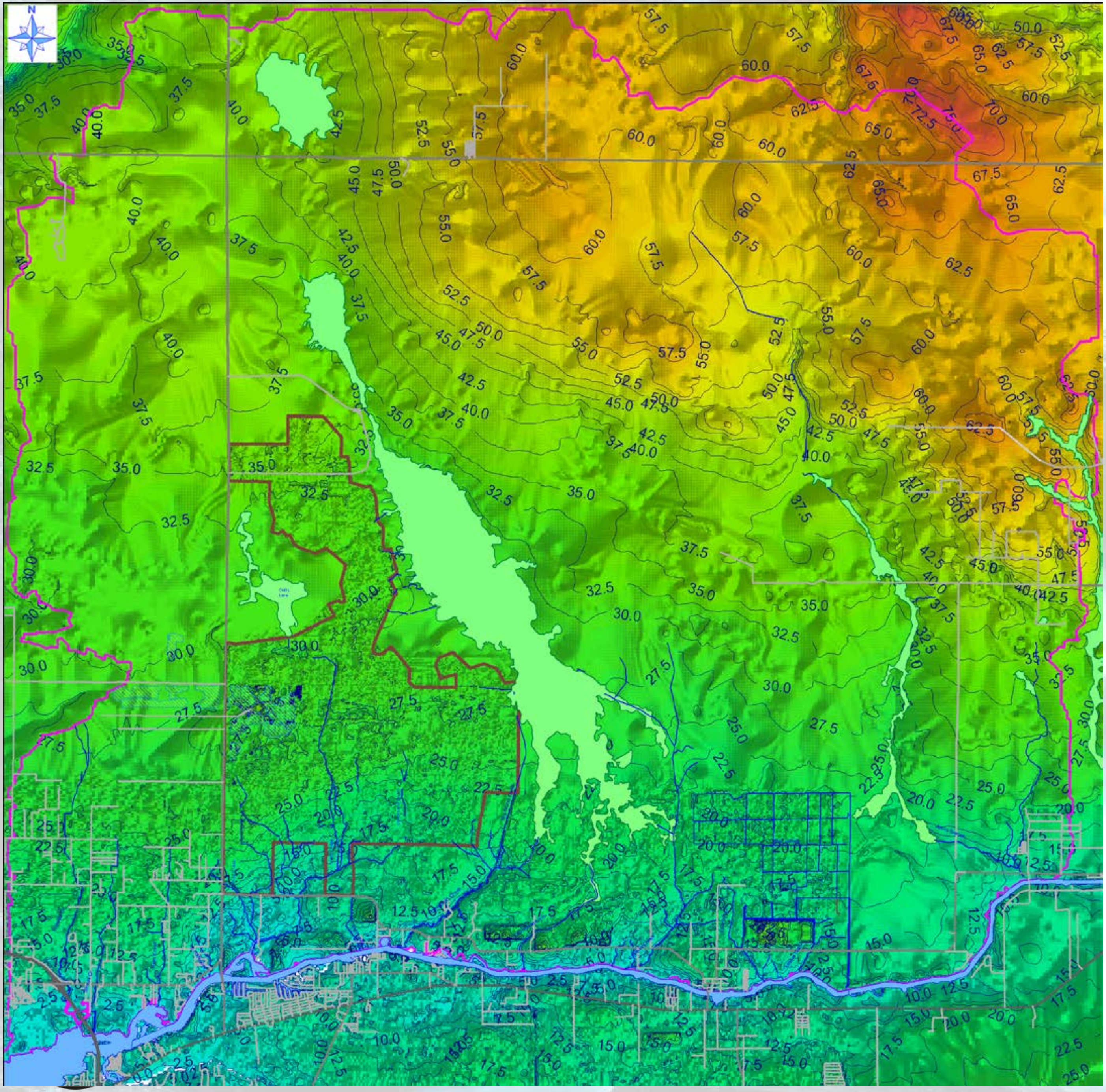
Integrated Model of Land Development

- Integrated simulation of a large scale land development in central Florida
- Issues: Fluctuating water table, dry and wet season, very large rainfall events







Mix of LIDAR and USGS map data

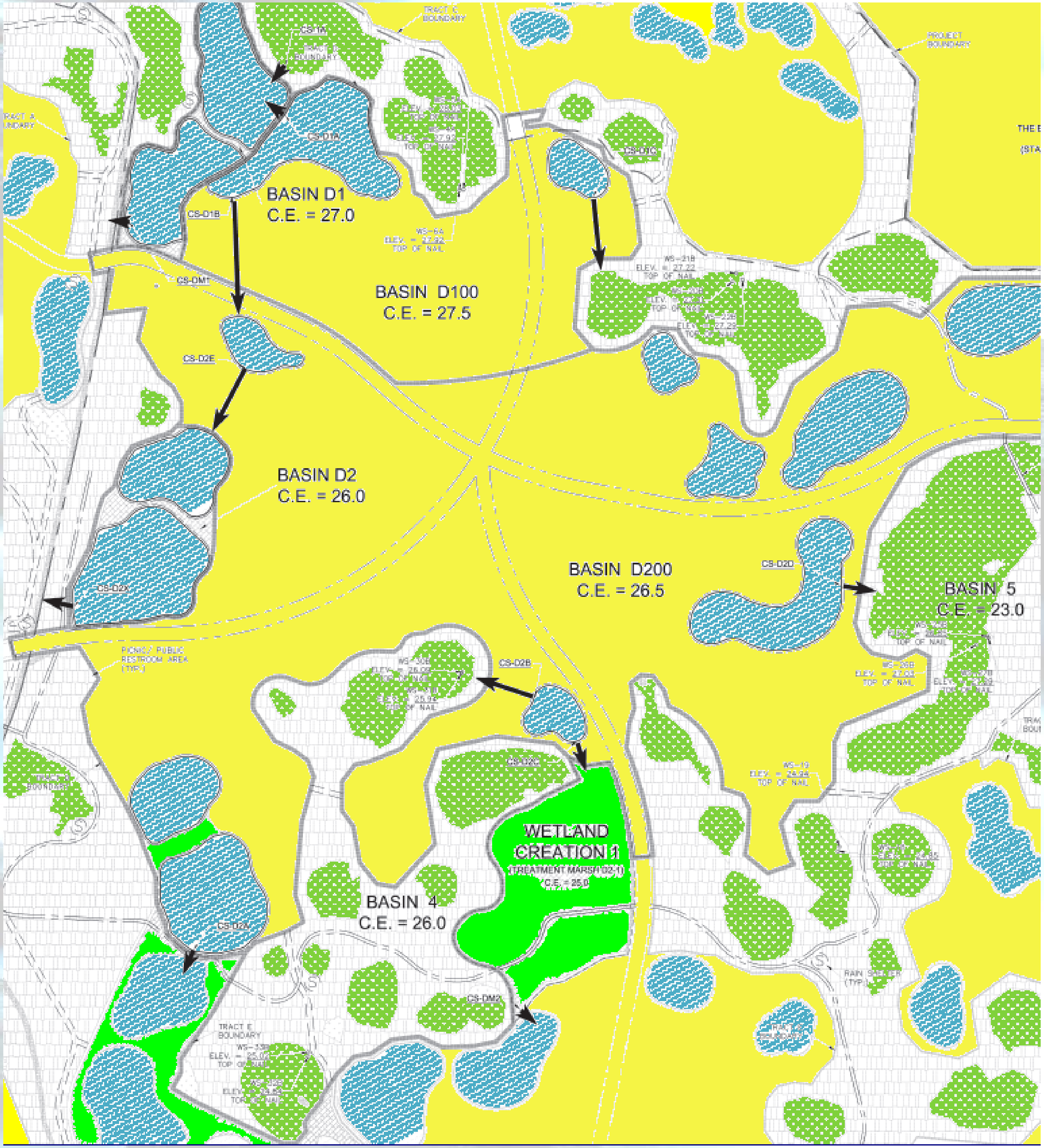
Mostly flat

Steeper near river and in central area

Existing Structures

Post Development Model Features

- 12 Treatment Marshes
- 130 Storm Water Ponds
- 130 Wetland Preserves
- 121 Structures



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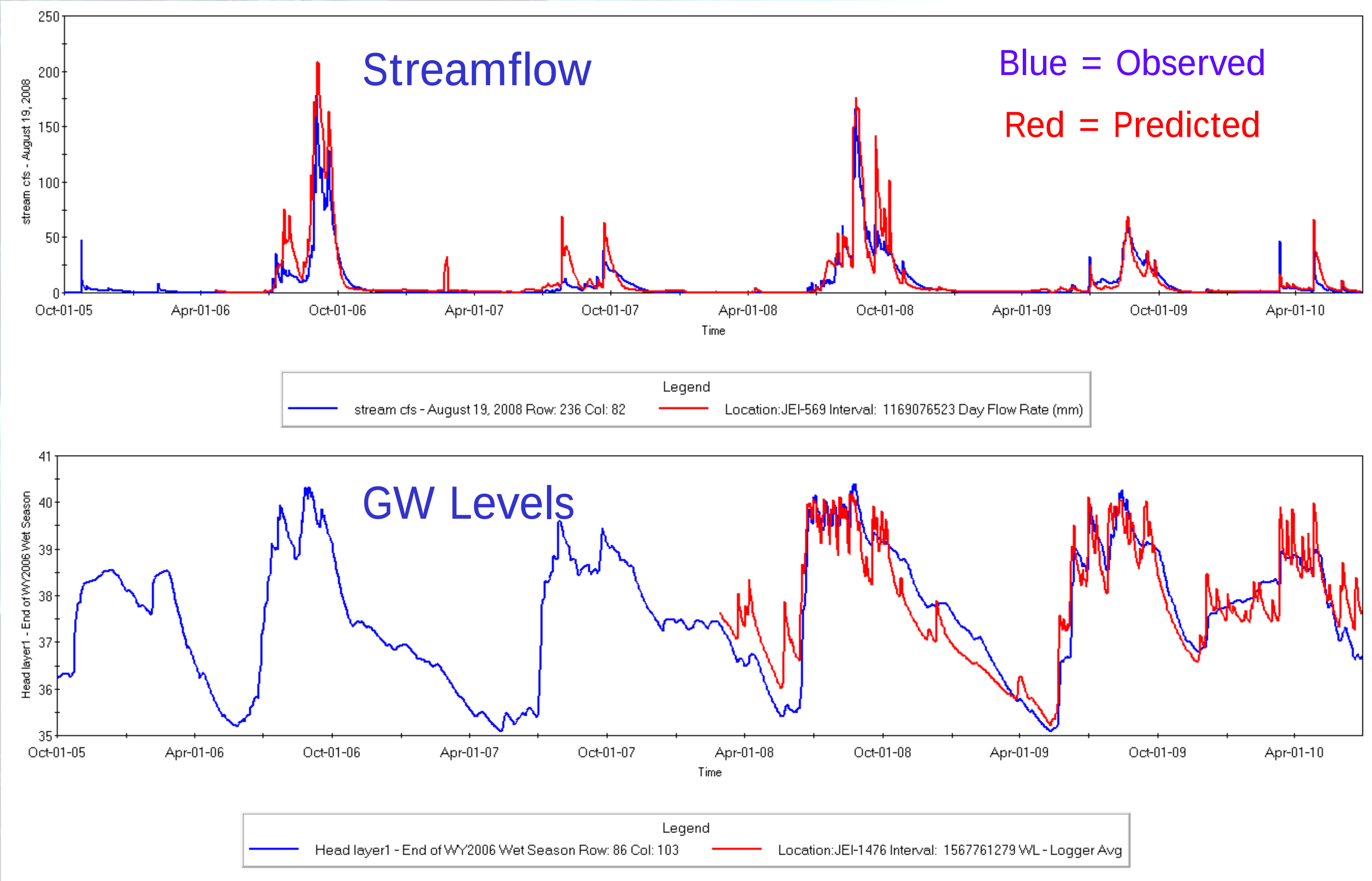
Seasonality in SW Flows and GW Levels



- Wet Season/Dry Season simplification only applies to the SW system (GW response is more complex).

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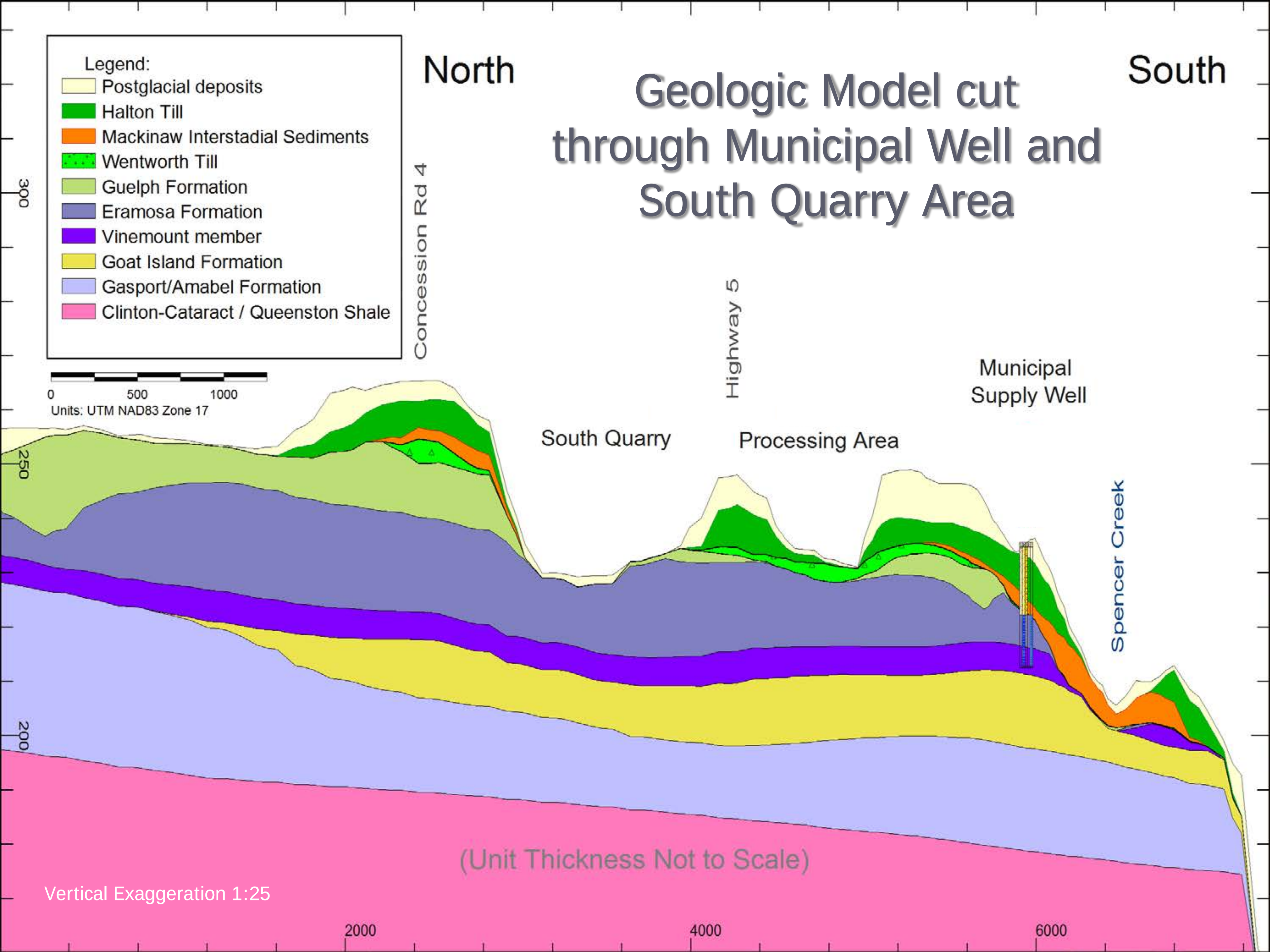
Florida: Integrated Calibration Lessons

- Standard practice for SW modeling in Florida is to change soil properties for wet or dry season simulations
  - Surficial sands are assigned the properties of clay during the wet season so that storm runoff from the sands can be approximated.
  - In reality, once GW levels rise to surface during the wet season, additional recharge is rejected (the geology does not change!)
- Lessons learned:
  - Uncoupled SW modelling can lead to parameter “fudging” to represent GW feedback during the wet season
  - Steady state GW conditions simply never occur
  - Only integrated model calibration can represent the seasonal patterns and fluctuations
    - Similar issues occur in Canada with frozen ground and snow melt

Integrated Modelling of a Quarry

- Analysis of inflows into a quarry or mine excavation can be particularly complex because of the integrated capture of groundwater, surface water runoff, snow and rainfall precipitation.
- Integrated modelling provides not only a complete water budget, but a breakdown of each component and an estimate of the actual impact of the excavation

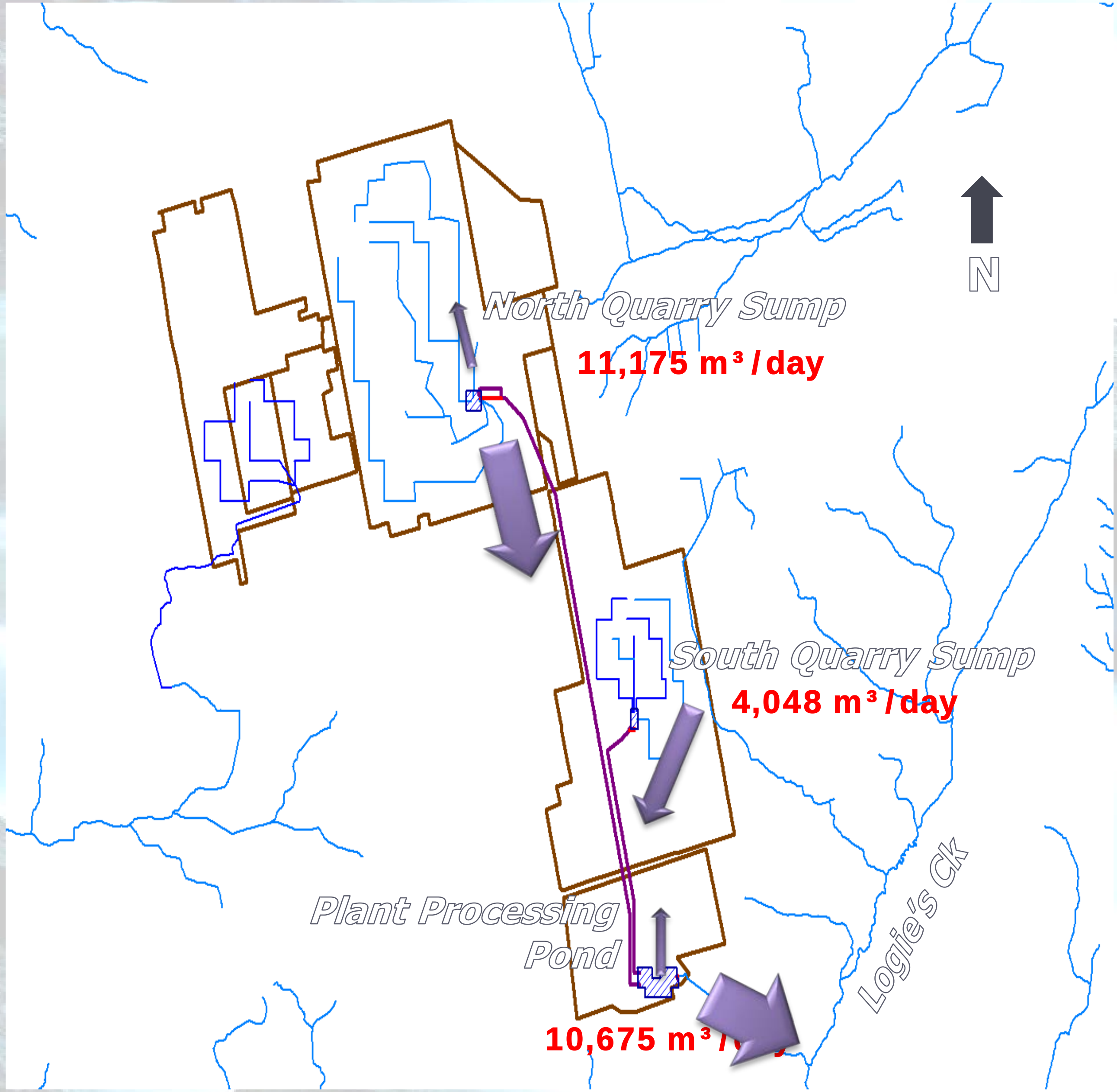


Geologic Model cut through Municipal Well and South Quarry Area
North
South
Legend:
Postglacial deposits
Halton Till
Mackinaw Interstadial Sediments
Wentworth Till
Guelph Formation
Eramosa Formation
Vinemount member
Goat Island Formation
Gasport/Amabel Formation
Clinton-Cataract / Queenston Shale
0
500
1000
Units: UTM NAD83 Zone 17
Concession Rd 4
Highway 5
South Quarry
Processing Area
Municipal Supply Well
Spencer Creek
300
250
200
2000
4000
6000
(Unit Thickness Not to Scale)
Vertical Exaggeration 1:25

Integrated SW and GW Contribution to the Pit

Flow Schematic between multiple excavations

(With Average Takings)



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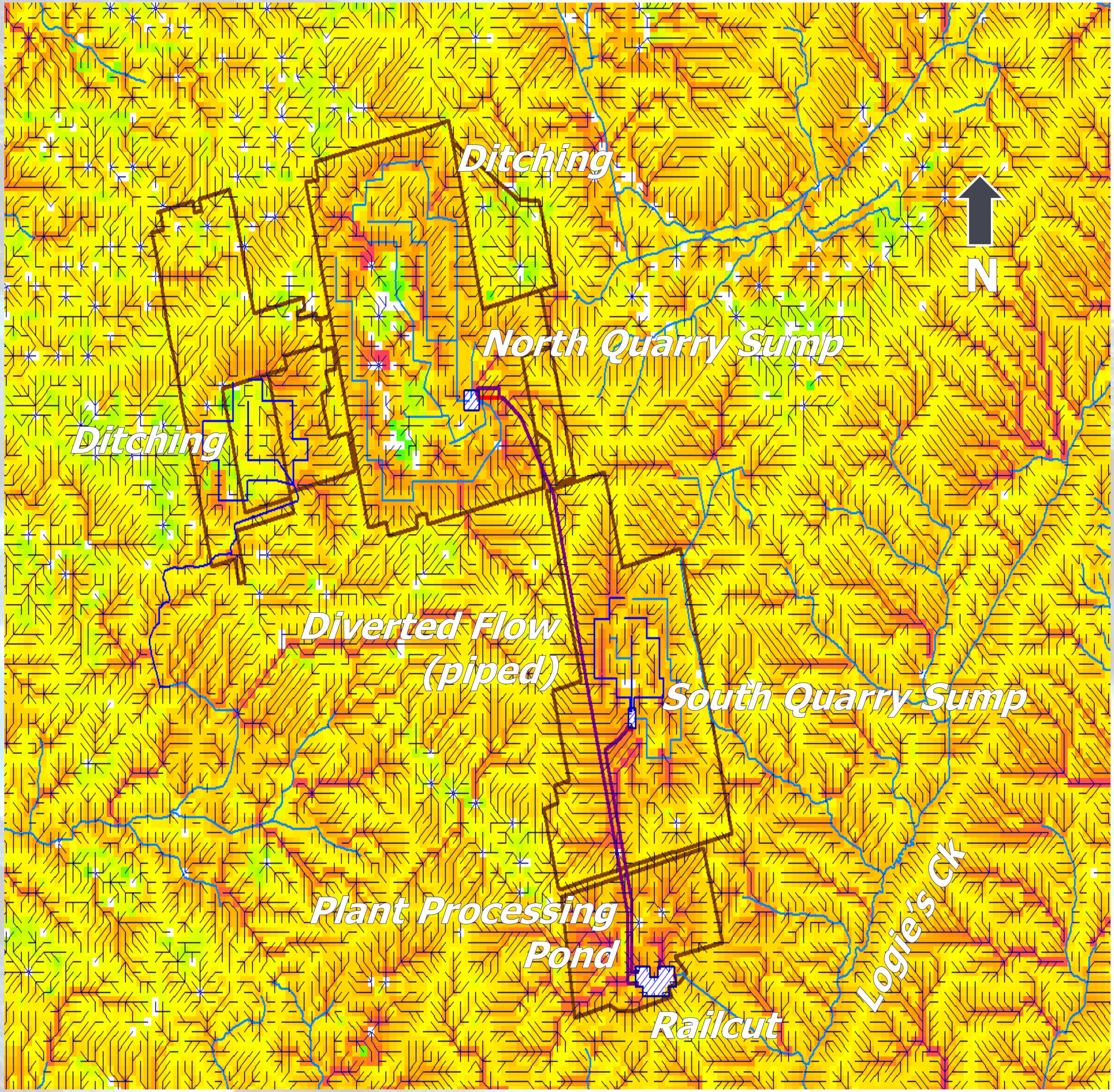
Overland Flow Simulation

(With Average Accumulating Overland Runoff)



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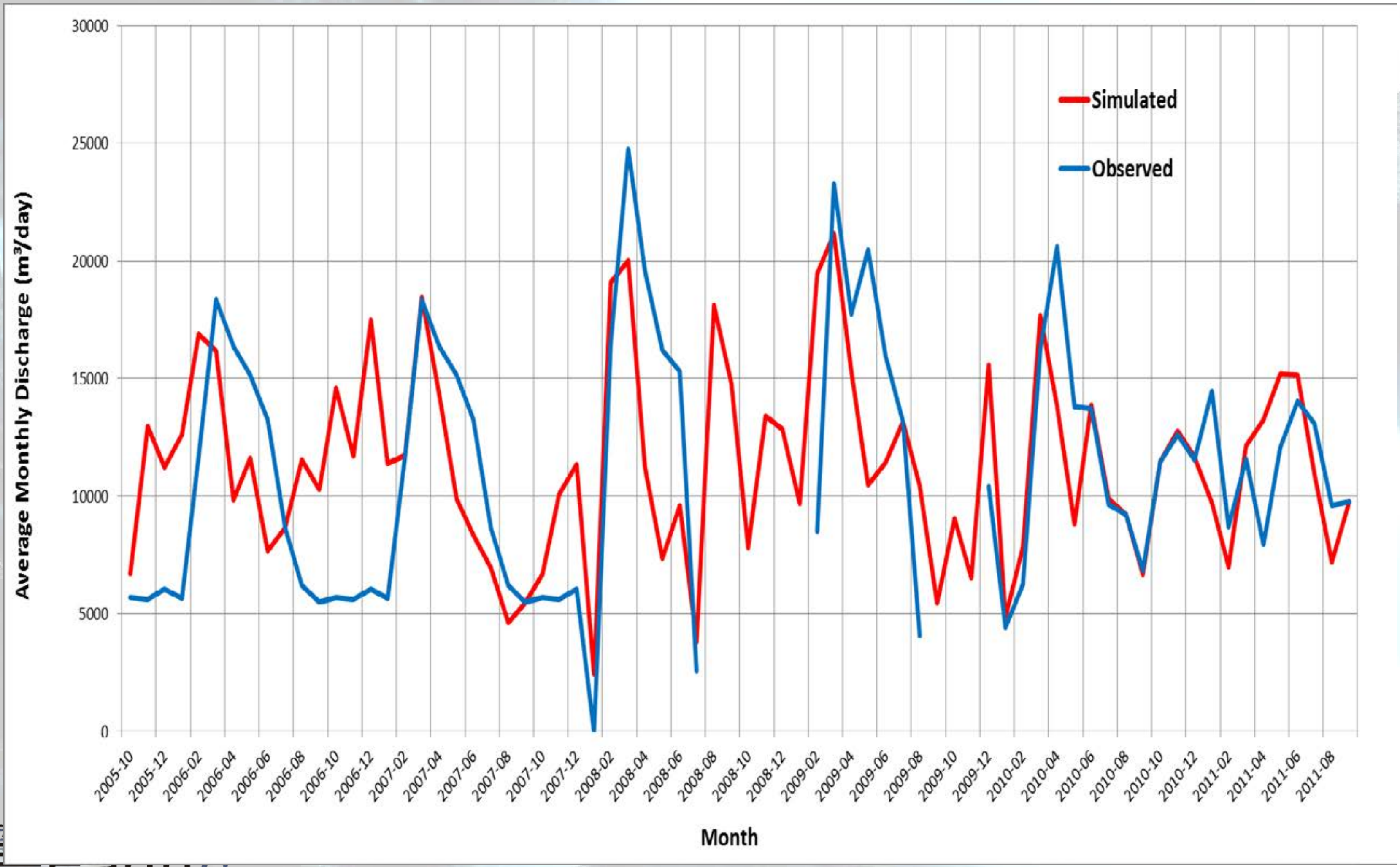
Quarry – Calibration to Offsite Discharge



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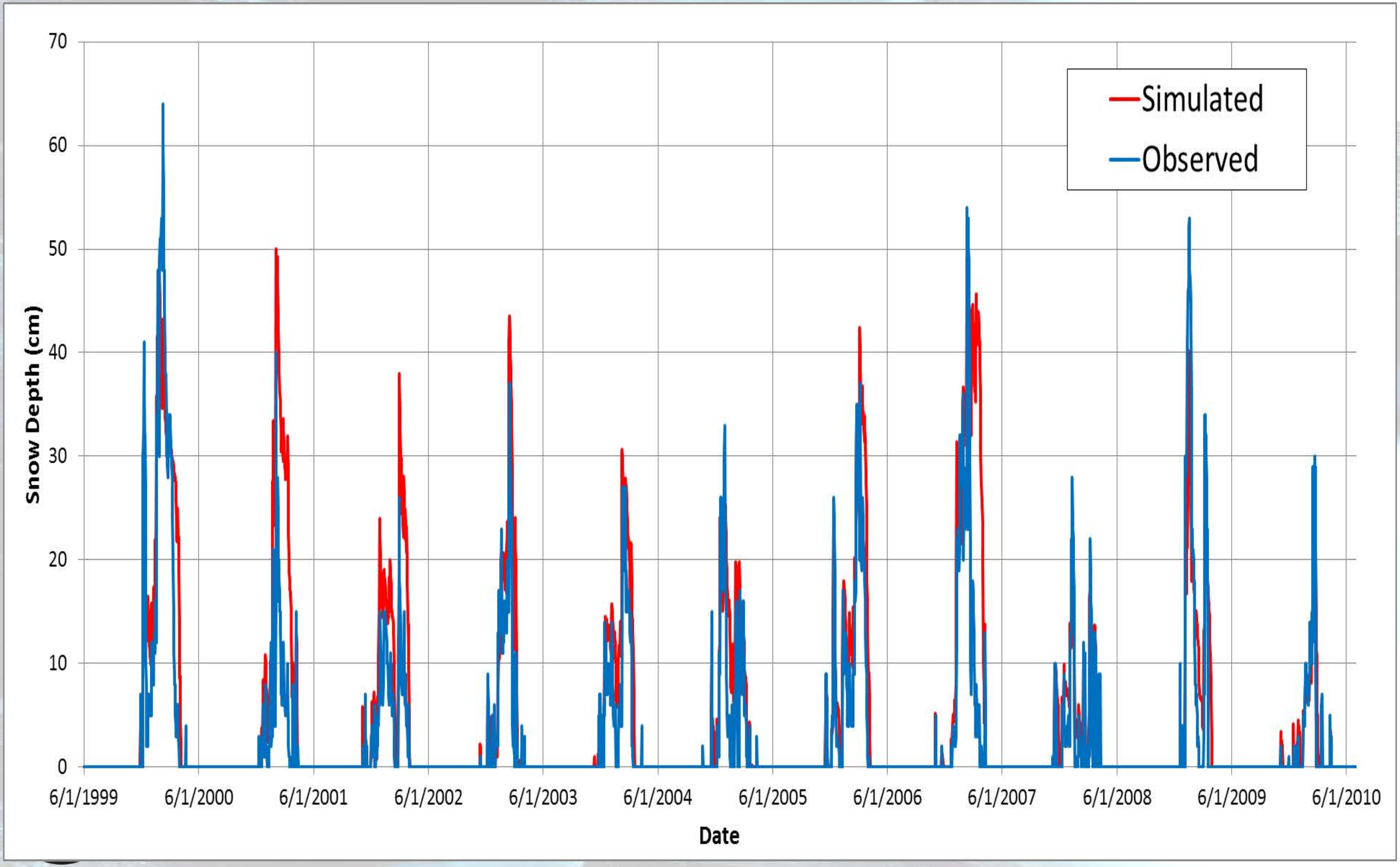
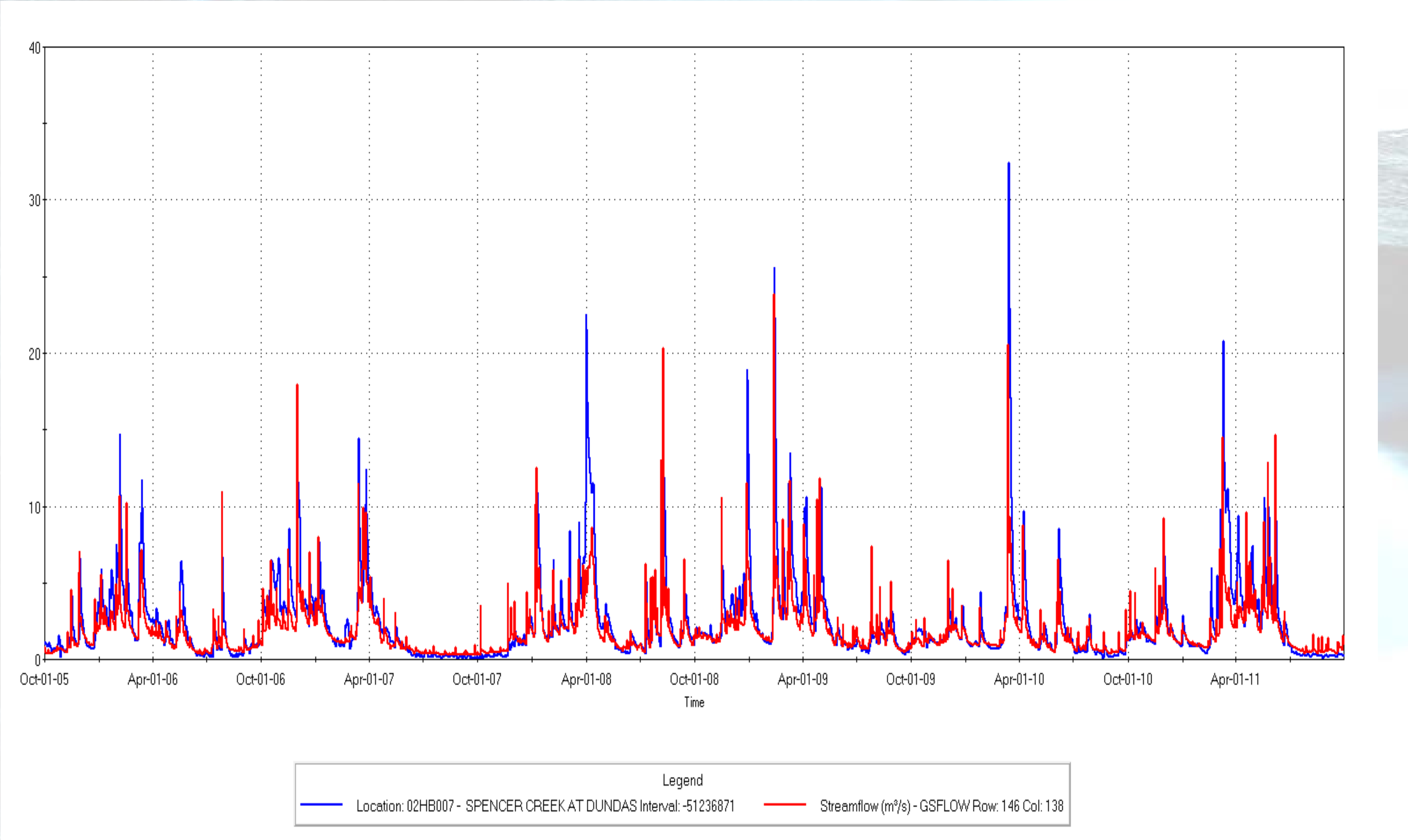
Snowpack Submodel



Streamflow



40
30
20
10
0
Oct-01-05
Apr-01-06
Oct-01-06
Apr-01-07
Oct-01-07
Apr-01-08
Oct-01-08
Apr-01-09
Oct-01-09
Apr-01-10
Oct-01-10
Apr-01-11
Time
Legend
Location: 02HB007 - SPENCER CREEK AT DUNDAS Interval: -51236871
Streamflow (m³/s) - GSFLOW Row: 146 Col: 138

Integrated Calibration: Quarry and Mine Impact

- Integrated model calibration becomes even more important where significant pumping and water management occur
- Baseflow separation techniques or simple quarry water budget calculations cannot represent the complexities of:
  - Snow pack accumulation and melt
  - Evapotranspiration from intermittent lakes and quarry ponds
  - Inflows from multiple aquifer layers
- Again, significant efforts to independently calibrate a SW or GW model would be of limited value

USGS Climate Change Impact Assessment Model

- **USGS Approach:**
- *"Because a fully coupled model can have long runtimes, however,* ***uncoupled models*** *of the groundwater and surface-water system were constructed* ***before*** *the fully coupled model…."* (USGS 2013, Page 11)

USGS
science for a changing world

Groundwater Resources Program
Climate and Land Use Change Research & Development

Simulation of Climate-Change Effects on Streamflow, Lake Water Budgets, and Stream Temperature Using GSFLOW and SNTEMP, Trout Lake Watershed, Wisconsin

Scientific Investigations Report 2013–5159

U.S. Department of the Interior
U.S. Geological Survey

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Re-Conceptualization during Integrated Calibration

- Key Issue: The uncoupled SW calibration generated high ET rates in the smaller lakes that, during final integrated calibration, were found to be incorrectly compensating for lake losses to the lower aquifer system.
  - *“the value of revisiting model conceptualization and calibration with the fully coupled GSFLOW model is demonstrated, even after improvements gained from sequentially linked calibration. Therefore, it is expected that fully coupled models will benefit from final calibration, even if the forward run times make the calibration computationally expensive.” (USGS 2013, Page 69)*
- In summary: *Integrated calibration*, and even re-conceptualization during this final phase, is necessary.
  - **This is why we do integrated modelling!**

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Conclusions

- Integrated Modelling is different; It requires:
  - Integrated calibration strategies
    - Don’t become attached to your initial uncoupled calibration estimates!
    - Consider re-conceptualization, even late in the integrated calibration
  - Integrated data management
    - Data silos and barriers will only hide the relationships and response lag between the systems
    - Please stop by my booth if you would like to talk about data mangement....
  - An integrated and balanced modelling team
    - The skill, multi-disciplinary knowledge, and ability of the SW and GW experts to address their “blind spots” is far more important than the choice of model code

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