Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

WaterTech 2012

Modelling Surface-Groundwater Interactions using Integrated Hydrologic Models

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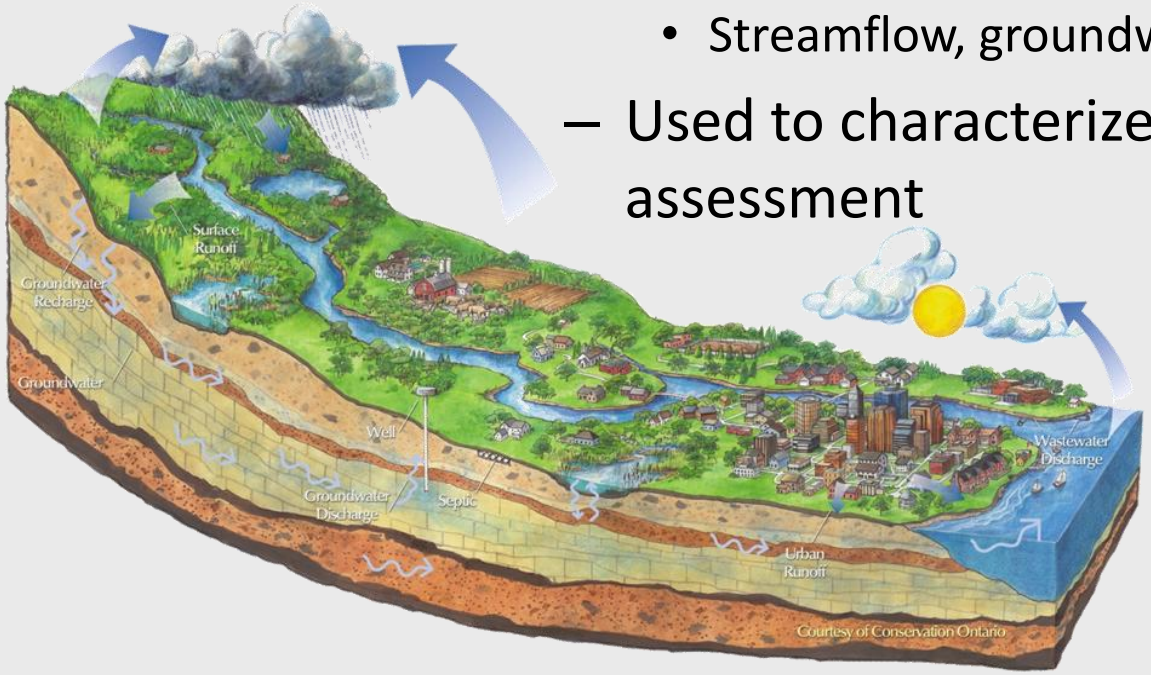
Presentation Outline

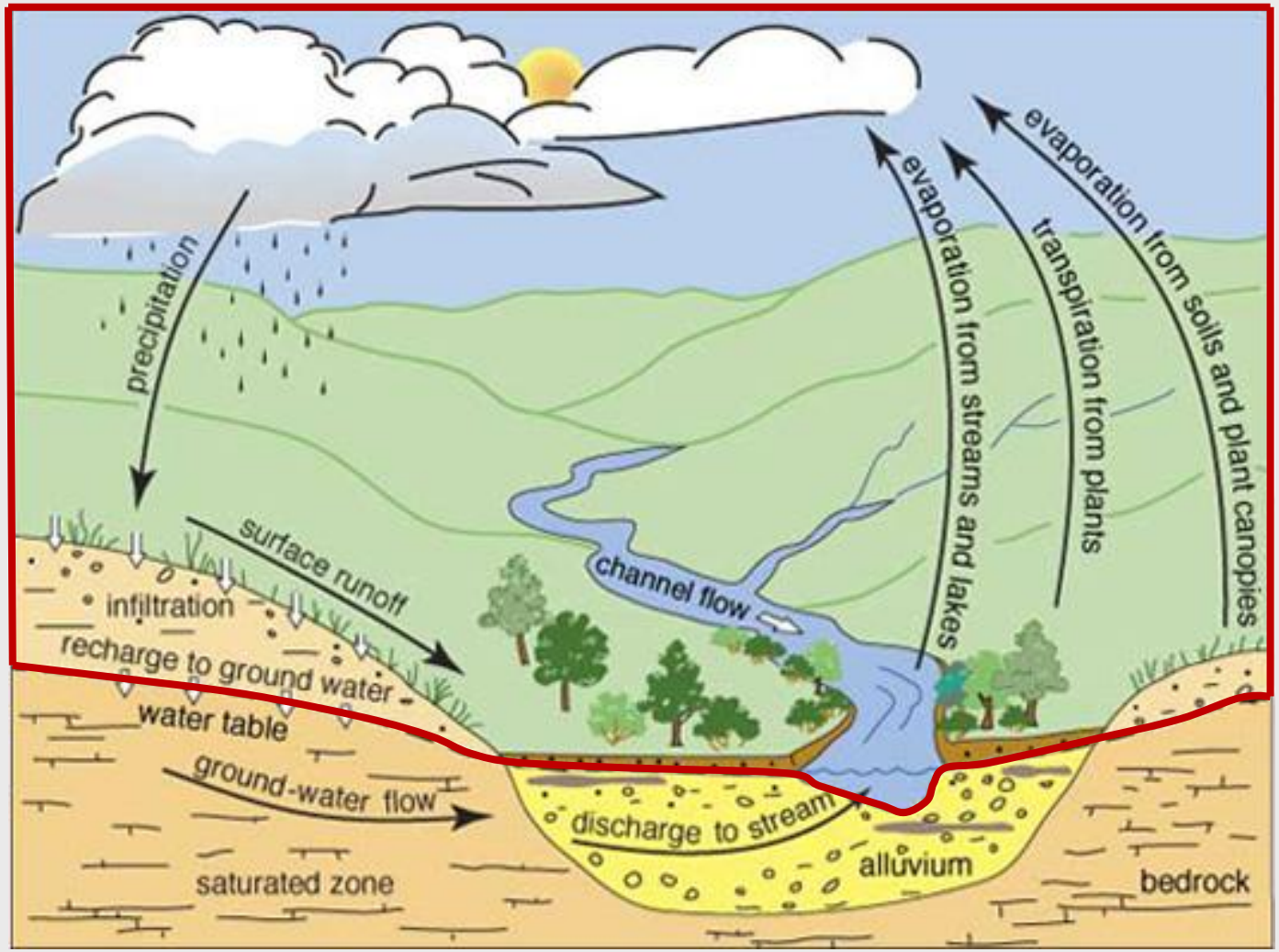
- What are “integrated models”
- Why aren’t they widely applied?
- Integrated Model Assessment & Technical Guidance Document
- Why use integrated models?
- Lessons Learned

Hydrologic Models

- What is a Hydrologic Model?
  - Representation of the physical watershed, and simulates the hydrologic response of the watershed to precipitation events
  - Model is calibrated against observed conditions
    - Streamflow, groundwater levels
  - Used to characterize hydrology or for impact assessment

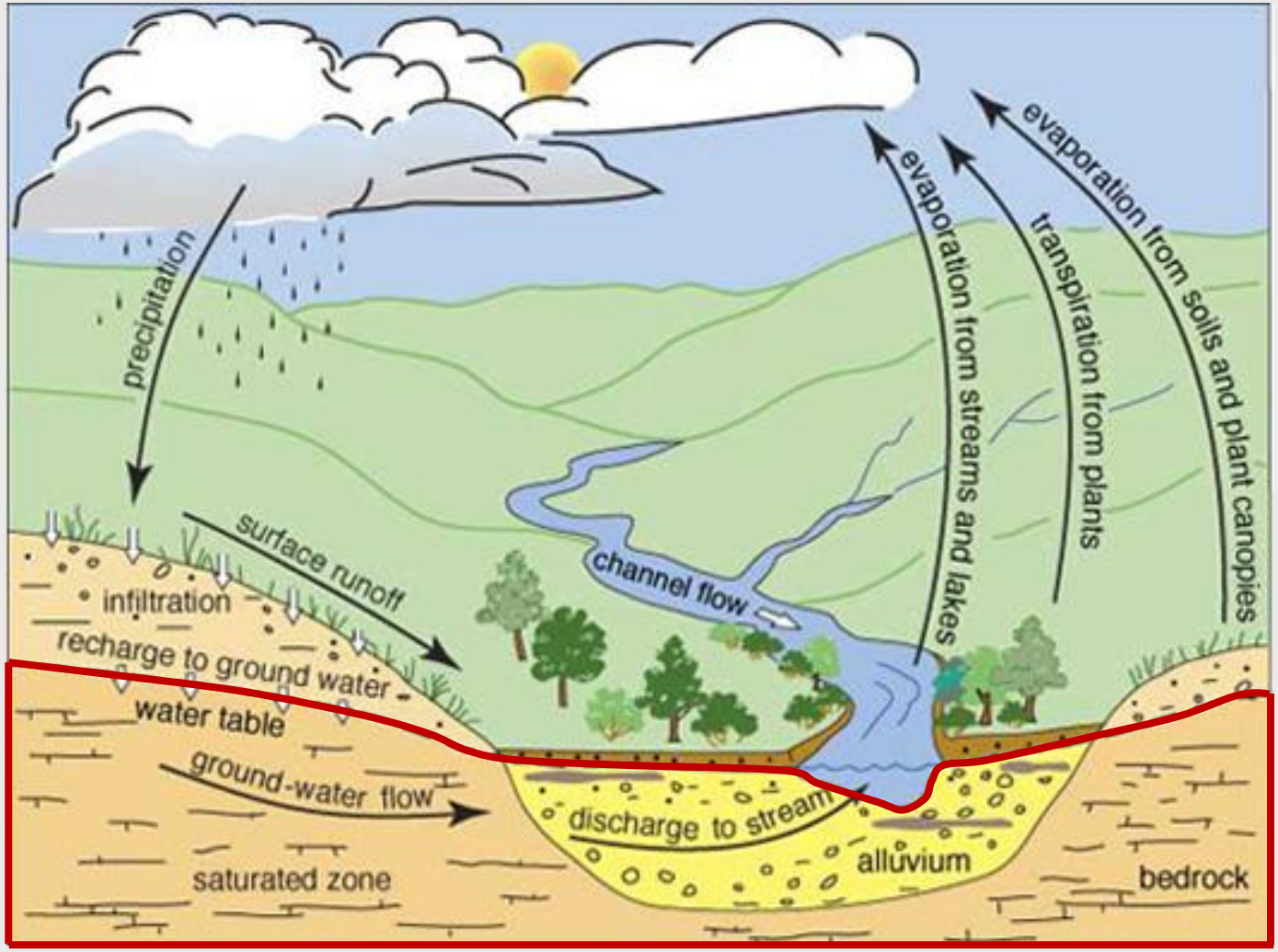


Surface Water Models



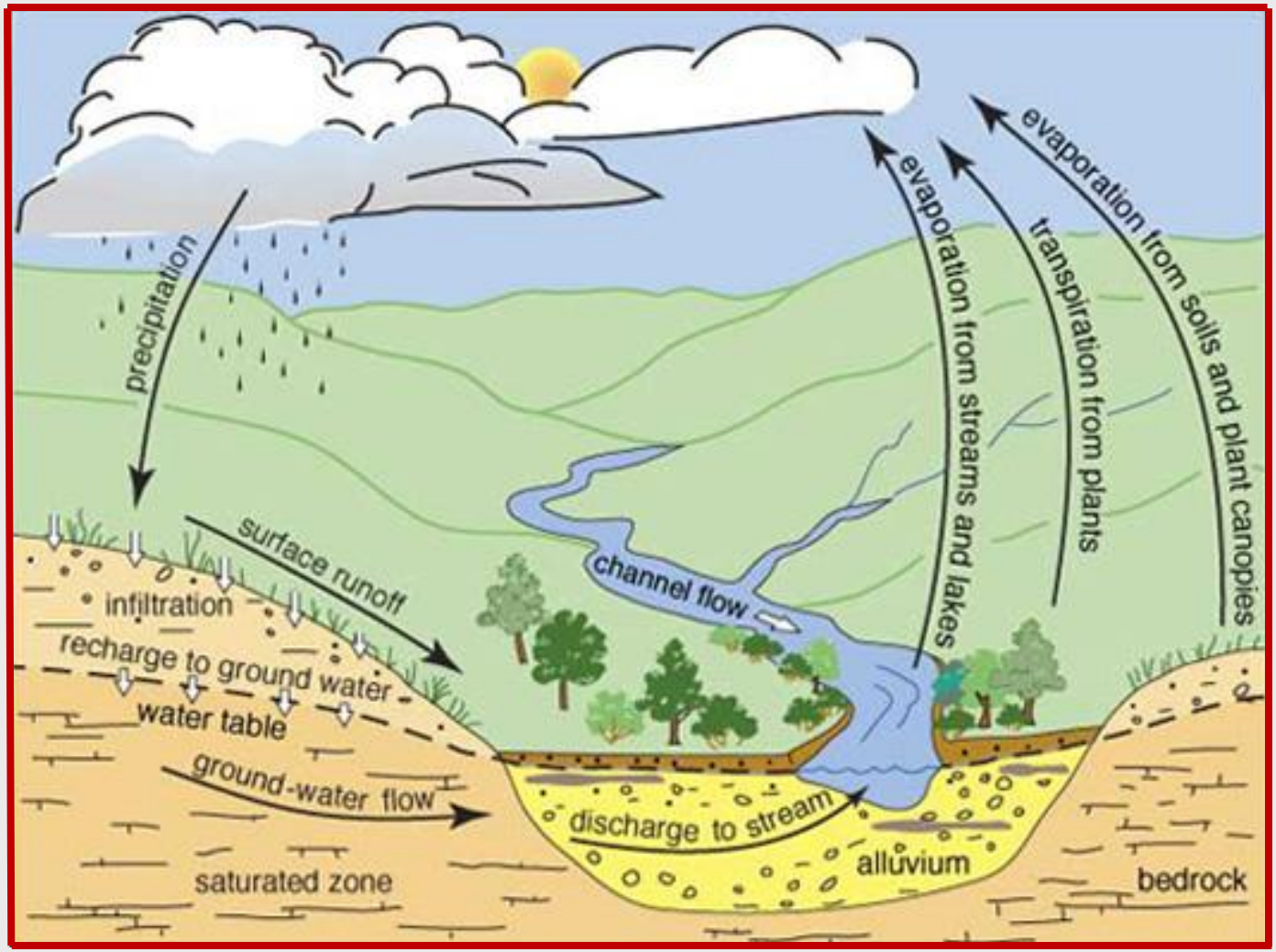
- Detailed representation of the surface water system
- Empirical representation of the groundwater system

Groundwater Models



- Physical representation of the groundwater system
- Neglects surface water processes

Integrated Models



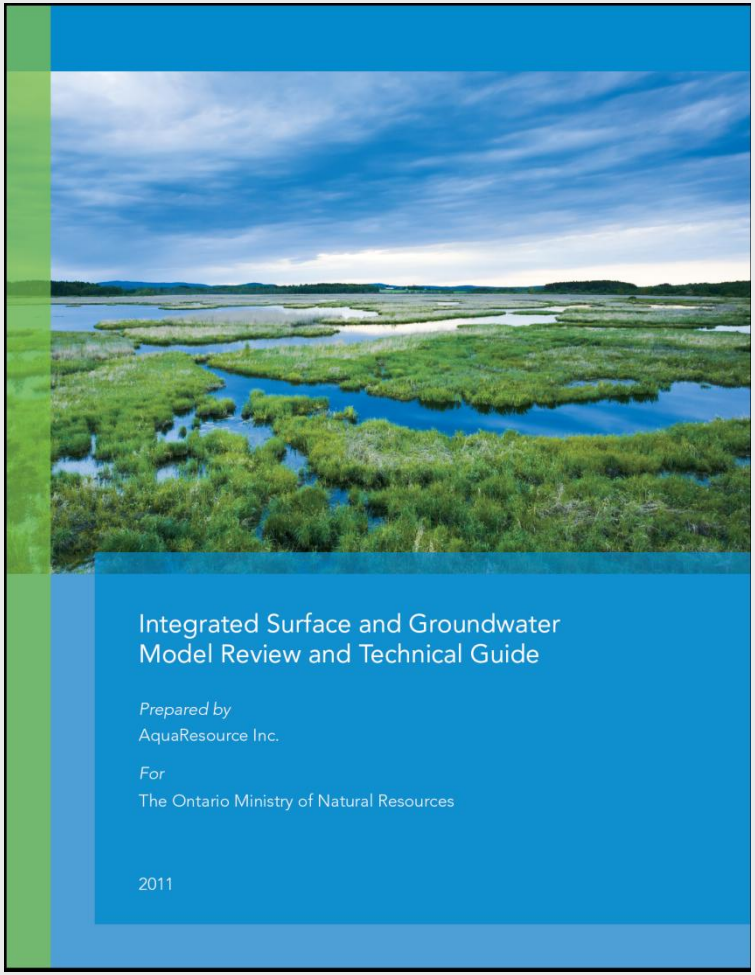
- Includes fully dynamic, physical representations of both the surface and groundwater systems.
- Allows for feedbacks and interactions between the systems to be modelled

Why isn't it being done already?

- While gaining interest in Canada, has not seen wide-spread application.
- Why?
  - Seen as an unproven technology in Canada
  - Should we be making more complex models?
  - Very long run-times, how to calibrate?
  - Inter-discipline cooperation
    - Requires knowledge of hydrology, open-channel hydraulics, and hydrogeology

Guidance Document

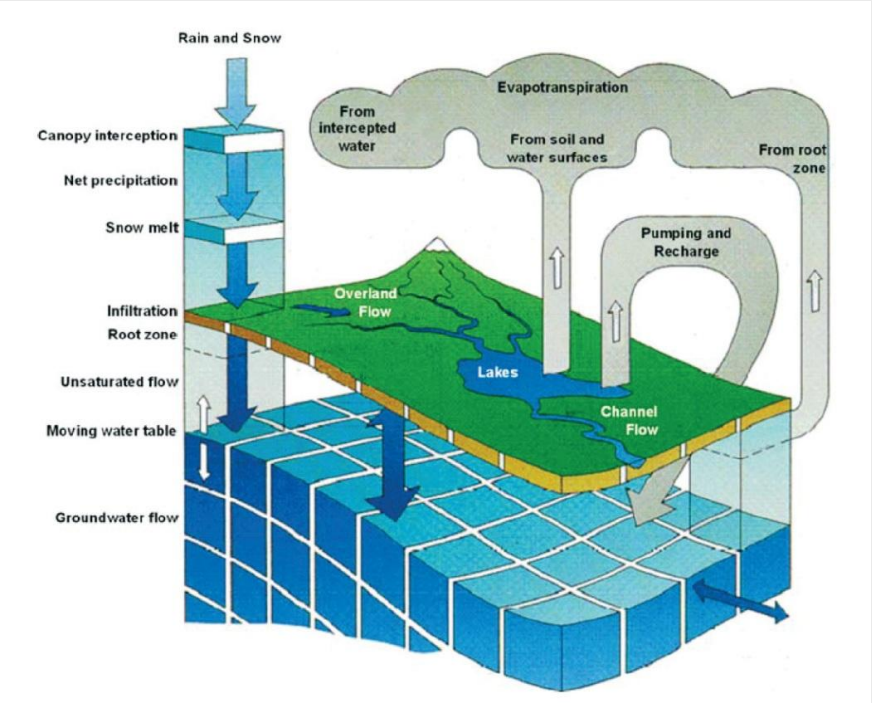
- Ontario Ministry of Natural Resources initiated a pilot study to investigate the applicability/usability of integrated models.
- Goals included
  - Review of several model codes
  - Application of three codes to test subwatersheds
  - Develop guidance for other water resource practitioners in developing integrated models



Available at www.waterbudget.ca

Integrated Models Investigated

- Reviewed the abilities of:
  - GSFLOW, HydroGeoSphere, MIKE-SHE, MODHMS, ParFlow
- Developed integrated models for the same watershed using:
  - GSFLOW
    - USGS
  - HydroGeoSphere
    - Universities of Laval/Waterloo
  - MIKE-SHE
    - DHI



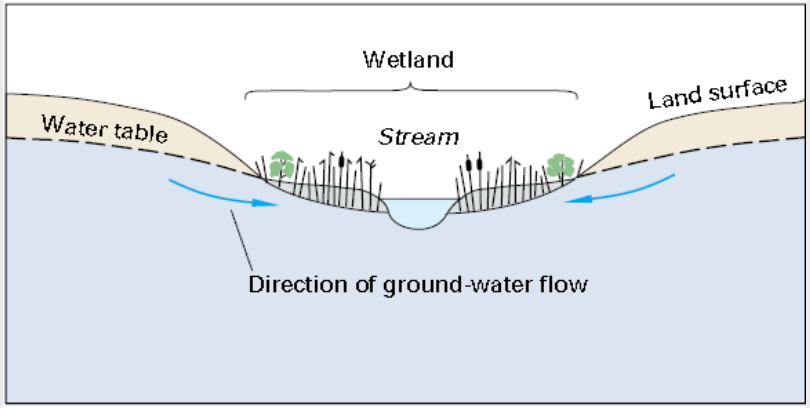
Why use Integrated Models?

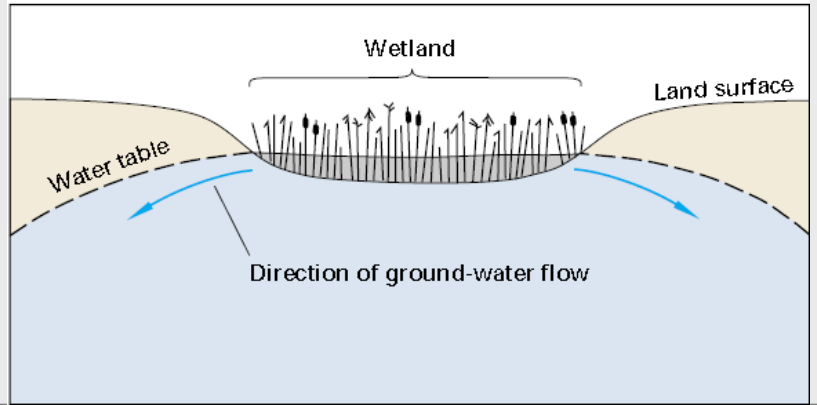
- Represents the interactions/feedbacks between the two systems
  - Runoff characteristics can be influenced by depth to water table
  - Stream leakage to groundwater system is limited by the amount of streamflow
- Offers a more complete representation of actual conditions
- Allows for the characterization of surface/groundwater interactions.

Integrated Modelling Allows…

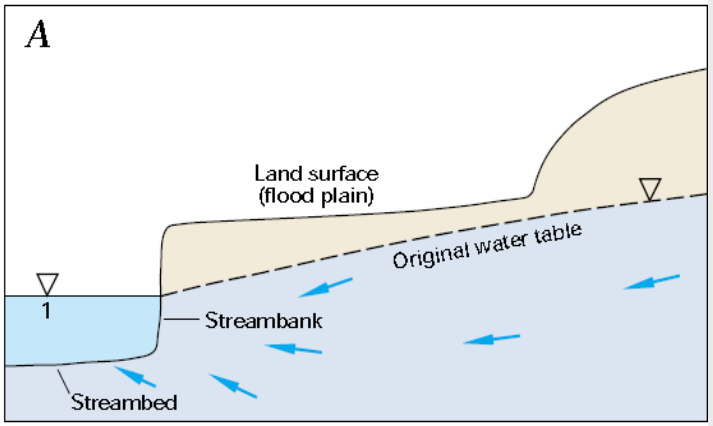
Wetland Characterization

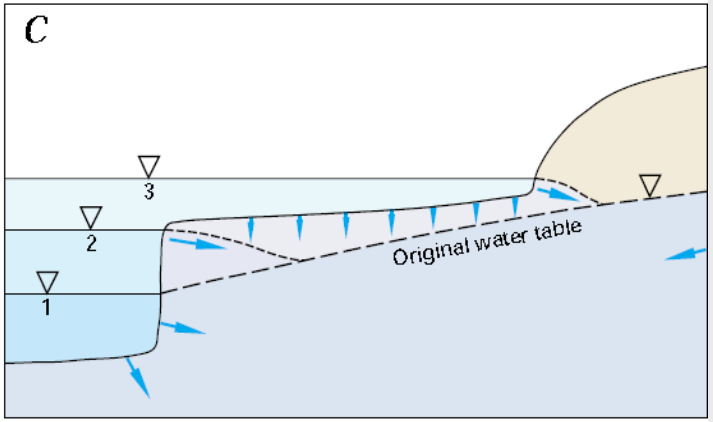
Discharging/Recharging Wetlands





Consideration of flooding as a recharge process





More Complete Watershed Characterization

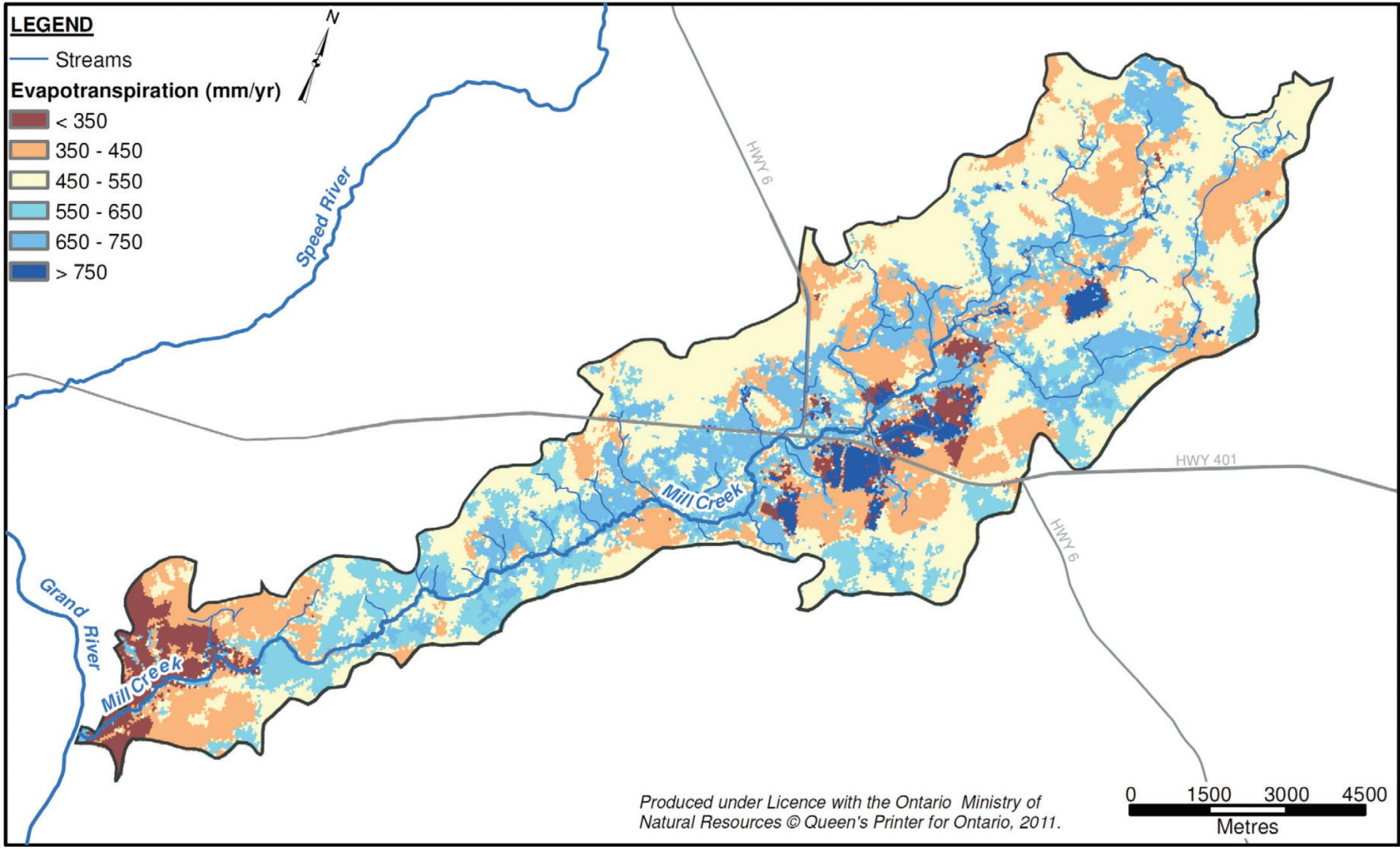
Integrated Water Budget Estimates

Year	Precip-itation	ET	Overland to River (Runoff)	Drain to River (Interflow)	Baseflow to River	Groundwater In	Groundwater Out	Storage	Error
1999	864	550	144	7	103	280	265	76	0
2000	958	573	185	9	123	274	274	68	0
2001	818	500	188	9	119	273	276	-2	0
2002	821	511	194	10	127	269	281	-32	0
2003	877	521	189	9	115	278	269	51	-1
2004	898	523	223	11	138	292	301	-6	0
2005	902	532	215	10	121	271	276	19	0
Average	877	530	191	9	121	277	277	25	0

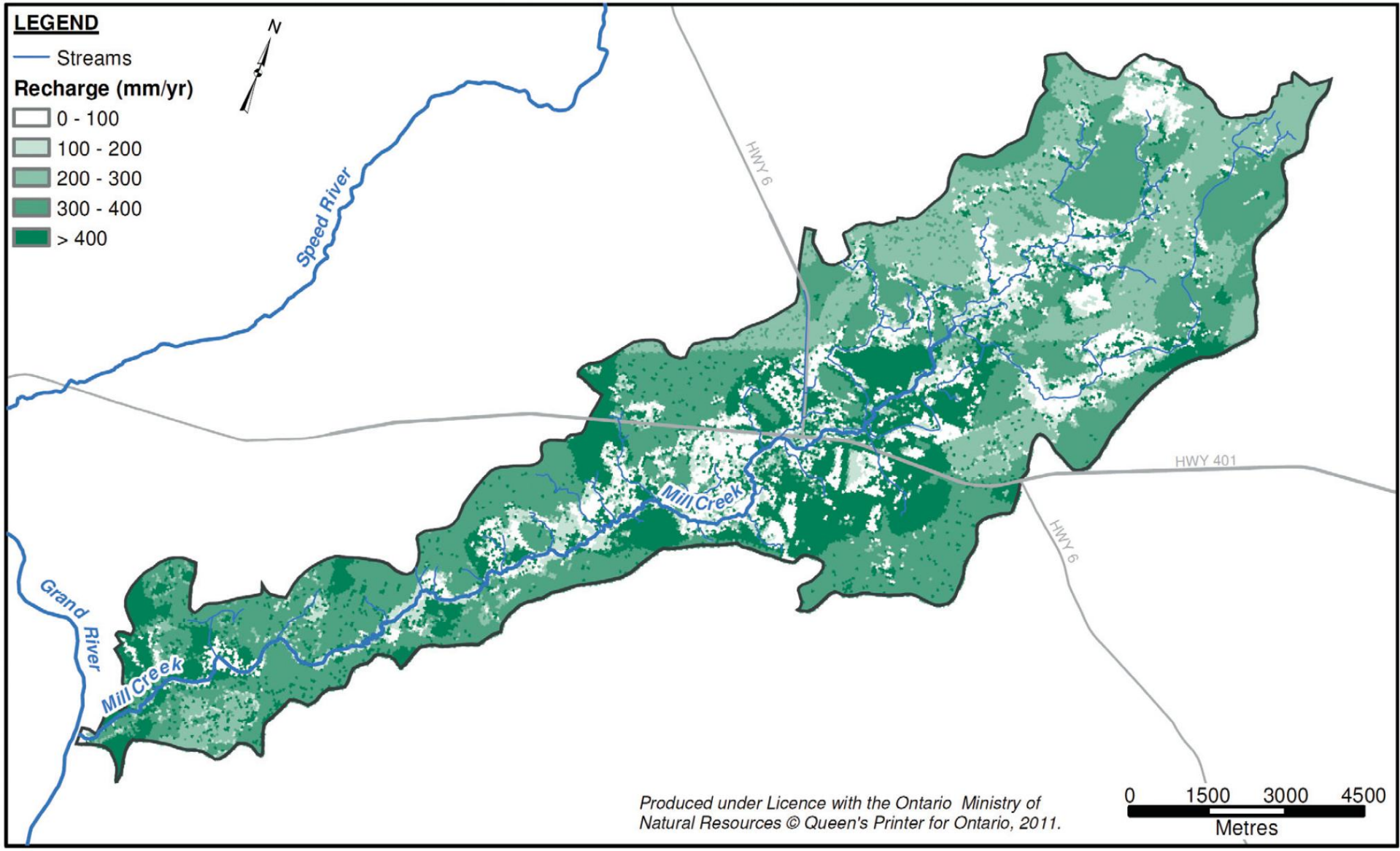
(mm/yr)

- Allows one to investigate year-to-year variability
- Provides a quantification of flows within and between subwatersheds

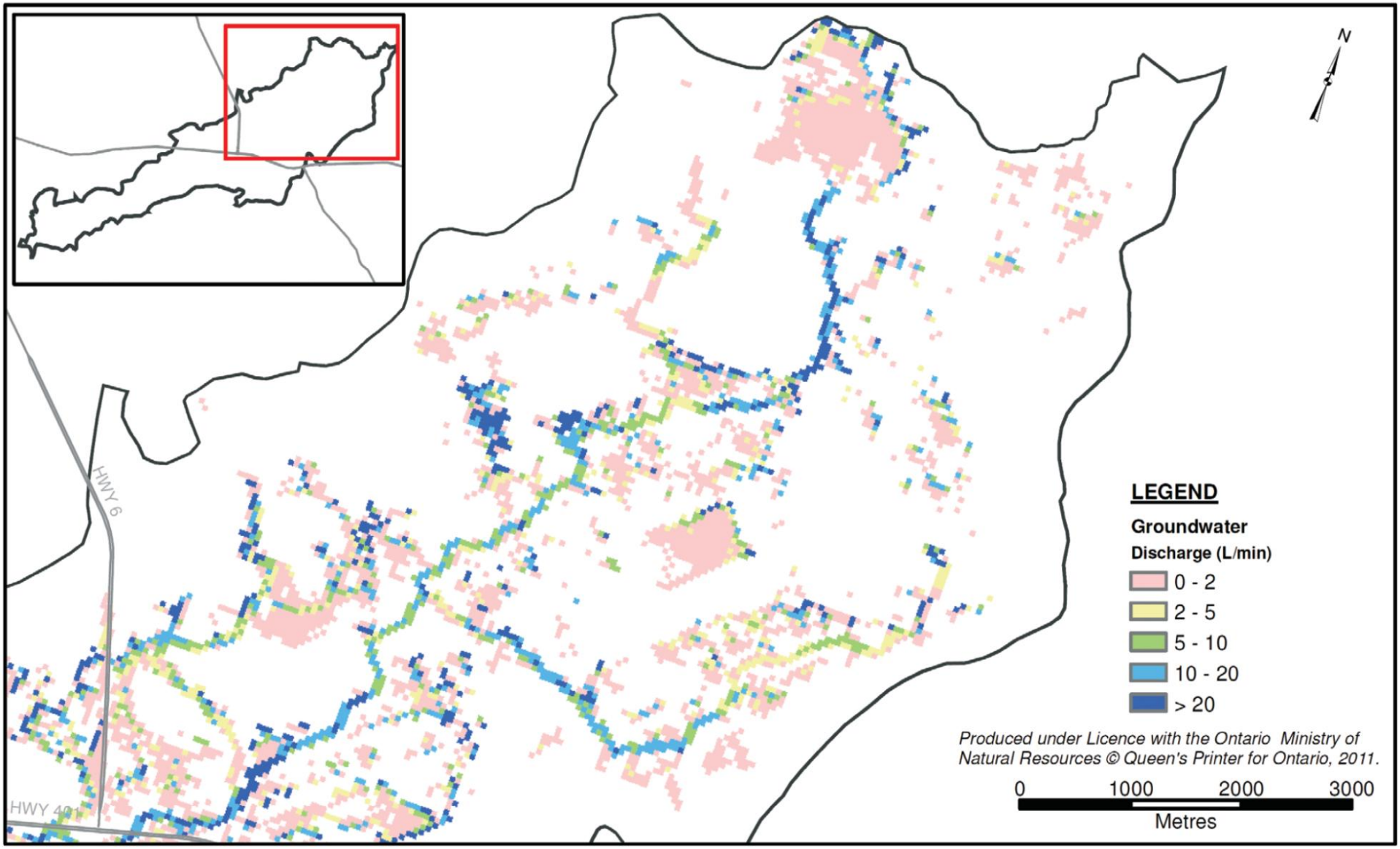
Evapotranspiration



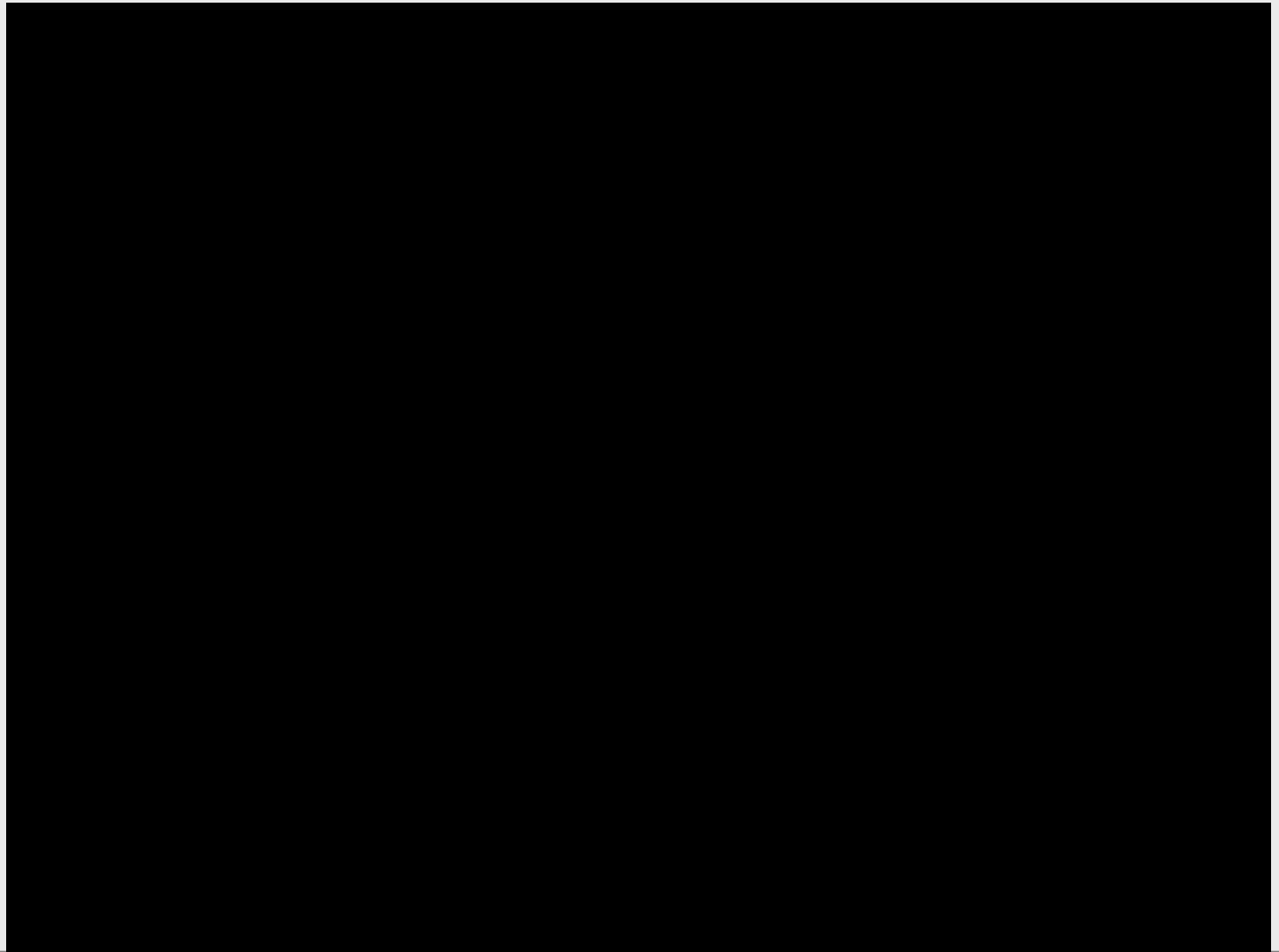
Groundwater Recharge



Groundwater Discharge

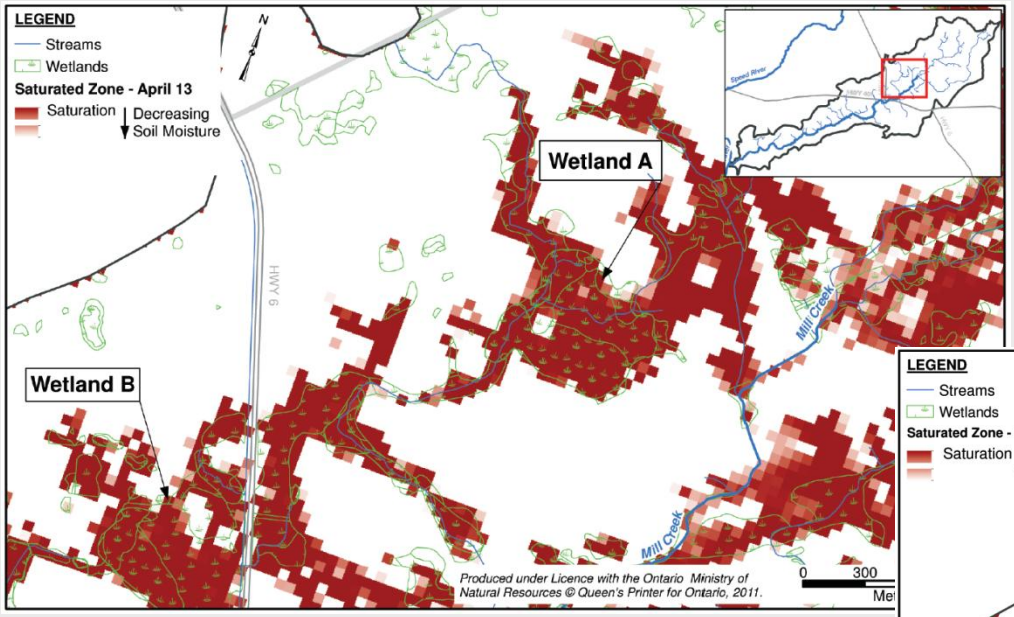


Unsaturated Zone Deficit Animation

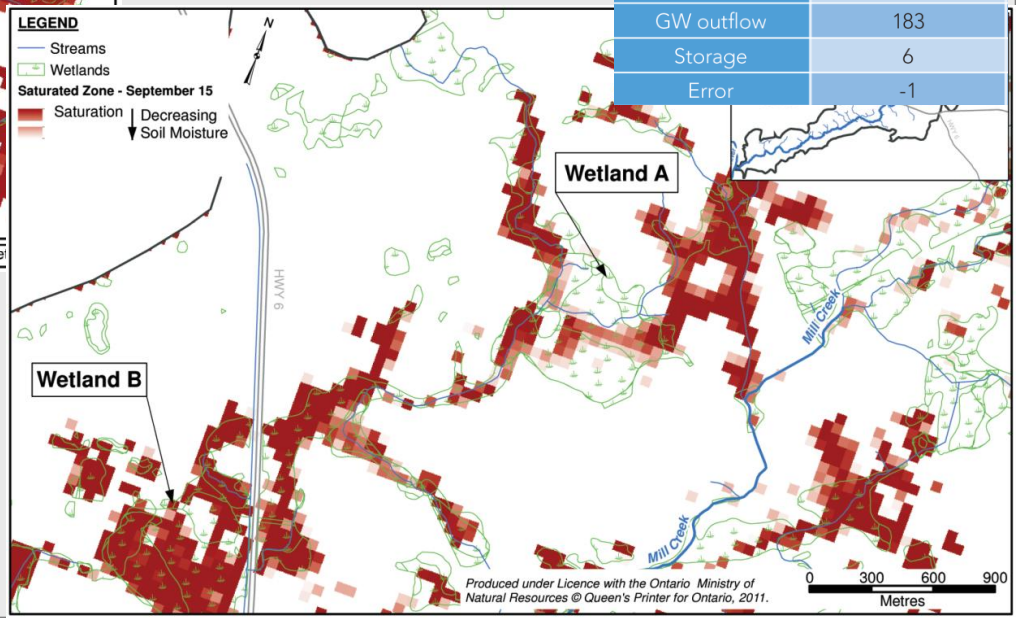


Wetland Characterization

Are Wetlands Supported by Groundwater Discharge, or Overland Flow?

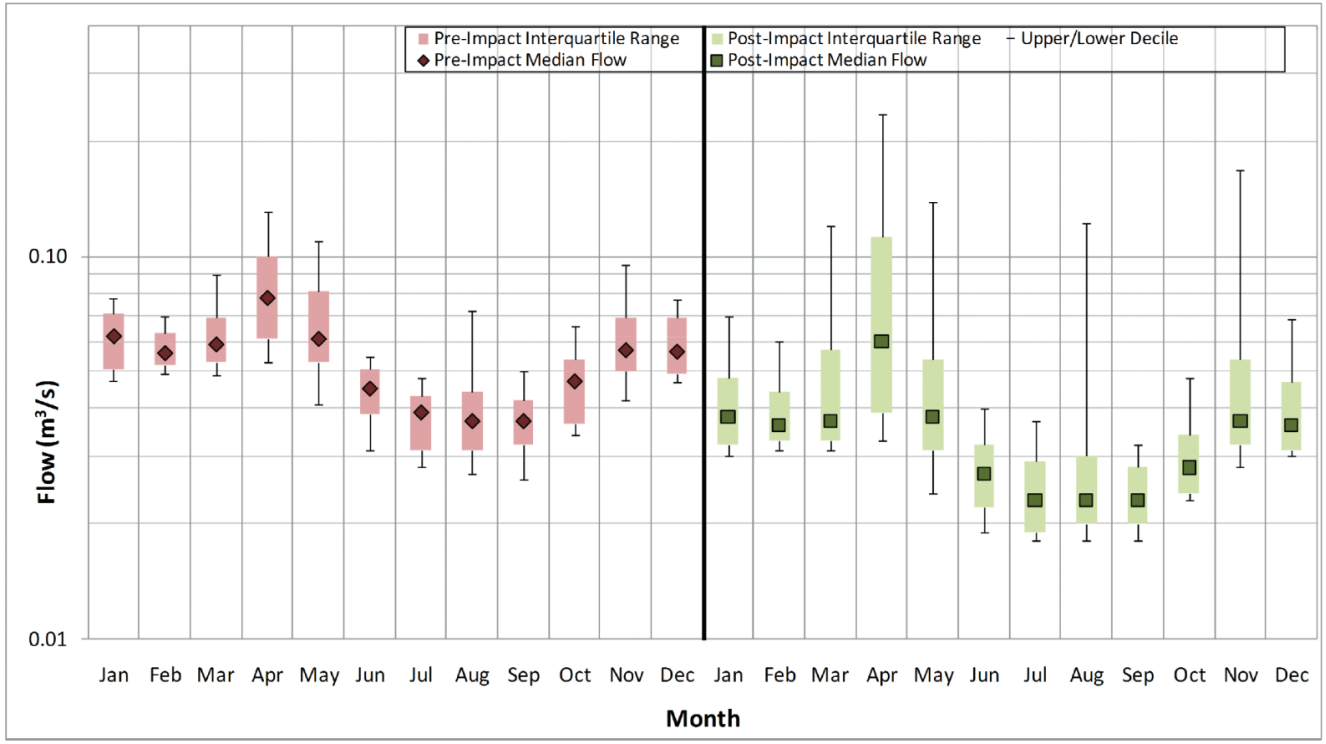


	Wetland Region (mm per unit area of Wetland/yr)
Precipitation	804
Evapotranspiration	667
Overland Inflow	1527
Overland Outflow	155
Overland to River	1790
Interflow to River	36
Baseflow to River	70
GW inflow	576
GW outflow	183
Storage	6
Error	-1



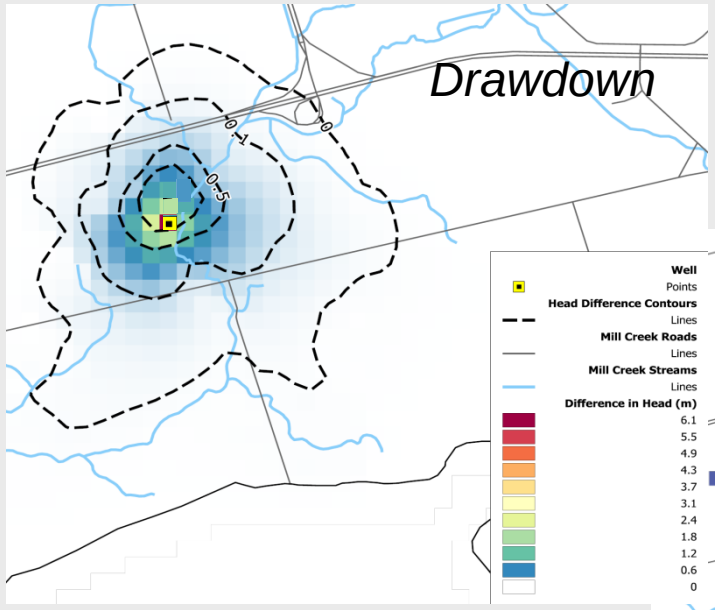
Impact Assessment

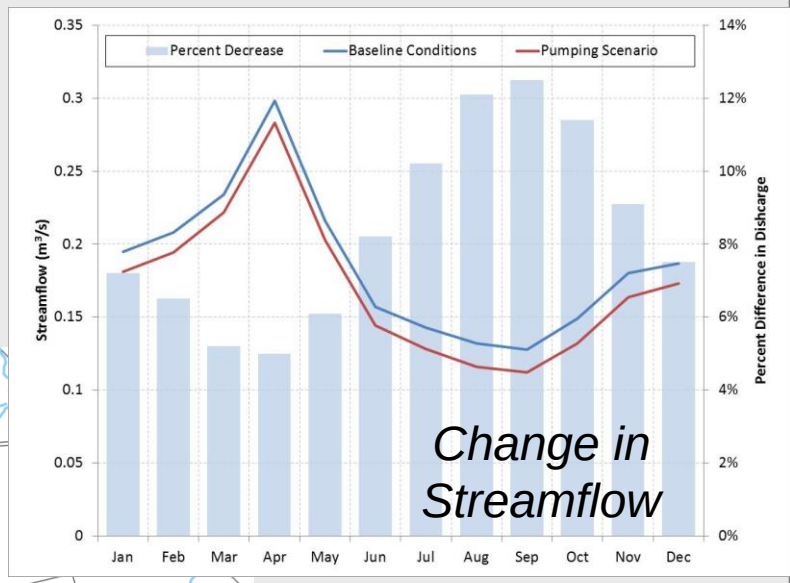
- Allows one to assess level of impact as it relates to the "*complete streamflow regime*"
- Example, pre/post impact from increased groundwater withdrawals and land development

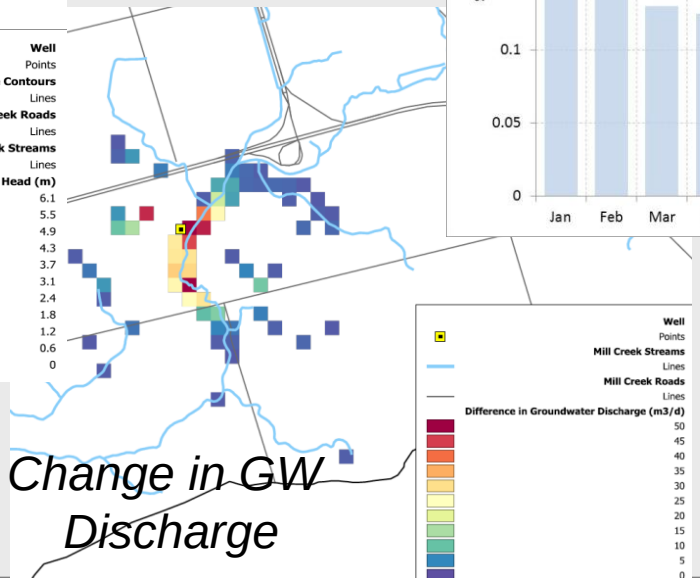


Impact Assessment

- Groundwater Withdrawals
  - Assess impact of new withdrawals on groundwater levels, discharge and streamflow

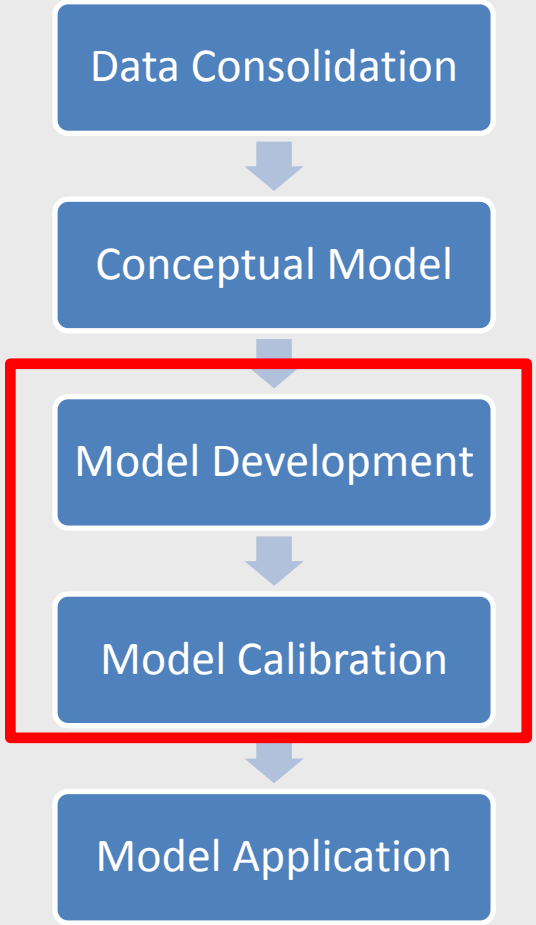






Lessons Learned

- Similar project structure as traditional modelling studies
- Model development and and calibration should proceed in a step-wise approach
  1. Build simplified integrated model, focussing on SW processes. Rough calibration (e.g. annual flow volumes)
  2. Develop and initially calibrate GW model in traditional GW model code (MODFLOW, FEFLOW)
  3. Incorporate calibrated saturated zone properties (e.g. layer structure, conductivities) into integrated model. Final calibration
- Integrated teams are a must!



Integrated Modelling Hurdles

- Seen as an unproven technology in Canada
  - Not valid, used world-wide
- Should we be making more complex models?
  - Integrated modelling is not always required. BUT, where supported by data, it can answer questions that are unable to be addressed by traditional models.
- Very long run-times, how to calibrate?
  - Model construction/calibration time can be reduced with efficient model codes, structured model development frameworks and experience
- Inter-discipline cooperation
  - Make surface water and groundwater people work together

Thank you!

- Acknowledgements
  - Mike Garraway – Ontario Ministry of Natural Resources
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  - John Paul Jones – University of Waterloo/Alberta Innovates
  - Pat Delaney – DHI

Questions?

Summary

- Hydrologic models replicate the hydrologic response of a watershed by considering the physical makeup of the watershed
- Integrated models include a physical representation of both the surface and groundwater flow systems
- Models can be used for two general applications
  - Increase level of knowledge/understanding of a system
    - Quantifying water budget components at a watershed/subwatershed scale
    - Identifying key local features that are critical to maintaining the quantity and timing of flows
  - Impact Assessments
    - What if scenarios? (e.g. land use change, climate change, increased water withdrawals)

Different Types of Models

- Empirical
  - Uses fitting parameters to relate input (precipitation) to output (streamflow), without consideration of the underlying physical processes.
  - Benefits
    - Relatively straightforward to set up
    - Minimal input data requirements
    - Can achieve good fit to observations
  - Disadvantages
    - Can’t be used to understand the behavior of local scale features
    - Not well suited to impact assessment

Different Types of Models

- Physically-based
  - Uses mathematical representations of individual hydrologic processes to produce the overall hydrologic response (streamflow) from climatic inputs
  - Benefits
    - Can provide understanding of individual processes (e.g. infiltration, groundwater recharge).
    - Can be used to characterize hydrology of local scale features\
    - Well suited to impact assessments
  - Disadvantages
    - High level of input data required
    - Simulation run times are often longer
    - Calibration can be more difficult.

Why Use Models?

- Models allow one to:
  - Better understand the hydrologic response of the system and identify key hydrologic functions
    - Spatial and temporal variability
    - Quantify water balance components
  - Assess the impact of land use changes on a watershed's hydrology.