Impact of Climate Change on Water Resources in the Grand River Watershed and in Canada

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The entire global scientific community has a consensus on the question that human beings are responsible for global warming and he [Bush] has today again expressed personal doubt that that is true.
**Climate Change**

**Climate** encompasses the temperatures, humidity, rainfall, atmospheric particle count and numerous other meteorological factors in a given region over long-term periods of time.

**Climate change** is any long-term significant change in the average weather that a given region experiences.

**Dersertification**

**Global Warming**

**Meltdown**

**Desertification**
Impact of Climate Change

**Brook Trout**
Optimum spawning and incubation temperature:
6 ~ 9 °C
50% mortality rate at 11.7 °C

**Lulworth Skipper**
7 weeks earlier appearance in UK
In 2007

National emblems originate in the natural world
Sources of water that are “useful” or “potentially useful(?)” to humans
Plenty of water does not necessarily mean plenty of water resource. Sometimes it means a disaster.
Potentially (?) Useful Water

Desalination

Frozen water

Ground water
Water Cycle and Distribution

- **Freshwater (0.3%)**
  - Surface Water
  - Groundwater (30%)
- **Saline Water (98%)**
- **Atmospheric Water (0.04%)**
- **Frozen Water (69%)**

Evaporation:
- 380,000 km³ = total water evaporated
- Evaporation 320,000 km³

Precipitation:
- Precipitation 284,000 km³
- Precipitation 96,000 km³

Infiltration:
- Infiltrates

Oceans
Accessibility and Vulnerability: Renewal Interval

As it is more accessible, it is more vulnerable.
Climate change threatens global water resource availability and often has a significant impact on components of the hydrological cycle. It affects the availability of freshwater for domestic use, food production, industrial usage and hydro-power generation. Climate change also affects the safety and quality of the human and natural environment through an increase in floods, droughts and erosion, and a decrease in water quality and ecosystem diversity.

[Wagener and Franks, Regional Hydrological Impacts of Climate Change – Impact Assessment and Decision Making, 2005]
Global Climate Model

Atmosphere

Ocean

Land Surface

Coupler

Ice Sheet
Global Warming Predictions

Glacial Melting

Sea Level Rise

Temperature Rise
Integrated Management and Modelling

**Attempt to account for all interactions between surface and subsurface flow regimes**

Conceptually superior to linked simulators or iteratively coupled simulators

Complex (more processes, highly nonlinear)
Integrated Water Resource Management and Modelling

- Integrated water resource management and planning is important and necessary.
- The physically-based surface water and groundwater flow HydroGeoSphere model can simulate overland/channel flow, variably-saturated flow, ET, density-driven flow and transport, etc.
- Conceptual and mathematical improvement is required for seamless integration of certain components.
- Numerical stability and efficiency has become a key issue with an increasing number of physical and chemical processes, different temporal and spatial scales involved, and highly nonlinear nature of the equations, and so on.
Application of Multiple Analysis Techniques

Conceptualization

Analytical Solutions

Groundwater Age/Life Expectancy

Numerical Analysis
Conceptualization

Mathematical Modeling

Numerical Modeling

\[ - \nabla \cdot \omega_m \bar{q} + \Gamma_o \pm Q = \omega_m \frac{\partial \theta_s S_w}{\partial t} \]
An Intensively-Monitored Case Study: Pine River, ON

(after Conant, 2004)
 STREAMBED INFILTRATION AND EXFILTRATION PATTERNS FROM TEMPERATURE DATA

(after Conant, 2004)
Subsurface Temperature
**Fluid/Energy Exchange**

Fluid exchange with atmospheric interactions vs. without atmospheric interactions.
Influence of Climate Change on Water Resources in Regional-Scale Watersheds: An example in the Grand River Watershed

<table>
<thead>
<tr>
<th>Water Budget Parameter</th>
<th>Value (mm/year)</th>
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<tbody>
<tr>
<td>Precipitation</td>
<td>930</td>
</tr>
<tr>
<td>Evapotranspiration</td>
<td>605</td>
</tr>
<tr>
<td>Surface Flow Out of GRW</td>
<td>313.5</td>
</tr>
<tr>
<td>Infiltration</td>
<td>465</td>
</tr>
<tr>
<td>Exfiltration</td>
<td>170</td>
</tr>
<tr>
<td>Recharge</td>
<td>186</td>
</tr>
<tr>
<td>Groundwater Flow Out of GRW</td>
<td>~ 0</td>
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<tr>
<td>Groundwater Pumping</td>
<td>11.5</td>
</tr>
</tbody>
</table>
Calibration for Long-Term Averages

Surface Drainage Networks

Simulated vs. Observed

\[ y = 1.0304x \]

\[ R^2 = 0.9959 \]

Calculated Flow (m³/s)
Observed Flow (m³/s)

Stream Discharge

\[ y = 1.004x \]

\[ R^2 = 0.9959 \]

Calculated Subsurface Head (m)
Observed Subsurface Head (m)

Subsurface Head

\[ R^2 = 0.997 \]

Observed vs. Calculated Subsurface Head
Synthetic Climate Change Scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Change in actual precipitation throughout simulation, relative to 1960-1999 levels</th>
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<tbody>
<tr>
<td>1</td>
<td>-5%</td>
</tr>
<tr>
<td>2</td>
<td>+5%</td>
</tr>
<tr>
<td>3</td>
<td>+10%</td>
</tr>
<tr>
<td>4</td>
<td>+15%</td>
</tr>
<tr>
<td>5</td>
<td>+20%</td>
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<table>
<thead>
<tr>
<th>Scenario</th>
<th>Recharge (mm/year)</th>
<th>Change relative to base case (mm/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>186</td>
<td>-</td>
</tr>
<tr>
<td>1</td>
<td>176.5</td>
<td>-9.5</td>
</tr>
<tr>
<td>2</td>
<td>198</td>
<td>12</td>
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<tr>
<td>3</td>
<td>207</td>
<td>21</td>
</tr>
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<td>4</td>
<td>216.5</td>
<td>30.5</td>
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<tr>
<td>5</td>
<td>226</td>
<td>40</td>
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</table>

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Nodally-averaged change in depth-to-water table (m)</th>
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</thead>
<tbody>
<tr>
<td>Base</td>
<td>0.0</td>
</tr>
<tr>
<td>1</td>
<td>+0.48</td>
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<tr>
<td>2</td>
<td>-0.36</td>
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<tr>
<td>3</td>
<td>-0.64</td>
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<tr>
<td>4</td>
<td>-0.88</td>
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<tr>
<td>5</td>
<td>-1.08</td>
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</table>
DEPTH TO WATER TABLE [m]:
DRIEST vs. WETTEST SCENARIOS

Scenario 1: Driest

Scenario 5: Wettest
Climate Change and Water Resources in Canada

• Evidences of climate change are mounting.
• Water demand will continue to increase while water quality keeps deteriorating.
• Two critical questions rise:
  – What are the plausible impacts that future climate change may have on our limited water resources?
  – What adaptive strategies can be implemented to mitigate such impacts?
• A science-based framework that fully-integrates climate change & surface/subsurface flow is relevant to sound policy decisions, particularly at continental & trans-border scales.
Selection of Hydrologic Model

- Precipitation
- ET
- Sediment Thickness
- Soil Type
- Geology
- Land Use

Legend:
- inland water bodies
- Acrisols
- Cambisols
- Chernozems
- Podzoluvisols
- Rendzinas
- Ferralsols
- Gleysols
- Phaeozems
- Lithosols
- Fluvisols
- Kastanozems
- Luvisols
- Greyzems
- Nitosols
- Histosols
- Podzols
- Arenosols
- Regosols
- Solonetz
- Andosols
- Rankers
- Vertisols
- Planosols
- Xerosols
- Yermosols
- Solonchaks
- Misc. Land Units

Legend (mm/yr):
- < 25
- 26 - 50
- 51 - 100
- 101 - 200
- 201 - 300
- 301 - 400
- 401 - 500
- 501 - 750
- 751 - 1,000
- 1,001 - 1,500
- 1,501 - 2,000
- 2,001 - 3,000
- 3,001 - 5,000
- 5,001 - 8,000
- > 8,000

Legend (mm/yr):
- 0 - 200
- 201 - 400
- 401 - 600
- 601 - 800
- 801 - 1,000
- 1,001 - 1,200
- 1,201 - 1,400
- 1,401 - 1,600
- 1,601 - 1,800
- 1,801 - 2,000
- 2,001 - 2,200
- 2,201 - 2,400
- 2,401 - 2,600
- 2,601 - 2,800
- 2,801 - 3,000
- > 3,000

Land Use:
- > 75% crops
- > 75% forest
- > 75% pasture and browse
- > 75% barren and sparsely vegetated
- 50 - 75% crops
- 50 - 75% forest
- 50 - 75% pasture and browse
- 50 - 75% barren and sparsely vegetated
- > 50% artificial surface
- mixed
Numerical Model

- Continuous permafrost
- Discontinuous permafrost
- Upper unconsolidated sediment
- Lower unconsolidated sediment
- Sedimentary rock
- Fractured basement rocks
- Basement rocks
Calibration for the Averages of 1961-2000

Simulated Surface Water Depth Distribution

Map of Observed Major Rivers and 10 Largest Lakes

Major Lakes Water Level

Major Rivers Stream Discharge
HGS Infiltration/Exfiltration Compared to CCSM3.0 (Present-Day)

- Infiltration
+ Discharge
Depth to Water Table (Present-Day)
**Projection in 2099**

- **Change in Net Precipitation**
  - **CCSM3.0 (~155 km)**
  - **CRCM4.2 (~45 km)**

- **Change in Water Depth**
  - Decrease
  - Increase

- **Change in Water Table Elevation**
  - Decline
  - Rise

- **Stream Discharge**
Climate may be changing in a way that dry region would become drier and areas with high precipitation would become wetter.

Climate change (if any) has and will have an impact on water resource environment in Canada and elsewhere – there are many scientific evidences that water resource environment can be significantly influenced by climate.

An integrated approach (physical-chemical-biological mass and energy balance in atmosphere, land surface, and subsurface) is required to analyze the impact of climate change on water resource environment.

There are too many “it is likely to be …” or “it is highly probable that …” for climate change impact on water resources and thus it is a long way to go to make it sound science. We have much to do…
Potential impacts of climate change on Canadian water resources:

- a decline in water levels in both inland lakes and four Great Lakes,

- less groundwater recharge, dry-up of small streams, reduced wetland area, poorer water quality, and less wildlife habitat due to reduced summer water levels

- an increase in the frequency and severity of droughts and flooding.

- in the areas of Canadian Prairie, declined streamflow and more frequent droughts will have a significant impact on the efficiency of farming, heavily relying on irrigation.

- Permafrost melting is one of the most striking and visual signs of the impacts of climate change in Canada.
More science:

- Interdisciplinary observatories
- Efficient solution of nonlinear partial differential equations
- Novel probabilistic approaches
- High performance computing – homogeneous and heterogeneous parallel computing
- 4D visualization techniques
THANK YOU FOR YOUR ATTENTION!